ILP 2017

THE 12TH WORKSHOP OF THE INTERNATIONAL LITHOSPHERE PROGRAM TASK FORCE VI SEDIMENTARY BASINS

ILP Sedimentary Basins 2017 Cyprus

Dynamics of Sedimentary Basins and Underlying Lithosphere at Plate Boundaries and Related Analogues

29 OCTOBER - 02 NOVEMBER 2017

LIMASSOL, CYPRUS

Abstracts

ORGANIZERS

SPONSORS

COORDINATOR

Monday, 30 Nov	
Session 1: Dynamics of landscape evolution and its interaction with deep Earth processes Chair: Fadi Henri Nader (IFPEN) and Panos Papanastasiou (UCY)	
08:50	***Keynote session 1. LIPs and cratons: Lithospheric structure of the intracratonic basins in Siberia*** ***Irina M. Artemieva** (**University of Copenhagen, Denmark)***
09:20	**Magmatic underplating and continental rifting** *Hans Thybo, Irina Artemieva*
09:40	**Styles of active deformation and earthquake behavior of reactivated failed rift: examples from the Toyama trough, the Sea of Japan back-arc basins** *Tatsuya Ishiyama, Hiroshi Sato, Naoko Kato, Shin Koshiya, Makoto Matsubara, Susumi Abe*
10:00	**The origin of seismogenic source faults in the back-arc of the Japanese island arcs and their reactivation** *Hiroshi Sato, Tatsuya Ishiyama, Naoko Kato, Susumu Abe, Shinji Kawasaki, Akinori Hashima, Anne Van Horne, Johan Claringbould, Makoto Matsubara*
10:20	**Coffee Break + Posters**
10:50	**Subduction initiation at passive margins: insights from analogue modelling** *Antoine Auzemery, Ernst Willingshofer, Dimitrios Sokoutis, Jean-Pierre Brun*
11:10	***Linking orogenic deformation with processes active in forearc and back-arc sedimentary basins: examples from the Mediterranean systems*** *Liviu Matenco*
11:30	**Ancient Izanagi Slab found below eastern Asian continent** *Shuwen Dong*
11:50	**Characterizing geothermal potential in Europe with lithosphere-scale 3D thermal and rheological models** *Jon Limberger, Jan-Diederik van Wees, Magdala Tesauro, Jeroen Smit, Damien Bonté, Eszter Békési, Maarten Pluymaekers, Maartje Struijk, Mark Vrijlandt, Fred Beekman, Sierd Cloetingh*
12:10	**Making the lithosphere great again - A Global Geological Framework** *Benjamin van Wyk de Vries, Dougal Jerram*
12:30	**Lunch**

Session 2. Coupling Earth observation methodologies to solid Earth dynamics Chairs: Hans Thybo (University of Copenhagen) and Hiroshi Sato (University of Tokyo)	
14:00	***Keynote session 2. Joint application of thermo-mechanical and stratigraphic numerical modeling: the tectono-sedimentary evolution of asymmetric extensional basins*** ***Attila Balazs, Liviu Matenco, Didier Granjeon, Sierd Cloetingh (University of Utrecht, The Netherlands)***
14:30	**Temperature and compositional variations of the Australian upper mantle** *Magdala Tesauro, Mikhail Kaban, Alan Aitken*
14:50	**About the role of isostatic processes in the formation of a sedimentary cover of Greater Caucasus, its folded structure and a mountainous uplift (the factor analysis)** *Fedor Yakovlev, Yevgeni Gorbatov*
15:10	**Petroleum reservoir geomechanics modelling in the eastern Mediterranean basin** *Nikolaos Markou, Panos Papanastasiou*
15:30	**Coffee Break + Posters**
Session 3. Volcanism and related processes at all scales **Session 5. Geo-hazards and sustainable geo-resources** Chairs: Dimitrios Loukidis (University of Cyprus) and Chadi Abdallah (Lebanese NCSR)	
16:00	***Keynote session 3: Issues and challenges in deep water drilling*** ***Vassilios Kelessidis (Petroleum Institute, Khalifa University of Science and Technology, Abu Dhabi, UAE)***
16:30	***Space-time evolution of a volcanic field in an extended region: the example of Campi Flegrei (Italy)*** *Maurizio Torrente, Pietro Iannace, Alfonsa Milia*
16:50	**On the fracture propagation direction induced in hydraulic fracturing and CO2 geological storage** *Panos Papanastasiou*
17:10	**Flood Risk Assessment for Lebanon** *Chadi Abdallah, Rouya Hdeib*
17:30	**Platforms and image processing techniques for discriminating landslides in Lebanon** *Chadi Abdallah, Elsy Ibrahim, Jacques Harb, Dalia Abdelmassih, Fadi Hage Chehade*
17:50	**A review of analysis methods of geotechnical problems pertinent to offshore pipelines and the role of numerical simulations** *Dimitrios Loukidis*
18:10	**Posters**
18:40	**End of Session**

Posters

1	**Kinematic and depositional evolution of the External Dinarides orogenic system** Marianne van Unen, Liviu Matenco, Fadi Henri Nader, Romain Darnault, Oleg Mandic, Bruno Tomljenovic
2	**The Late Cretaceous Paleo-Pacific Reorganization: Insight from Eastern Asia and Implications to Intraplate Basin Geodynamics** Jianye REN, Xinong XIE, Ying SONG, Junxia ZHANG
3	**The first estimation of volumes of eroded rocks of the folded Alpine sedimentary cover of Greater Caucasus for three geodynamic models having different shortening of space** Fedor Yakovlev, Andrew Sorokin
4	**Break-up unconformity system at the extensional continental margins and its applications in the northern continental marginal basins of South China Sea** Xinong XIE, Jianye REN, Xiong Pang, Chao Lei
5	**Tectonic evolution of the Black Sea** Jeroen Smit
6	**Subduction initiation at passive margins: insights from analogue modelling** Antoine Auzemery, Ernst Willingshofer, Dimitrios Sokoutis, Jean-Pierre Brun
7	**3-D lithospheric-scale temperature modeling: application for the Hungarian part of the Pannonian Basin** Eszter Békési, Laszló Lenkey, Jon Limberger, Damien Bonté, Mark Vrijlandt, Ferenc Horváth, Sierd Cloetingh, Jan-Diederik van Wees
8	**The Middle Atlas Geological karsts forms: Towards Geosites characterization** Souhail Mounir, Naoufal Saoud, Jaouad Choukrad, Mohammed Charroud
9	**New insights on closed system dolomite recrystallization processes from clumped isotope ($\Delta 47$) thermometry and Laser Ablation U-Pb chronometry - Arab Fm. reservoirs (UAE)** Daniel Morad, Marta Gasparrini, Xavier Mangenot, Axel Gerdes, Magali Bonifacie, Sadoon Morad, Helge Hellevang, Fadi Henri Nader, Fatima Al Darmaki
10	**Asymmetric rift interaction: Insight from lithospheric-scale 3D thermo-mechanical numerical modeling** Attila Balazs, Katharina Vogt, Liviu Matenco, Sierd Cloetingh, Taras Gerya
11	**The petroleum prospects onshore Lebanon: example of the Qartaba anticline** Yara Bou Rizk, Ramadan Ghalayini, Veronique Kazpard
12	**Geodynamic Lead Mineralization Training of the Moroccan Hercynian Belt: Case of the Upper Moulouya Paleozoic Enlier** Saoud Naoufal, Charroud Mohammed, Mounir Souhail, Choukrad Jaouad, Hinaje Said

Tuesday, 31 Nov	
Session 4a. Sedimentary Basin systems and geo-resources Chairs: Ralf Littke (RWTH Aachen University) and François Baudin (UPMC)	
08:30	***Keynote session 4. Crustal structure and tectonic evolution along the African-Anatolian plate boundary offshore southern Cyprus.*** ***Sönke Reiche (RWTH Aachen University, Germany)***
09:00	***The Sediment Story of Miocene Sands in the Levant Basin*** *M.K. Davis, J. Ortega, S. Fenton, B. Gergurich*
09:20	**Crustal modeling in the northern Levant basin based on seismic interpretation** *Lama Inati, Fadi Henri Nader, Mathilde Adelinet, Jean-Claude Lecomte, Hermann Zeyen, Muhsen Elie Rahhal, Alexandre Sursock*
09:40	**Structural evolution of the SW Cyprus Belt compiled from onshore field observations and offshore seismic reflection profiles** *Vasilis Symeou, Catherine Homberg, Fadi Henri Nader, Romain Darnault*
10:00	**Source rocks, thermal history, and petroleum systems of the east Mediterranean, onshore-offshore Lebanon** *Samer Bou Daher, Ralf Littke, Fadi Henri Nader*
10:20	**Coffee Break + Posters**
11:00	**Geochemical and Petrographical Characterization of Potential Source Rock Intervals of Late Mesozoic to Cenozoic Age in the On- and Offshore Area of Cyprus** *Sebastian Grohmann, Susanne Fietz, Fadi Henri Nader, Maria Fernanda Romero-Sarmiento, Ralf Littke, Francois Baudin*
11:20	**An experimental and modeling approach for the effectiveness of the hypersaline solutions' physical properties on the settling velocity of sands.** *Konstantinos Albanakis, Angelos Mousouliotis*
11:40	**Consequences of the Messinian Salinity Crisis in clastics deposition in the Eastern Mediterranean Basin** *Angelos Mousouliotis, Konstantinos Albanakis*
12:00	**Tectonic control on sedimentation: inferences from the Sorbas Basin (SE Spain)** *Nevena Andrić, Liviu Matenco, Frits Hilgen, Hans de Bresser*
12:20	**Deformation bands in sedimentary basins: their role in structural analysis, depth-temperature-time determinations** *Laszlo Fodor, B. Beke, J. Csizmeg, L. Millar, A. Petrik, E. Szőcs, K. Hips*
12:40	**Sedimentary evolution of the siliciclastic-calciturbidite Middle Eocene Gercus Formation, NE-Iraq; Active tectonism and igneous activity approach** *Sa'ad Zeki Kader Al-Mashaikie*

13:00	**Lunch**
	Session 4b. Sedimentary Basin systems and geo-resources Chairs: Konstantinos Albanakis (Aristotle University Thessaloniki) and Efthymios Efthymiou (CHC, Cyprus)
14:00	**Late Miocene ("post-rift") deformation patterns in the Pannonian basin: the mechanisms of kilometre-scale differential vertical movements** *Laszlo Fodor, A. Balázs, F. Horváth, L. Matenco*
14:20	**Internal wave controlled slope angle and seafloor morphology at the Israel continental slope** *Sönke Reiche, Christian Hübscher, Steve Brenner, Christian Betzler, John K Hall*
14:40	**The tectono-stratigraphic evolution of the Levant margin offshore Lebanon** *Ramadan Ghalayini*
15:00	**Latest Edition of the Lebanese Lower Cretaceous Stratigraphy** *Sibelle Maksoud, Bruno Granier, Raymond Gèze, Dany Azar*
15:20	**Coffee Break + Posters**
16:00	**Geodynamics of and synchronous infill of flexural basins: The Northern margin of the Levant Basin, onshore Southern Cyprus** *Remy Deschamps, Nickolaos Papadimitriou, Christine Souque, Romain Darnault, Fadi Henri Nader, Christian Gorini, Vasilis Symeou, Catherine Homberg, Jean-Claude Lecomte*
16:20	**The Eratosthenes Carbonate Platform: An Explorationist's perspective** *Efthymios Efthymiou*
16:40	**Seismic structure of the Maranhão-Barreirinhas-Ceará margin, NW Brazil, from the MAGIC wide-angle seismic experiment** *Daniel Aslanian, Maryline Moulin, Philippe Schnürle, Alexandra Afilhado, Nuno Afonso Diaz, José Soares, Adriano Viana*
17:00	**Posters**
18:30	**Departure for Walking Tour to Limassol Old Center & Conference Dinner**
20:00	**Gala Banquet**

Wednesday, 01 Nov	
Session 6. Rock-fluids interactions in sedimentary basins Chairs: Marta Gasparrini (IFPEN) and Katie M. Davis (Noble Energy, USA)	
08:00	***Keynote session 6. Innovative approaches of carbonate diagenesis quantification (Δ47 thermometry - U/Pb chronometry) - towards appraisal in geological modeling*** ***Xavier Mangenot (IFPEN, France) Gasparrini, M., Montano, D., Bonifacie, M., Gerdes, A., Rouchon, V., Della Porta, G***
08:30	**A new workflow for assessing quantitative diagenesis and dynamic porosity/permeability evolution in reservoir rocks** *Steven Claes, Fadi Henri Nader, Souhail Youssef*
08:50	**Natural sealed fractures from the Montney-Doig unconventional reservoirs tied to burial and tectonic history of the Western Canada foreland basin** *Moh Belkacemi, Marta Gasparrini, Olivier Lacombe, Sébastien Rohais, Daniel Pillot, William Sassi, Tristan Euzen*
09:10	**MVT mineralization and associated hydrothermal dolomite in the upper Carboniferous - lower Permian Kinta Limestone (Perak, Malaysia): Field/microscopic observations, isotopic signatures and fluid inclusion studies** *Mumtaz Muhammad Shah, Michael Poppelreiter, Askury Abd Kadir, Choong Chee-Meng*
09:30	**New insights on closed system dolomite recrystallization processes from clumped isotope (Δ47) thermometry and Laser Ablation U-Pb chronometry - Arab Fm. reservoirs (UAE)** Daniel Morad, Marta Gasparrini, Xavier Mangenot, Axel Gerdes, Magali Bonifacie, Sadoon Morad, Helge Hellevang, Fadi Henri Nader, Fatima Al Darmaki
09:50	**Coffee Break**
Session 7. New concepts and results on the East-Mediterranean geology Chairs: Catherine Homberg (UPMC), Stelios Nicolaides (Ministry of Energy, Cyprus)	
10:15	***Keynote session 7. Integrated approach for tectono-sedimentary basin analysis of the Levant (East-Mediterranean region): Implications on petroleum potentials and exploration de-risking of frontier basins*** ***Fadi Henri Nader (IFPEN, France)***
10:45	**Mesozoic clastics in Cyprus: an exhaustive sedimentologic and petrographic study may lead to refine proposed eastern Mediterranean paleogeographic reconstructions** *Christian Blanpied, Ludovic Mocochain, S. Revillon, J.M. Kluska, and E. Deloule*
11:05	**Eratosthenes Seamount; The evolution of an isolated carbonate platform at a major plate boundary (offshore Cyprus)** *Nikolas Papadimitriou, Gorini Christian, Fadi Henri Nader, Remy Deschamps, Aurelie Tassy*

11:25	**Crustal structure across the Cyprus arc plate boundary from the Eratosthenes Seamount to south Turkey from an amphibian wide-angle seismic profile** *James Mechie, Christian Feld, Christian Hübscher, Jeremy Hall, Stelios Nicolaides, Cemil Gurbuz, Klaus Bauer, Keith Louden, Michael Weber*
11:45	**Deformation and metamorphism on the Northern Sporades: a field study from Skopelos and Alonnisos (Aegean Domain)** *Kristof Porkolab, Ernst Willingshofer, Dimitrios Sokoutis, Iverna Creton, Dimitrios Kostopoulos*
12:05	**A geochemical study of siliceous ferromanganese rocks of the Mamonia Complex, SW Cyprus** *Dimitrios Loukidis, Nikos Pasadakis, Eva Sotiropoulou, Kimon Christanis, Nikoletta Koulermou, Georgios Alevizos, Nikolaos Kallithrakas-Kontos*
12:25	**New deep seismic data in the Eastern Mediterranean / Levant province is paramount** *Philippe Schnürle, Daniel Aslanian, Maryline Moulin, Marina Rabineau*
12:45	**Announcement of the IFP Energies Nouvelles Prize Winners for best presentations**
13:00	**Lunch**
13:30	**Departure for Kourion and Paphos archaeological sites**
20:30	**Back to Limassol**

Talk preference

Title: LIPs and cratons: Lithospheric structure of the intracratonic basins in Siberia

Irina Artemieva

University of Copenhagen, Denmark, Irina@ign.ku.dk; iartemieva@gmail.com

Abstract

Geodynamic models of the formation and evolution of large sedimentary basins within the Precambrian cratons include thermal thinning, rifting, eclogitization, mantle metasomatism, and lithosphere flexural bending as a response to large-scale plate tectonics processes. These processes are clearly reflected in the thermal, density, and seismic velocity structure of the cratonic lithosphere.

The Siberian craton has undergone a series of large-scale magmatic events in the Phanerozoic, including the emplacement of the Siberian traps which cover the western half of the craton, the Devonian rifting at the eastern margin of the craton, several pulses of kimberlite magmatism mostly in the north-eastern part of the craton, and the Cenozoic rifting at the southern margin of the craton. Large-scale sedimentary basins in the craton are spatially correlated with these magmatic events, leaving the amagmatic parts of the craton to stay as sediment-free shields.

Based on a joint interpretation of geophysical data, such as thermal, seismic tomography, and gravity data, I demonstrate a significant lateral and vertical heterogeneity in the structure of the crust and the lithospheric mantle of the intracratonic basins in Siberia. This heterogeneity reflects the extent of the lithosphere reworking by a large-scale magmatism. The results indicate a possible source region for the Siberian LIP and the Baikal rifting.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Oral presentation

Title: Magmatic underplating and continental rifting

Authors: Hans Thybo[1,2] and Irina M Artemieva[3]

Affiliations: [1]Eurasia Institute of Earth Sciences, Istanbul Technical University, Turkey
[2]Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Norway
[3]Geology section, IGN, University of Copenhagen, Denmark

Abstract

Underplating was originally proposed as the process of magma ponding at the base of the crust and was inferred from petrologic consideration, often thought to be associated with extensional regions. The process may have main importance for the formation of continental crust with its characteristic low average density, and may have been mainly active during the early evolution of the Earth. However, despite the assumed importance of underplating processes and associated fractionation, the available geophysical images of underplated material remain relatively sparse and confined to specific tectonic environments. Direct ponding of magma at the Moho is only observed in very few locations, probably because the magma interacts with the surrounding crustal rocks. It appears that Large Igneous Provinces may be the only location where extensive underplating over large areas may have happened. The lack of data for testing this hypothesis demonstrates the need for new controlled source seismic data with long profiles at these locations. There is no direct discriminator between traditionally underplated material and lower crust magmatic intrusions in the form of batholiths and sill-like features, and here we include both these phenomena into the definition. Underplating in this sense is observed in a variety of tectonic settings, including island arcs, wide extensional continental areas, rift zones, and continental margins. Recent new data show that magmatic processes around Moho level may take the form of sill intrusions in the lower crust (at continental rift zones and slopes) as well as in the vicinity of major crustal intrusions, and that underplating may even take the form of massive magmatic intrusion into the crust in giant magma chambers. Rift zones may be characterised by being magma-poor or magma-rich. In the latter case, substantial addition of mafic-ultramafic magma to the lower crust/uppermost mantle may be regarded as an underplate. Such underplate may totally mask the crustal thinning from the extension by the process of “Magma-Compensated Crustal Thinning”. As such this process may lead to fundamental underestimation of the crustal thickness if the amount of underplate material is not take into account for calculation of β-factor. We review the structural styles observed by geophysical imaging and discuss these first order observations in relation to the Moho.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues
ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Talk

Title: Styles of active deformation and earthquake behavior of reactivated failed rift: examples from the Toyama trough, the Sea of Japan back-arc basins

Authors: Ishiyama, T.[1], Sato, H.[1] Kato, N.[1], Koshiya, S. [2], Matsubara, M. [3], and S. Abe[4]

Affiliations: 1 Earthquake Research Institute, University of Tokyo, Japan
2 Iwate University, Japan
3 NIED, Japan
4 JAPEX, Co. Ltd.

Contacts: ishiyama@eri.u-tokyo.ac.jp

Abstract

Contributions of crustal structures of back-arc rifts to their compressional reactivation and active tectonics remain insufficiently understood. In this study, we present how rift-related structures play essential roles on their reactivation, styles of active deformation, and present seismicity in the Toyama trough and nearby areas, the Sea of Japan back-arc basins. Our recent results of onshore-offshore deep to shallow seismic reflection profiles across the Toyama trough, one of the major back-arc failed rifts in the Sea of Japan, revealed that the back-arc rift structures have acted as mechanically and thermally weak zones and possibly play important roles in strain accommodation even at later post-rift stages (Ishiyama et al., 2017). In detail, the mechanical contrasts between the crustal thrust wedges composed of the pre-rift continental crust and high velocity lower crust caused by mafic intrusions into the rift axis during the rifting stage have fundamentally controlled the styles of active deformation during the post-rift compressional stress regime, including reactivation of active thrusts and fault-related folding, and dynamic subsidence during the Quaternary. Shallower high-resolution seismic reflection profiles also suggest Quaternary structural growth of the reactivated thrusts and thrust wedges, consistent with of folded and/or uplifted middle to late Pleistocene marine and fluvial terraces. In addition to these compressive reactivation, transfer faults highly oblique to the rift axis also appear to play important roles on active tectonics. The 1948 Fukui earthquake (M7.1), shallow intraplate earthquake event with a strike-slip faulting mechanism (Kanamori, 1973), resulted in more than 3,500 causalities and destructive damages on the infrastructures. While geophysical analyses on geodetic measurements based on leveling and triangulation networks clearly show coseismic left-lateral fault slip on a NNW striking vertical fault plane beneath the Fukui plain (Sagiya, 1999), no clear evidence for coseismic surface rupture has been identified based on both post-earthquake intensive fieldwork and recent reexamination of stereopair interpretations using 1/3,000 aerial photographs taken in 1948. Our new seismic section using more than 900 offline recorders revealed negative flower structures that deform Miocene volcaniclastic deposits and overlying Plio-Pleistocene sediments above the upward extension of the strike-slip fault plane of the 1948 event. Locations of these strike-slip fault-related structures are also consistent with Miocene transfer faults that offset syn- and post-rift sediments and underlying crustal wedges, suggesting that reactivation of transfer faults resulted in active strike-slip faulting including the 1948 seismic event. Networks of active dextral-slip faults within further interior of the pre-Neogene basement rocks and modern seismicity including devastating M>7 historical earthquakes may be related to similar transfer faults across the rift axis and/or their landward extension. These findings demonstrate that not only rift-related normal faults but also transfer faults have strong structural inheritances and played essential roles on their active reactivation and seismicity during the post-rift stress regime. Moreover, these results also contribute to the construction of the seismic source fault models for tsunamis and seismic hazard estimations of this region.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Talk preference

Title: The origin of seismogenic source faults in the back-arc of the Japanese island arcs and their reactivation

Authors: Sato, H[1], T.Ishiyama[1], N. Kato[1], S. Abe[2], S. Kawasaki[3], J. S. Claringbould[1], A. Hashima [1],, A. Van Horne [1, 5], M. Matsubara[4]

Affiliations: **1** ERI, The University of Tokyo, Tokyo, Japan
2 Japan Petroleum Exploration Co. Ltd., Tokyo, Japan
3 Japex Geoscience Institute, Co. Ltd. , Tokyo, Japan
4 National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan
5 University of Wyoming, Laramie, Wyoming, USA

Contacts: satow@eri.u-tokyo.ac.jp

Abstract The evolution of back-arc basins like those in the western Pacific and the Mediterranean region are controlled by asthenospheric-scale, slab processes which are short-lived. The Sea of Japan back-arc, for example, formed over a period of <20 My, in which rifting and extension of the Asian continental crust split the Mesozoic accretionary complexes of the main Japanese island arc from the Asian craton through a “saloon-door” opening mechanism. Back-arc opening was followed by a period of crustal shortening under the influence of plate convergence. New insights into back-arc basin development and the associated deformation of the overriding plate have emerged from seismic profiling studies conducted for the purpose of investigating the geometry of earthquake source faults in Japan. Most earthquake source faults were formed during the opening of the Sea of Japan, through several different processes. Where the continental crust was stretched, basin inversion is now observed. In the ENE-WSW trending intra-arc rift zones that developed between NE and SW Japan in response to the “saloon door” opening, large right-lateral displacements are occurring. A third class of seismogenic source faults is associated with multiple, failed-rift basins that formed along the Japan Sea coast of central and northern Honshu in the late stages of back-arc opening as new oceanic crust was produced in a multi-rift style opening. These marginal rift basins are floored by thick basalts, filled with thick sediments, and exhibit a mafic core. They are bounded by reverse faults that dip outward from the rift axis along the boundary between the mafic core and the pre-rift crust, and their basin fill has been highly deformed into fold-and-thrust belts, which has led to their being interpreted as the weakest part of the overriding plate. Shortening deformation in the overriding plate has been controlled by subduction dynamics of the Pacific and Philippine Sea plates. In SW Japan, E-W trending compressional structures formed as a result of strong resistance to subduction of the young (15 My) and buoyant Shikoku Basin along the paleo-Nankai Trough in the late Miocene. The resumption of subduction at 5 Ma is recorded in the presence of subhorizontal Pliocene sediments overlying folded Miocene basin fill in the back-arc region. When the motion of the Philippine Sea plate shifted westward at ~ 1 Ma, pre-existing faults were reactivated as strike-slip. Nearly simultaneously, retreat of the Ryukyu Trench associated with the opening of the Okinawa Trough has produced strong seismicity in Kyushu and the southern Korean peninsula as a result of slab-rollback and/or trench retreat along the Ryukyu arc.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues ILP Task Force (VI) on Sedimentary Basins

Poster

Subduction initiation at passive margins: insights from analogue modelling

Antoine Auzemery[1], Dimitrios Sokoutis[1,2], Ernst Willingshofer[1], and Jean-Pierre Brun[3]

[1] Faculty of Geosciences, Department of Earth Sciences, Utrecht University, Budapestlaan 4, 3508 TA Utrecht, The Netherlands.
[2]University of Oslo, Department of Geosciences, Oslo, Norway
[3]Université Rennes 1, Géosciences Rennes, UMR 6118 CNRS, bat. 15 - Campus de Beaulieu, 263 Av du général Leclerc, BP 74205, 35042, Rennes Cedex, France.

Passive Margins are of particular scientific and economic interest and host key archives of earth system dynamics. Their formation and evolution has been well explored through geological, geophysical and modelling studies. However, it is poorly understood how passive margins turn into active margins, eventually leading to the subsequent development of subduction zones. This study aims at exploring favourable rheological and kinematic conditions that favour the development of subduction zones along passive continental margins through lithosphere-scale analogue modelling.

It is widely accepted that subduction demands rupturing of the brittle crust to allow for over-thrusting of the continental lithosphere and then the sinking of the oceanic lithosphere into the asthenospheric mantle. While the first stage is control by the ductile strength of the continental crust, the over-thrusting depends mainly on the strength of the lithospheric mantle as well as its negative buoyancy. However, processes which lead to the rupture and the over-thrusting of the stable oceanic lithosphere during subduction has long been a subject of debate. Parameters are not well quantified and it is still unclear where subduction is initiated and how it develops afterward. The lack of natural examples and the fact that most of subducted margins are highly deformed or buried at depth foster speculations on the early stages of subduction. Numerically based models propose different answers to resolve the issues. But in most cases, to overcome the high lithosphere strength, it requires special circumstances as a pre-existing fracture zone, a high-density contrast between the ocean and the continent or external forces such as small-scale plumes. These hypotheses are consistent and rational

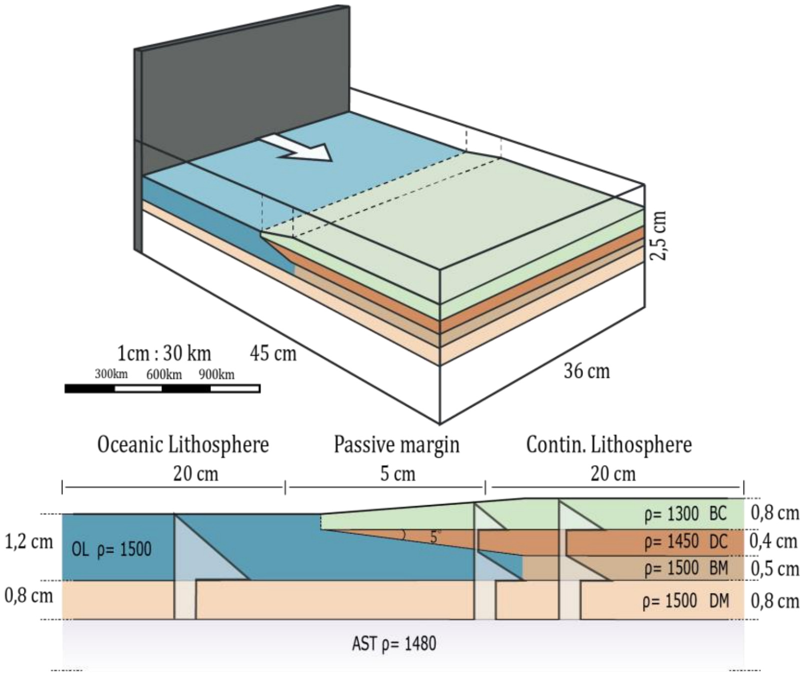


Figure 1: (a) Experimental setup: four-layers continental lithosphere and a two layers oceanic lithosphere resting on a high-density low-viscosity fluid representing the asthenosphere. White arrow indicates the shortening that is applied via the moving wall. (b) strength profiles showing lateral variation in lithospheric strength at initial stage of deformation. The model is scaled according to the criteria of geometrical, rheological, dynamical and kinematic similarity.

but highly steer the location and the dynamics of

subduction. In contrast, we use analogue modelling to test a reasonable homogeneous model of subduction initiation at passive margin without using pre-existing constraints. We use different sets of experiments to test successively the role of lithosphere strength, convergence angle, and convergence rate, to identify favourable parameters combination for subduction initiation. The model consists of a four layers continental lithosphere and a two layers oceanic lithosphere. These two domains are separated by a wedge-shaped margin which simulate the necking zone of the common passive margin, without however particular weakness zones (Fig. 1).

The preliminary results show that subduction will most likely occur at slow convergence rate for an intermediate effective viscosity in the lithospheric mantle (10^22 Pa.s). The typical tectonic regimes we obtain are as follows: rupture, over-thrusting and sinking (Fig. 2). The rupture typically takes place at the transition from the continent to the passive margin and occurs during a phase of accretion where the oceanic crust deforms the passive margin by ocean-ward out-sequence thrusting (1). Coevally, the former passive margin is flexed downward and describes a deep basin. Subsequently, when the driving forces underpass the strength of the lithosphere, the down-flexed passive margin is cut by the evolving subduction fault and is being thrusted under the continent. This phase of deformation may actually lead to the partial delamination of continental mantle (2). The transition to the sinking stage is characterised by the development of a shear zone in the viscous part of the mantle lithosphere, which accommodates the sinking of the subducting slab aided by its negative buoyancy (3). This sequence of deformation leads to the (partial) subduction of the passive margin and could predict the juxtaposition of shallow water, platform-type deposits on deep marine sediments.

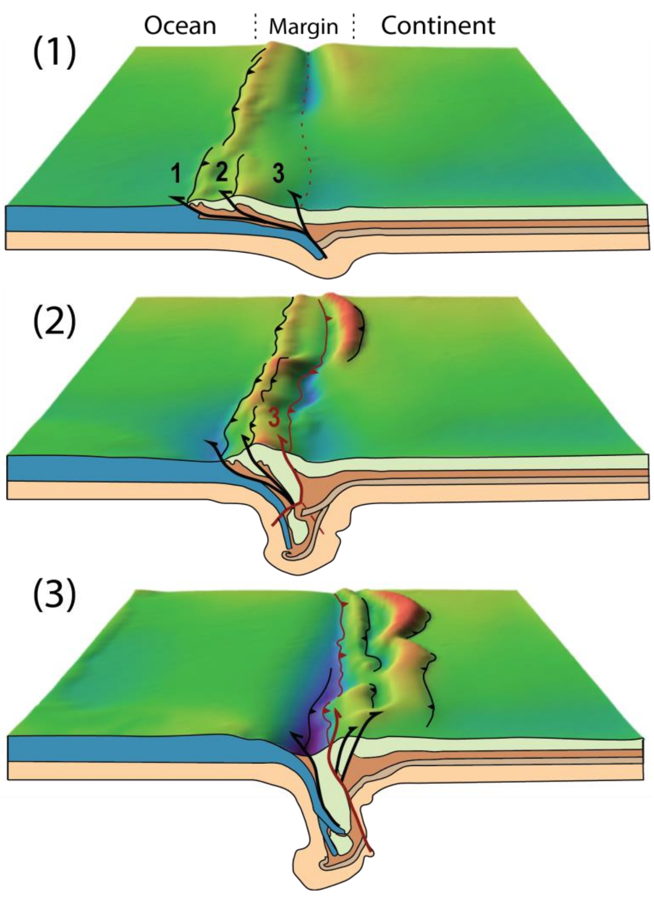
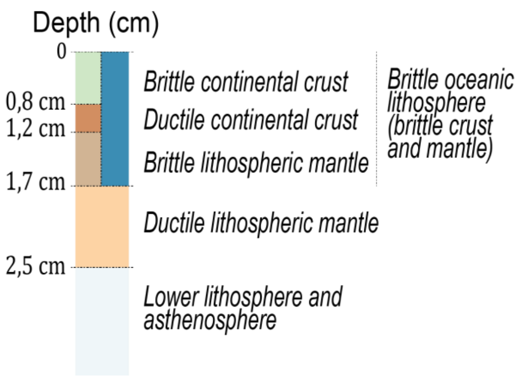


Figure 2: Examples of analogue models for spontaneous initiation at passive continental margins. Three tectonic regimes are observed: (1) Rupture of the lithosphere during a phase of accretion. (2) Under-thrusting by partial delamination of continental mantle. (3) Development of a shear zone in the ductile mantle and sinking of the lithosphere. The moving-wall pushes the oceanic lithosphere at a constant velocity of 0,5 cm/h representing 3,3 cm/year in nature.



Talk preference

Title: Linking orogenic deformation with processes active in forearc and back-arc sedimentary basins: examples from the Mediterranean systems

Liviu Matenco

University of Utrecht, Faculty of Geosciences, Netherlands, liviu.matenco@uu.nl

Abstract

The large number and distribution of syn- to post- orogenic sedimentary basins in Mediterranean orogens offers the possibility of studying the link between basin formation and orogenic evolution in collisional settings and at active continental margins. The mechanics of relict forearc basins and their kinematic relationships with sedimentation is often less understood due to fragmentation by subsequent collision or post- orogenic deformation and is markedly distinct from observations at active margins, in particular in inferring the balance between subduction erosion and subduction accretion. At the same time, classical models of orogenic evolution assume that back arc basins form in the hinterland of orogens, collapsing the upper plate above oceanic subduction zones. This is a common characteristic thought to apply to all low-topography orogens of Mediterranean type driven by the fast roll-back of genetically related slabs. In the case of the Dinarides, such an extensional evolution is recorded both far at the interior of the orogen creating the larger Pannonian Basin, but also superposed over the main mountain chains, demonstrating the gradual migration of the couple contraction - extension towards the Adriatic foreland. Such a migration is an often example in Mediterranean orogens and result in a complex evolution sedimentary basins that change from contractional to extensional as a function of the spatial position of the back-arc mechanics at any given time. Mediterranean orogens often diverge from the typical scenario by widespread extensional deformation taking place during moments of continent-continent collision and by the interference of such deformation driven by different subduction zones. For instance, the formation of the Pannonian back-arc basin is generally related to the rapid Miocene roll-back of a slab attached to the European continent. The present-day extensional geometry of the Pannonian back-arc formed essentially during the Carpathians collision and was also driven by an additional Middle Miocene roll-back of a Dinaridic slab. As a result, crustal thickening takes place in the foreland of the orogen, while the gradual extension is migrating and thinning the crust in a foreland direction. The mechanics of back-arc extension and forearc accretion and their interplay is of key importance for the evolution of the sedimentary basins. As long as the extension remained asymmetric at the beginning of its evolution, the subsidence in the normal faults hanging-wall remains moderate and the subsidence in forearc and back-arc basins remains moderate. When the extension changed to symmetric, the larger amounts of regionally induced subsidence connected the sedimentation in a larger realm where back-arc and fore-arc basins are connected. We exemplify this mechanics with examples observed during the evolution of few Mediterranean areas.

Ancient Izanagi Slab found below eastern Asian continent

Shuwen Dong[1,2†], Ying Song[3], Chengshan Wang[4], Fuqin Zhang[5], Rui Gao[3], Yueqiao Zhang[2], Siqi Huang[3], Keyu Liu[1,6], Andrei Stepashko[7]

1. 2. School of Geoscience and Engineering, Nanjing University , China
2. SinoProbe Center, Chinese Academy of Geological Sciences
3. Geology Department, China University of Petroleum (East China)
4. School of the Earth Sciences and Resources, China University of Geosciences (Beijing)
5. Institute of Geology and Geophysics , Chinese Academy of Sciences
6. Department of Applied Geology, Curtin University of Technology
7. Kosygin Institute of Tectonics and Geophysics, Far Eastern Branch, Russian Academy of Sciences

swdong@nju.edu.cn, yingsong@upc.edu.cn, chshwang@cugb.edu.cn, fqzhang64811@sohu.com, gaorui@cags.ac.cn, zhangyq@nju.edu.cn, shi7huang@163.com, keyu.liu@csiro.au, stepashko@itig.as.khb.ru

Abstract: The Izanagi Plate (Paleo-Pacific Plate) is believed to have been subducted beneath East Asia since the Jurassic with a subsequent formation of the trench-arc-basin system of the modern western Pacific margin in the Cenozoic. A newly acquired multichannel deep seismic profile by the SinoProbe Project in northeast China reveals a group of westerly dipping sub-Moho reflections that could be traced down to deep earth. The features of these mantle reflectors are comparable to those observed on other deep seismic sections elsewhere, which have been proved to represent ancient subduction zones. By coupling with independent surface tectonic evidence and seismic tomography models, we interpret that these westward dipping reflections in the mantle represent relics of the extinct Izanagi Plate. This new finding is significant for understanding the eastern Asia tectonics and for reconstructing plate kinematics of the Pacific Ocean.

Characterizing geothermal potential in Europe with lithosphere-scale 3D thermal and rheological models

J. Limberger[1*], J.-D. van Wees[1,2], M. Tesauro[1,3], J. Smit[1], D. Bonté[1], E. Békési[1,2], M. Pluymaekers[2], M. Struijk[2], M. Vrijlandt[2], F. Beekman[1] and S. Cloetingh[1]

1 Utrecht University, Department of Earth Sciences, PO Box 80021, 3508 TA Utrecht, The Netherlands
2 TNO, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
3 Università degli Studi di Trieste, via Weiss 1, Palazzina C 34127 Trieste, Italy

*J.limberger@uu.nl

We present an updated thermal and rheological model of the European lithosphere based on a new stochastic thermal modelling work flow. The work flow has been developed to estimate subsurface temperatures from site- to regional-scale, up to the depth of the lithosphere-asthenosphere boundary (LAB). Our model is composed of four layers, consisting of sediments, upper crust, lower crust and lithospheric mantle [1]. Thermal properties, including radiogenic heat production and temperature- and pressure-dependent bulk thermal conductivity are assigned on the base of broad-scale lithological variation within the European crust [1,2]. Thermal properties are corrected with a 1D steady-state temperature approximation, assuming only vertical heat flow. Using these corrected thermal properties, the 3D thermal field is calculated with a conjugate-gradient method, assuming fixed temperatures at the surface and at the base of the lithosphere. Further improvements of the thermal model are obtained by applying data assimilation, aiming at consistency between temperature and heat flow observations and tectonic model predictions. An Ensemble Smoother Multiple with Data Assimilation (ES-MDA) method is used to assimilate temperature data and improve prior estimates of thermal properties and the thermal field, based on borehole temperature data [3].

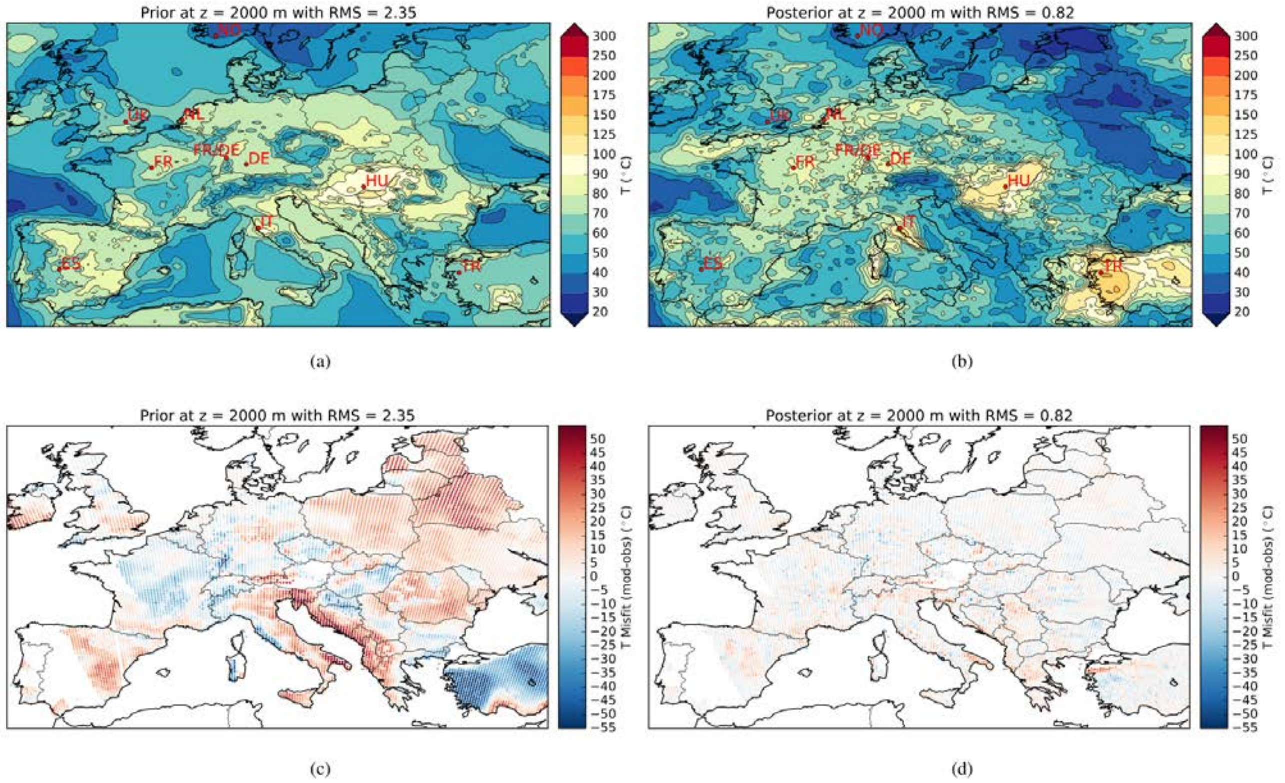


Figure 1. Depth slice at 2000 m depth (below ground level), extracted from the 3D temperature model. **A.** Temperatures of the prior (forward) 3D temperature model. **B.** Temperatures of the posterior (inverse) 3D temperature model. **C.** Misfit of prior model (observed temperatures minus modelled temperatures). **D.** Misfit of posterior model.

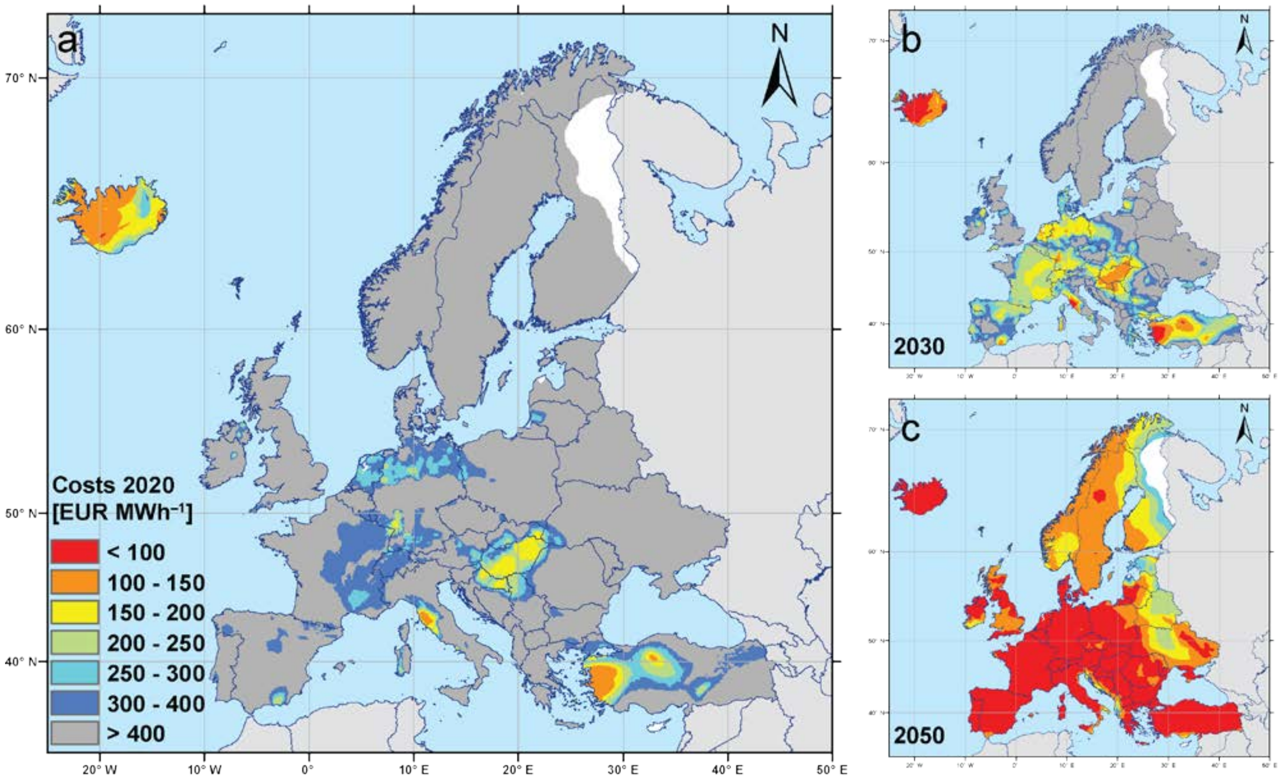


Figure 2. Economic potential of power generation using enhanced geothermal systems in Europe [4]. Maps indicate values of calculated minimum levelized costs of electricity in **A.** 2020, **B.** 2030 and **C.** 2050.

Based on the new thermal model we update the European rheological model and estimate the integrated strength of the lithosphere. To cope with the lack of (public) borehole temperature data in Europe, we calibrate our European thermal model with available regional thermal models. The method generates a range of thermal properties and temperatures which allow for further uncertainty assessments, vital for de-risking geothermal prospects within site-scale models and useful for improving volumetric estimates of (supercritical) geothermal resources based on regional-scale thermal models (e.g. [4]).

References and acknowledgements

[1] Tesauro, M., Kaban, M., Cloetingh, S., 2008. EuCRUST-07: A new reference model for the European crust. Geophys Res Lett 35, 1–5.

[2] Hartmann, J., Moosdorf, N., 2012. The new global lithological map database GLiM: A representation of rock properties at the Earth surface. Geochem Geophy Geosy 13, Q12004.

[3] Emerick, A., Reynolds, A., 2013. Ensemble smoother with multiple data assimilation. Comput Geosci 55, 3–15.

[4] Limberger, J., Calcagno, P., Manzella, A., Trumpy, E., Boxem, T., Pluymaekers, M., van Wees, J.-D., 2014. Assessing the prospective resource base for enhanced geothermal systems in Europe. Geothermal Energy Science 2, 55–71.

The research leading to these results has received funding from the European Community‘s Seventh Framework Programme under grant agreement no. 608553 Project IMAGE (**http://www.image-fp7.eu**).

Title: Making the lithosphere great again - A Global Geological Framework

Authors: van Wyk de Vries B [1], Jerram D A [2,3]

Affiliations:
1 Université Clermont Auvergne, Observatoire du Physique du Globe de Clermont, Laboratoire Magmas et Volcans, UMR6524-CNRS, FRANCE
2 Prof II, Centre for Earth Evolution and Dynamics (CEED), University of Oslo. NORWAY
3 Director, DougalEARTH Ltd., Solihull. UK

Contacts: ben.vanwyk@uca.fr, dougal@dougalearth.com

In global affairs, such as for climate change and for the sustainability of our natural resources, geology/earth sciences has taken the back stage to other factors such as ecosystems. This can also be said for the level of exposure in secondary school teaching in many countries. But the rocks are ultimately the foundation of all life and all raw materials. Seuss recognised this in his coinage of the term 'biosphere' in 1875, seeing life as an integral part of the lithosphere, and a geological process. The forgetting of this fact leads to wrong assessments of ecosystems, poor understanding of resources, and of how the Earth system works. This is especially so in terms of the appreciation of geological systems in basins and rifts.

In order to help rectify this deficiency, I and numerous colleagues have been working on a Global Geological Framework, to be presented in a way that can convey the global system in a clear and accessible way for both specialists and non-specialists. The framework allows any geological site (including ecological or economic) to be seen in the context of the global Earth system. Thus its relevance can be fully appreciated. In this presentation I review those previous frameworks that have existed and explain the development of the current one.

We propose one that could be adopted as a standard to be used internationally for geosciences and geoscience outreach. The value of the framework is that it allows to place a site clearly and simply in its setting, and can be used to compare and contrast sites. It also provide a quick and easy appreciation of the broader Earth system. We provide three types of representation that can be used together. The first is the core table (**Figure 1**), which holds all geological environments and processes in a generalised way. The second is a schematic cut through the Earth showing the different geological spheres and their interactions. The third is a system diagram that schematically depicts the links and evolution of the system in question.

To illustrate the use and demonstrate the methodology we provide examples for various UNESCO World Heritage sites where such a framework is indispensable for comparing sites. We use Grand Canyon, The Chaîne des Puys - Limagne fault, Vatnajokull national park, as examples to show how the framework can be used to discriminate between sites and to represent their value for all a multiple of outreach purposes to stakeholders from global to local, government to individual.

Finally, we have realised that our table is best represented by symbols of geological phenomena, and processes, and we propose an initial 'Geomoji' set of these that can be used in broadening the outreach of our science (**Figure 2**). The ‘Geomoji’ icons are a move to allow simple globally recognised symbol of key parts of the system and, once in place, would be a part of internationally recognised symbols used in information signs and documents for the general public.

This presentation will be an opportunity to review those related to basins as part of the global Geological system to make basins great again.

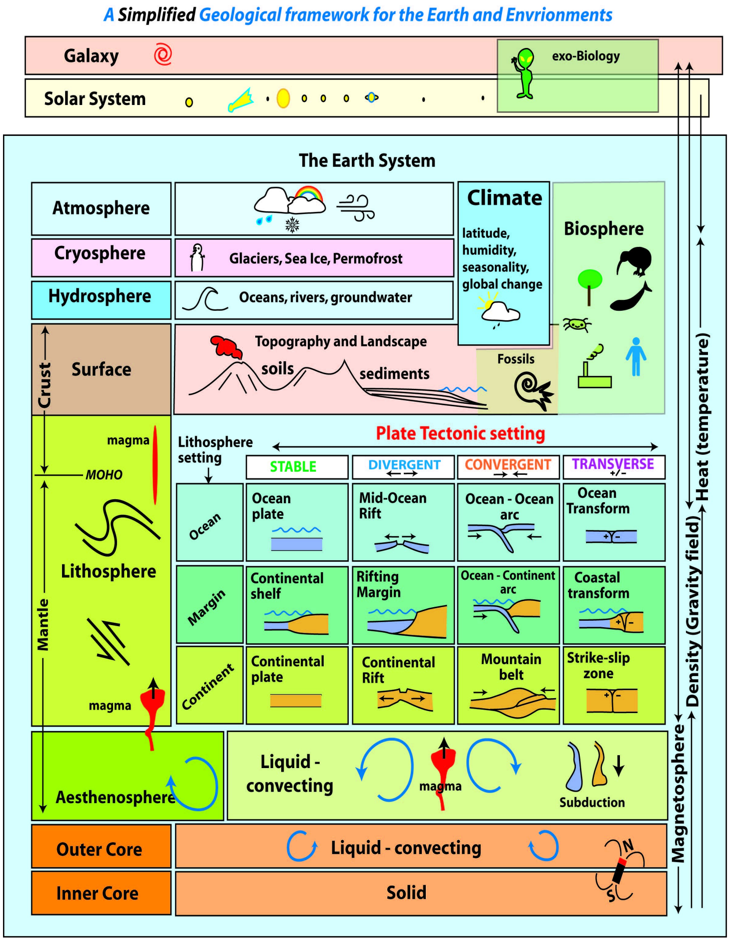


Figure 1. The Global Geological Table suggested to be used as a framework for Making the Earth Great Again. This boldly goes from the core to the galaxy and beyond to encompass all the Earth system and its external influences.

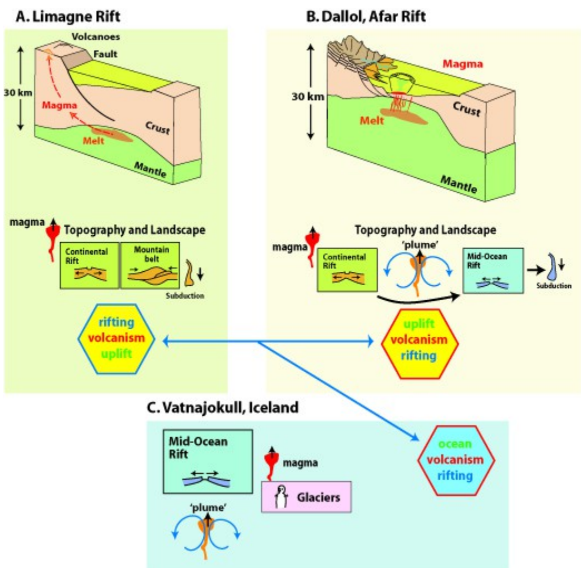


Figure 2. 'Geomoji' use in discriminating basin environments. An illustration of the use of the global geological framework for three basin / rift environments. **A**. The Limagne Rift (with the Chaîne des Puys) – a passive rift driven partly by lithospheric subduction of the alps. **B**. The Afar rift (with Dallol) – a continental hot spot related rift. **C**. Vatnajökull, Iceland, which is a mid-ocean ridge with hot spot interactions.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract

Talk preference

Title: Joint application of thermo-mechanical and stratigraphic numerical modeling: the tectono-sedimentary evolution of asymmetric extensional basins

Authors: Balázs A[1], Matenco L[1], Granjeon D[2] and Cloetingh S[1]

Affiliations: **1** Tectonics Group, Utrecht University, Utrecht, the Netherlands;
2 IFP Energies Nouvelles, Rueil-Malmaison, France

Contacts: a.balazs@uu.nl, l.c.matenco@uu.nl, didier.granjeon@ifpen.fr, s.a.p.l.cloetingh@uu.nl

Abstract text

The formation and evolution of extensional basins are controlled by the overall crustal and lithospheric thinning linked to their rheological layering, amount and rates of extension, as well as surface processes, such as erosion and sedimentation coupled with climatic variations. Understanding the inherent connections between large-scale tectonic and local basin-scale surface processes requires the joint application of thermo-mechanical and stratigraphic modeling techniques (Figure 1).

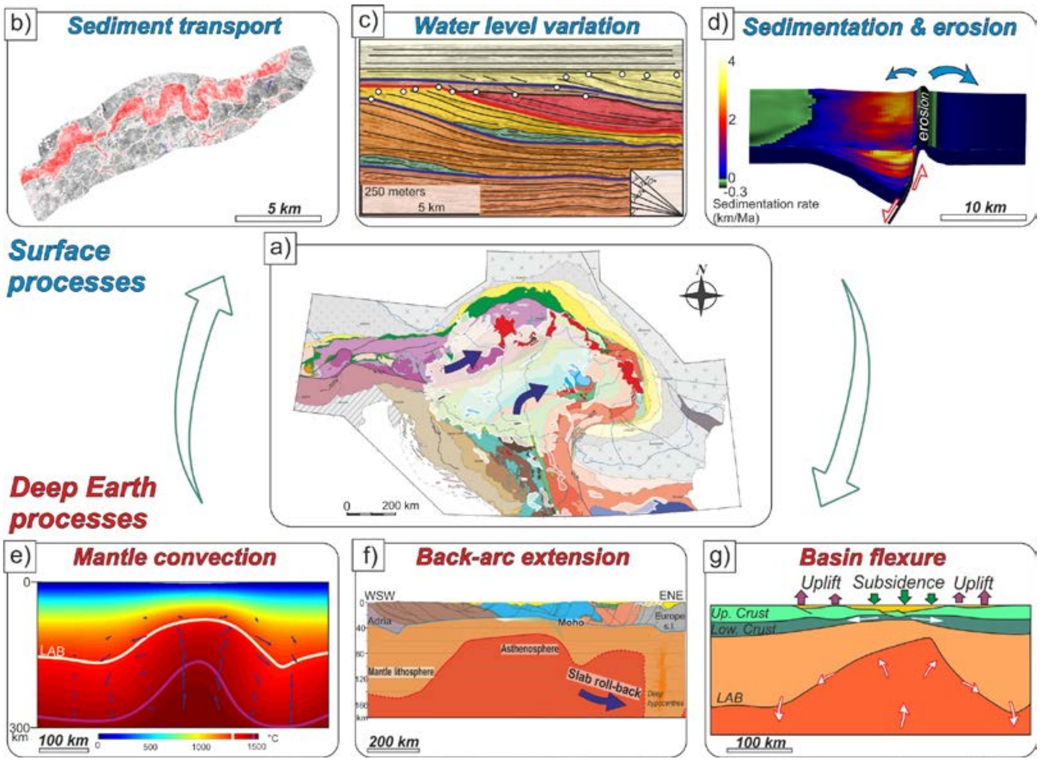


Figure 1. Synthesis of the main surface and tectonic processes that affect the formation and evolution of asymmetric back-arc basins, analyzed in our integrated numerical modeling study.

In this study we applied the coupled thermo-mechanical lithospheric-scale 2D code Flamar v12 (Burov, 2007) and the high-resolution 3D deterministic stratigraphic software DionisosFlow (Granjeon, 2014). We conducted a series of experiments to analyze the extension, subsidence and thermal evolution of an initially thick, hot lithosphere with a pre-existing suture zone resulting from an earlier orogenic phase (Balázs et al., 2017a, b). In such settings, the syn-rift subsidence rates are initially low to moderate and are associated with uplift pulses, creating asymmetric sub-basins where extensional deformation migrates in space and time. The subsequent post-rift times are characterized by kilometer-scale differential vertical movements caused by further mantle dynamics enhanced by sediment re-distribution and lower crustal flow effects.

The modeled tectonic subsidence and uplift rates and half-graben geometries are imported into the 3D stratigraphic modelling code. Our modeling of a 120 km × 150 km area shows that such scenarios are associated with continental alluvial to shallow-water sedimentation and footwall erosion during the early stages of the syn-rift, followed by rapid deepening during the subsequent syn-rift evolution. Finally, during the following post-rift times the basins are filled by a large-scale prograding shelf-margin slope system. This modeling quantifies forcing factors, such as tectonics, sea-level and climatic variations associated with water and sediment influx. The sedimentary architecture evolution is analyzed by the modeled paleo-water depth, erosion and sedimentation rates and lithology distribution inside the half-grabens and neighboring areas. Our modeling highlights the differences between the low-order tectonic and higher order sea-level and climatic-driven transgressive-regressive cycles and we analyze the auto-cyclic nature of the depositional systems. Our results are compared with geological and geophysical constraints from the Pannonian Basin of Central Europe and the South China Sea.

References

Balázs A., Burov E., Matenco L., Vogt K., Francois T., Cloetingh S., 2017: Symmetry during the syn- and post-rift evolution of extensional back-arc basins: the role of inherited orogenic structures. Earth and Planetary Science Letters 462, 86-98.

Balázs A., Granjeon D., Matenco L., Sztanó O., Cloetingh S., 2017: Tectonic and climatic controls on half-graben sedimentation: inferences from numerical modelling. Tectonics

Burov E., 2007. The role of gravitational instabilities, density structure and extension rate in the evolution of continental margins. Geol. Soc. London Spec. Publ. 282, 139-156.

Granjeon D., 2014. 3D forward modeling of the impact of sediment transport and base level cycles on continental margins and incised valleys, Int. Assoc. Sedimentol. Spec. Publ. 46, 453-472.

Temperature and compositional variations of the Australian upper mantle

Magdala Tesauro (1,2), Mikhail K. Kaban (3), Alan R.A. Aitken (4)

(1) Università di Trieste
(2) Department of Earth Sciences, Utrecht University
(3) GeoForschungsZentrum Potsdam (GFZ)
(4) University of Western Australia

mtesauro@units.it, kaban@gfz-potsdam.de, alan.aitken@uwa.edu.au

The Australian continent has on average a low topography (< 1000 m) in comparison to the other continental plates and the crust is progressively younger from west (Archean-Proterozoic) to east (Phanerozoic). The oldest terranes composing the Australian continent are represented by three main Archean cratons: West Australia, the North Australian Craton, and the South Australian Craton, which formed about 1.8 Gyr and were assembled to the Rodinian supercontinent during the Proterozoic by 1.3–1.1 Ma. Rodinia broke up ~ 800 Ma and, in the late Palaeozoic, the fold belt structures of the Phanerozoic Tasman Orogen were accreted, in different stages, onto the eastern margin of the Precambrian cratons.

The crust and upper mantle of the Australian continent have been deeply investigated in the last two decades using a variety of geophysical methods. The resulting models have revealed the robust large-scale features of the continental lithosphere of Australia, i.e., faster seismic wave speeds in the Archean and Proterozoic cratons in the West, North and South Australia and slower wave speeds in the eastern Phanerozoic margin. Furthermore, it has been identified the area of low seismic wavespeeds in the uppermost mantle beneath central Australia, underlain by fast wavespeeds, more typical of the continental lithosphere. This layered velocity structure may have a thermal origin, due to the redistribution of high heat producing elements within the crust or reflects the presence of amphibole.

To discern temperature and compositional variations of the Australian upper mantle, we apply an iterative technique, which jointly interprets seismic tomography and gravity data. This technique consists in removing the effect of the crust from the observed gravity field and topography. In the second step, the residual mantle gravity field and residual topography are inverted to obtain a 3-D density model of the upper mantle. The inversion technique accounts for the notion that these fields are controlled by the same factors but in a different way (e.g., depending on depth and horizontal dimension of the heterogeneity.) This enables us to locate the position of principal density anomalies in the upper mantle. Afterwards, the thermal contribution to the density structure is estimated by inverting the seismic tomography model AusREM (http://rses.anu.edu.au/seismology/AuSREM/index.php). We improve the initial thermal and compositional models iteratively. The final thermal model, compared to the initial one, shows temperatures higher by 100-150 °C in the Archean and Proterozoic upper mantle. Furthermore, we observe larger iron depletion in the Western Australian craton than in the Proterozoic terranes. At the depths larger than 150 km, the depletion becomes negligible beneath the Proterozoic regions, while it persists in the Western Australian craton also below the bottom of the lithosphere. We interpret this feature as the result of the leakage of mantle depleted, possibly caused to by the erosion of the lithospheric mantle, which was formerly thicker than in present days.

About a role of process of an isostasy in formation of a sedimentary cover of Greater Caucasus, its folded structure and a mountainous uplift (the factor analysis)

Yakovlev F.L., Gorbatov Ye.S., Institute of physics of the Earth of RAS, Moscow, Russia
e-mail: yak@ifz.ru , e.s.gor@mail.ru

The reality of natural processes of formation of sedimentary basins with the subsequent formation of folded and faulted structure in layered complexes and the uplift of mountains has to be reflected in regular changes of many parameters that have relation to structure and to character of development. Use of methods of statistics for the analysis of such parameters in this case will give material for a suggestion of the realistic models. This task has been solved for the sedimentary cover of Greater Caucasus by new methods of structural geology. The region is well studied, but there are different interpretations of its history of development and structure [Saintot et al., 2006; Leonov, 2007]. There are materials of the detailed structural cross-sections with a total length about 500 km, suitable for such researches [Yakovlev, 2015].

Among important parameters of structure the dimension of fold-related shortening in large blocks of rocks has to play a key role in the geodynamics study. For restoration of pre-folded structure of a sedimentary cover and for definition of important data of modern structure, the method of "geometry of folded domains" was used [Yakovlev, 2009]. The system of hierarchy of seven levels which is uniting objects of the different size from the deformed grains (the 1-st level) and usual folds (2nd one) to the folded systems of type of Greater Caucasus (6th) and mobile belts (7th level) was one of theoretical bases of the method. "Folded domains" (the third level, modern width about 1-2 km along a profile, unites packages of layers with a thickness of 0.5-2 km) and “structural cells” (the fourth level, width of 3-7 km, embrace a sedimentary cover of 10-15 km thickness) participated in measurement of shortening and in a restoration of pre-folded and modern structure. Deformations of "domains" are described by a strain ellipsoid with which the measured parameters of folds are compared, such as an inclination of the axial plane of folds, interlimb angles of folds, an inclination of an envelope plane of folds and other (fig. 1A). Three kinematic operations were applied in a restoration of the domain up to their pre-folded state (fig. 1 B): 1) – rotation (to a state of II), 2) horizontal simple shearing (to a state of III), 3) horizontal lengthening or clean shearing (to a state of IV). As a result, the segment of the line of a profile obtains other length and an inclination in horizontally layered medium. Thereafter all domains were united, taking into account displacements on faults.

“Structural cells” were allocated by aggregation of domains so that their general width in a pre-folded state approximately was equal (or some lesser) to the thickness of entire sedimentary cover. The relation of width of modern structure and pre-folded one is calculated as the value of shortening of a “structural cell”. For the subsequent calculations, the full thickness of a sedimentary cover, depth of the line of a profile of domains in stratigraphic model (based on age of rocks and thicknesses of deposits) and altitude of line of cross-section are used. It allows calculating the depth of sole of the cover (i.e. depth of basement top), conditional height of a cover top and an eroded part of sedimentary rocks (fig. 2, the stage 3).

For calculations, the most general model of development of the region, which is hypothetical partly, was also used (fig.2). Entire thickness of sedimentary cover was accumulated for the end of stages 1. At a stage 2, the folding with complete shortening took place without uplift and erosion of top of the cover. At the stage 3, the uplift and erosion of the upper part of sediments occurred (fig. 2). For 24 profiles, 505 domains were selected and then were integrated in 78 structural cells. For all cells, values of next six parameters were measured (*) or calculated: (1) the initial thickness of the sedimentary cover or depth of basement top (DBT) at a stage 1 (b1*); (2) values of shortening (Sh*); (3) DBT at a stage 2 after shortening (b2); (4) DBT at the

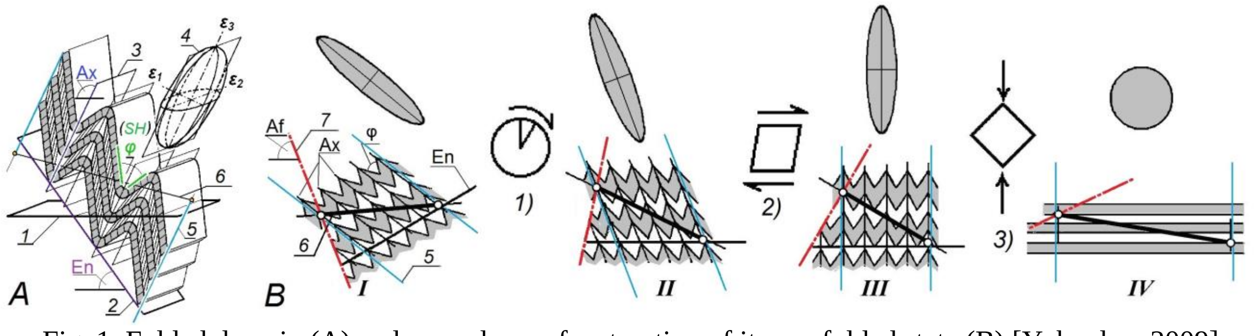


Fig. 1. Folded domain (A) and procedures of restoration of its pre-folded state (B) [Yakovlev, 2009].
1 – horizontal plane; 2 – an inclination of initial layering (En – dip angle); 3 – the fold axial plane (Ax – dip angle); 4 – strain ellipsoid (φ – interlimb angle, i.e. shortening value); 5 – boundaries of domains; 6 – length and angle of tilting of segment of cross-section line for the domain; Af – dip angle of fault plane.

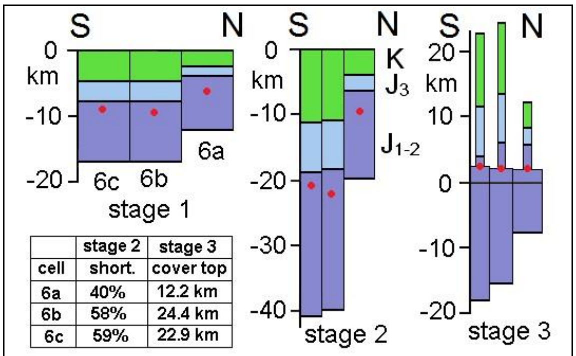


Fig. 2. Stages of structural cell development and calculations of parameters. Tfan zone.

stage 3 after an uplift of mountains (b3); (5) amplitudes of a neotectonic uplift (b3-b2*); (6) differences of depths of the basement between stages of 1 and 3 (b3–b1). The matrix of correlations for these parameters was calculated. The strong pair correlations, essential to understanding of processes of structure formation, were found, for example, (2/5) R = 0.818; (2/6) R = -0.461; (1/6) R = 0.379; (1/2) R = -0.023; (1/4) R = 0.708. It was also revealed at the qualitative level, that the depth of basement top in the modern structure in general tends to keep that level, which it acquired at the end of sedimentation. For understanding of a relation how parameters are connected to processes of structure formation, a factor analysis was used [Yakovlev, Gorbatov, 2016], in which pair correlations are not lost, but more general processes are important (table 1).

It was revealed that all data set is explained by two factors (summarized weight is 87%). The most significant factor, F1, is connected with the shortening value (2). The basement depth after a folding formation (3) and amplitude of an uplift (5) depends on it. The second factor F2 is connected with the initial depth of the basement (1) and it is interpreted as action of an isostasy. Modern depth of the basement (4) and a difference of depths of the basement (6) directly depends on it. Process of folding formation and of depended from shortening a new depth of basement top (parameter 3, loadings F1 0.736 and F2 0.665) is connected with influence of both factors. Participation of an isostasy in formation of structure should be connected with changes of density of rocks of crust up to density of mantle rocks in such large volumes, which are not stipulated by modern geodynamic models.

Table 1. Factor loadings for parameters

Parameters, (*) = “measured”		Factor loadings F1	Factor loadings F2
1	b1*	0.022	**0.790**
2	Sh*	**0.938**	-0.195
3	b2	**-0.736**	0.665
4	b3	-0.158	**0.982**
5	b3–b2*	**0.957**	0.050
6	b3–b1	-0.219	**0.853**
Weight %		60	27

Based on a supposition of the existence of permanent isostatic balance in the nature, an approximate calculation of changes of thickness of a crystalline part of crust for several stages of development of Greater Caucasus according to observed depths of the sea, thicknesses of sedimentary rocks and the shortening value was made for Chiaur (southern part of Caucasus in center) and Tfan (axial part of South-Eastern Caucasus) zones. Basal conglomerates of the bottom of entire sedimentary cover (Sinemurian) fix the 40 km thickness of crystalline continental crust. Fast immersion of structure and the beginning of accumulation of deep-sea (-3 km?) non-carbonated pelites of Lower Jurassic since Pliensbachian was followed by destruction of crystalline crust up to 25 km of thickness. At the end of process of accumulation of sediments of 15 km of thickness in the Eocene at the shallow-water sea, the thickness of crystalline crust has been further decreased on 11.5 km up to 13.5 km. The horizontal shortening of blocks in 50% (double), the uplift and an erosion of the top part of a sedimentary cover showed the calculated thickness of crystalline crust in 29.5 km thickness, that is on 2.5 km more, than simple increase in its thickness due to deformation. Rocks of the initial Moho level (for beginning of Jurassic, 40 km) exist on a depth about 100 km now. Thereby, it was defined that the volume of a crystalline part of crust, which got mantle density, is up to 60% of initial thickness. Processes of folding formation and of the shortening together with neotectonic uplift and erosion, which exist under the control of isostasy, could not take place without such transformations of densities of rocks.

Leonov Ju. G., (ed.). 2007. The Greater Caucasus in the Alpine Epoch. Moscow: Geos. 368 P. (in Russ.)

Saintot A., Brunet M.-F., Yakovlev F., Sébrier M., Stephenson R., Ershov A., Chalot-Prat F. & Mccann T. 2006. The Mesozoic–Cenozoic tectonic evolution of the Greater Caucasus. European Lithosphere Dynamics. (eds. Gee, D. G., Stephenson, R. A.). Geological Society, London, Memoirs. 32. pp. 277–289.

Yakovlev F.L. 2009. Reconstruction of Linear Fold Structures with the Use of Volume Balancing // Izvestiya, Physics of the Solid Earth. Vol. 45. No. 11. pp. 1025–1036.

Yakovlev F. L. 2015. Multirank strain analysis of linear folding on the example of the Alpine Greater Caucasus. Doctoral habil. thesis. Moscow: IPE RAS. 2015. Manuscript. 472 P. (in Russ.) http://yak.ifz.ru/

Yakovlev F.L., Gorbatov Ye.S. 2016. An identification of the main processes of formation of the Alpine Greater Caucasus based on parameters of the balanced model of its structure (the factor analysis) / Tectonophysics and actual problems in the Earth’s sciences: Materials of reports of the All-Russian conference – in 2 volumes. - V. 1. M.: IPE RAS. pp. 304-313. (in Russ.)

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Oral presentation

Title: Petroleum Reservoir Geomechanics Modelling in the Eastern Mediterranean Basin

Authors: Markou N.[1,2] and Papanastasiou P.[1]

Affiliations: [1] Department of Civil and Environmental Engineering, University of Cyprus, Nicosia, Cyprus
[2] Hydrocarbons Service, Ministry of Energy, Commerce, Industry and Tourism, Nicosia,Cyprus

Contacts: nmarkou@mcit.gov.cy, panospap@ucy.ac.cy

Abstract

Geomechanics integration into basin geology and reservoir modelling is an emerging application. It is based on the long history of rock mechanics which is continuously enhanced with new measurements, methods and computational tools. These advances couple efficiently the geomechanics with reservoir fluid mechanics and produce detailed dynamic earth representation models for the petroleum industry (Fjaer *et al.*, 2008; Zoback, 2010)

The proposed study will incorporate the regional understanding of geology, rock mechanics and tectonics in the Eastern Mediterranean basin and develop a local earth mechanical model for providing data for drilling simulators and coupling with reservoir flow simulators. Pore pressure, insitu stresses and rock deformations will be calculated using stress and strain constitutive equations, which are constructed and calibrated with material parameters derived from available data, correlations and analogues. In the first phase a computational earth mechanical model will be developed considering the regional basin evolution, depositional environment and tectonic activity during the geological history of the basin. In the second phase we will assess the geomechanical dynamics impact on the reservoir performance for different production scenaria, while further inside on the geomechanical applications related to pore pressure prediction, fault activation, reservoir deformation and deliverability will be investigated.

The Eastern Mediterranean basin evolved through the Triassic to Mid-Jurassic passive rifting tectonic episode, which followed by further regional extension and spreading, with periodic eustatic sea-level lowering until Early Cretaceous. Then, compressive stresses affected the area since the Late Cretaceous with plate convergence of Africa to Eurasia. That compressional tectonic regime resulted in regional structural deformations and formation of the Cyprus Arc thrust belt and the Syrian Arc. This was followed by a period of tectonic quiescence and subsequent extensive clastic depositions. During the Early Miocene, the second Syrian Arc compressional episode was taken place which further deformed the area with folds, reverse faults and strike-slip faults. At Late Miocene, the basin was covered rapidly by a thick section of Messinian Evaporites as a result of the isolation of Mediterranean Sea from the Atlantic Ocean. The rest overlying interval since present day consists of Pliocene-Pleistocene siliciclastic sediments deformed by salt movements and regional tectonics (Montadert *et al.*, 2014).

As a sample application, we present in Figure 1 profiles showing the model initial prediction for vertical stress (Sv) and pore pressure (Pp) in MPa for a typical geological section in the Eastern Mediterranean. The x- and y-axes present the 2D plane grid cells. The best estimates for the insitu vertical stress, minimum horizontal stress, and abnormal pore pressure with depth is shown in Figure 2a. Figure 2b shows the vertical effective stress which is a major parameter that governs deformation and failure in the rock formations. These parameter estimates can be further refined using well log data and observations at the wellbore scale. The Finite Element model after initial calibration with all data can provide the parameters elsewhere and predict their dynamic evolution with the reservoir production (Papanastasiou *et al.*, 2017).

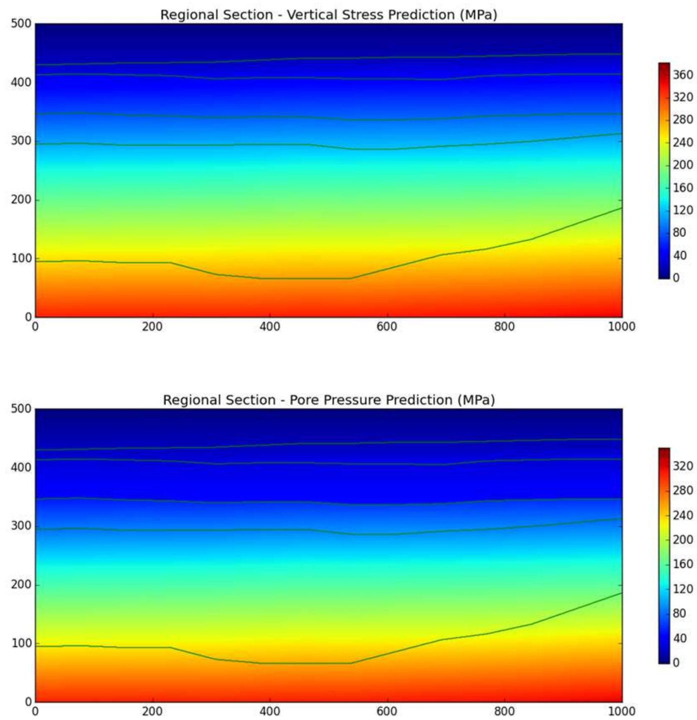


Figure 1: Stress profiles showing the model prediction for vertical stress (Sv) and pore pressure (Pp) in MPa for a typical geological section in the Eastern Mediterranean.

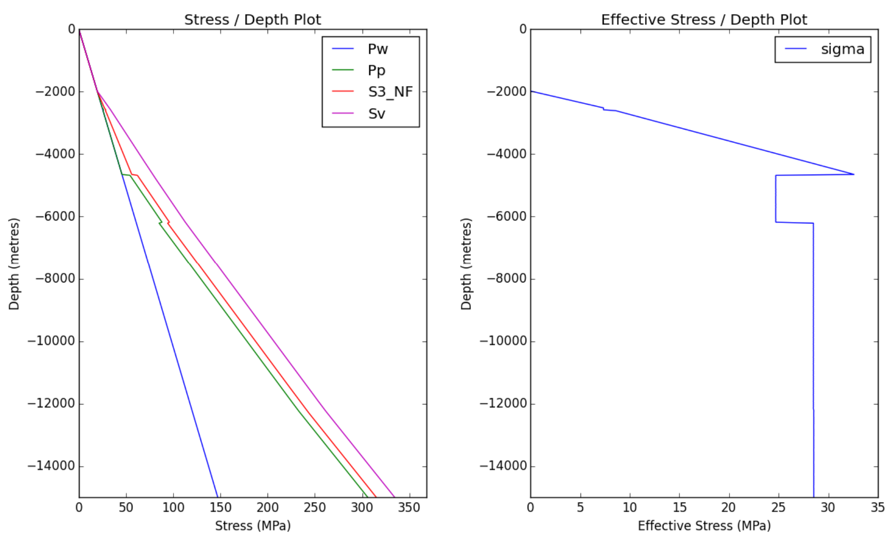


Figure 2: Estimating stress and pore-pressure values for a vertical section along the regional profile.

References:

Fjaer, E., Holt, R.M., Raaen, A.M., Risnes, R., and Horsrud, P., 2008. Petroleum Related Rock Mechanics, 2nd Edition. Elsevier Science.

Montadert, L., Nicolaides S., Semb, P.H., and Lie O., 2014. "Petroleum Systems Offshore Cyprus" *in* L. Marlow, C. Kendall and L. Yose, eds., Petroleum Systems of the Tethyan Region: AAPG Memoir 106, p. 301–334.

Papanastasiou, P., Sarris, E., and Kyriacou, A., 2017. "Constraining the in-Situ Stresses in a Tectonically Active Offshore Basin in Eastern Mediterranean", J. Petrol. Sc. Eng., 149, 208-217.

Zoback, M.D., 2010. Reservoir Geomechanics. Cambridge University Press.

Talk preference

Title: **Issues And Challenges In Deep Water Drilling**

Authors: Prof. Vassilios C. Kelessidis

Affiliations: Petroleum Institute, a part of Khalifa University of Science and Technology,
Abu Dhabi, United Arab Emirates

Contacts: vkelessidis@pi.ac.ae

Abstract

Sedimentary basins around the world containing valuable hydrocarbon resources are found at ever increasing water depths because of the great advances in seismic acquisition, processing and interpretation. The ever increasing world appetite for more hydrocarbons to feed the moderately by ever increasing demand for more energy worldwide can be satisfied with the assessment and later production of these hydrocarbon resources at ever increasing water depths.

We will present the major challenges that our industry faces when drilling in deep or ultra deep waters. Challenges identified include drilling and non drilling issues like weather. We will focus on drilling parameters which include tight pressure margins leading to narrow drilling windows, major well control issues particularly related to risers, drilling through thick salt layers, having large temperature variations from bottom to top affecting fluid flows, dealing with gas hydrates.

We will present, the risks associated when drilling in deep waters, the possible solutions to such problems that have been developed by the industry and will analyze case studies with successful and unsuccessful mitigation of these challenges.

Talk preference

Space-time evolution of a volcanic field in an extended region: the example of Campi Flegrei (Italy)

Torrente MM[1], Iannace P[1] and Milia A[2]

1 DST, Università del Sannio, Benevento, Italy;
2 IAMC, Consiglio Nazionale delle Ricerche, Naples, Italy

torrente@unisannio.it, p.iannace@alice.it, alfonsa.milia@iamc.cnr.it

The interplay between lithospheric extension, magmatism and volcanism affects the magma migration within the crust regulating frequency, volume and location of volcanic eruptions. The Campania margin (Italy), part of the Tyrrhenian Sea back-arc basin, features Quaternary continental extension, crustal magma bodies, recurrent large-volume ignimbrites and the active Vesuvius, Ischia and Campi Flegrei volcanoes. It thus provides an ideal place to investigate both the space-time evolution of a volcanic field in an extensional region and the connection between massive eruptions and regional tectonic events.
The rifting processed at the Campania margin produced three structural depressions: Campania Plain, Gaeta Bay, and Naples Bay (Fig. 1). During the Lower Pleistocene NW-SE normal faults gave rise to the Campania Plain basin that is filled by a >3 km succession of clastic and volcanic rocks. Since middle Pleistocene NE-SW normal faults controlled the geomorphologic and sedimentary evolution of the margin and formed structural highs (e.g. Sorrento Peninsula) and depressions (Naples Bay and Salerno Bay) (Milia and Torrente, 1999). Fourth-order depositinal sequences (100 ka) have been reported in the Quaternary succession of the Campania margin (Milia and Torrente, 1999, 2015).

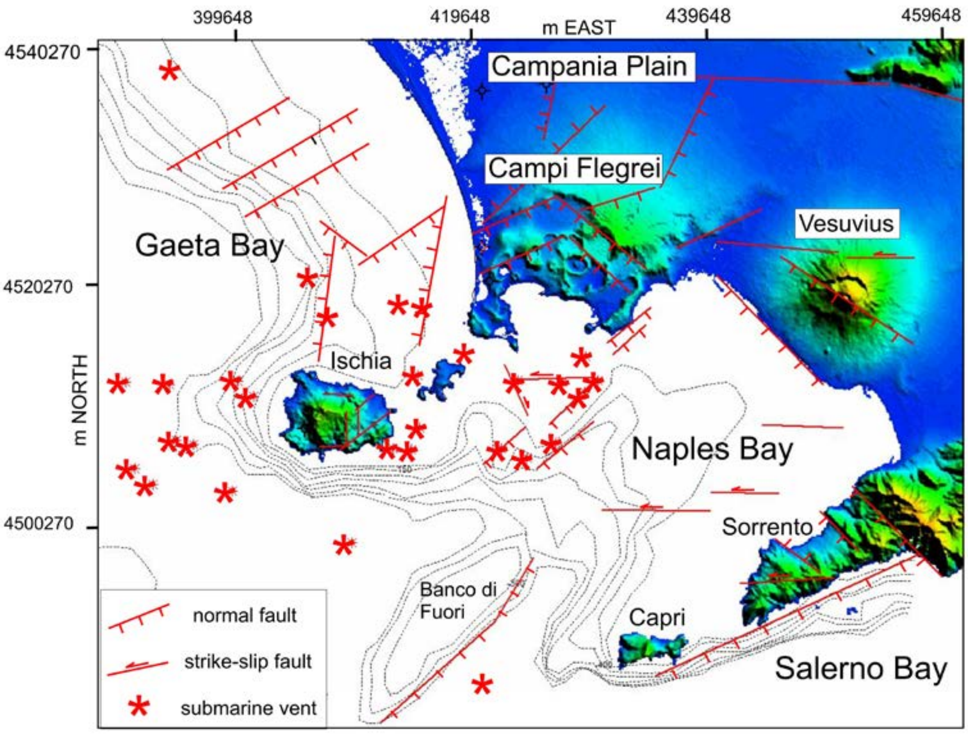


Figure 1. Tectonic map of the Campania Margin displaying volcanoes and domes of Naples Bay and southern Gaeta Bay. Modified from Torrente and Milia (2013).

Campi Flegrei is a high-risk volcanic area and displays outstanding example of crustal deformations. It is sited in the southern part of the Campania Plain and border with Naples and Gaeta bays (Fig. 1). Since 0.3 Ma, voluminous ignimbrites were emplaced in the Campanian Plain (De Vivo et al. 2001) that culminated at 39 ka with the Campania Ignimbrite eruption (V.E.I.=7) that is the largest magnitude explosive event of the Mediterranean area over the past 200 ka. The Campi Flegrei volcanic field comprises several monogenic

volcanoes (tuff cones and tuff rings), and rare lava domes; the oldest dated volcanic activity occurred at 0.08 Ma and the last volcanic eruption occurred in A.D.1538 at Monte Nuovo. The Neapolitan Yellow Tuff (V.E.I.=5), with an assessed total volume of 50 km3 DRE, erupted in the Campi Flegrei area 15 ka ago. The source, subsidence region and structure controlling the emission of Campania Ignimbrite and Neapolitan Yellow Tuff is a critical element to evaluate the volcanic hazard of Campi Flegrei. The available literature reports two alternative models of ignimbrite emission at Campi Flegrei: caldera or regional faults. The choice of the volcano-tectonic model of Campi Flegrei also depends on the amount and distribution of these ignimbrites in the adjacent marine area.
We built a geological-geophysical database of the Campania margin made up of single-channel and multichannel seismic reflection profiles and shallow and deep well stratigraphies. Using seismic stratigraphy, basin analysis and structural geology approaches in a dedicated GIS environment we interpret our database. By means of information technology, we made 3D geological models to develop solution that explain the stratigraphic and structural complexity (e.g. relationship between volcanic units and faults) of the region. We made a 3D reconstruction of a volcanic field in the marine areas of Naples Bay and Gaeta Bay. Such submarine volcanoes are comparable in size to the edifices of Campi Flegrei and Vesuvius, and are controlled by regional normal faults trending NW-SE, NE-SW, NNE-SSW and E-W (Torrente and Milia, 2013). Furthermore we interpreted Campi Flegrei as a structural depression due to asymmetrical subsidence along normal separation faults trending NE-SW and NW-SE and reconstructed the architecture of the ignimbrites (Milia and Torrente, 2007, 2011). The ignimbrites and the submarine volcanoes formed during late Quaternary rifting event of the Campania margin characterized by: WSW-ENE extension direction; re-activated, as oblique normal faults, of previous NW-SE and NE-SW structures; formation of new NNE-trending normal faults. Besides the structural control of regional faults on ignimbrite emission is confirmed by new stratigraphic and 40Ar/39Ar geochronological data of the 501 m-deep hole drilled at Campi Flegrei (De Natale et al., 2016).
From the results obtained we conclude that:
1. There is a link between volcanic eruptions and stages of tectonic subsidence.
2. Faults activity and volcanism migrated with time.

References

De Natale, G., Troise C., Mark D., Mormone A., Piochi M., Di Vito M.A., Isaia R., Carlino S., Barra D., Somma R. (2016) The Campi Flegrei Deep Drilling Project (CFDDP): New insight on caldera structure, evolution and hazard implications for the Naples area (Southern Italy), Geochem. Geophys. Geosyst., 17, doi:10.1002/2015GC006183.
De Vivo B., Rolandi G., Gans P.B., Calvert A., Bohrson W.A., Spera F.J., Belkin H.E. (2001) New constraints on the pyroclastic eruptive history of the Campanian volcanic Plain (Italy). Miner. Petrol., 73, 47–65.
Milia A., Torrente M.M. (1999) Tectonics and stratigraphic architecture of a pery-Tyrrhenian half-graben (Bay of Naples, Italy). Tectonop., 315, 297-314.
Milia A., Torrente M.M. (2007) The influence of paleogeographic setting and crustal subsidence on the architecture of ignimbrites in the Bay of Naples (Italy). Earth Planet. Scie. Lett., 263, 192-206.
Milia A., Torrente M.M. (2011) The possible role of extensional faults in localizing magmatic activity: a crustal model for the Campanian Volcanic Zone (Eastern Tyrrhenian Sea, Italy). Journ. Geolog. Soc., 68, 471-484.
Milia A., Torrente M.M. (2015). Tectono-stratigraphic signature of a rapid multistage subsiding rift basin in the Tyrrhenian-Apennine hinge zone (Italy): a possible interaction of upper plate with subducting slab. J. Geodyn. 86, 42–60. http://dx.doi.org/10.1016/j.jog.2015.02.005.
Torrente M.M., Milia A. (2013) Volcanism and faulting of the Campania margin (Eastern Tyrrhenian Sea, Italy): a three-dimensional visualization of a new volcanic field off Campi Flegrei. Bull. Volcanol., 75 (6: 1-13), doi 10.1007/s00445-013-0719-0.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Oral presentation

Title: On the fracture propagation direction induced in hydraulic fracturing and CO2 Geological Storage

Author: Panos Papanastasiou[1]

Affiliations: [1] Department of Civil and Environmental Eng., University of Cyprus, Nicosia, Cyprus
Contacts: panospap@ucy.ac.cy

Abstract

Among the outstanding technical issues in hydraulic fracturing is the fracture containment. In CO2 geological storage and the risks of hydraulic fracturing and migration of CO2 in upper formations and to the atmosphere, the wellbore CO2 injectivity and the storage capacity of the formation.

We present a contribution on these issues based on results of the modelling work of hydraulic fracturing in weak formations. The work was initially carried out with finite element analysis with a fully coupled elastoplastic hydraulic fracturing model and later was extended to analytical work based on a Mohr-Coulomb dislocation model where the complete slip process that is distributed around the crack tip was replaced by superdislocations that are placed in the effective centers of plastic deformation. We found that plastic yielding provides a shielding mechanism near the tip resulting in an increase of the effective fracture toughness. Higher pressure is needed to propagate a fracture in a weak elastoplastic rock and the created fracture is shorter and wider than an elastic-brittle fracture (Papanastasiou, 1999; Sarris and Papanastasiou, 2013)

Scaling of the FEM and analytical results enables the identification of a dominant parameter, which defines the regimes of brittle to ductile propagation and the limit at which a mode-1 fracture cannot advance. We found that the brittleness or ductility in hydraulic fracturing is a function of both rock strength and stress field and cannot be considered in isolation as a function of one parameter. Furthermore, the stress-field relevant to fracture plane depends on the direction that the fracture front will propagate. A fracture front that advances in the vertical direction propagates under anisotropic stress field, hence in a more ductile regime, where as a fracture front that advances in the horizontal directions is more likely to propagate in a brittle regime.

As an example we present in Figures 1 and 2 results of analytical dislocation models for a frictionless material or undrained analysis and for a frictional material and drained conditions, respectively. The dominant loading parameter is shown in the horizontal axis in terms of the plastic rock parameters. The results at the RHS of the curves are interpreted to correspond to a fracture front that propagates vertically whereas moving to the LHS the results correspond more to a fracture front that propagates horizontally. It is clear that much higher energy is dissipated in plastic deformation around the tip of the fracture that propagates vertically. The dashed lines in both figures show the results of the model with rock properties impaired by the CO2 corrosive action. For the damaged material the limit beyond no fracture will propagate in mode-1 has moved to the left. Close to that limit all the predicted quantities have greater values than in the case of the original material suggesting that the damaged material exhibits more ductile behavior compared to the original one.

We conclude that a hydraulically induced vertical fracture from CO2 injection is more likely to propagate horizontally than vertically, remaining contained in the storage zone. The horizontal fracture propagation will have a positive effect on the injectivity and storage capacity of the formation.

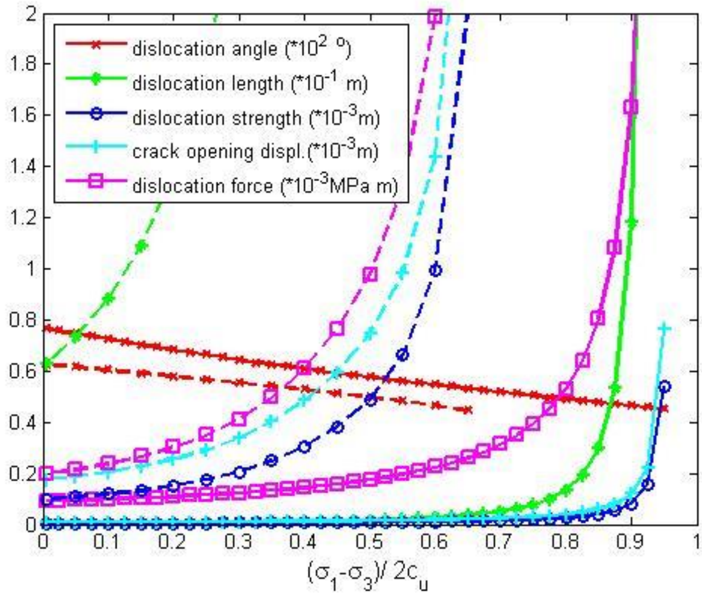


Figure 1. Calculated quantities vs ductility number for undrained analysis and large scale yielding with material original values (solid lines) and impaired values (dashed lines).

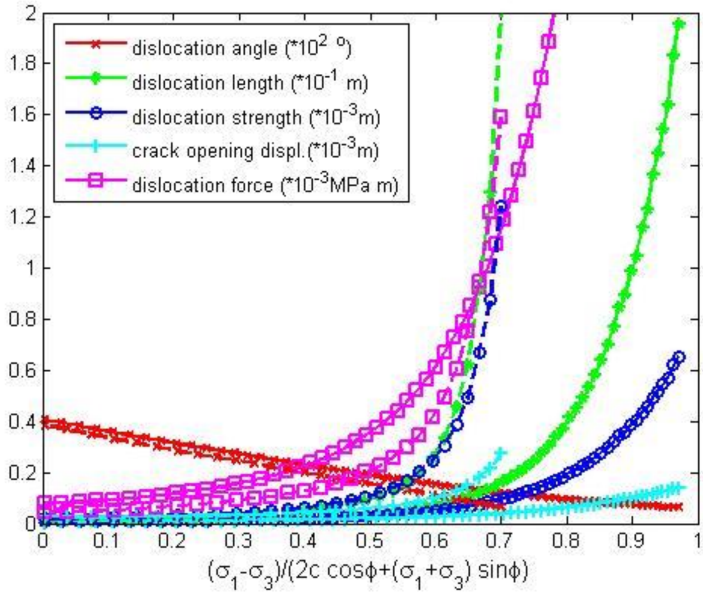


Figure 2. Calculated quantities vs ductility number for drained frictional analysis and large scale yielding with material original values (solid lines) and impaired values (dashed lines).

References:

1. Papanastasiou P. The effective fracture toughness in hydraulic fracturing. Int. J. Fracture, 96, pp.127-147 (1999).
2. Sarris E., Papanastasiou P. Numerical Modelling of Fluid-Driven Fractures in Cohesive Poro-elastoplastic Continuum, Int. J. Num. Anal. Methods Geomechanics, 37 (12), 1822-1846 (2013).
3. Papanastasiou P, Papamichos E and Atkinson C. On the Risk of Hydraulic Fracturing in CO2 Geological Storage, Int. J. Num. Anal. Meth. Geomech. 40, 1472-1484 (2016).

Flood risk assessment for the Lebanon

Abstract

Of all natural disasters, floods affect the greatest number of people worldwide and have the greatest potential to cause damage. Nowadays, with the emerging global warming phenomenon, this number is expected to increase. The Eastern Mediterranean area, including Lebanon (10452 Km^2, 4.5 M habitant), has witnessed in the past few decades an increase frequency of flooding events. This study profoundly assess the flood risk over Lebanon covering all the 17 major watersheds and a number of small sub-catchments. It evaluate the physical direct tangible damages caused by floods. The risk assessment and evaluation process was carried out over three stages; i) Evaluating Assets at Risk, where the areas and assets vulnerable to flooding are identified, ii) Vulnerability Assessment, where the causes of vulnerability are assessed and the value of the assets are provided, iii) Risk Assessment, where damage functions are established and the consequent damages of flooding are estimated. A detailed Land Cover\Use map was prepared at a scale of 1/ 1 000 using 0.4 m resolution satellite images within the flood hazard zones. The detailed field verification enabled to allocate and characterize all elements at risk, identify hotspots, interview local witnesses, and to correlate and calibrate previous flood damages with the utilized models. All filed gathered information was collected through Mobile Application and transformed to be standardized and classified under GIS environment. Consequently; the general damage evaluation and risk maps at different flood recurrence periods (10, 50, 100 years) were established. Major results showed that floods in a winter season (December, January, and February) of 10 year recurrence and of water retention ranging from 1 to 3 days can cause total damages (losses) that reach 1.14 M$ for crop lands and 2.30 M$ for green houses. Whereas, it may cause 0.2 M$ to losses in fruit trees for a flood retention ranging from 3 to 5 days. These numbers differs according to the flooding season, cultivation type and the agro-climatic zone. The flood damage equivalence to constructions summed up to reach 32 M$ for residential structures, 29 M$ for non-residential structures, and 5 M$ for the Syrian refugees tents, while structures' content losses were estimated at 27M$, 54M$, 7 M$ respectively for the same flood frequency. The total length of affected road networks during flooding is 1589km with an estimated cost of 565M$. The total number of affected population reached 82,000 while the number of effected vehicles is 62,000 for a 50year recurrence period

PLATFORMS AND IMAGE PROCESSING TECHNIQUES FOR DESCRIMINATING LANDSLIDES IN LEBANON

Abdallah, C., *Ibrahim, E., Harb, J., Abdelmassih, D., Hage Chehade, F.*

Landslides represent a serious threat to human life and activities in most mountainous areas. However, due to the rugged nature of such terrain, it is often difficult to detect such phenomena in remote areas. Hence, satellite imagery offers many attractions for the examination of landslides in such environments, especially in less developed nations in which resources are stretched and levels of environmental information limited. There is a need to ensure that the techniques and images used are effective, reliable, and cheap in terms of the amount and accuracy of data that can be extracted. Nevertheless, satellite images have been used worldwide to visually identify large landslides without differentiating other types of landslides. Moreover, the reliability in detecting mass movements can differ to a wide extent according to the processing technique used and the sensor chosen in addition to the overall mapping errors of visual image interpretation may vary between 60 and 90% when different surveyors are making the interpretation and judgment, even of the same area. Taking Lebanon as a case study, this paper compares the applicability of different satellite data sensors (Landsat (Thematic Mapper), IRS, SPOT(4), ALOS (AVNIR-2), IKONOS) and preferred image-processing techniques (False Colour Composite ‘FCC’, pan-sharpen, principal-component analysis ‘PCA’, Anaglyph) for the mapping of different mass wasting recognized as landslides, rock and debris falls, and earth flows. Moreover, Differential interferometry synthetic aperture radar (DInSAR) based on multi sensor approach has been also used allowing the identification of the status of land stability. In this context, several imageries acquired from different platform; ENVISAT- 29 scenes on a span of six years, ERS1/2 -27 scenes on a span of eight years, and ALOS-PALSAR- 8 scenes on a span of two years, were used to build up an adequate relatively short baseline interferograms. On a local sites, Aerial drones was used to monitor the huge earthflow of Kfarnabrakh and to build time series of this failure. Results from satellite imagery revealed over 10, 000 different landslides over the whole country and allowed on the national level to observe displacement exceeding ~8 cm/yr using DInSAR. While aerial drone helped to calculate wasted areas and volumes that exceeded the 700 sqm and 15,000 qm in one failure respectively.

Key words: Mass movements, InSAR, image processing, mountainous areas,

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Talk preference

Title: A review of analysis methods of geotechnical problems pertinent to offshore pipelines and the role of numerical simulations

Authors: Loukidis D[1]

Affiliations: **1** University of Cyprus, Cyprus

Introduction

Offshore pipelines need to be designed against hazards imposed by sudden events, such as earthquakes, and the adverse effects of the soft soil conditions characterizing the seabed. This presentation reviews two major geotechnical problems involved in the geohazard assessment for subsea pipelines: 1) slope stability (landslides) and 2) the propagation of seismic fault rupture through soft sediments, pointing to the particularities introduced by the presence of much softer geomaterials than commonly encountered in onshore applications (Randolph & Gourvenec 2011).

Slope stability

The stability of slopes has been traditionally assessed using limit equilibrium methods (such as the various popular methods of slices) for the calculation of the quantity called factor of safety (FS), which is, in essence, the ratio of the actual shear strength of the soil to that needed to have the slope at incipient failure. Under seismic conditions, apart from the FS, slope safety can be quantified alternatively by the critical seismic coefficient k_c, i.e. the horizontal pseudo-static acceleration that needs to be applied to the slope to bring it to incipient failure (Kramer 1996). Moreover, the k_c can be subsequently used as input in Newmark sliding block analysis or empirical equations for the estimation of the permanent slope displacements caused by earthquakes. Interestingly, the limit equilibrium solutions produce FS (or k_c) values that are valid for materials that follow an associated flow rule, i.e. the dilation angle ψ (which quantifies how much the geomaterial tends to dilate during shearing failure) is equal to the friction angle ϕ (Loukidis 2003). Finite element analysis of slope stability reveals that k_c (and consequently FS) decreases with decreasing dilatancy angle ψ (Figure 1). However, geomaterials, in general, have dilatancy angle values distinctively lower than the friction angle. Soft sediments (e.g. loose sand, soft clay, calcareous ooze), in particular, are characterized by very small ψ values (close to zero). In addition, under the undrained conditions prevalent in the seismic problem, the apparent ψ is equal to zero. As a consequence, the actual k_c of submarine slopes is expected to be 15% to 30% smaller than that obtained using classical limit equilibrium approaches and, thus, application of a correction factor is needed. Alternatively, analysis of potential submarine landslides could be done using numerical methods (e.g. finite element analysis), which effectively can handle $\psi<\phi$.

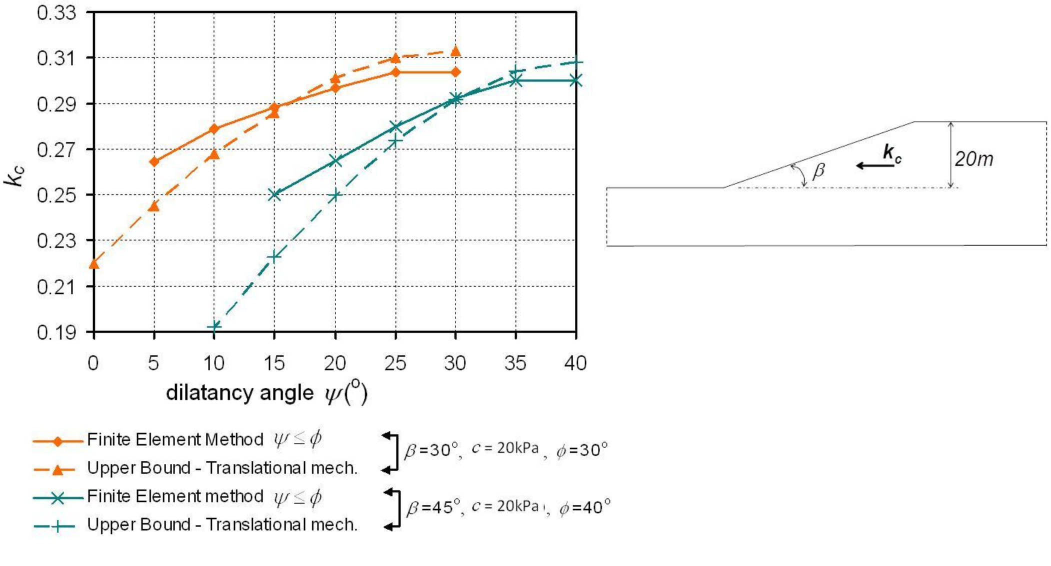


Figure 1. Examples of the effect of dilatancy angle ψ on the calculated critical seismic coefficient k_c.

Loose coarse-grained sediments are also highly susceptible to earthquake-induced liquefaction. In slopes, this phenomenon leads to rapid slope failures (flow liquefaction). If a submarine slope under a given seismological environment is identified as susceptible to develop flow liquefaction, the limit equilibrium computations need to be performed not with the friction angle operable under static conditions (which is usually larger than 28^o) but with an apparent friction angle ϕ_a, which is of the order of 7^o to 15^o. Otherwise, advanced coupled numerical analysis (finite element or finite difference methods) combined with advanced constitutive models for the soils must be employed. The validity and rigorousness of such simulations has been continuously increasing in recent years.

Fault rupture deformations

In earthquake-prone regions, it is almost inevitable that long pipelines would have to cross over seismically active faults. Fault slippage of significant magnitude (such as that associated with a major seismic event) would generate substantial deformations in the overlying sedimentary cover. These deformations are quite localized in the case of dense/stiff soils and become more defused in the case of loose/soft soils. Special considerations have to be made in the design of pipelines for the length of their path passing through a zone of significant distortion of the seafloor. Numerical analyses have shown that for fault slippage displacement larger than roughly 1% of the thickness of the soil cover H, the width L of the distortion zone (Figure 2) is equal to 1.0 to 2.0 times the H. In the case of coarse-grained soils, there is a slight deviation between the aforementioned proportionality between L and H (Loukidis et al. 2009). But for practical purposes, it can be assumed that L/H is constant. Finally, the center of the distortion zone does not lie necessarily on the straight projection of the fault plane (as seen in the bedrock), but tends to deviate towards the hanging wall. The location of the center of the distortion zone depends on the type and density of the soil cover, the type of the fault and the fault dip angle β.

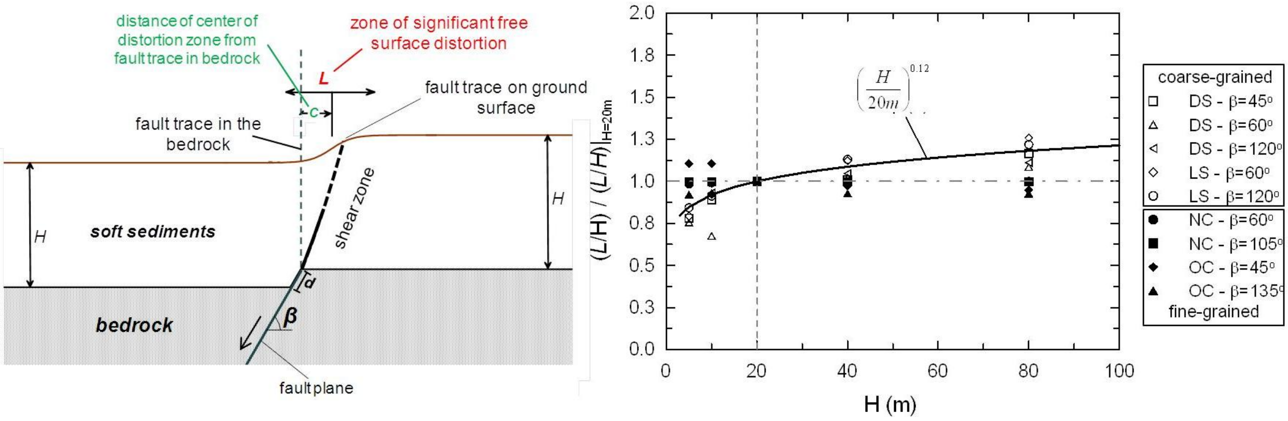


Figure 2. Effect of soil cover thickness H on the width L of the zone of significant free surface distortion.

References

Kramer, S. L. (1996). *Geotechnical Earthquake Engineering*, Prentice Hall. New York.

Loukidis, D., Bandini, P. & Salgado, R. (2003). Stability of seismically loaded slopes using limit analysis. *Géotechnique*, 53(5), 463-480.

Loukidis, D. Bouckovalas, G. D. & Papadimitriou, A. G. (2009). Analysis of fault rupture propagation through uniform soil cover. *Soil Dynamics and Earthquake Engineering*, 29(11), 1389-1404.

Randolph, M. & Gourvenec, S. (2011). *Offshore geotechnical engineering*. CRC Press.

Kinematic and depositional evolution of the External Dinarides orogenic system

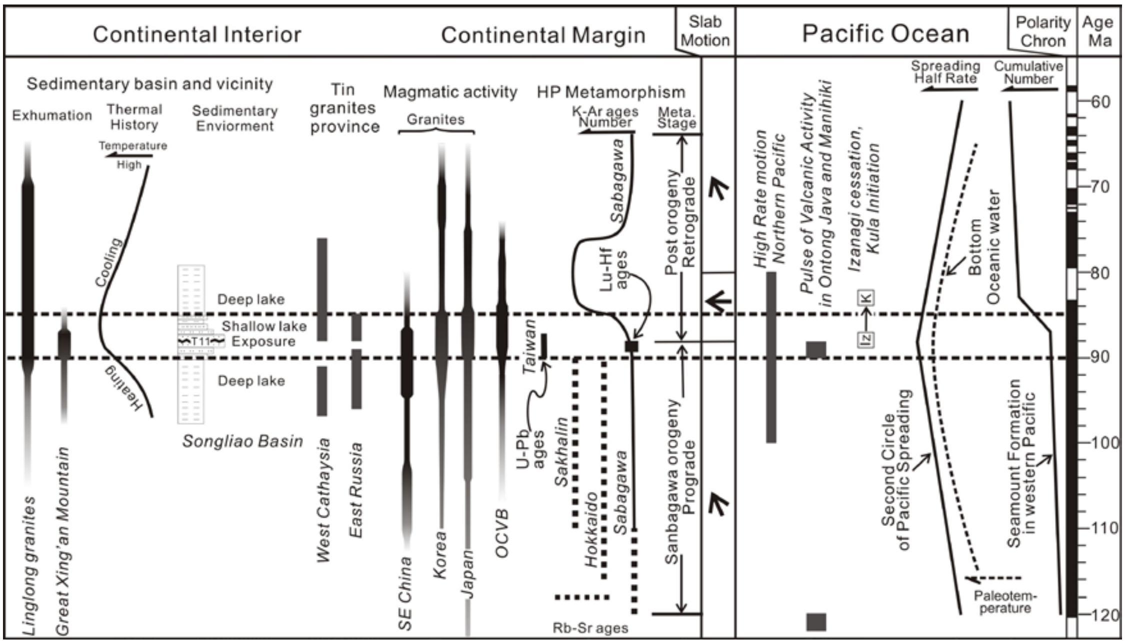
Authors: Marianne van Unen[1,2], Liviu Matenco[2], Fadi H. Nader[1], Romain Darnault[1], Oleg Mandic[3], Bruno Tomljenovic[4]

Affiliations: 1- IFP Energies Nouvelles, Rueil-Malmaison, France; 2 - Utrecht University, Faculty of Geosciences, Utrecht, The Netherlands; 3 - Natural History Museum Vienna, Austria; 4- University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, Croatia

Contacts: Marianne.van-unen@ifp.fr, l.c.matenco@uu.nl, fadi.henri-nader@ifp.fr, romain.darnault@ifp.fr, oleg.mandic@NHM-WIEN.AC.AT, bruno.tomljenovic@oblak.rgn.hr

Abstract

The construction of two crustal scale profiles across the orogenic collisional system of the External Dinarides of Montenegro, Croatia and Bosnia- Herzegovina integrates new geological information of deformation. This orogenic system is characterized by a lateral variability of contractional deformation driven by along strike changes in the mechanics of collision and subduction dynamics. We study the connection along the orogenic strike between the Miocene - Quaternary Adriatic indentation in the Southern Alps - Dinarides system with the subduction of the Ionian domain in the Albanides-Hellenides and the mantle dynamics associated with the evolution of the Aegean slab. In this context, the transition from indentation in the Dinarides to the observed balance between external contraction and internal extension in the Hellenides was thought to be accommodated in the Albanides segment, but the effects in the External Dinarides remained less known. Based on the age and distribution of syn-kinematic turbidites, classical studies of the Dinarides have inferred an Eocene episode of major shortening in the entire Dinaridic chain. Significant amounts of thrusting were accommodated in particular by the Budva-Cukali zone in the external nappes (>30 km) and at the lower nappe contact of the Durmitor unit in Montenegro. We have built a number of kinematically controlled orogenic profiles to study the lateral and depth variations in deformation style and to derive the importance and timing of various tectonic events affecting the orogen throughout Mesozoic - Cainozoic times in the External Dinarides. Our results demonstrate that a generalized moment of Miocene extension effected the entire External Dinarides, creating either Miocene basins (such as the Sarajevo basin) or exhuming rocks previously buried in various metamorphic degrees at nappe contacts. The extension reactivated the inherited NE-dipping thrust contacts, and induced large-scale exhumation (~7km) of the SW-ward located footwalls associated with half grabens filled with lacustrine endemic sedimentation in more external Dinarides nappes. This was subsequently followed by widespread Latest Miocene - Quaternary inversion that transferred the contractional deformation from the internal Dinarides in the NW to the present day continental subduction recorded in the SE External Dinarides of Montenegro, affecting all the inherited nappe-stacking and extensional structures. This along strike-transfer still takes place presently along a complex system of thick-skinned thrusts that transfers their offsets gradually to a more external position via dextral strike slip faults, reaching tens of kilometers of offsets. The new kinematic analysis in map view and cross-sections gave the ability to perform a novel balancing and restoration of the stratigraphic package to its initial depositional configuration and to perform thermal modeling constraining the main episodes of structural deformation, source rock maturation and fluid flow migration. Direct extrapolation from the sedimentary thicknesses, paleo-thermometers, and basin modeling provide estimates on the thickness of eroded series. These methods help to better predict the current petroleum potential of the External Dinarides and serve as an example for other orogenic collisional systems worldwide.


Continental Interior
Continental Margin
Slab Motion
Pacific Ocean
Polarity Chron
Age Ma
Sedimentary basin and vicinity
Exhumation
Thermal History
Sedimentary Enviorment
Temperature
High
Cooling
Heating
Deep lake
Shallow lake
T11
Exposure
Deep lake
Songliao Basin
Tin granites province
Magmatic activity
Granites
HP Metamorphism
K-Ar ages Number
Meta. Stage
Sabagawa
Lu-Hf ages
Post orogeny Retrograde
Sanbagawa orogeny Prograde
Taiwan
U-Pb ages
Sakhalin
Hokkaido
Sabagawa
Rb-Sr ages
Linglong granites
Great Xing'an Mountain
West Cathaysia
East Russia
SE China
Korea
Japan
OCVB
High Rate motion Northern Pacific
Pulse of Valcanic Activity in Ontong Java and Manihiki
Izanagi cessation, Kula Initiation
Iz
K
Spreading Half Rate
Bottom Oceanic water
Second Circle of Pacific Spreading
Paleotem-perature
Cumulative Number
Seamount Formation in western Pacific
60
70
80
90
100
110
120

The first estimation of volumes of eroded rocks of the folded Alpine sedimentary cover of Greater Caucasus for three geodynamic models having different shortening of space

Yakovlev F.L., Sorokin A.A. Institute of physics of the Earth of RAS, Moscow, Russia
e-mail: yak@ifz.ru , aas@ifz.ru

Use of calculation of erosion volumes for a upper part of folded complexes can be one of ways of checks of structural and geodynamic models. These theoretically predicted volumes can be compared to volumes of deposits of molasse in foreland basins, which were accumulated when the forming of a folding and of an uplift of a mountain building took place. Such comparison allows to make conclusions about realness of geodynamic models, which are checking [Yakovlev, Sorokin, 2016].

Three essentially different types of geodynamic models were put forward for the structure of Alpine Greater Caucasus. The differences in values of shortening of sedimentary cover and in styles of behavior of the Hercynian metamorphic basement are discerning these models from each other. The first developed model [Milanovsky, 1968] was related to the fixism conception; a shortening of a sedimentary cover and of blocks of the basement was absent in this model. The second type of models exists in a large number of versions, for example, [Dotduyev, 1987]; the principles of plate tectonics were used as their theoretic base. In these models, the considerable shortening of structures of a sedimentary cover (at least 80%) is supposed. An accretionary prism above the rigid and not deformed basement, which was subducted under the Caucasus, was most typical feature of the structure. The third developed model is the balanced structure of a sedimentary cover; it was created as a result of direct measurement of fold related shortening by methods of structural geology [Yakovlev, 2009; 2012; 2015]. Shortening in this model for relatively small blocks was found as about 50%, such deformations embraces both the sedimentary cover, and the basement beneath.

The method of measurement of value of shortening on the first step and of a restoration of structures of the cover on the second one bases on notions of tectonophysics [Yakovlev, 2009]. Structures of a sedimentary cover and larger structures are considered as set of objects of seven hierarchical levels, from intra-layer objects (deformed grains) and usual small folds to entire mobile belt. According to this hierarchic system, usual folds (the 2nd level, the width is 0.05 – 0.2 km) unite as "folded domains" (the 3d level, from 0.5 to 1.5 km), these domains unite as "structural cells" (the 4th level, from 5 to 10 km). Deformations of folded domains are described by an ellipsoid of deformations, which is connected with its geometrical parameters (inclination of fold axial plane, interlimb angle et cetera). Materials of 24 detailed structural profiles with a total length about 500 km were divided into 505 domains and its parameters were measured. Each domain was restored to its pre-folded situation by the sequence of kinematic operations such as: 1) rotation, 2) horizontal simple shearing and 3) stretching or pure shearing [Yakovlev, 2009; 2012]. At the same time, the ellipse of deformations became a circle, and the modern segment of the cross-section line in the domain got other length and an inclination, forming the pre-folded structure. Combination of such 3-10 domains in each of “structural cells” allowed ascertaining the modern width and the pre-folded width of structures. Thereby the value of shortening for such cells were easily calculated. The known position of domains in an entire stratigraphic column of the cover, based on age of rocks and on the depth, and also the value of shortening and altitude of section line on the ground in a cell, allowed to restore the modern depth of a sole of a folded sedimentary cover (i.e. of a top of basement) and volume of eroded rocks [Yakovlev, 2009; 2015]. For the Greater Caucasus, the dataset of 78 such structural cells was saved up that allowed to make reliable structural generalization for the western and eastern parts of this folded system.

Volumes of eroded rocks as a difference between the volume of neotectonic uplift of Greater Caucasus [Milanovsky, 1968] and the volume of the mountain topography were counted for model of the first type. Polygons of the map of size of 20x30 minutes of coordinate grid were used for calculations, and average sizes of neotectonic raisings during 15 m. y. in these polygons were estimated ([Grachev, 1997] after [Milanovsky, 1968]). Of course, volumes of uplift of all polygons were summed up finally. Average height of a neotectonic uplift was estimated at 3-5 km in neotectonic map, the volume of a raising totally was calculated as 279 thousand km^3. The volume of a modern mountain building was counted according to the digital map of a topography of Greater Caucasus, it was 119 thou. km^3. Thus, the volume of erosion for entire Greater Caucasus was counted as 160 thou. km^3, and for those part of building, which is source of sediments for the Black Sea basin - 87 thou. km^3. Calculations for the basin of the Black Sea separately were important because only Greater Caucasus delivered material in these forelands and sea basins. In the third model, which has the balanced structure, the “virtual” or theoretical position of top of sedimentary cover after upraising with the parallel erosion was estimated as 10-15 km in average for 78 "structural cells".

Volumes of an uplift and erosion for the third model [Yakovlev, 2015] were counted also on the same polygons with some interpolations and extrapolations. The volume of erosion was estimated as 826 thou. km^3 for entire Greater Caucasus and 448 thou. km^3 for the part, which related to sedimentary basins of the Black Sea. Authors themselves did not evaluate eroded rocks volume for the second model with very large shortening [Dotduyev, 1987], but they do not object to traditional estimates of an uplift in 3-5 km (after [Milanovsky, 1968]). In the absence of their data, we estimated possible erosion using the idea of preservation of volumes of rocks at all processes. The announced in the model a minimal shortening of 200 km for the structure of 50-60 km modern width gives shortening of 80% (the relation 250 / 50 km). Taking into account the average initial thickness of a sedimentary cover of Greater Caucasus in 13 km and the modern depth of the basement about 10 km, declared in the model, an erosion during of uprising in accretionary prism was evaluated as 55 km. Proportional increase in volume of erosion in comparison with the balanced model in this case (55 km against 15 km) gives for the second model (accretionary prism) the volume of 2950 thou. km^3 as minimum for entire Greater Caucasus and 1601 thou. km^3 for basins of the Black Sea part.

Collecting of materials on thicknesses of complexes of the molasse represented a difficult task. For this purpose, several maps and some materials of geophysical profiles were used. Calculations of volumes were made also on polygons of coordinate grid. The volume of Cainozoic deposits in all basins surrounding Greater Caucasus was evaluated as 2609 thou. km^3, including very big thickness (10-15 km) in the basin of the Southern Caspian Sea. The volume of sediments for the part of the basin of the Black Sea was 592 thou. km^3. Comparison of volumes of erosion for three models with the counted volume of sediments, which exists in nature, was made. Erosion volume for the first model (fixism) was 15% of the actual volume of sediments in Black sea basins (87/592), on the balanced model – 76% (448/592), the model of an accretionary prism gave 270% (1601/592). Thereby comparison to three geodynamic models shows the realness only of the model of the balanced structure [Yakovlev, 2015] in which a joint shortening of structures both sedimentary cover and the basement has moderate estimates – about 50%.

Dotduyev S.I. 1987. Nappe structure of the Greater Caucasus Range // Geotectonics. 20. pp. 420-430.

Grachev A.F. (Head Ed.). 1997. Map of the neotectonics of Northern Eurasia. Scale 1:5000000 Moscow: Ministry for Protection of the Environment and Natural Resources Russia; Russian Academy of Sciences. (in Russ.)

Milanovsky E.E. 1968. Neotectonics of the Caucasus. Moscow: Nedra. 483 P. (in Russ.)

Yakovlev F.L. 2009. Reconstruction of linear fold structures with the use of volume balancing // Izvestiya, Physics of the Solid Earth. Vol. 45, No. 11. pp. 1025–1036.

Yakovlev F.L. 2012. Methods for detecting formation mechanisms and determining a final strain value for different scales of folded structures // Comptes Rendus Geoscience. 344 (3–4). pp. 125-137.

Yakovlev F.L. 2015. Multirank strain analysis of linear folding on the example of the Alpine Greater Caucasus. Doctoral habil. thesis. Moscow: IPE RAS. 2015. Manuscript. 472 P. (in Russ.) http://yak.ifz.ru/

Yakovlev F.L., Sorokin A.A. 2016. The comparison of geodynamic models of development of the Alpine Greater Caucasus based on the parameter of "volume of eroded rocks" // Tectonophysics and actual problems in the Earth's sciences: Materials of reports of the All-Russian conference – in 2 volumes. V. 1. Moscow: IPE RAS. pp. 314-322. (in Russ.).

Break-up unconformity system at the extensional continental margins and its applications in the northern continental marginal basins of South China Sea

Xinong Xie[1], Jianye Ren[1], Xiong Pang[2] and Chao Lei[1]

[1] China University of Geoscience (Wuhan), China
[2] China National Offshore Oil Shenzhen Ltd. Corporation, China

---

Break-up unconformity was defined as a basin-wide unconformity separating the underlying syn-rift deposits from the overlying post-rift strata when continental crust breaks up and oceanic crust starts to occur (Falvey, 1974). This concept "break-up unconformity" includes two aspects. Firstly, it is a basin-wide unconformity between syn-rift deposits and post-rift strata. Secondly, its occurrence is time equivalent to the onset of sea-floor spreading, especially implying the moment when lithosphere has been broken up and the oceanic crust emerges. McKenzie(1978) firstly proposed a pure shear pattern of lithospheric break-up, with a quantitative stretching model of rift basin, focusing on the uniform stretching and instantaneous break-up. In extensional basins, break-up unconformity is recognized as the base of the large scale stable depression strata, which started to develop after the ceasing of normal fault activity in synrift period. In general cases, this unconformity is the most distinct surface in seismic profile. Following McKenzie, the break-up unconformity could be traced from the rift-depression transition surface within continental basins to the upper surface of the oldest oceanic crust nearby ocean basins. Our study in the northern continental margins of the South China Sea, however, shows that the phenomenon in fact is far more complicated. The surface on the oldest oceanic crust, representing a traditional break-up unconformity, is not time equivalent to the rift-depression transition surface within continental basins. Instead, from ocean basin to continental slope and continental shelf, the location of the basement surfaces within different tectonic units changes from oceanic crust and continental mantle, to middle-lower and upper continental crust in a regular pattern. Therefore, these tectonically revolutionary surfaces of various hierarchies within the sedimentary strata in the extensional epicontinental basins are the records of lithosphere stretching and breaking up process. In order to better reveal the continental break-up processes from basin-filling sequences, we combine these relevant unconformities into an assemblage defined as “break-up unconformity system”. In this termination, some key unconformities include, such as, the “rifting onset unconformity” or “basement unconformity” corresponding to initiation of continental crust rifting, the “continental crust breakup unconformity” corresponding to totally continental crust rifting and subsequent mantle emergency, and the “(lithosphere) breakup unconformity” corresponding to break-up of the whole lithosphere.

The lithospheric break-up process in South China Sea recorded by “break-up unconformity system” is thus not instantaneous but progressive, which differs from the traditional model. This concept has been successfully applied into the study of the northern continental marginal basins, South China Sea. This work provides a strata correlating framework from continental basin to oceanic basin, and also improves the understanding of the lithosphere extension and break-up processes before the establishment of sea-floor spreading system. The results helps to clarify the structural patterns and forming process of the continental margins in South China Sea, and to elaborate the evolutionary history of the whole sea basin expansion, and also provides effective guidance on the petroleum explorations in deep-water and super deep-water areas, South China Sea.

*This study was funded by National Natural Science Foundation of China (grant no. 91528301).

Talk preference

Title: Tectonic evolution of the Black Sea

Author: Smit J

Affiliation: Department of Earth Sciences, Utrecht University, PO Box 80.021, 3508 TA Utrecht, the Netherlands

Contact: j.h.w.smit@uu.nl

Abstract text

Since the switch from passive margin to active margin tectonics (subduction of the Tethys Ocean) in Late Triassic times, the Northern Tethys margin has known a history of repeated (back-arc) basin opening and closure and accretion of small continental blocks and intra-oceanic island arcs. It appears that the early Mesozoic history is more important in understanding different aspects of the Black Sea than previously thought. Here the history of the Black Sea Basin is discussed from the onset of rifting in the Barremian to the present.

The two Black Sea sub-basins, separated by the Mid-Black Sea High do not necessarily share the same history. The Upper Barremian-Aptian initiation of rifting of the Western basin is documented in different places around the basin from the Crimea to the Central Pontides, rifting in the eastern basin remains poorly documented. Two very different ages for the opening of the eastern basin dominate in literature: Early Cretaceous (more or less contemporaneous with the opening of the western basin) and Paleogene. These uncertainties and potentially different opening ages evidently cause problems for any reconstruction attempt.

Any attempts to reconstruct the opening of the Black Sea Basin are hampered by the lack of data from the basin itself, related to its narrow margins and great depth (in particular well data and therefore age control). Constraints from the basins margins and regional geology are therefore key in understanding the Black Sea. The compilation of the available local geological and geophysical data with regional plate tectonic constraints formed the basis for a new paleo-tectonic reconstruction. This reconstruction sheds a new light on the kinematics and mechanics of the opening and development of the Black Sea and its margins.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues ILP Task Force (VI) on Sedimentary Basins

Poster

Subduction initiation at passive margins: insights from analogue modelling

Antoine Auzemery[1], Dimitrios Sokoutis[1,2], Ernst Willingshofer[1], and Jean-Pierre Brun[3]

[1] Faculty of Geosciences, Department of Earth Sciences, Utrecht University, Budapestlaan 4, 3508 TA Utrecht, The Netherlands.
[2]University of Oslo, Department of Geosciences, Oslo, Norway
[3]Université Rennes 1, Géosciences Rennes, UMR 6118 CNRS, bat. 15 - Campus de Beaulieu, 263 Av du général Leclerc, BP 74205, 35042, Rennes Cedex, France.

Passive Margins are of particular scientific and economic interest and host key archives of earth system dynamics. Their formation and evolution has been well explored through geological, geophysical and modelling studies. However, it is poorly understood how passive margins turn into active margins, eventually leading to the subsequent development of subduction zones. This study aims at exploring favourable rheological and kinematic conditions that favour the development of subduction zones along passive continental margins through lithosphere-scale analogue modelling.

It is widely accepted that subduction demands rupturing of the brittle crust to allow for over-thrusting of the continental lithosphere and then the sinking of the oceanic lithosphere into the asthenospheric mantle. While the first stage is control by the ductile strength of the continental crust, the over-thrusting depends mainly on the strength of the lithospheric mantle as well as its negative buoyancy. However, processes which lead to the rupture and the over-thrusting of the stable oceanic lithosphere during subduction has long been a subject of debate. Parameters are not well quantified and it is still unclear where subduction is initiated and how it develops afterward. The lack of natural examples and the fact that most of subducted margins are highly deformed or buried at depth foster speculations on the early stages of subduction. Numerically based models propose different answers to resolve the issues. But in most cases, to overcome the high lithosphere strength, it requires special circumstances as a pre-existing fracture zone, a high-density contrast between the ocean and the continent or external forces such as small-scale plumes. These hypotheses are consistent and rational

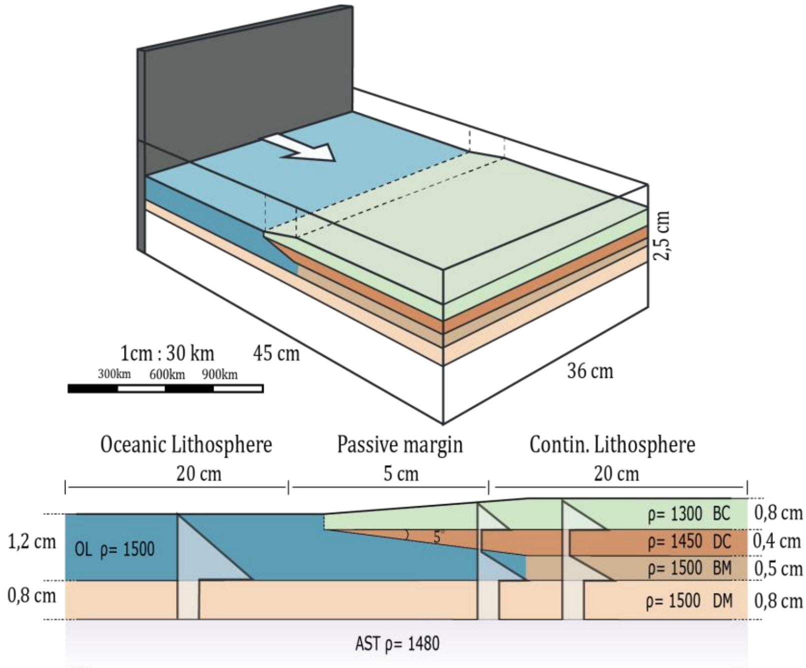


Figure 1: (a) Experimental setup: four-layers continental lithosphere and a two layers oceanic lithosphere resting on a high-density low-viscosity fluid representing the asthenosphere. White arrow indicates the shortening that is applied via the moving wall. (b) strength profiles showing lateral variation in lithospheric strength at initial stage of deformation. The model is scaled according to the criteria of geometrical, rheological, dynamical and kinematic similarity.

but highly steer the location and the dynamics of

subduction. In contrast, we use analogue modelling to test a reasonable homogeneous model of subduction initiation at passive margin without using pre-existing constraints. We use different sets of experiments to test successively the role of lithosphere strength, convergence angle, and convergence rate, to identify favourable parameters combination for subduction initiation. The model consists of a four layers continental lithosphere and a two layers oceanic lithosphere. These two domains are separated by a wedge-shaped margin which simulate the necking zone of the common passive margin, without however particular weakness zones (Fig. 1).

The preliminary results show that subduction will most likely occur at slow convergence rate for an intermediate effective viscosity in the lithospheric mantle (10^22 Pa.s). The typical tectonic regimes we obtain are as follows: rupture, over-thrusting and sinking (Fig. 2). The rupture typically takes place at the transition from the continent to the passive margin and occurs during a phase of accretion where the oceanic crust deforms the passive margin by ocean-ward out-sequence thrusting (1). Coevally, the former passive margin is flexed downward and describes a deep basin. Subsequently, when the driving forces underpass the strength of the lithosphere, the down-flexed passive margin is cut by the evolving subduction fault and is being thrusted under the continent. This phase of deformation may actually lead to the partial delamination of continental mantle (2). The transition to the sinking stage is characterised by the development of a shear zone in the viscous part of the mantle lithosphere, which accommodates the sinking of the subducting slab aided by its negative buoyancy (3). This sequence of deformation leads to the (partial) subduction of the passive margin and could predict the juxtaposition of shallow water, platform-type deposits on deep marine sediments.

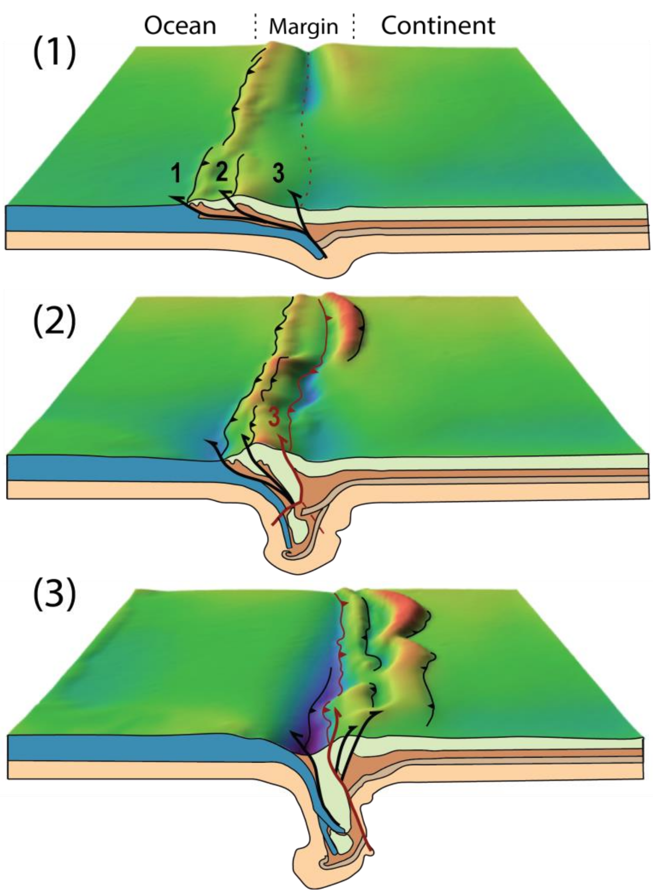
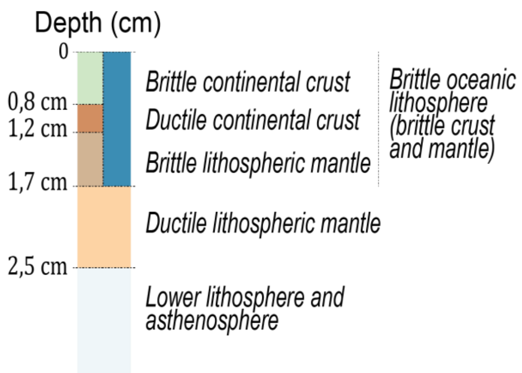


Figure 2: Examples of analogue models for spontaneous initiation at passive continental margins. Three tectonic regimes are observed: (1) Rupture of the lithosphere during a phase of accretion. (2) Under-thrusting by partial delamination of continental mantle. (3) Development of a shear zone in the ductile mantle and sinking of the lithosphere. The moving-wall pushes the oceanic lithosphere at a constant velocity of 0,5 cm/h representing 3,3 cm/year in nature.



3-D lithospheric-scale temperature modeling: application for the Hungarian part of the Pannonian Basin

Eszter Békési (1), László Lenkey (2), Jon Limberger (1), Damien Bonté (1), Mark Vrijlandt (4), Ferenc Horváth (2)(3), Sierd Cloetingh (1), and Jan-Diederik van Wees (1)(4)
(1) Department of Earth Sciences, Utrecht University, Budapestlaan 4, 3584 CD Utrecht, Netherlands, e-mail: e.bekesi@uu.nl
(2) Department of Geophysics and Space Science, Eötvös Loránd University, Pázmány Péter sétány 1/c, 1117 Budapest, Hungary
(3) Geomega Ltd, Zsil u. 1, 1093 Budapest, Hungary
(4) TNO Utrecht, Princetonlaan 6, 3584 CB Utrecht, Netherlands

Hungary is one of the most suitable countries in Europe for geothermal development, as a result of large amounts of Miocene extension and associated thermal attenuation of the lithosphere. For geothermal exploration, it is crucial to have an insight into the subsurface temperature distribution.

Hereby a new thermal model of Hungary is presented extending from the surface down to the lithosphere-astenosphere boundary (LAB). Subsurface temperatures were calculated through a regular 3D grid with a horizontal resolution of 2.5 km, a vertical resolution of 200 m for the uppermost 7 km, and 3 km down to the depth of the LAB. The model solves the heat equation in steady-state, assuming conduction as the main heat transfer mechanism. At the top and the base, it adopts a constant surface temperature and basal heat flow condition. For the calibration of the model, temperature measurements were collected from the Geothermal Database of Hungary. The model is built up by six sedimentary layers, upper crust, lower crust, and lithospheric mantle, where each layer has its own thermal properties. The prior thermal properties and basal condition of the model is updated through the ensemble smoother with multiple data assimilation technique.

The prior model shows a misfit with the observed temperatures, which is explained fundamentally by groundwater flow in Mesozoic carbonates and other porous sedimentary rocks. The updated models considerably improve the prior model, showing a better fit with measured records. The updated models mimic the effect of convection by modifying the thermal conductivity of the layers. Additionally, the updated models are capable to reproduce the thermal effect of lithospheric extension and the sedimentary infill of the Pannonian Basin. Results indicate that the hottest areas below 3 km are linked to the basement highs surrounded by deep sub-basins of the Great Hungarian Plain. Our models provide an indication on the potential sites for future EGS in Hungary and can serve as an input for geothermal resource assessment.

The Middle Atlas Geological karsts forms: Towards Geosites characterization

Souhail MOUNIR [(1)], Naoufal SAOUD [(1)], Mohammed CHARROUD[(1)]

(1) Laboratory of Georesources and environnement, FST – USMBA, Morocco

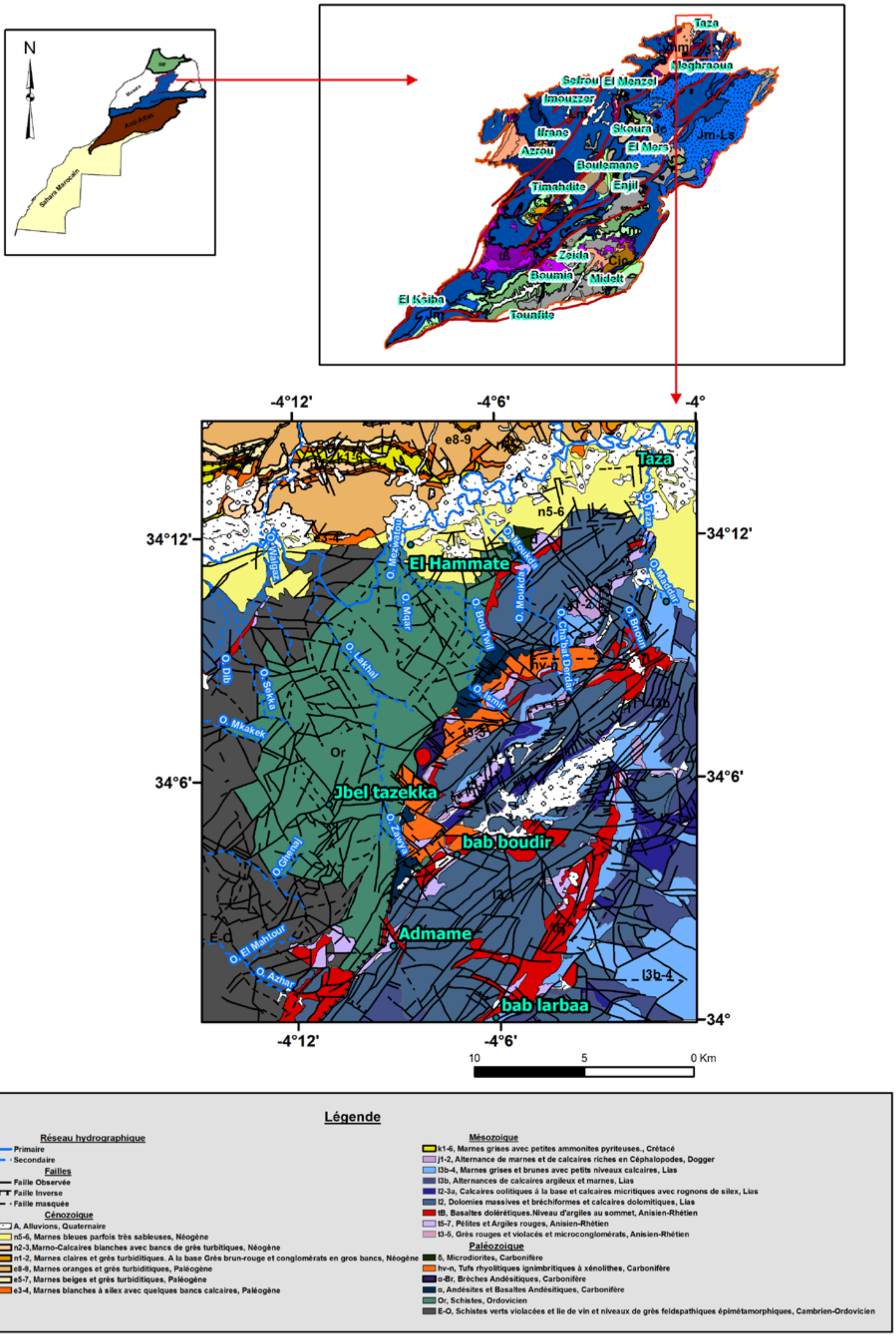
Abstract

Geodiversity, rich limestone Jurassic formations and huge water reservoir, are natural characteristics of the Middle Atlas Chain of Morocco, which they offer various karstic geosystems forming geological, tectonic and hydro-geomorphological history, where Atlas orogeny has affected the eastern part of the Middle Atlas. Nevertheless, they ensure karsts evolution and repartition along this zone.

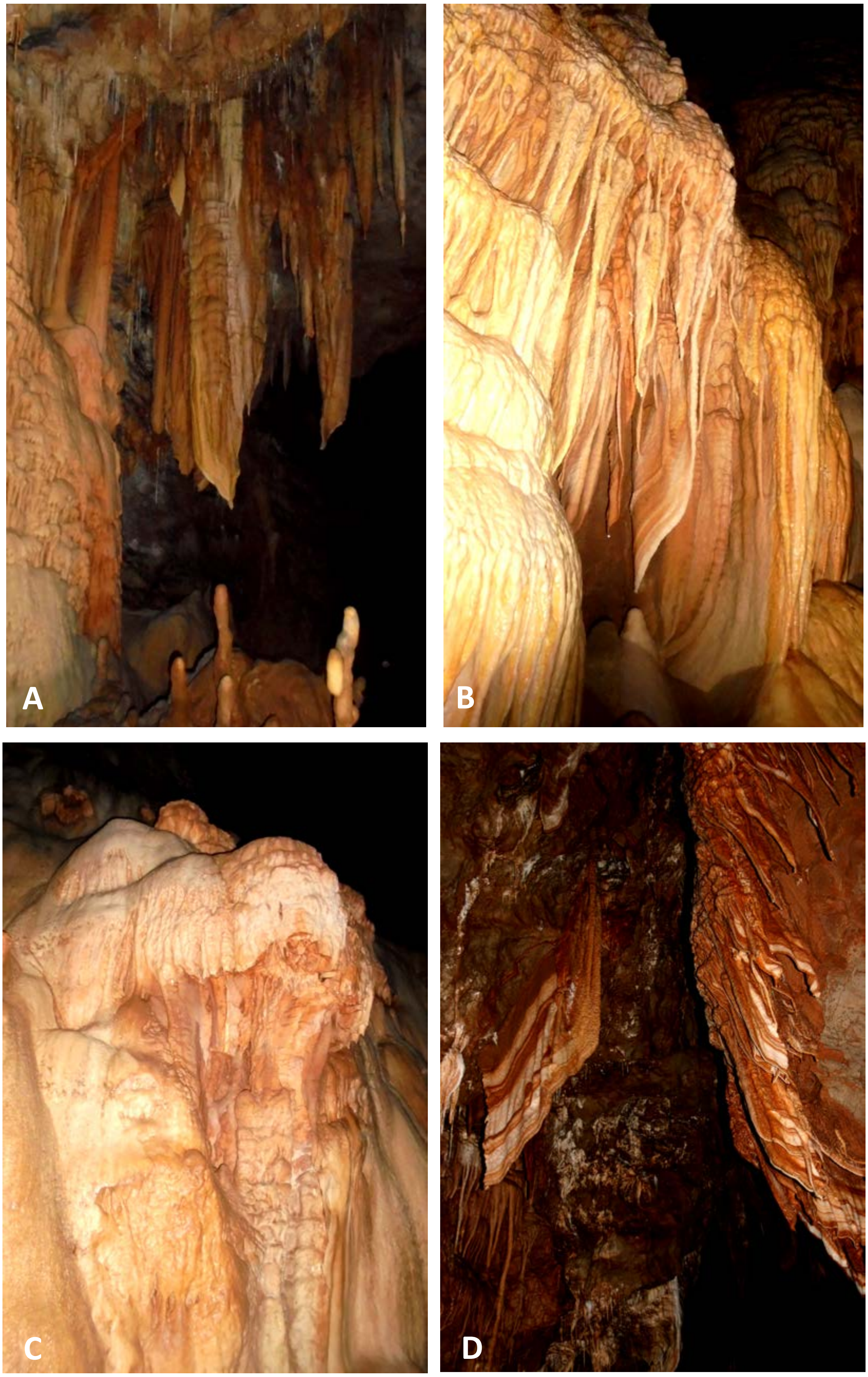
The present study makes evidence of some Middle Atlasic karst touristic offer specifies in term of genesis, structures and function that assign public developed thematic according geological funds identification, classification and grouping as kind of “Geosits”.

In fact, the proposed patrimony valorisation process related to these all rich structures, consist to “Geoparc” creation in the Middle Atlas domain, and to its qualification in front of worldwide instances as UNESCO, thing which can guide elsewhere the development lever in this region.

Keyword: Geology, Karst, Geosite, Geoheritage, Middle Atlas, Morocco



Geology of the Taza region extracted from the geological map of TAZA at 1/50000 modified



A / B: The karstic forms (stalagmite and stalactite) of the Chaara cave

C / D: The karstic modeling of the Friwatou sinkhole

Topic 6: Rock-fluids interactions in sedimentary basins

Poster preference

Title: New insights on closed system dolomite recrystallization processes from clumped isotope (Δ_{47}) thermometry and Laser Ablation U-Pb chronometry - Arab Fm. reservoirs (UAE)

Authors: Morad, D.[1], Gasparrini, M.[2], Mangenot, X.[2,3], Gerdes, A.[4], Bonifacie, M.[3], Morad, S.[5], Hellevang, H.[1], Nader, F.H.[2], Al Darmaki, F.[6], Bin Ishaq, W.[6]

Affiliations:
1 University of Oslo, Norway ;
2 IFP Energies nouvelles, Rueil-Malmaison, France;
3 IPGP, Paris, France ;
4 Goethe Universität Frankfurt, Germany
5 Petroleum Intitute, Abu Dhabi, UAE
6. Abu Dhabi Gas Development Co. Ltd. (Al Hosn Gas), Abu Dhabi, UAE

Contacts: d.j.morad@geo.uio.no; marta.gasparrini@ifpen.fr;

Dolostones of the Arab Fm. (Arabian Gulf) are among the largest oil and gas reservoirs in the world. Diagenesis of these reservoirs has been studied (e.g. Swart et al., 2005; Morad et al., 2012; Nader et al. 2013, Morad et al., submitted), though uncertainties still exist on how these dolomites, and related intercrystalline pores, formed. The combined application of novel techniques like clumped isotope (Δ_{47}) thermometry and laser ablation U-Pb chronometry (Gasparrini et al., in press) could bring new light in understanding the origin and distribution of heterogeneities in such dolomitic reservoirs.

It has been suggested (Swart et al. 2005, Morad et al. 2012; Nader et al., 2013) that the dolomites from the Arab Fm. formed in the Upper Jurassic (~150-154 Ma) during major syn-sedimentary to early diagenetic processes (i.e. sabkha-evaporative and seepage-reflux dolomitization models), at surface temperature conditions. However, oxygen isotope data ($\delta^{18}O_{carb}$) suggest that some of the dolomites formed (or were reset during burial) at relatively high temperatures (Morad et al., 2012). Recently, Swart et al. (2016) conducted a clumped isotope study on the Arab Fm. dolomites from the Ghawar field (Saudi Arabia). They recorded temperatures between 25 and 125 °C for the dolomites and $\delta^{18}O_{fluid}$ of the parent fluids between 0 and 8 ‰ (SMOW), pointing rather towards a local resetting of the original sedimentary signature by basinal fluids. Interestingly, the reset dolomites seem to correspond to the highly porous and permeable zones of the reservoir (super-K zones).

Here, a detailed diagenetic study has been conducted on the Upper Jurassic Arab Fm. from a gas anticline field onshore Abu Dhabi (Morad et al., submitted). Variable porosity-permeability values were recorded in similar dolomitized facies, suggesting that the reservoir properties are not only linked to the original depositional heterogeneities. Additionally, a spread in the $\delta^{18}O_{carb}$ values of the dolomites (-1 to -4,5 ‰; PDB), suggests that processes, other than early dolomitization from marine Late Jurassic fluids, have affected the reservoir units. The samples also display variable textures at the microscopic scale, going from tight dolomicrite to coarser dolomite crystal mosaics with better reservoir properties.

Clumped isotope (Δ_{47}) data for 15 dolomite samples of this field indicate that the dolomites record temperatures in the range 43-82 (±6) °C. Also the lowest temperatures are too high for carbonates that precipitated from seawater, even under arid climate conditions and in very restricted environments.

Laser ablation U-Pb chronology on 7 of these 15 dolomite samples indicate two populations with ages of about 130-135 Ma (Late Jurassic) and 92-96 Ma (Late Cretaceous), respectively (Fig. 1). Both populations are too young compared to depositional age and suggest a reset of the dolomite system by multiple events.

The data overall suggest a selective recrystallization of some portions of the dolomitic reservoirs by high temperature fluids during burial. They also suggest that the recrystallization affected the dolomites at different moments of the basin evolution (~130-135 and ~92-96 Ma) and was not a continuous process.

The data also indicate that the recrystallization occurred in a closed system: the process was driven by the same dolomite pore-fluids evolving during fluid-rock interaction through time. The temperature-$\delta^{18}O_{fluid}$ data from the studied field share similarities with those from the Gahwar field (Swart et al. 2016), suggesting that the dolomite recrystallization process occurred in a similar manner in reservoirs far from each other (i.e. at basin scale), thus allowing conceptual scenarios to be drawn, which could be extrapolated to reservoirs of the Arab Fm. located in other areas of the Arabian platform.

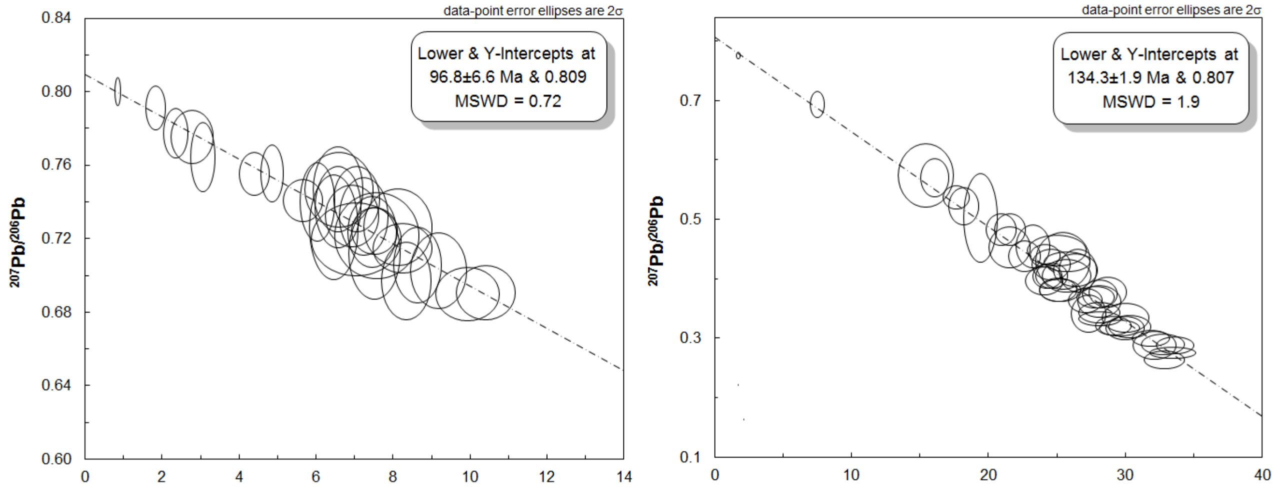


***Figure 1**: Tera-Wasserburg diagrams (^{238}U-^{206}Pb - ^{235}U/^{206}Pb) illustrating the isochrones reconstructed for two dolomite samples and indicating absolute ages of recrystallization at 96.8 Ma (left) and 134.3 Ma (right), respectively.*

The major implication for oil and gas industry is that the reservoir properties changed through time due to burial recrystallization of the original early dolomites and that they are not only controlled by the origin and distribution of precursor facies and depositional environments.

In order to build realistic reservoir models and better predict the distribution of the more porous-permeable zones in such dolomitic reservoirs, a research approach given by two complementary tasks seems to be needed:
1) Characterize the events of early dolomite recrystallization by applying advanced analytical techniques (i.e. Δ_{47} thermometry and U-Pb chronometry) which overcome the limits normally encountered in establishing the diagenetic evolution of fine crystalline carbonate reservoirs (Gasparrini et al., in press);
2) Implement the characterization data from such advanced diagenesis study in reservoir modelling approaches (e.g. geostatistics; Gasparrini et al., 2017), aiming to simulate the distribution of heterogeneities due to mutual interactions of facies and diagenesis, by including also the effects of dolomite recrystallization.

References

- Gasparrini, M., López-Cilla, I., Blázquez-Fernández, S., Rosales, I., Lerat, O., Martín-Chivelet, J., Doligez, B., 2017. A multidisciplinary modeling approach to asses facies-dolomitization-porosity interdependence in a Lower Cretaceous platform (northern Spain). In: MacNeil, A.J., Lonnee, J., Wood, R. (eds), *Characterization and modeling of carbonate reservoirs*. *SEPM Special Publication*, 109. SEPM (Society for Sedimentary Geology), Tulsa, Oklahoma. DOI: 10.2110/sepmsp.109.07
- Gasparrini, M., Mangenot, X., Montano, D., Bonifacie, M., Gerdes, A., Rouchon, V., Della Porta, G., in press (this conference). Innovative approaches of carbonate diagenesis quantification (Δ_{47} thermometry - U/Pb chronometry) - towards appraisal in geological modeling. *ILP2017 Sedimentary Basins*, 29th October – 2nd November, Limassol (Cyprus).
- Morad, S., Al-Aasm, I.S., Nader, F.H., Ceriani, A., Gasparrini, M., Mansurbeg, H., 2012. Impact of diagenesis on the spatial and temporal distribution of reservoir quality in the Jurassic Arab D and C members, offshore Abu Dhabi oilfield, United Arab Emirates. *GeoArabia*, 17(3): 17-56.
- Morad, D., Nader, F.H., Gasparrini, M., Marchionda, E., Hellevang, H., submitted. Comparison of diagenetic and reservoir quality evolution between the anticline crest and flank of a carbonate gas reservoir, Upper Jurassic Arab Fm., United Arab Emirates (UAE). *Sedimentary Geology.*
- Nader, F.H., De Boever, E., Gasparrini, M., Liberati, M., Dumont, C., Ceriani, M., Morad, S., Lerat, O., Doligez, B., 2013. Quantification of diagenesis impacts on reservoir properties of the Jurassic Arab D and C members (offshore, U.A.E). *Geofluids*, 13(2): 204-220.
- Swart, P.K., Cantrell, D.L., Westphal, H., Handford, C.R., Kendall, C.G., 2005. Origin of dolomite in the Arab-D reservoir from the Ghawar field, Saudi Arabia: Evidence from petrographic and geochemical constraints. *Journal of Sedimentary Research*, 75: 476-491.
- Swart, P.K., Cantrell, D.L., Arienzo, M.M., Murray, S.T., 2016. Evidence for high temperature and ^{18}O enriched fluids in the Arab-D of the Ghawar Field, Saudi Arabia. *Sedimentology*, 63(6): 1739–1752.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Poster preference

Title: Asymmetric rift interaction: Insight from lithospheric-scale 3D thermo-mechanical numerical modeling

Authors: Balázs A[1], Vogt K[1], Matenco L[1], Cloetingh S[1] and Gerya T[2]

Affiliations: **1** Tectonics Group, Utrecht University, Utrecht, the Netherlands; **2** Geophysical Fluid Dynamics Group, ETH Zurich, Switzerland

Contact: a.balazs@uu.nl

Abstract text

Location of continental rift initiation is often controlled by pre-existing suture zones representing major rheological heterogeneities in the lithosphere (e.g., Buiter and Torsvik, 2014; Smit et al., 2016). Many of such basins show along-strike variations of subbasin geometries and subsidence patterns indicating that extensional basin formation is inherently a 3D process. This is especially pronounced when extension affects suture zones with opposing subduction polarities. We analyzed the extensional reactivation and interactions between lithospheric suture zones that are observed in many back-arc systems (Csontos and Vörös, 2004).

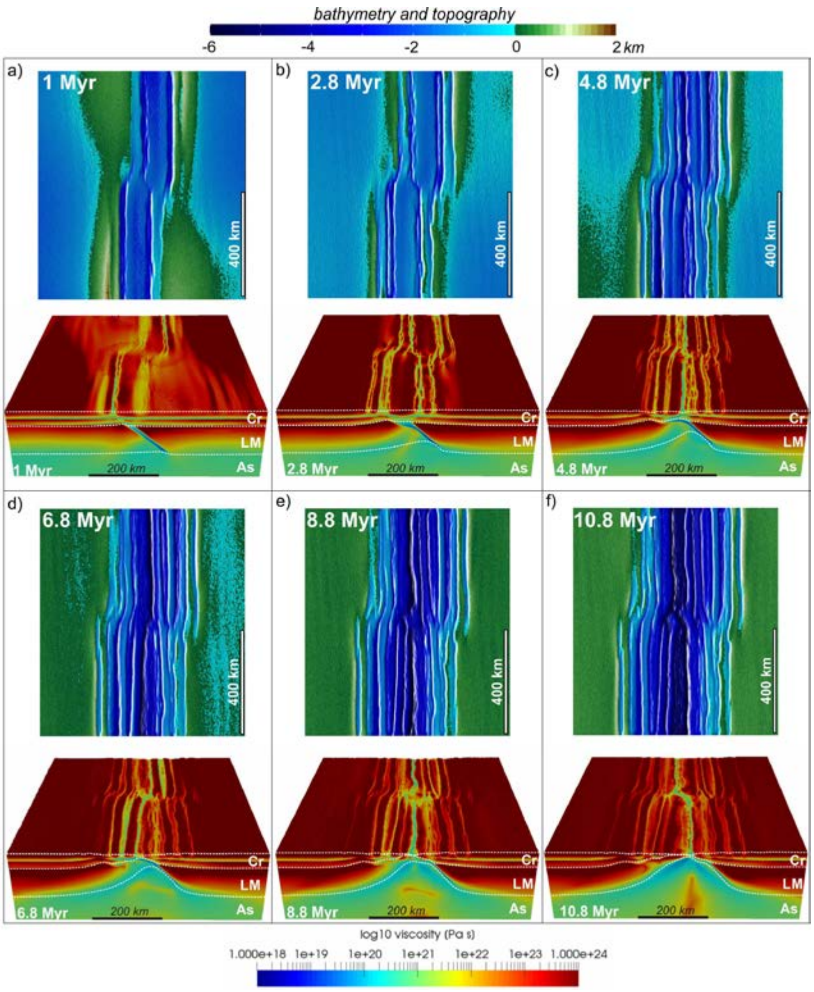


Figure 1. Linkage of asymmetric basin systems along interacting lithospheric weakness zones shown by the topography and bathymetry (upper figures) and effective viscosity (lower figures) results. Cr – Crust, LM – Lithospheric mantle, As – Asthenosphere.

In this study we applied a coupled thermo-mechanical lithospheric-scale 3D finite-difference code (e.g., Liao and Gerya, 2015) to solve the mass, momentum and energy conservation equations for incompressible media using visco-plastic rheologies. We conducted a series of experiments to analyze the extension, subsidence and thermal evolution of an initially thick, hot lithosphere with one (Balázs et al., 2017) or two pre-existing suture zones (Figure 1) resulting from an earlier orogenic phase. Modeling shows that during extension the lithospheric weakness zone is progressively re-distributed below the Moho. The rapid, initially asymmetric crustal and lithospheric thinning evolves toward a more symmetrical lithospheric appearance after ~11 Myr reaching continental break-up. Crustal geometries show striking differences on the two passive margins: above the re-distributed weakness zone high-offset rotated normal faults develop with significant exhumation, while the other margin shows a series of lower offset normal faults (Figure 2). The transition zone between the opposing weakness zones accommodates the difference in deformation style resulting in a wide linkage zone, which kinematics varies during extension. Our results are compared with the Cretaceous-Paleogene extension of the South China Sea and the Miocene Pannonian back-arc basin of Central Europe.

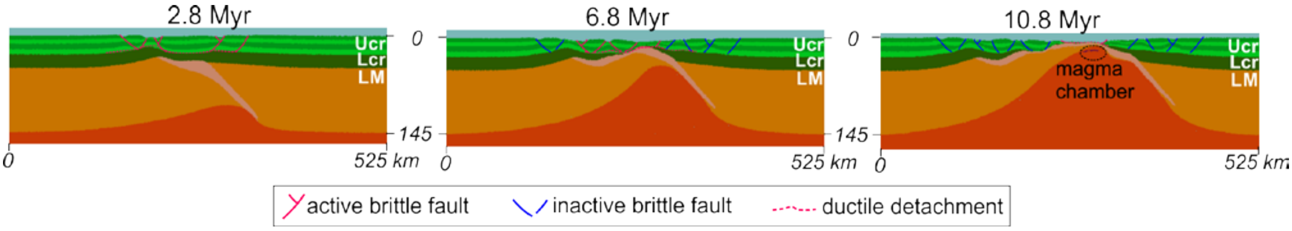


Figure 2. Structural evolution of our reference model shown by phase configuration. 2D section perpendicular to the weakness zone located ca. 250 km far from the transition zone. Ucr – upper crust, Lcr – lower crust, LM – lithospheric mantle.

References

Balázs A., Burov E., Matenco L., Vogt K., Francois T., Cloetingh S., 2017: Symmetry during the syn- and post-rift evolution of extensional back-arc basins: the role of inherited orogenic structures. Earth and Planetary Science Letters 462, 86-98.

Buiter S.J.H., Torsvik T.H., 2014: A review of Wilson Cycle plate margins: a role for mantle plumes in continental break-up along sutures? Gondwana Res. 26, 627–653.

Csontos L., Vörös A., 2004: Mesozoic plate tectonic reconstruction of the Carpathian region. Paleogeogr. Paleoclimatol. Paleoecol. 210, 1-56.

Liao J., Gerya T., 2015: From continental rifting to seafloor spreading: insight from 3D thermo-mechanical modeling. Gondwana Res. 28, 1329-1343.

Smit J., van Wees J-D., Cloetingh S., 2016: The Thor suture zone: From subduction to intraplate basin setting. Geology 44, 707-710.

Title: The petroleum prospects onshore Lebanon: example of the Qartaba anticline

Authors: Yara Bou Rizk [(1)], Ramadan Ghalayini [(2)]

Affiliations: **1** Lebanese University, Faculty of Sciences, Hadath, Lebanon;
2 Lebanese Petroleum Administration, Beirut, Lebanon

Contacts: yarabourizk@gmail.com **,** ramadanghalayini@gmail.com

Abstract

The Qartaba anticline is a 10 Km long structure located along the Levant margin onshore Lebanon. It has long been considered as a promising target for hydrocarbon exploration and could be analogous to producing Triassic hydrocarbon fields in the nearby Palmyra basin of Syria. The challenge in Lebanon, however, is that the pre-Jurassic geology is unknown as the oldest outcrops are of Jurassic age and there are no wells penetrating deeper units. This leads to large uncertainties regarding the Triassic petroleum system in Lebanon and therefore the potential of the Qartaba anticline is poorly understood. In this contribution, we attempt to investigate the possibility of having a working Triassic petroleum system onshore Lebanon by undertaking regional correlations and comparisons with similar structures in Syria. First, we estimated the timing of trap formation along the Qartaba anticline by adopting regional structural analogues. Second, we chose a hypothetical well location and constructed 2D burial plots in order to determine the source rock maturation and timing of hydrocarbon expulsion. Third, we assessed the reservoir and seal quality through regional correlations and GDE maps. Lastly, we integrated all the results in order to provide a likely scenario for the filling of the Qartaba anticline and therefore assess the viability of a working petroleum system onshore, in particular at the location of the Qartaba anticline. The results of this work provide a good framework for understanding the petroleum system in Lebanon and the workflow could be adopted to other potential structures in the Levant region.

Geodynamic Lead Mineralization Training of the Moroccan Hercynian Belt: Case of the Upper Moulouya Paleozoic Enlier.

Naoufal SAOUD[(1)], Mohammed CHARROUD[(1)], Said HINAJE[(1)], Jaouad CHOUKRAD [(2)] Souhail Mounir[(1)]

[(1)] *FST, FES laboratory of Georesources and environnement*
[(2)] *Fac. Sciences Dhar el Mehraz, Laboratory of Geodynamic and natural resources.*
Correspondance Adress : saoud.naoufal@gmail.com

Abstract

The Upper Moulouya Paleozoic enlier, is a part of the Moroccan Hercynean belt. It is located at the junction position of the High Atlas in south, and the Middle Atlas to the west. The basement outcrops as schists and mica schists with some amphibolites dated Cambro-ordovician, and the all is intruded by late Hercynian granitic intrusions which appear as small stipend at the village of Zaida and Boumia.

The Paleozoic geodynamic setting characterises a shallow platform affected by rifting, generating the establishment of subsiding basins. The deformation is poly-phased and well expressed in the Upper Moulouya by its late Hercynian to post-collisionel granitic intrusions. This subsiding basin is characterized by an extensive to transpressive tectonic settings.

However the Mesozoic stratigraphic evolution illustrates a thick liasic carbonate sequences deposited on Triassic sediments which are basically formed by arkose and conglomerates intercalated clay beds. The geodynamic evolution corresponding to this Mesozoic stage corresponds to structures which were developed contemporary to the central Atlantic opening into the west.

This poly-phased deformation presents the major steps of the Upper Moulouya geodynamic structuration, that is especially distinguished by the implementation of several mineralization kinds mostly associated to lead massive sulphide (PbS), note:

- The “Skarn” mineralisation of Paleozoic basment which is cashed within Cambro - Ordovician series of Aouli. (Fe), (Ba), (Pb), (Mn), (Ag).
- The “Stratoïd” mineralization of Triassic Mesozoic cover, that is fled into the arkos series of Zaida. (Fe), (Ba), (Pb), (Mn).
- The “MVT” Mineralization of Liasic Mesozoic cover within the Mibladéne carbonated series. (Pb), (Ag), (Mn).

The deposits of Aouli and Zeida are contemporary, and originate from the same source, while that of Mibladen would be come from another recovery hydrothermal event. Field data and geodynamic

reconstruction of Paleozoic, Triassic and Jurassic evolution of the Upper Moulouya which are based on structural, litho-stratigraphic and petrography analysis allowed us to conclude the relationship between the Paleozoic basement and its Mesozoic cover, where we find that inherited accidents from the Hercynian orogeny present the key factor in remobilization process of mineralization from basement up to the cover. This remobilization is probably due to repetitive working of a profound detachment fault responsible for the transport of mineralization from the deep crust up to the surface.

Crustal structure and tectonic evolution along the African-Anatolian plate boundary offshore southern Cyprus

Authors: Reiche S[1], Hübscher C[2], Welford K[3], Ehrhardt A[4] and Hall J[3]

Affiliations: **1** Institute for Applied Geophysics and Geothermal Energy, RWTH Aachen University, Aachen, Germany;
2 Institut für Geophysik, Universität Hamburg, Hamburg, Germany;
3 Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Canada;
4 Federal Institute for Geosciences and Natural Resources, Hannover, Germany

Contact: sreiche@eonerc.rwth-aachen.de

Plate tectonic convergence between Africa and Anatolia is accommodated along the Cyprus Arc – a narrow region that stretches from the Levant region in the east towards the Hellenic Arc further west. The tectonic situation directly south of Cyprus is particularly complex due to the presence of two prominent topographically elevated blocks situated at the leading tips of the African and Anatolian plates: Eratosthenes Seamount rises 1.5 km above the surrounding seafloor and has entered the convergence zone as the northern edge of the African plate. The similarly elevated and plateau shaped Hecataeus Rise is attached to the southern Cyprus margin and belongs to the Anatolian side of the collision zone (Figure 1). Previous workers interpreted this structure as an offshore extension of the Troodos ophiolite (Robertson, 1998a) or as an accreted crustal unit (Rotstein and Ben-Avraham, 1985).

Our current tectonic understanding of this area has tremendously benefited from results obtained in the course of Ocean Drilling Program (ODP) Leg 160, particularly by showing a switch from subduction to incipient continent-continent collision between Cyprus and Eratosthenes Seamount around the Pliocene-Pleistocene transition (Robertson, 1998b). However, coarse spacing and limited penetration of previously collected seismic profiles have complicated interpretation of strata not sampled at ODP sites and several pieces of this regional tectonic puzzle remain to be solved. Here we integrate previous results and interpretation of newly collected seismic profiles into an up-to-date tectonic picture along this incipient collision zone, starting with the deep crustal structure and working our way up to the shallow sedimentary cover.

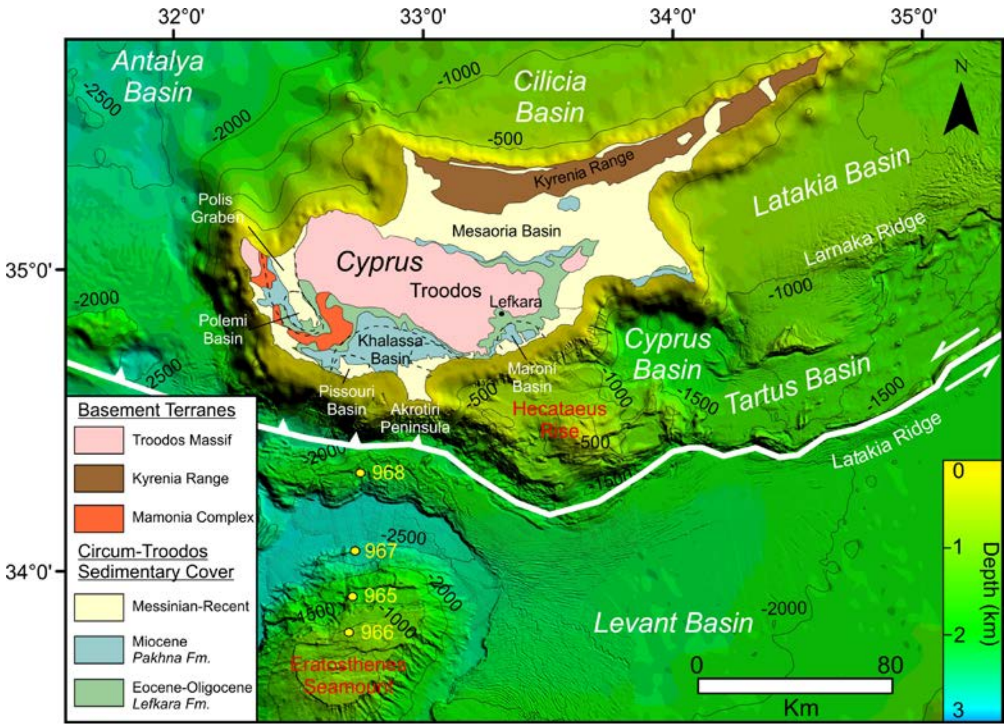


Figure 1. Map showing the bathymetry of the offshore Cyprus region. A simplified geological map of Cyprus was drawn after Kinnaird and Robertson (2012). Cyprus lineaments and sedimentary basins were delineated after Robertson et al. (1991). The bold white line represents the inferred location of the African-Anatolian plate boundary. Yellow dots represent ODP Leg 160 drill sites.

Wide-angle seismic lines covering the area between Eratosthenes Seamount and the Hecataeus Rise provide insight into the crustal structure and composition across the collision zone. Velocity models obtained by forward ray trace modelling suggests that the Hecataeus Rise is composed of an up to 7 km thick sedimentary cover underlain by approximately 25 km thick crust of ambiguous affinity. Velocity models show no evidence for the presence of high-velocity ophiolites such as those present onshore Cyprus. However, a connection between Cyprus and the Hecataeus Rise has evidently existed since at least Miocene times as attested by the offshore continuation of onshore Cyprus structural lineaments. Velocity models reveal the presence of high-velocity (> 7 km/s) lower crustal blocks along the southern foot of the Hecataeus plateau. These coincide with highs in the magnetic field and may represent remnants of Tethyan oceanic crust along a transform margin.

Densely spaced seismic reflection profiles image the uppermost few kilometres beneath the Cyprus/ Hecataeus-Eratosthenes collision zone and allow for reconstructing its Late Miocene to Recent tectonic evolution. A phase of significant northwest-southeast directed Pliocene tectonic convergence is observed along the southern part of the Hecataeus plateau where several anticlinal structures experienced reactivation and growth. At the same time, shortening between Cyprus and Eratosthenes Seamount was accommodated by allochthonous salt advance where kilometre thick Messinian evaporites were moved across post-Messinian strata while carrying an intact roof of post-Messinian sediments along.

A chain of tectonic events occurred around the Pliocene-Pleistocene transition – most notably including drastic subsidence of Eratosthenes Seamount (Whiting, 1998) and rapid uplift of Cyprus (Kinnaird et al., 2011). Our data reveal a coeval change from northwest-southeast to northeast-southwest directed compression at the northeastern part of the Hecataeus plateau and vertical separation between Cyprus and the Hecataeus Rise. Shortening at the plate boundary was accommodated primarily along the foot of the Hecataeus plateau, where autochthonous salt inflation and significant sediment accretion occurred. These observations are consistent with a model of collision initiation between Cyprus and Eratosthenes Seamount. Such incipient continent-continent collision led to vertical separation between these two tectonic entities while coupling between Cyprus and westward moving Anatolia initiated the observed change in convergence direction.

References

Kinnaird, T., Robertson, A., 2012. Tectonic and sedimentary response to subduction and incipient continental collision in southern Cyprus, easternmost Mediterranean region. In: Robertson, A.H.F., Parlak, O., Ünlügenç, U.C. (Eds.), Geological Development of Anatolia and the Easternmost Mediterranean Region. Geological Society, London, Special Publications 372, pp. 585-614.

Kinnaird, T.C., Robertson, A.H.F., Morris, A., 2011. Timing of uplift of the Troodos Massif (Cyprus) constrained by sedimentary and magnetic polarity evidence. Journal of the Geological Society 168, 457-470.

Robertson, A.H.F., 1998a. Mesozoic–Tertiary tectonic evolution of the easternmost Mediterranean area: Integration of marine and land evidence. In: Robertson, A.H.F., Emeis, K.-C., Richter, C., Camerlenghi, A. (Eds.), Proceedings of the ODP, Scientific Results, vol. 160. Ocean Drilling Program, College Station, TX, pp. 723-782.

Robertson, A.H.F., 1998b. Tectonic significance of the Eratosthenes Seamount: a continental fragment in the process of collision with a subduction zone in the eastern Mediterranean (Ocean Drilling Program Leg 160). Tectonophysics 298, 63-82.

Robertson, A.H.F., Eaton, S., Follows, E.J., McCallum, J.E., 1991. The role of local tectonics versus global sea-level change in the Neogene evolution of the Cyprus active margin. In: Macdonald, D.I.M. (Ed.), Sedimentation, Tectonics and Eustasy. International Association of Sedimentologists, Special Publication 12, pp. 331-372.

Rotstein, Y., Ben-Avraham, Z., 1985. Accretionary processes at subduction zones in the eastern mediterranean. Tectonophysics 112, 551-561.

Whiting, B.M., 1998. Subsidence record of early-stage continental collision, Eratosthenes platform (Sites 966 and 967). In: Robertson, A.H.F., Emeis, K.-C., Richter, C., Camerlenghi, A. (Eds.), Proceedings of the ODP, Scientific Results, vol. 160. Ocean Drilling Program, College Station, TX, pp. 509-515.

The Sediment Story of Miocene Sands in the Levant Basin

M.K. Davis, J. Ortega*, S. Fenton*, B. Gergurich**

Noble Energy, Houston, Texas

Abstract

Sediment transport into the deepwater Levant Basin has been explained by various models in the past and much of the focus has used a regional approach to address this issue. In this work, we delve into the petrologic character of the Miocene sedimentary sequence present, which is critically important to both the Tamar producing field as well as to other discovered fields not yet on production. The work presented here will develop a model petrology framework for the facies and architecture of the reservoirs found in the Tamar sands, in the context of their overall sedimentary setting.

The Miocene section observed in the Levant deepwater consists of four main intervals representing distinct depositional systems and underlying controls on those systems. The primary focus of this work is to describe the depositional facies and petrology of the upper and lower Tamar reservoirs in the Early Miocene as seen in core. The sedimentary architecture of the Tamar reservoirs in the Levant deepwater basin consists of sand-rich, relatively unconfined basin floor fan complexes. Sandstones within this framework are predominantly medium to fine grained quartz arenites and variations in grain size and quartz maturity reveal an evolving pattern of depositional lobes across the basin which can be used to track the sedimentary features.

The depositional system established in the Miocene of the Levant Basin produces remarkably consistent petrology across a wide regional area however local variations are observed in individual fields and we can demonstrate that these variations can be used to delineate individual fan complexes~~.~~

Talk preference

Title: Crustal modeling in the northern Levant basin based on seismic interpretation

Authors: Inati L[1,2,3,4], Lecomte J-C[1], Zeyen H[5], Nader FH[1], Adelinet M[1], Rahhal ME[4], Sursock A[2].
Affiliations:
1 IFP Energies Nouvelles, Geology Department, 1 and 4 Av. Bois Préau, 92852 Rueil Malmaison, France
2 National Center for Geophysical Research, CNRSL, Bhannes- El Metn, Lebanon
3 Université Pierre et Marie Curie, 4 Place Jussieu 75005 Paris, France
4 Ecole Supérieure des Ingénieurs de Beyrouth, Université Saint Joseph, Mar Roukoz Beirut, Lebanon
5 Département des Sciences de la Terre, UMR 8148 GEOPS, Université Paris-Sud, CNRS, Université Paris-Saclay, France
Contacts: lamainati@hotmail.com, jean-claude.lecomte@ifpen.fr, hermann.zeyen@u-psud.fr, fadi-henri.nader@ifpen.fr, mathilde.adelinet@ifpen.fr, muhsin.rahal@usj.edu.lb, asursock@cnrs.edu.lb.

The deep structure of the Levant basin (easternmost Mediterranean region), known to be the site of rifting in the Late Paleozoic and Early Mesozoic, as well as the nature of its crust, continental versus oceanic, are still controversial due to the lack of data especially in the northern part of the basin. The object of this study is to deduce the structure and the nature of the crust underlying the northern part of the Levant basin (offshore Lebanon), that has major implications on constraining potential petroleum systems.

The interpretation of five 2D PSTM seismic reflection sections (14 s TWT) covering the northern Levant Basin revealed a total of 10 horizons, among which, one is interpreted as an interface that may represent the Moho. The interpretation of seismic packages and their bounding surfaces as well as the seismic facies analysis were constrained by published 2D seismic interpretations of the northern Lebanese offshore.

The time horizons were converted into depth surfaces which were used to constrain the 2D crustal models integrating free-air gravity anomaly, geoid heights and topography data. Moho depth and the sediments thickness were constrained by the estimated depths of the interpreted horizons on the five PSTM seismic lines. The models representing five sections across the northern Levant basin, show a progressively attenuated crystalline crust in an EW direction (away from the basin's eastern margin). The crystalline crust is best interpreted as a strongly thinned continental crust under the Levant basin, represented by two distinct components, an upper and a lower continental crust. The Moho appears to be situated between 15.5 and 17 km towards the northern Lebanese coast and deepens to reach up to 20-23 km in the southern Lebanese offshore.

Estimated surface heatflow in the basin is around 40 mW/m^2, which is lower than reported values for the onshore and the margin. These differences in heatflow values between the offshore, the margin and the onshore have an important impact on hydrocarbon maturation and should be taken into account for better petroleum systems modelling and assessment.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Talk

Structural evolution of the SW Cyprus Belt complied from onshore field observations and offshore seismic reflection profiles

Symeou, V[1,2], Homberg C.[1], Nader F.H. [2] and Darnault R.[2]

1 Universite Pierre et Marie Curie, ISTEP, 4 place Jussieu, 75005, Paris, France
2 IFP Energies nouvelles, Geosciences Division, 1-4 Avenue du Bois-Preau, 92852, Rueil Malmaison, France

Correspondence to: V. Symeou (symeouvas@gmail.com)

The island of Cyprus represents a key area in order to understand the structural evolution of the Eastern Mediterranean. This contribution reviews the structural evolution of the Cyprus Arc System, by connecting offshore seismic reflection profiles and onshore data from the Cyprus Island where Late Cretaceous to Neogene sedimentary series are outcropping. Based on the onshore observations, the geological maps and information from existing boreholes, a cross-section of the SW part of the island is proposed. Structural field data and bio-stratigraphic dating were gathered especially in the area of the Polis Basin in order to comprehend the main geometries and to obtain key information in order to constrain the timing of tectonic activity. These data are combined to propose cross-sections and maps at different key periods which illustrate the structural evolution of SW Cyprus since Late Cretaceous. Onshore and offshore observations highlight the deformation, in the form of NW-SE to E-W trending thrusts, flexural basins and normal faults. Although more difficult to constrain, strike-slip faults are inferred at least during the late deformation stages.

The Troodos ophiolites are obducted in Late Cretaceous time and the erosion of the sequence produced the deep pelagic grey bentonitic clays of the Kannaviou Formation. Erosion of the juxtaposed Mamonia Melange produced the pelagic red argillaceous Kathikas Formation, which is overlain by the deep pelagic Lefkara Formation deposits. Renewed SW verging thrusting activity in Oligocene to Early Miocene time is indicated from a major unconformity as Maastrichtian sediments are overlain by Burdigalian shallow marine deposits. Thrusting results in the growth of reef carbonates on the highs of the hanging-wall (Terra Member) while in the flexural basin shallow and hemi-pelagic sediments are deposited (Mid-Miocene Pakhna Formation). Late Miocene activity is identified from the folding of Pakhna Formation sediments and the deposition of reef on the eastern flank of the basin (Koronia Member). In Plio-Pleistocene time, the collision of the Eratosthenes Seamount with Cyprus uplifts the island resulting in a strong thrusting activity which creates small basins like the Polis Basin where the clastics of the Nicosia Formation are deposited and other offshore basins.

In all, the structural evolution of Cyprus is closely tied with the compressional regime that is active since Late Cretaceous time. Thrusting activity and flexural basins identified onshore can be correlated with the forward propagation thrusting model proposed offshore. From the interpretation of reflection seismic data, Miocene thrusting activity is observed as the offshore Larnaca Ridge and Latakia Ridge displace the sedimentary cover either side of the thrusts, later resulting in the creation of flexural basins such as the Cyprus Basin. An important thrust bordering a flexural basin infilled by Plio-Pleistocene sediments is evidence of the active nature of the Cyprus Arc until Recent times and could be associated with the convergent movement of the African plate. Concluding, tectonic structures related with the Late Cretaceous obduction of the Troodos ophiolites play a major role in the Neogene deformation and the related pattern of sedimentation. By Plio-Pleistocene time the deformation style becomes more complex as a strike-slip component is observed, as a response to the expulsion of the Anatolian microplate towards the West.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract

Talk preference

Title: Source rocks, thermal history, and petroleum systems of the east Mediterranean, onshore-offshore Lebanon

Authors: Samer BOU DAHER[1], Ralf LITTKE[2], Fadi H. NADER[3]

Affiliations: **1** Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Volgade 10, 1350 Copenhagen, Denmark.
2 Energy & Mineral Resources Group (EMR), Institute of Geology and Geochemistry of Petroleum and Coal, RWTH Aachen University, Lochnerstrasse 4-20, 52056 Aachen, Germany.
3 Geology Department; Geosciences Division IFP Energies Nouvelles - 1&4 Av. de Bois-Préau 92852 Rueil-Malmaison Cedex, France.

Contacts: sabo@ign.ku.dk, ralf.littke@emr.rwth-aachen.de, fadi-henri.nader@ifpen.fr

Abstract text,

Due to the successful exploration activities in the east Mediterranean during the last 10 years, a number of studies have been performed to understand the discovered and the potential petroleum systems for future exploration targets.

As with the rest of the east Mediterranean realm, the Lebanese onshore-offshore territories can be divided into three different domains: offshore, margin, and onshore. Each of these domains experienced a different burial and thermal history, particularly during the Cenozoic, and thus requires a different set of source rocks to charge its potential petroleum systems.

In the first part of this talk we will present source rock data collected from the immature outcropping rock succession onshore Lebanon covering the Upper Jurassic to Paleocene interval, and including kerogen type II, IIS, and III. Then we will discuss the possible extension of some of these source rock intervals into the offshore Levant basin where they might be participating in active thermogenic petroleum systems. A particular focus will be on the Campanian-Maastrichtian source rocks and the lessons learned from this organic matter rich succession and the upwelling system that resulted in its deposition.

In the second part we will show results of 3D thermal history modelling and discuss the potential petroleum systems in the different domains. In the offshore, there is an Upper Cretaceous-Miocene petroleum system with a mixed thermogenic and biogenic charge, sealed by the Messinian salt and intra-Miocene shales. Along the margin, a Jurassic-Lower Cretaceous petroleum system was charged from type II and III Jurassic and Lower Cretaceous source rocks, sealed by Lower Cretaceous marls and volcanics. In the onshore, a Permo-Triassic petroleum system charged from Triassic source rocks is sealed by Upper Triassic evaporites.

ILP Task Force (VI) on Sedimentary Basins
Oral presentation Submission

Title: Geochemical and Petrographical Characterization of Potential Source Rock Intervals of Late Mesozoic to Cenozoic Age in the On- and Offshore Area of Cyprus

Authors: Grohmann[1 2 3], Fietz[3],Nader[1], Romero-Sarmiento[1], Baudin[2], Littke[3]
Affiliations: **1** IFPEN, Rueil-Malmaison, France
2 ISTEP - Paris Cedex 6, Paris, France
3 LEK – RWTH Aachen University, Aachen, Germany
Contacts: Sebastian.Grohmann@emr.rwth-aachen.de , sfietz@sfu.ca , fadi-henri.nader@ifp.fr , maria-fernanda.romero-sarmiento@ifpen.fr , francois.baudin@upmc.fr , Ralf.Littke@emr.rwth-aachen.de

Introduction

The Eastern Mediterranean Sea has become an important exploration target, since large gas field discoveries have been made by petroleum companies during the last decade. While e.g. Israel, Lebanon, and Egypt are well studied in terms of their petroleum systems, there is almost no data available dealing with petroleum source rocks in the area around Cyprus.

With this contribution, we present newly generated geochemical and petrographical data of organic rich intervals of Late Mesozoic to Cenozoic age from both the onshore and the offshore area of Cyprus. Onshore samples were collected from several outcrops along the island, whereas the offshore samples originated from four IODP Leg 160 wells, which penetrate the upper part (down to 600 m, Late Cretaceous) of the Eratosthenes Seamount and its northern flank. All samples were analyzed using a combination of organic geochemical and petrographic methods (e.g. kerogen isolation, Rock-Eval pyrolysis, organic petrography and palynofacies, elemental analysis, bulk kinetics, biomarkers) in order to investigate the evolution of the source rock properties in a complex tectono-stratigraphic sedimentary basin.

Results/Discussion

67 samples of potential organic rich intervals were collected from the onshore region of Cyprus. The obtained results indicate the presence of organic-rich sections within at least two different geological formations. The first one corresponds to the Upper Pakhna Formation, which is mainly composed of Tortonian coral reef carbonates, and spans a wide range of different, proximal to distal facies (Eaton & Robertson, 1992). Locally, dark mudstones with high TOC contents of up to 5 wt.% are interbedded between beige grainstones. The organic matter (OM) within these rocks is mainly composed of marine type II kerogen. However, organic petrography and palynofacies also indicate a minor contribution of land derived particles. Rock-Eval pyrolysis reveals a fair hydrocarbon generation potential (S2 = 11 to 15 mg HC/g rock) and bulk-kinetics a mean activation energy of 52 kcal/mol for maximum kerogen transformation. Vitrinite reflectance values (VR_r = 0.3 to 0.4%) and Rock-Eval results of the isolated kerogen (T_{max} = 400 to 410 °C) indicate a very low maturity of the OM. Nevertheless, minor regional fluctuation in maturity can be observed. On a regional scale, however, the Upper Pakhna Formation shows high variations in its organic richness, with locally no organic matter at all. This can be explained by the formation of several sub-basins around the Troodos massif during the Miocene (Eaton & Robertson, 1993). These small basins (with diameters of approximately 50 km) reached only in very restricted areas conditions that were suitable for the deposition and preservation of OM. Therefore, predicting the lateral distribution of OM in this area is hardly possible based on the current data density.

The second organic rich interval was found within the Middle Triassic Vlambouros Formation. Shaly layers, rich in plant remains are interlayered between calcarenites and show low to moderate TOC contents of around 1 wt.%. For these units, organic geochemical data reveal that the OM is of low maturity (VR_r = 0.5%, T_{max} = 430 °C). However, it is almost complety composed of terrestrial type III kerogen and shows nearly no petroleum generation potential (S2 = 0.1 to 0.5 mg HC/g rock).

In addition, 44 samples from offshore Cyprus were retrieved from the IODP Leg 160. Wells 966 and 967 comprise samples from Upper Cretaceous to Messinian age. The samples represent kerogen type II-bearing, organic matter rich (0.5 to 9 wt.% TOC) marine marls and shales, which may have been deposited during high primary productivity phases and were preserved under sub- to anoxic conditions, indicated by relatively low Pr/nC_{17} compared to Ph/nC_{18} ratios. All investigated samples are thermally immature with average T_{max} values of 414 °C and a maximum VR_r of 0.3%. However, bitumen staining indicates hydrocarbon generation in underlying source rock intervals. Furthermore, S2 values of 11.4 mg HC/g rock and up to 49.7 mg HC/g rock in the Bartonian to Pribonian intervals propose a generally high hydrocarbon generation potential in areas of deeper burial.

Outlook

It is known from already discovered fields such as Aphrodite and Leviathan that gas in the northern Eastern Mediterranean Sea is mainly of biogenic origin (Needham, 2013; Wygrala et al., 2014). Therefore, also rocks with low amounts of TOC and low burial depths could serve as source rocks in that area and might be accounted for the generation of significant amounts of hydrocarbons.

All collected data will be implemented into one large-scale numerical model, which will not only focus on the area of Cyprus, but also include the results of previous studies such as those by Bou Daher et al. (2014, 2015, 2016), which focused on the eastern margin of the Levant Basin. Based on the gathered data in combination with different possible depositional models, the initial distribution of OM within the respective source rock intervals will be simulated. Subsequently, petroleum system modeling will be applied to establish one large 3D model of this complex tectono-stratigraphic sedimentary basin in order to provide insights into hydrocarbon generation and migration and predict possible accumulations within the Eastern Mediterranean Sea.

References

Bou Daher, S., Nader, F. H., Strauss, H., & Littke, R., 2014. Depositional environment and source-rock characterization of organic-matter rich Upper Santonian–Upper Campanian carbonates, northern Lebanon. Journal of Petroleum Geology, 37(1), 5-24.

Bou Daher, S., Nader, F. H., Müller, C., & Littke, R., 2015. Geochemical and petrographic characterization of Campanian–Lower Maastrichtian calcareous petroleum source rocks of Hasbayya, South Lebanon. Marine and Petroleum Geology, 64, 304-323.

Bou Daher, S., Ducros, M., Michel, P., Hawie, N., Nader, F. H., & Littke, R., 2016. 3D thermal history and maturity modelling of the Levant Basin and its eastern margin, offshore–onshore Lebanon. Arabian Journal of Geosciences, 9(6), 1-27.

Eaton, S., & Robertson, A., 1993. The Miocene Pakhna Formation, southern Cyprus and its relationship to the Neogene tectonic evolution of the Eastern Mediterranean. Sedimentary Geology, 86(3-4), 273-296.

Needham, D.; Hosler, J.; Nowak, S.; Christensen, C.; Ffrench, J., 2013. The Tamar Field from Discovery to Production. AAPG European Regional Conference, Barcelona.

Wygrala, B.; Rottke, W.; Kornpihl, D.; Neumaier, M.; Al-Balushi, A.; Marlow, L., 2014. Assessment of Controlling Factors in Mixed Biogenic and Thermogenic Petroleum Systems - A Case Study from the Levantine Basin. AAPG Annual Convention and Exhibition, Houston, Texas.

An experimental and modeling approach for the effectiveness of the hypersaline solutions' physical properties on the settling velocity of sands.

Authors: Albanakis K., Mousouliotis A.

Affiliations: Laboratory of Physical Geography, Aristotle University of Thessaloniki, Faculty of Science, Department of Geology, Department of Physical and Environmental Geography, Greece

Contacts: albanaki@geo.auth.gr, amousoul@geo.auth.gr

Abstract

Settling velocity of fine particles is well described by Stokes Law, but when it comes to sand size particles, where the Stokes Law does not apply, the settling velocity can only be estimated by Heywood tables or by approximating equations. Settling velocity of particles is an important parameter for the simulation of turbidity currents. A good approximating solution has been implemented by Gary Parker in an open source e-book using MS EXCEL (Parker G., 2007). In the present work this MS EXCEL has been improved to include in the calculations the temperature and the kinematic viscosity of the water from zero salinity to the upper end of concentration with sea-salt. This concentration is the limit where precipitation of evaporites and especially salt occurs. These conditions should have prevailed during Messinian Salinity Crisis in the Mediterranean. The density of the sea water, the brine and the grain has also been considered. Several simulations of the settling speed of grain- sized sands have been performed. The results have been tested by creating brines by dissolving sea-salt to water (up to 400g of salt to 1kg of water). The settling velocity has been measured in a vertical cylinder by means of a HD movie camera in a “close-up” distance from the cylinder and 120 frames/sec, using one group size of grains each time (1.5-1 mm, 1-0.5 mm, up to 0.0125-0.064 mm). The experimental and the simulating results were appreciably close, considering the simulation is based in an approximating mathematical solution. Having verified the simulating model, the calculating tool was used to simulate settling speeds of different grain sizes on different salt solutions. A comparison table was created for the ratio of settling speed of fresh-water to brine and sea-water brine, for coarse and of fine grains. The results show that there is no significant difference in the settling speed between fresh-water and sea-water, but when it comes to brines the settling speed of fine sand was 2.0 times slower in the brine than in sea-water. In contrast, the settling speed of coarse sand was only 1.3 times slower in the brine. It is believed that these results indicate that a

turbidite in brine water is more effective in differentiating the sand grains thus transporting and depositing more close-related in size coarse grains, with fewer fines, creating a more porous deposition, than a turbidite in sea-water. The research is continued by testing this assumption by turbidite models and by experiments in tanks.

References

Dietrich, E. W., 1982, Settling velocity of natural particles, Water Resources Research, 18 (6), 1626-1982.

Parker, Gary. E-book., 2007. 1D Sediment Transport Morphodynamics with applications to Rivers and Turbidity Currents. http://csdms.colorado.edu/wiki/1D_Sediment_Transport

Rimoldi, B., Alexander, J. and Morris, S., 1996. Experimental turbidity currents entering density-stratified water: analogues for turbidites in Mediterranean hypersaline basins. *Sedimentology*, *43*(3), pp.527-540.

Consequences of the Messinian Salinity Crisis in clastics deposition in the Eastern Mediterranean Basin

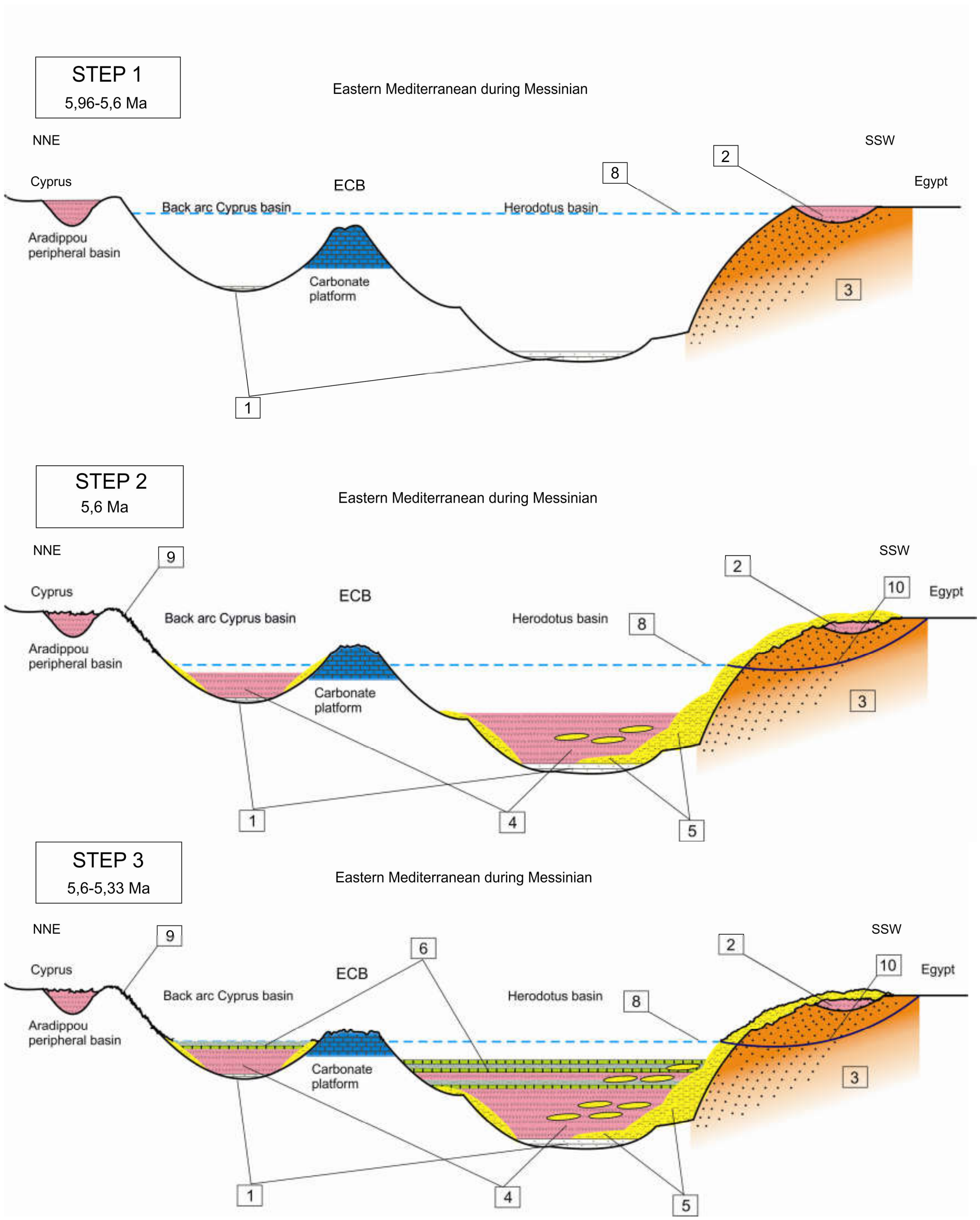
Authors: Mousouliotis A., Albanakis K.

Affiliations: Laboratory of Physical Geography, Aristotle University of Thessaloniki, Faculty of Science, Department of Geology, Department of Physical and Environmental Geography, Greece

Contacts: amousoul@geo.auth.gr, albanaki@geo.auth.gr

Abstract

This work provides a brief description of the Messinian Salinity Crisis and focuses on the deposition of detrital sediments, at the base of the Messinian salt which may be a primary target for the hydrocarbon exploration companies' offshore Cyprus. These clastic accumulations might represent the distal sand sheets of the Nile Cone and may be very important to petroleum play in the area. This is the first time; an attempt is made to unite the sedimentological and geological evolution of the River Nile, the Nile Delta, the Nile Deep Sea Fun and the Herodotus Basin, in respect to the Messinian Salinity Crisis. Purpose of this work is to give an overall picture of this confoundedly great system, from the creation of the Nile River until the sedimentary load transports into the deep Herodotus Basin. For this purpose, old and recent bibliography have been compiled and compared, identifying the controversies and finally focusing on the authors' assumptions on the potential petroleum play, based on logical geological assumptions and the literature.


STEP 1
5,96-5,6 Ma
Eastern Mediterranean during Messinian
NNE
SSW
Cyprus
ECB
Egypt
Back arc Cyprus basin
Herodotus basin
Aradippou
peripheral basin
Carbonate
platform
1
2
3
8
STEP 2
5,6 Ma
Eastern Mediterranean during Messinian
NNE
SSW
Cyprus
ECB
Egypt
Back arc Cyprus basin
Herodotus basin
Aradippou
peripheral basin
Carbonate
platform
1
2
3
4
5
8
9
10
STEP 3
5,6-5,33 Ma
Eastern Mediterranean during Messinian
NNE
SSW
Cyprus
ECB
Egypt
Back arc Cyprus basin
Herodotus basin
Aradippou
peripheral basin
Carbonate
platform
1
2
3
4
5
6
8
9
10

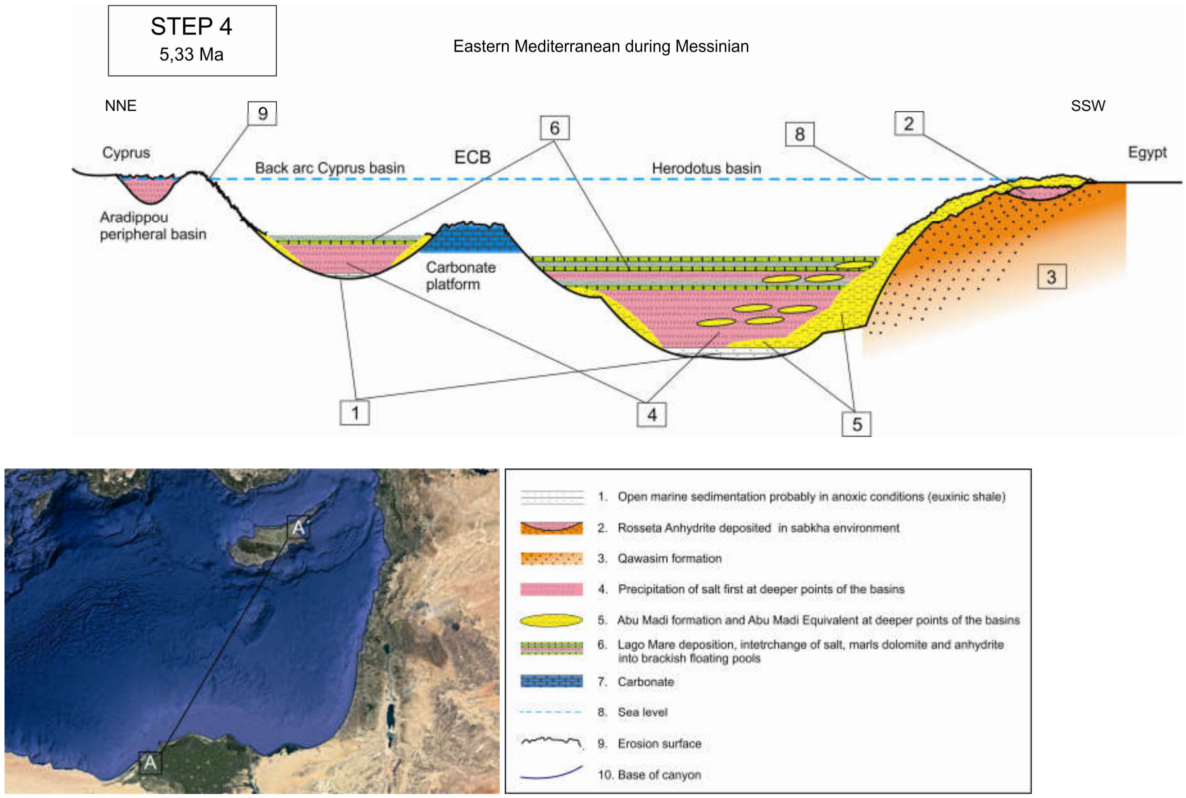


Figure 17: Model of salt deposition during MSC in the cross section A-A´. Step 1, deposition of massive anhydrites in peripheral basins without any significant sea level drop. Step 2, precipitation of massive halite coeval with Messinian clastics deposition. Step 3, Lago Mare in brackish floating pools. Step 4, Zanclean reflooding which led to the restoration of normal marine conditions.

References

Aal, A.A., El Barkooky, A., Gerrits, M., Meyer, H., Schwander, M. and Zaki, H., 2000. Tectonic evolution of the Eastern Mediterranean Basin and its significance for hydrocarbon prospectivity in the ultradeepwater of the Nile Delta. *The Leading Edge*, *19*(10), pp.1086-1102.

Gladstone, R., Flecker, R., Valdes, P., Lunt, D. and Markwick, P., 2007. The Mediterranean hydrologic budget from a Late Miocene global climate simulation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *251*(2), pp.254-267.

Loncke, L., Gaullier, V., Mascle, J., Vendeville, B. and Camera, L., 2006. The Nile deepsea fan: an example of interacting sedimentation, salt tectonics, and inherited subsalt paleotopographic features. *Marine and Petroleum Geology*, *23*(3), pp.297-315.

Montadert, L., Lie, Ø., Semb, P.H. and Kassinis, S., 2010. New seismic may put offshore Cyprus hydrocarbon prospects in the spotlight. *First Break*,*28*(4).

Montadert, L., Nicolaides, S., Semb, P.H. and Lie, Ø., 2014. Petroleum systems offshore Cyprus. AAPG Memoir 106: Petroleum Systems of the Tethyan Region, pp. 301-334

Talk preference

Title: Tectonic control on sedimentation: inferences from the Sorbas Basin (SE Spain)

Authors: Nevena Andrić[1,2], Liviu Matenco[1], Frits Hilgen[1] and Hans de Bresser[1]

Affiliations: **1** Utrecht University, Faculty of Geosciences, Department of Earth Sciences, Utrecht, The Netherlands;
2 University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

Contact: nevena.andric52@gmail.com

Abstract text

Understanding the interplay between normal faulting and deposition is important for reconstructing the evolution of asymmetric extensional basins. Still, it is poorly understood how the sedimentary environment responds to the changes of faulting rates and how these faulting pulses can be recognized in the distal depositional environment, i.e. far from the active margin.

The optimal place to study these questions is Sorbas Basin in the Betic Cordillera of SE Spain. The influence of normal faulting on sedimentation was studied by means of detailed sedimentological and field kinematic analysis. The new results demonstrate a close relationship between high-order depositional cycles and stages of activity of individual normal faults. The high-order depositional cycles recorded different rates of faulting activity and moments of tectonic quiescence which controlled the evolution of the depositional slope, amount and character of sediment supply. Furthermore, the structural reorganization following the stages of basin development influenced low-order depositional cycles.

Following basin initiation, syn-kinematic deposition of the Sorbas Basin was predominantly characterized by a wide spectrum of subaqueous gravity flows. The flow generation, types and transformation mechanisms were highly regulated by a fault-controlled slope. This resulted in characteristics syn-kinematic sedimentary patterns which can be distinguished from a 'background' sedimentation in the distal basin environment away from the active margin.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Poster / Talk preference (no preference)

Title: Deformation bands in sedimentary basins: their role in structural analysis, depth-temperature-time determinations

Authors: Fodor L[1], Beke B[1], Csizmeg J[2], Millar L[3], Petrik A[1], Szőcs E[1], Hips K[1]

Affiliations: **1** MTA-ELTE Hungarian Academy of Sciences, Geol., Geophy. Space Science Res. Group
2 Vermilion Budapest Október 23 u. 8-10, Hungary
3 Dept. Civil and Environmental Engineering, University of Strathclyde, Glasgow, UK

Contacts: lasz.fodor@yahoo.com

Abstract text,
Deformation bands (DB) are strain localization structures which play important role in sedimentary basins dominated by clastic sediment infill. They are widespread in such rocks and should be present in all basins. They are similar to but distinct with respect of faults, particularly in their deformation mechanism. Instead of frictional sliding characteristic for faults, deformation bands are formed by grain rotation, grain boundary sliding, and, during later steps of their evolution, by cataclisis. The DBs could form only in relatively unconsolidated material, thus they provide information on early structural evolution, prior to formation of “true” faults.
In this presentation we would like to take attention to these structures, which may be used in analysis of the upper part of sedimentary basins. Our study area of the northern Pannonian basin where we studied formations having been sedimented just before, during and after the main rifting phase.
One side of the application of DBs is the refining the brittle structural evolution of the host sediments. The basic concept is that deformation bands show clear variation in type (mechanism) depending on the burial of the host rock; thus the deformation is pressure-dependent in a semi-quantitative way. In this manner, formation mechanism of DBs gives us relative chronology of brittle structures. In this way we were able to give much more detail in structural evolution of the study area with respect to evolution deduced only from fault-slip analysis (Petrik et al. 2014, 2016). As an example, for pre-rift deformation phase, we could demonstrate 3 events instead of one, deduced earlier only from faults.
On the other hand, with a combined methodology, one can determine depth (pressure) – temperature – time conditions of certain structural elements and of the host rocks. The frame of the ‘time factor’ is coming from regional structural analysis, mostly from fault-slip analysis. Then we used subsidence analysis, based on available thickness and stratigraphic data. In next step, we can calibrate the burial depth of the sample during a given deformation phase by crossing the subsidence curve of the host rock with the age interval of the fracturing phase; this gives us the depth (z, pressure) axis. We combined subsidence analysis with thermal modelling using knowledge on heat flow history. Thermal modelling can thus predict temperature for a given deformation phase and for a given time span. We moved one step forward: this temperature estimates were cross-checked with information coming from structural diagenesis. We checked diagenetic minerals in the host rock and also in the DBs. Authigenic albite during DB formation could constraint formation temperature of 60-65°C, while authigenic quartz post-dating DB formation formed near the temperature of ~ 80-90°C. Crossing these temperature data with subsidence and thermal modelling we could establish of time and depth when DBs terminate to form, ca. 650-1200m, at the late stage of syn-rift phase.
Finally, DBs play role in fluid flow analysis. DBs can promote fluid flow along the structure in their

early evolutionary step, play barrier against flow during later steps, and, finally, when changed to faults, can again guide fluid motions along the evolved late brittle structure.

Research is supported by OTKA grant No. 113 013.

Petrik, A., Beke, B., Fodor, L. (2014): Combined analysis of faults and deformation bands reveals the Cenozoic structural evolution of the southern Bükk foreland (Hungary). — Tectonophysics 633, 43–62.

Petrik, A., Beke, B., Fodor, L., Lukács, R. (2016): Cenozoic structural evolution of the southwestern Bükk Mts. and the southern part of the Darnó Deformation Belt (NE Hungary). — *Geologica Carpathica*, 67/1, 83–104.

Sedimentary evolution of the siliciclastic-calciturbidite Middle Eocene Gercus Formation, NE-Iraq; Active tectonism and igneous activity approach

Sa'ad Zeki A. Kader Al-Mashaikie, Dept. of Geology, Collage of Sciences, Univ. of Baghdad, Baghdad, Iraq. e-mail: magnesite2006@gmail.com

Abstract

This paper aims to discuss the depositional evolution of the Gercus Formation with intense tectonic activities in the Iraqi Zagros Foreland Basin. The Gercus Formation is tectonostratigraphically subdividing into 4 distinctive units in which facies types and successions reflect igneous volcanism and seismic/tectonic activities. The lower Unit-A of drack gray to black color reveals successive siliciclastic/claciturbidite rocks reveals slump/deformed dolomite, dolomite breccia, ball and pillow dolomite interbedded with gray to black shale. The Unit-B reveals of red and gray color successive interbedded of slump/deformed siliciclastic sandstone/shale and siliciclastic/calciturbidite of deformed dolomite and shales characterized by submarine channels. The Unit-C reveals interbedded red and gray successions of siliciclastic/claciturbidite with intense submarine channels and slump/deformed structures. The Unit-D composed of sandstone/shale successions interbedded with almost lens like wedged carbonate beds. This unit characterized by submarine channels with sigmodal type. Intense red color is characterized unit B, C and D with increases in the siliciclastic sediments upward the sequence. All units are characterized by specific types of sedimentary structures reveals turbidity origin cf. load, flute, scoured and groove casts, sand and clay balls and pillows, slump, slide and deformed beds…etc.

Petrographic analysis reveals majority of carbonate, chert, chalcedony and volcanic fragments which refers to the effect of volcanicity on the border with Iran in the NE. these are supported with intense red color of the sandstone and mudstone and the basaltic flows in northern part of the basin. The presences of important percentages of pyroxene grains with basic and ultrabasic fragments reveals the subduction and the origin of the mantle sheet in the NE border of the Zagros Basin

The whole successions of the Gercus Formation reveal intense effect of turbidity currents, which are evident from the characteristic facies types of submarine channels, fans and pelagic/hemipelagic mud. These facies are most probably reflect the intense effect of seismic activity synsedimentation of the formation.

Key word; Gercus, tectonics, seismicity, calciturbidite, siliciclastic turbidite, pyroxene, chert and chalcedony.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Poster / Talk preference (no preference)

Title: Late Miocene ("post-rift") deformation patterns in the Pannonian basin: the mechanisms of kilometre-scale differential vertical movements

Authors: Fodor L[1], Balázs A[2], Horváth F[1], Matenco L[2]

Affiliations: **1** MTA-ELTE Hungarian Academy of Sciences, Geol., Geophy. Space Science Res. Group
2 Utrecht University, Utrecht, the Netherlands
3 Eötvös Loránd University, Department of Geophysics, Budapest, Hungary

Contacts: lasz.fodor@yahoo.com

Abstract text

The Pannonian back-arc basin is formed due to lithospheric extension within the Alpine-Carpathian-Dinaridic orogens (e.g., Horváth et al., 2015). Reserches in the last decades clarified several aspects of the nature and structural evolution of the basin. The major conclusion gained is that, despite some general evolution trend from initial rifting through post-rift thermal cooling to a final neotectonic inversion phase, all basin-forming process show temporal and spatial variations. Fault pattern and the timing and amplitudes of major deformation evens show differences in the sub-basins of the back-arc system.

Extensional deformation migrated in space and time. Earliest extension is recorded in the SW and western part of the basin, from ~19-18 Ma and terminated ~15-14 Ma. In contrast, major extension occurred later in the NE part of the basin, starting possibly from 14Ma, and, in the east, could continue up to ~ 8 Ma. The Late Miocene is traditionally thought to represent the post-rift phase characterised by slow thermal subsidence. Despite this reginal process, local deformation features changed structural geometry and sediment pattern across the basin.

The SW and southern basin part has been subjected to regional contractional deformation. Seismic sections clearly demonstrate ongoing and probably continuous contraction in several sub-basins from the latest Middle Miocene. The related structures are folds, often reactivating the Middle Miocene syn-rift normal faults. In the central-western part of the basin, Late Miocene deformation could have a transpressional to transtensional character: several major fault zones were reactivated as sinistral or dextral strike-slip or reverse-strike-slip faults. This type of deformation started earlier in the southern basin part, as early as 14 Ma, and accelerated from 12 Ma. This transpression was locally overprinted with slight extension after ca. 9 Ma. The northern basin part is either marked by modest, but noticeable normal faulting or tectonic quiescence. Here contractional structures, related to neotectonic inversion, only occurred in the Pliocene. Finally, in the eastern sub-basins normal faulting continued up to ~ 8 Ma (Tari 1994, Fodor et al. 2005, Matenco and Radivojevic, 2012, Balázs et al. 2016). Neotectonic inversion is less pronounced, locally created strike-slip and normal-strike-slip faults. The variable structural patterns influenced the sedimentary architecture and transport processes, mainly the progradation direction of clastic shelf slopes: the northwestern normal faults deviated progradation to fault-parallel direction, while the southern contractional folds forced the slope toward fold tip regions (Fodor et al. 2013).

The continuous contraction can be connected to northward motion of the Adriatic plate, and

superimposed on lithospheric scale subsidence processes. The interaction and effects of mantle dynamics and the motion of Adria and associated intra-plate stresses on rate of subsidence in different sub-basins should be quantified by further numerical modelling.

Research is supported by OTKA grant No. 113 013.

Balázs A., Matenco L., Magyar I., Horváth F., and S. Cloetingh 2016. The link between tectonics and sedimentation in back-arc basins: new genetic constraints from the analysis of the Pannonian Basin. Tectonics, 35, 1526–1559, doi: 10.1002/2015TC004109

Fodor, L., Bada, G., Csillag, G., Horváth, E., Ruszkiczay-Rüdiger, Zs. Palotás, K., Síkhegyi, F., Timár, G., Cloetingh, S., Horváth, F. (2005): An outline of neotectonic structures and morphotectonics of the western and central Pannonian basin. — Tectonophysics 410, 15–41. doi:10.1016/j.tecto.2005.06.008.

Fodor, L.I., Sztanó, O., Magyar, I., Törő, B., Uhrin, A., Várkonyi, A., Csillag, G., Kövér, Sz., Lantos, Z., Tőkés, L. (2013): Late Miocene depositional units and syn-sedimentary deformation in the western Pannonian basin, Hungary. — 11th Workshop on Alpine Geological Studies & 7th European Symposium on Fossil Algae. Abstracts & Field Guides. Schladming, 8-14th September 2013. (ed: Schuster, R.). Berichte der Geologischen Bundesanstalt, 99, 33–34.

Horváth, F. Musitz B., Balázs, A.,Végh, A. Uhrin, A. Nádor, A. Koroknai, B., Pap, N., Tóth, T., Wórum, G. 2015: Evolution of the Pannonian basin and its geothermal resources. — Geothermics 53 328–352.

Matenco, L., and D. Radivojević 2012. On the formation and evolution of the Pannonian Basin: Constraints derived from the structure of the junction area between the Carpathians and Dinarides, Tectonics, 31(6), TC6007.

Tari, G. 1994: Alpine Tectonics of the Pannonian basin. — PhD. Thesis, Rice University, Texas, USA. 501 pp.

Internal wave controlled slope angle and seafloor morphology at the Israel continental slope

Authors: Reiche S[1], Hübscher C[2], Brenner S[3], Betzler C[4] and Hall JK[5]

Affiliations: **1** Institute for Applied Geophysics and Geothermal Energy, RWTH Aachen University, Aachen, Germany;
2 Institut für Geophysik, Universität Hamburg, Hamburg, Germany;
3 Department of Geography and Environment, Bar-Ilan University, Ramat-Gan, Israel;
4 Institut für Geologie, Universität Hamburg, Hamburg, Germany;
5 Geological Survey of Israel, Jerusalem, Israel.

Contact: sreiche@eonerc.rwth-aachen.de

Internal gravity waves are widely present in world's oceans, travelling along the interface between water layers of different densities. Bottom slopes encountered by internal waves are classified by the ratio of seafloor inclination and angle of internal wave energy propagation. In regions of critical seafloor inclination (ratio of 1), internal waves transfer their energy to the ocean bottom most efficiently and may influence sedimentary processes on the continental shelve and slope (Cacchione et al., 2002).

Little is known about the presence and sedimentological impact of internal waves in the Eastern Mediterranean Sea. In this study, we investigate the role of internal waves in forming two fields of nearly slope parallel sediment waves, extending more than 100 km along the Israel continental slope. Based on subbottom profiler and bathymetric data, we show that sediment wave fields cover depth intervals of 80 m – 130 m and 190 m – 350 m, respectively. Sediment waves are characterized by amplitudes of approx. 5 m, wavelengths of approx. 500 m, an upslope climbing appearance and a downslope decrease in amplitude. The two sediment wave fields are separated by a zone of flat seafloor morphology, reduced sediment thickness and remarkably constant slope angle of around 1° – 1.3°.

Mooring data from our study area are used for assessing the presence of internal waves. These data were recorded six meters above the seafloor at 120 m water depth near the transition between the upper sediment wave field and the morphological flat zone. Preliminary analysis suggests that the cross slope internal wave spectrum comprises significant energy of internal tides at semi-diurnal frequencies. We further use a 2D seismic image of the water column for direct observations of internal waves. These data reveal the presence of wavy reflections in the water column at around 175 m and 120 m water depth, interpreted as higher frequency internal waves that interact with the seafloor of the continental slope.

Based on historical CTD data (MEDAR Group, 2002), we compute the Brunt-Vaisala frequency as a measure of ocean density stratification and the angle of internal wave energy propagation for semi-diurnal internal tides. Based on high-resolution bathymetric data (approx. 200 m x 200 m), retrieved from EMODnet (Schaap and Moussat, 2013), we calculated the ratio of slope angle to the angle of internal wave energy propagation for various depth intervals. Results show that seafloor sediment wave fields, including the zone of flat seafloor morphology, are predominately restricted to areas of critical slope inclination and major density stratification.

Such observations point to a relation between seafloor sediment waves and internal waves offshore Israel. The morphological flat zone of constant seafloor inclination (1° – 1.3°) may represent a zone of most intensive internal wave induced turbulence (breaker zone) where sediments are resuspended an potentially carried away by along-slope ocean currents. Further up and down the continental slope, seafloor sediment waves may evolve as a consequence of oscillatory flow induced by higher frequency internal waves.

References:

Cacchione, D.A., Pratson, L.F., Ogston, A.S., 2002. The Shaping of Continental Slopes by Internal Tides. Science 296, 724-727.

MEDAR Group 2002. MEDATLAS/2002 database. Mediterranean and Black Sea database of temperature salinity and bio-chemical parameters. Climatological Atlas. Institut Français de Recherche pour L´Exploitation de la Mer, (IFREMER) Edition & Instituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), 4 CD-ROM

Schaap, D.M.A., Moussat, E., 2013. EMODNet Hydrography – Seabed Mapping – Developing a higher resolution digital bathymetry for the European seas, Geophysical Research Abstracts, vol. 15, EGU2013-3620, EGU General Assembly 2013, Vienna, Austria.

The tectono-stratigraphic evolution of the Levant margin offshore Lebanon

Ghalayini, R. [(1)]

[(1)] *Exploration consultant, Lebanese Petroleum Administration*

The Levant margin offshore Lebanon exhibits a complex deformation history in relation with the regional geodynamic evolution and with the activity of the adjacent Levant Fracture System (LFS). This contribution presents a new interpretation of this margin and sheds more light on its tectono-stratigraphic evolution based on well and geophysical data.

The Levant margin is characterized today by a broad platform offshore south Lebanon, termed the Saida-Tyr plateau (STP). It is bordered by large crustal faults to its north and west, separating it from the deep Levant basin. Geophysical data indicate the presence of strong gravity anomalies below this plateau together with elevated Mesozoic units relative to the remainder of the basin. This could indicate that the STP is underlain by a crust of a different type than that of the basin and could be similar to that of Eratosthenes.

A new interpretation based on 3D seismic data and tied to deep exploration wells onshore have updated the stratigraphic subdivisions of the STP. In particular, the Mesozoic units documented onshore are most probably extending offshore with a potential presence of a Triassic sequence suspected in seismic data. This new interpretation also points to the presence of two sets of normal faults affecting the Mesozoic. They consist of ENE-WSW and E-W trending faults which cross-cut the Mesozoic units. Their geometry, displacement and trend resemble to a large extent the multitude of faults documented onshore, in particular with those described along the southern Lebanese margin. It is likely that an early Cretaceous local extension was responsible for the creation of these faults. Along the STP, the absence of deformation markers in the overlying Pliocene units together with the low to inexistent seismic activity recorded, indicate that these faults are no longer active offshore.

The Saida fault is located at the northern boundary of the STP and is marked by a large vertical displacement (>2 km). It shows evidence of dextral strike-slip movement as of the Late Miocene in relation with the LFS. It extends eastward to Lebanon and separates Mount Lebanon into two blocks having a different structural style. The Saida fault shows strong similarities with the E-W Jhar fault in Syria, which also exhibits a complex geologic history with a recent dextral strike-slip motion. Similarly to the Saida fault, it marks a sharp boundary between crustal blocks and separates the Palmyrides ranges into two blocks with each having a different structural style. Both faults are separated by about 80 km of lateral displacement. By considering the total 106 km displacement documented along the LFS in its southern Dead Sea segment together with the likely ~25 km of shortening in Lebanon, it is very possible that the Saida-Jhar structure are a single fault that was separated by the LFS as of the Late Miocene.

.

New concepts and results on the East-Mediterranean geology

Talk

Title: Latest Edition of the Lebanese Lower Cretaceous Stratigraphy

Authors: Maksoud S.[1,2], Granier B.[3,4], Gèze R.[1], Azar D.[1,2]

Affiliations: *1- Lebanese University, Faculty of Science II, Fanar, Natural Sciences Department, Fanar - El-Matn, PO box 26110217 (Lebanon)*
2- Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, People's Republic of China
3- Université de Bretagne Occidentale (UBO), UMR 6538 Domaine Océanique, 6, avenue Le Gorgeu - CS 93837, 29238 Brest Cedex 3 (France)
4- Department of Ecology and Evolutionary Biology, The University of Kansas, 1200 Sunnyside Avenue, Lawrence, Kansas 66045 (USA);

Contacts: cybellemaksoud@gmail.com, bruno.granier@univ-brest.fr, raymondgeze@gmail.com, azar@mnhn.fr

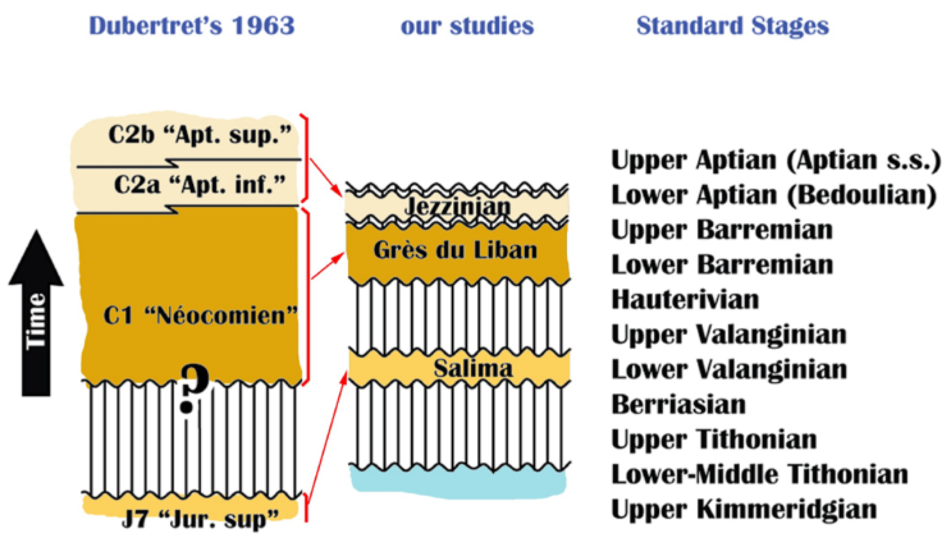
Abstract:

Louis Dubertret is considered as the father of the modern stratigraphy in the Levantine area. He contributed in the mapping of the region and his work is still the base for any geological or paleontological act in Lebanon. However, the stratigraphical units he symbolized and mapped from the Lower Cretaceous ("J7 = terminal Jurassic, C1 = Neocomian, C2a = Lower Aptian and C2b = Upper Aptian", and later renamed by Walley respectively as "Salima, Chouf, Abeih and Mdairej Formations") are all facies-driven. This concept is nowadays outdated, and thus the Lebanese stratigraphy was in need for a full revision.

Since five years, we began a complete revision of the Lower Cretaceous in Lebanon based on holistic approach of stratigraphy. Consequently and based on micropaleontologic, biostratigraphic and lithostratigraphic detailed studies, we were able to better understand the real depositional environments of the Lower Cretaceous, to identify its stratigraphical discontinuities, to give the micropalaeotological assemblages for each phase of this epoch and to define their real ages. Therefore the Salima oolitic limestones, appears to be bounded by two discontinuities, with the lower one corresponding to a hiatus spanning at least the Berriasian stage. The upper discontinuity would be equivalent to the duration of the Late Valanginian substage and the Hauterivian stage. Thus Salima oolitic limestones are Early Valanginian in age.

As for the “Chouf Formation” of Walley or “Grès de base” of Dubertret, or the “Grès du Liban” of Heybroek that we adopt; we found (*contra* Dubertret) that its base is marine, followed by a rapid regression and massive fluvial deposition intermingled in several localities by extremely rich continental fauna and flora. We found as well that the stratigraphical layers corresponding to the lower part of “C2a” of Dubertret or the “Abeih Formation” of Walley (considered by these authors as entirely marine deposition), are just a lateral change in facies within the sandstone corresponding to the “Grès du Liban”, being continental at their base, attested by massive charophytes remains, followed by a rapid transgression evidenced by the oolithic Mreijat limestone bed. We treat the lower part of “C2a” or the “Abeih Formation” as an integral part of the “Grès du Liban”. The stage “Grès du Liban” ends with a regression followed by an unconformity which marks the lower boundary of the following stage. We attribute the “Grès du Liban” an age of Early Barremian.

The “Grès du Liban” is followed by the Jezzinian (a regional stage that we created recently) that embraces the upper part of “C2a” of Dubertret corresponding to the grainy facies followed by the muddy “Falaise de Jezzine” or “Falaise de Blanche” (“C2b” of Dubertret or the Mdairej Formation of Walley). The Jezzinian is also an unit framed by two sequence boundaries. This stage represents a lagoon protected by a grainy barrier, and emcompasses the transition of Late Barremian – early Bedoulian (Late Barremian – Early Aptian). The transgressive strata above the Jezzinian starts in the lower Aptian.



Keywords: Lebanon, Valanginian, Barremian, Bedoulian, Aptian, Jezzinian

Geodynamics of and synchronous infill of flexural basins: The Northern margin of the Levant Basin, onshore Southern Cyprus

Authors : R. Deschamps[1], Nikolaos Papadimitriou[1, 2], C. Souque[1], R. Darnault[1], F. H. Nader[1], C. Gorini[2], V. Simeou[1] ; C. Homberg[2] ; J.C. Lecomte[1]

[1] Geology Department, Geosciences Division, IFP Energies nouvelles (France)
[2] ISTeP, UMR 7193, CNRS, F-75005 Paris (France)

The eastern Mediterranean basin, considered as a frontier basin, is known as a tectonically complex region where giant hydrocarbon fields have been discovered in the past decade, such as Leviathan, Tamar, Dalit and Aphrodite-A fields (www.nobleenergyinc.com). New insights on the geodynamic development of the Eastern Mediterranean region has been provided by recent studies.

In this region, the distribution of the sedimentation is directly linked to the relative motion of the African, the Eurasian, and the Anatolian plates since the Cretaceous onwards. Present-day deformations are poorly constrained because the absence of exploration wells, which makes it difficult to understand the tectonostratigraphic evolution of the northern Levant margin since the Cretaceous. Cyprus is a key area to assess the link between the deformation and the sedimentation in the Northern margin of the Levant Basin, as the whole structuration and sedimentation recorded the geodynamic history, especially during the Miocene. The study of two basins located in South Cyprus Polis Basin in the South-West, and Limassol Basin in the South) permitted to study both the sedimentary fill and the deformation of these basin since the Cretaceous through field data.

The objective of this contribution is to investigate the timing and the mechanisms of flexural subsidence as well as the sedimentary filling of the Polis and the Limassol basins located onshore Cyprus, and to show how this is linked with the geodynamics of the region.

The Limasol and Polis basins are bounded to the North by the Troodos ophiolite complex, and to the South by the external Cyprus arc thrust belt. These basins have a complex sedimentary infill directly linked with the N-S Cyprus arc compression, as well as the strike slip movement due to the Levant fault activity and the Anatolian fault, that accommodate the compression of the African plate and the Eurasian plate.

Based on fieldwork, tectono-stratigraphic reconstructions across the Polis Basin and the Limassol basin was constructed from the Late Cretaceous onward in order to propose a model of the evolution of the NortherLevant margin.

Concepts of sequence stratigraphy, facies distribution analysis as well as structural analysis invoke tectonically controlled stratigraphic evolution, and enable us to propose a link between the stratigraphic evolution of onshore Cyprus with the major geodynamic events that occurred in the Eastern Mediterranean region since the Late Cretaceous.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Talk preference

Title: The Eratosthenes Carbonate Platform: An Explorationist's perspective

Authors: Efthymiou E

Affiliations: **1** Cyprus Hydrocarbons Company;

Contacts: e.efthymiou@chc.com.cy

Abstract text,
The Eratosthenes Seamount is thought to be a piece of continental crust (continental block) that rifted from the Levant margin in the Mesozoic and has since then undergone multiple deformational events. Following Late Triassic to Early Jurassic rifting, the Eratosthenes block remained isolated from the Sina block and evolved as a carbonate passive margin until the Late Cretaceous. In the Late Cretaceous the block was submerged and carbonate platform sedimentation ceased. Oligocene and Miocene compression uplifted the Eratosthenes block to the photic zone, hence restating the growth of reefs in the Miocene. The last major tectonic event that re-submerged the Eratosthenes block to its present depths, is its collision with the island of Cyprus. Collectively the geologic evolution of Eratosthenes provides favourable conditions for the development of hydrocarbon systems, one of which is proven by the Zohr discovery in 2015 and more recently by the Onesiphoros West well in the Cyprus Exclusive Economic Zone.
From an oil and gas exploration perspective there is the potential for multiples stacked petroleum systems within the Eratosthenes Continental Block. With approximately 4Km of sediments, multiple source rocks and a world class evaporitic seal, the main challenge for this exciting new play is identifying the location of porous rock (reservoir). Carbonates are living organisms and their paleo geographical distribution is controlled by a number of factors such as climate, sea level, presence of clastic sediment, plate tectonics etc. An integrated approach is needed combining basin analysis, paleogeography, paleoclimate, seismic facies recognition together with existing well information, in order to identify possible exploration targets.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Talk preference (please delete one, or show no preference)

Title: Seismic structure of the Maranhão-Barreirinhas-Ceará margin, NW Brazil, from the MAGIC wide-angle seismic experiment

Authors: D. Aslanian[1], M. Moulin[1], P. Schnürle[1], F. Gallais[1], A. Afilhado[2,3], N. A. Dias[2,3], J. Soares[4], R. Fuck[4], J.A. Cupertino[5], A. Viana[5] & MAGIC team*

Affiliations: **1** Ifremer-Géosciences Marines, Brest, France
2 Instituto Dom Luis (IDL), Faculdade de Ciências da Universidade de Lisboa, Portugal
3 Instituto de Geociências, Universidade de Brasília, Brasília, Brazil
4 PETROBRAS, Petróleo Brasileiro S.A., Rio de Janeiro, Brazil

Contacts: Daniel.Aslanian@ifremer.fr

The structure of the North-East equatorial Brazilian margin was investigated during the MAGIC (Margins of brAzil, Ghana and Ivory Coast) seismic experiment, a collaborative project conducted in August-September 2012 by Ifremer, Univ. Brasilia, FCUL (Univ. Lisboa) and Petrobras. This project focuses on the North-Western Brazilian margin and the Equatorial Atlantic Ocean bounded to the North by the São Paulo Double Fracture Zone and to the South by the Ceará-Potiguar and the East Ghana-Ivory Coast-Togo-Benue system well-marked by the Romanche Fracture Zone. It's main objective is to understand the fundamental processes which lead to the thinning and finally to the breakup of the continental crust in a specific context of a pull-apart system with two strike-slip borders. The survey consists of 5 deep seismic profiles totaling 1900 km of marine multi-channel seismic reflection and wide-angle acquisition with 143 deployments of short-period OBS's from the IFREMER pool. Three of the profiles were extended into land using land stations from the Brazilian pool.
The analysis of the seismic dataset reveals from SW to NE 5 distinct NW-SE-oriented domains:
a) The unthinned continental crust thickness increases from 32 km in the Borborema-Ceará to 40 km in the Barreirinhas-Parnaiba province and the Ilha da Santana Platform
b) The necking zone, where crustal thickness thins to about 10 km, is about 30 km wide at Borborema-Ceará, 50 km at Ilha da Santana, but considerably wider (>125 km) at the Barreirinhas margin at the corner of the pull-apart system, with two steps first in the upper crust then in middle/lower crust;
c) An intermediate domain, composed of the southern deep Basin II and the shallower Northern basin III, extending into the São Paulo Double Fracture Zone, with volcano-sedimentary to volcanic (lava flows) layers. Below the basement, a 2-3 km thick layer with very high velocity (7.4-7.6 km/s) and marked by reflections at the top and base is observed at Basin II. This layer is followed continuously towards the continent and joins the fourth continental layer imaged only beneath the Parnaiba-Barreirinhas province, but is absent bellow Basin III, and is interpreted as exhumed lower continental crust.
d) a 60 km-wide domain, bounded to the SW by a NW-SE volcanic line, that consists in a 5 km thick crust presenting 2 layers characterized by high acoustic velocity and interpreted as proto-oceanic crust and overlain by 5.5 km of sedimentary deposits
e) a 5 km thick oceanic crust consisting of 2 layers and overlain by 5.5 km of sedimentary deposits, spanning between the two main fracture zones that fringe the Maranhão-Barreirinhas-Ceará segment.
We propose here an evolution of this margin and its segmentation in a geodynamical context.

Keywords : MARANHÃO-BARREIRINHAS-CEARÁ BASIN, PULL-APART, DEEP SEISMIC STRUCTURE, SEGMENTATION

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Topic 6: Rock-fluids interactions in sedimentary basins

Invited Key Note

Title: Innovative approaches of carbonate diagenesis quantification (Δ_{47} thermometry - U/Pb chronometry) - towards appraisal in geological modeling

Authors: Mangenot, X.[1,2], Gasparrini, M.[1], Montano, D.[1,3], Bonifacie, M.[2], Gerdes, A.[4], Rouchon, V.[1], Della Porta, G.[3]

Affiliations: **1** IFP Energies nouvelles, Rueil-Malmaison, France;
2 IPGP, Paris, France
3 Università Statale di Milano, Milan, Italy
4 Goethe Universität, Frankfurt, Germany

Contacts: xavier.mangenot@ifpen.fr; marta.gasparrini@ifpen.fr

Geological modeling is the discipline which tries to numerically reproduce complex geology by covering different time and space scales. The used numerical models correspond to a gridded, schematic representation of the subsurface geology (at basin and reservoir scales) and are realized with different approaches by integrating available geological data, physical/chemical laws governing natural phenomena and appropriate calibration methodologies.

With the term DIAGENESIS we refer to a large variety of processes (including cementation, recrystallization, fracture healing) that occur in sedimentary rocks (including reservoir-, seal- and source-rocks) all along their complex history (from shallow to deep burial to uplift) as a result of fluid-rock interaction over time. Such diagenetic processes may severely modify the sediment initial features and particularly the mineralogy and crystal size (i.e. reactive potential), the porosity and permeability (i.e. flow properties), and the pore-water chemistry (i.e. isotope and elemental composition). Understanding these processes, the temperature (T), pressure (P) and timing (t) at which they occur, as well as the geochemistry of the driving fluids ($\delta^{18}O$, salinity, etc.) play a crucial role in the reconstruction of conceptual models, which aim to predict the occurrence, in time and space, of the diagenetic modifications. This has a strong impact on the confidence of subsequent basin and reservoir models, whose accuracy critically affects the simulations of: 1) basin evolution, hydrocarbons generation and fluids (water, oil, gas) migration and 2) heterogeneity distribution in potential fluid reservoirs.

Since the 80', conventional characterization approaches try to reconstruct the above diagenetic parameters (T, P, t, $\delta^{18}O$, salinity etc.) by combining the observation of sedimentary rocks under different microscopes (i.e. petrography) with analysis of diagenetic minerals (i.e. geochemistry) and of paleo-fluids trapped within these minerals (i.e. fluid inclusions). Despite the number of petrographic and analytical tools available and the endless literature addressing these problematics, the reconstruction of past diagenetic parameters (T, P, t, $\delta^{18}O$, salinity etc.) in sedimentary basins and reservoirs often remains under constrained. This results from both the analytical challenge of performing the required analyses on the minute sample amounts available from diagenetic mineral phases, and the lack of appropriate tracers for some of the hunted diagenetic parameters.

Recent analytical developments promise to overcome common petrographic and analytical limitations and open new perspectives for unraveling the CARBONATE diagenesis key parameters with a higher degree of confidence and precision (otherwise impossible to obtain), by extending the application limits of the conventional approaches. The application of these innovative characterization techniques may contribute to improve conceptual diagenesis models and in parallel furnish more quantitative input for the successive modelling.
This contribution will focus specifically on: 1) the carbonate clumped isotopes thermometer (referred as Δ_{47}) and 2) the carbonate U-Pb isotopes chronometer via laser ablation (LA-ICP-MS).

The former allows obtaining the absolute crystallization temperatures of carbonate minerals and a precise estimation of the oxygen composition of the parent fluids (i.e. $\delta^{18}O_{fluid}$). The latter allows obtaining the absolute timing of carbonate crystallization (including cementation, replacement, recrystallization, dolomitization) directly on thin sections and also from low U-bearing phases.

Despite the huge potential, the applicability fields of such techniques are underexplored and their limits and drawbacks still need to be understood. Recent research consisted in applying these techniques on well-known carbonate diagenesis case studies, to validate their precision and geological coherence, as well as to determine the geological conditions, that could disturb their faithful application. Within this framework, the following attempts of validation were performed :
1) The comparison between the temperature (T) and $\delta^{18}O$ of carbonate parent fluids from the clumped isotopes (Δ_{47}) technique and the T-salinity obtained from the conventional microthermometry of fluid inclusions (Mangenot et al., accepted; in revision). The combination of these two techniques also opened the perspective towards a novel approach to determine fluid paleo-pressures (P) through time (Honlet et al. submitted).
2) The comparison between absolute ages (t) of diagenetic carbonates from U-Pb chronometry (by LA-ICP-MS) and relative ages assigned to the same carbonates, based on their geometric relationships with volcanic/metamorphic minerals of known ages (Montano et al., 2017). Coupling Δ_{47} and U-Pb may help improving basin thermal calibrations (Mangenot et al. 2017; in preparation).

Different carbonate units served the scope: the Middle Jurassic carbonate platform reservoirs of the intracratonic Paris basin (France), the Maastrichtian-Danian microbial carbonates of the Salta rift basin (Argentina), the Miocene of the Ries impact crater lake (Germany).

Further validation is necessary to understand the limits of these innovative characterization approaches before applying them routinely to serve both basin and reservoir research. Such validation should address different geological contexts (passive margins, rifts, fold and thrust belts) and carbonate minerals precipitated under a variety of physico-chemical conditions, in basins having experienced contrasting geodynamics evolutions. Once this step of validation is achieved a new wave of R&D could start by integrating these approaches, and the quantitative constraints that they furnish, in geological modeling functionalities (i.e. thermal, kinematic, reactive transport and geostatistical) aiming to reduce simulation uncertainties.

References

- Honlet, R., Gasparrini, M., Muchez, P., Swennen, R., John, C., submitted. A novel approach to geobarometry by combining fluid inclusion and clumped isotope (Δ_{47}) thermometry in hydrothermal dolomite (Cantabrian Zone, northern Spain). *Terra Nova*.
- Mangenot, X., Gasparrini, M., Bonifacie, M., Gerdes, A., Rouchon, V., 2017. An emerging thermo-chronometer to resolve longstanding enigmas in sedimentary basin analysis - Δ_{47}/(U-Pb). *Goldschmidt Conference*, 13-18th August, Paris (France).
- Mangenot, X., Gasparrini, M., Rouchon, V., Bonifacie, M., accepted. Basin scale thermal and fluid-flow histories revealed by carbonate clumped isotopes (Δ_{47}) – Middle Jurassic of the Paris Basin depocenter. *Sedimentology*.
- Mangenot, X., Bonifacie, M., Gasparrini, M., Götz, A., Ader M., Rouchon, V., in revision. Coupling Δ_{47} and fluid inclusion thermometry on carbonate cements to precisely reconstruct the temperature, salinity and $\delta^{18}O$ of groundwater in sedimentary basins. *Chemical Geology*.
- Mangenot, X., Gerdes, A., Gasparrini, M., Bonifacie, M., Rouchon, V., in preparation. An emerging thermo-chronometer for carbonate bearing-rocks. *Geology*.
- Montano, D., Gasparrini, M., Gerdes, A., Della Porta, G., 2017. U-Pb absolute dating of marine and lacustrine carbonates by *in situ* LA-ICP-MS. *IFPEN Report* 67253, pp. 182.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

~~Poster~~ / Talk preference (please delete one, or show no preference)

A new workflow for assessing quantitative diagenesis and dynamic porosity/permeability evolution in reservoir rocks.

Claes S[1,2], Nader FH [1] and Youssef S[3]

1 IFP Energies nouvelles, Geosciences Division, Georesources Department, France
2 KU Leuven University, Leuven, Belgium
3 IFP Energies nouvelles, Geosciences Division, Geochemistry-Petrophysics Department, France
Contact: fadi-henri.nader@ifpen.fr

Heterogeneity is an inherent characteristic of reservoir rocks. It relates to their sedimentary origin (depositional environments), burial history, and diagenesis. The occurrence, the impacts and the relative timing of the different diagenetic phases (e.g. dissolution, cementation) in reservoir rocks can be determined by a wide variety of techniques such as petrographical analysis and geochemical analysis. It is well known that their effects on reservoir properties (e.g. porosity and permeability) are important however, it remains difficult to quantify such impacts. Nowadays, computational requirements, which hampered in the past the number of heterogeneities taken into account in reservoir models, especially on a sub-meter scale, start to become resolved. New workflows for quantifying the 3D pore space of reservoirs in a dynamic approach can be henceforth developed and applied.

Through this contribution, we aimed for the development of a new approach to calculate the influence of diagenetic phases on the porosity and permeability of sandstone reservoir rocks in 3D, based on combined experimental measurements and numerical quantitative analyses. This involves (i) petrographic quantification of porosity and cement proportions in 2D and 3D (the use of micro-CT and image analysis); (ii) mathematical shape description of the pore shapes; (iii) numerical flow simulations; and (iv) analysis of the relation between diagenesis and the Representative Elementary Volume (REV). In addition, we present a workflow for laboratory experiments to simulate the diagenetic process of pore blocking calcite cement dissolution in a typical sandstone reservoir.

The investigated reservoir rocks are collected from the Lower Jurassic, Luxembourg Sandstone Formation, outcropping in Belgium. These include two major rock-types based on diagenesis. First, poorly cemented sandstones yielded a bulk porosity in the order of 21% (with 6 to 8% micropores not visible by Micro-CT), and a permeability ranging between 476 and 601mD. Well cemented sandstones still show a bulk porosity in the order of 12.5% (6% micropores), and permeability values from 5.6 to 136mD. The experimental dissolution procedure applied on the poorly cemented sandstone sample resulted in a homogeneous dissolution of the calcite phase and eliminated 7.5% of calcite cement (originally 9%). The bulk-porosity and permeability increased from 21.4 to 30.7 %, and 374 to 1300 mD, respectively. The same dissolution procedure was applied to the well cemented sample, though the dissolution patterns became heterogeneous linked with the formation of a preferential dissolution pathway. These results demonstrate that different original compositions of the sandstones lead to distinct dissolution patterns. Mathematical pore shape description was also achieved and highlighted the difference between lithologies and diagenetic stages.

Talk preference

Title: Natural sealed fractures from the Montney-Doig unconventional reservoirs tied to burial and tectonic history of the Western Canada foreland basin

Authors: Belkacemi, M.[1,2], Gasparrini, M.[1], Lacombe, O.[2], Rohais, S.[1], Pillot, D.[1], Sassi, W.[1], Euzen, T.[3]

Affiliations: **1** IFP Energies nouvelles, Rueil-Malmaison, France;
2 UPMC, Paris, France ;
3 IFP Technologies (Canada) Inc., Calgary, Canada

Contacts: marta.gasparrini@ifpen.fr

Characterizing the factors controlling the occurrence of natural fractures in fine-grained deposits such as the mudstones, is key to better understand the evolution of porosity and permeability in these tight rocks (Gasparrini et al., 2014). This understanding can provide additional constraints to calibrate basin and reservoir models for the exploration and production of unconventional resources.

A multidisciplinary approach (including sedimentology, fracture diagenesis and fluid inclusion microthermometry) has been applied for the first time to natural mineralized fractures (i.e. veins) hosted by the Lower-Middle Triassic Montney-Doig unconventional resource play of the Western Canadian Sedimentary Basin. The aim was to define the factors controlling the occurrence of natural fractures in relation with the host rock properties as well as with the geological evolution of the Canadian Cordillera fold-and-thrust-belt and the associated foreland basin (Vandeginste et al., 2012; Pana and Van der Pluijm, 2015; Rohais et al., submitted).

Forty-five core samples (2100-2500 m in depth) were collected from two wells from an unconventional field in British Columbia. These sediments present variable mineralogy and organic content (TOC of 1.2 to 3.7 wt% measured with the *Rock-Eval 6 Shale Play* protocol; Romero-Sarmiento et al. 2016) and were deposited in shoreface to offshore environments (Crombez et al. 2016).

Three generations of mineralized fractures were identified. The first generation of vertical fractures is cemented by a calcite precipitated at about 110 °C from basinal brines and which carries oil and aqueous inclusions recording the migration which occurred in the Cretaceous (~100Ma). The second generation of horizontal fractures is cemented by calcite that carries mono-phase liquid CH_4±CO_2 inclusions, indicating that they formed after gas generation, probably at higher temperatures. The third generation of vertical fractures shows petrographic evidence for post-dating the second generation, and also contains monophase liquid CH_4±CO_2 inclusions.

The cathodoluminescence response and the oxygen and carbon isotopic signature ($\delta^{18}O$ and $\delta^{13}C$) are very similar for all the studied calcite cements, irrespective of the fracture orientation and core provenance, suggesting calcite parent fluids in equilibrium with the host rock. This suggests that the Montney-Doig formations behaved like a closed system through time, and possibly acted as the source rocks of the unconventional system, at least in this part of the basin.

Host rock facies and matrix diagenesis partially controlled the occurrence of the fractures. Indeed, vertical veins are more abundant in the coarser facies (coarse siltstone and very fine sandstone) and in hemipelagic facies (calcispheric dolosiltstones) which have undergone early cementation, whereas the horizontal veins are rather localized in very fine facies (clay and silt).

The three identified generations of fractures were integrated to the burial history of the Montney-Doig formations and discussed within the broader context of the basin geodynamic evolution (Fig. 1). The vertical fractures (first generation) possibly opened during the Late Cretaceous when vertical movements of the foreland were limited and rapid sedimentation of the Colorado Group occurred (Pana and Van der Pluijm, 2015; Ducros et al., 2017, Rohais et al., submitted). The horizontal fractures (second generation) possibly opened close to maximum burial (Early Paleogene) as a result of overpressures induced by CH_4 generation, in association with compressive horizontal stresses (also recorded to the South-West; Vandeginste et al. 2012), which would have lowered the main vertical stress. The vertical fractures (third generation) possibly opened during the uplift of the basin (Late Paleogene) as a result of the diminished far-field horizontal stress.

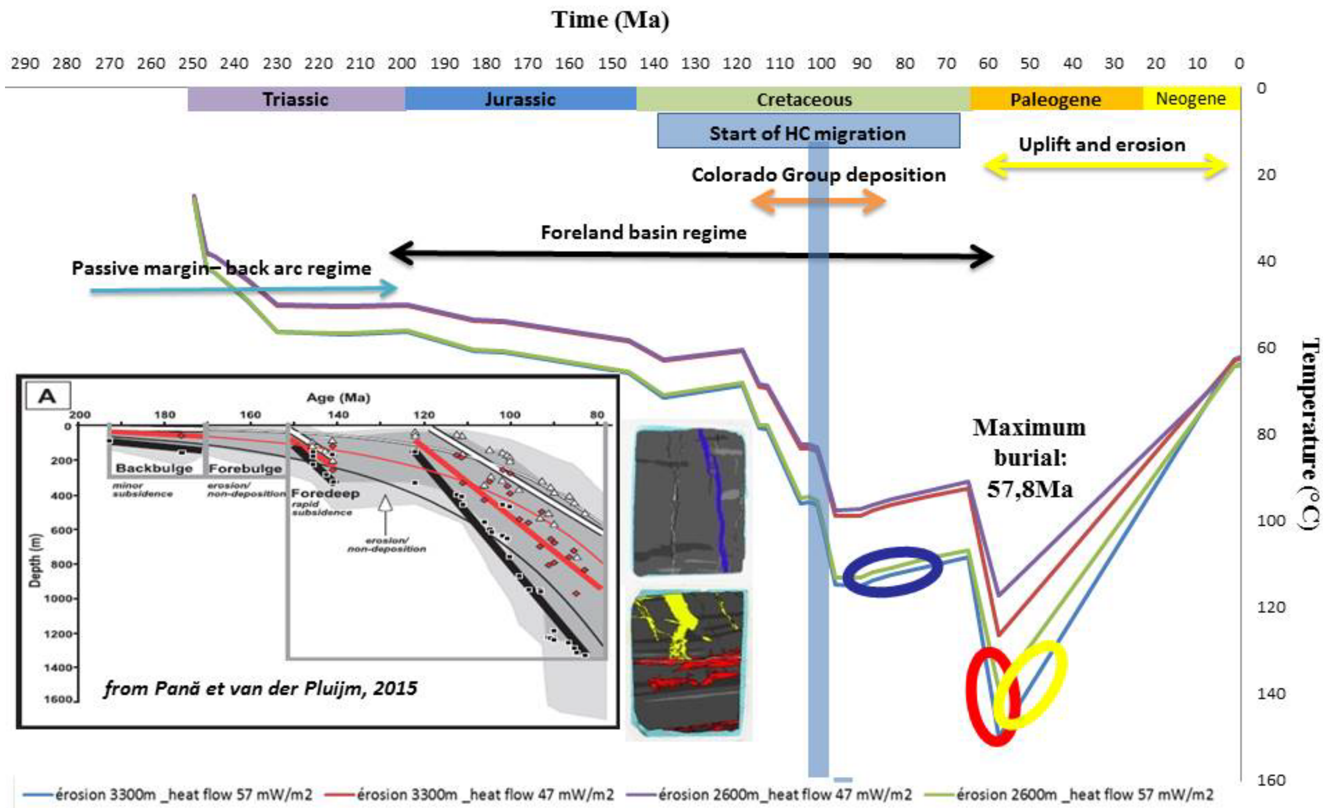


***Figure 1**: Thermal evolution of the Montney-Doig Fms., from deposition to present day, modelled with TemisFlow® according to different scenarios of heat-flow and Cenozoic erosion (Ducros et al., 2017). The main stages of the basin evolution are reported together with representative examples (in thin sections) of the three generations of mineralized fractures (first vertical-blue, second horizontal-red, third vertical-yellow) and the possible time-temperature frame for their occurrence. The sketch in the insert represents the tectonic subsidence envelope with regional subsidence trends for a reference well in west-central Alberta (Pana and Van der Pluijm, 2015).*

References

- Crombez, V., Rohais, S., Baudin, F. and Euzen, T. 2016. Facies, well-log patterns, geometries and sequence stratigraphy of a wave-dominated margin: insight from the Montney Formation (Alberta, British Columbia, Canada). Bulletin of Canadian Petroleum Geology, v. 45, p. 474–505.
- Gasparrini, M., Sassi, W., Gale, J.F.W., 2014. Natural sealed fractures in mudrocks: a case study tied to burial history from the Barnett Shale, Fort Worth Basin, Texas, USA. *Marine and Petroleum Geology*, 55: 122-141.
- Ducros, M., W. Sassi, R. Vially, T. Euzen, and V. Crombez, 2017. 2-D Basin modeling of the Western Canada sedimentary basin across the Montney-Doig system: implications for hydrocarbon migration pathways and unconventional resources potential, in Mahdi A. AbuAli, Isabelle Moretti, and Hege M. Nordgård Bolås, eds., Petroleum Systems Analysis: AAPG Memoir 114, p. 113–130.
- Pana, D.I., Van der Pluijm, B.A., 2015. Orogenic pulses in the Alberta Rocky Mountains: radiometric dating of major faults and comparison with the regional tectonostratigraphic record. *Geological society of America Bulletin*, 127(3-4), 480-502.
- Rohais, S., Crombez, V., Euzen, T., Zonneveld, J.P., submitted. Subsidence dynamics of the Montney Formation (Lower Triassic, Western Canada Sedimentary Basin): insights for its geodynamic setting and wider implications. *Bulletin of Canadian Petroleum Geology*.
- Romero-Sarmiento, M.F., Pillot, D., Letort, G., Lamoureux-Var, V., Beaumont, V., Huc, A.Y., Garcia, B., 2016. New Rock-Eval method for chracterization of unconventional shale resource systems. *Oil and Gas Science and Technology*, 71(3), 37.
- Vandeginste, V., Swennen, R., Faure, J.-L., Osadetz, K., Roure, F., 2012. Paleostress evolution in the Canadian Cordilleran foreland fold-and thrust belt west of Calgary. *Geologica Belgica*, 15, 42-53.

Talk preference

Title: **MVT mineralization and associated hydrothermal dolomite in the upper Carboniferous - lower Permian Kinta Limestone (Perak, Malaysia): Field/microscopic observations, isotopic signatures and fluid inclusion studies**

Authors: Shah MM[1], Poppelreiter MC[2], Kadir, AA[3] and Chee-Meng C[3]

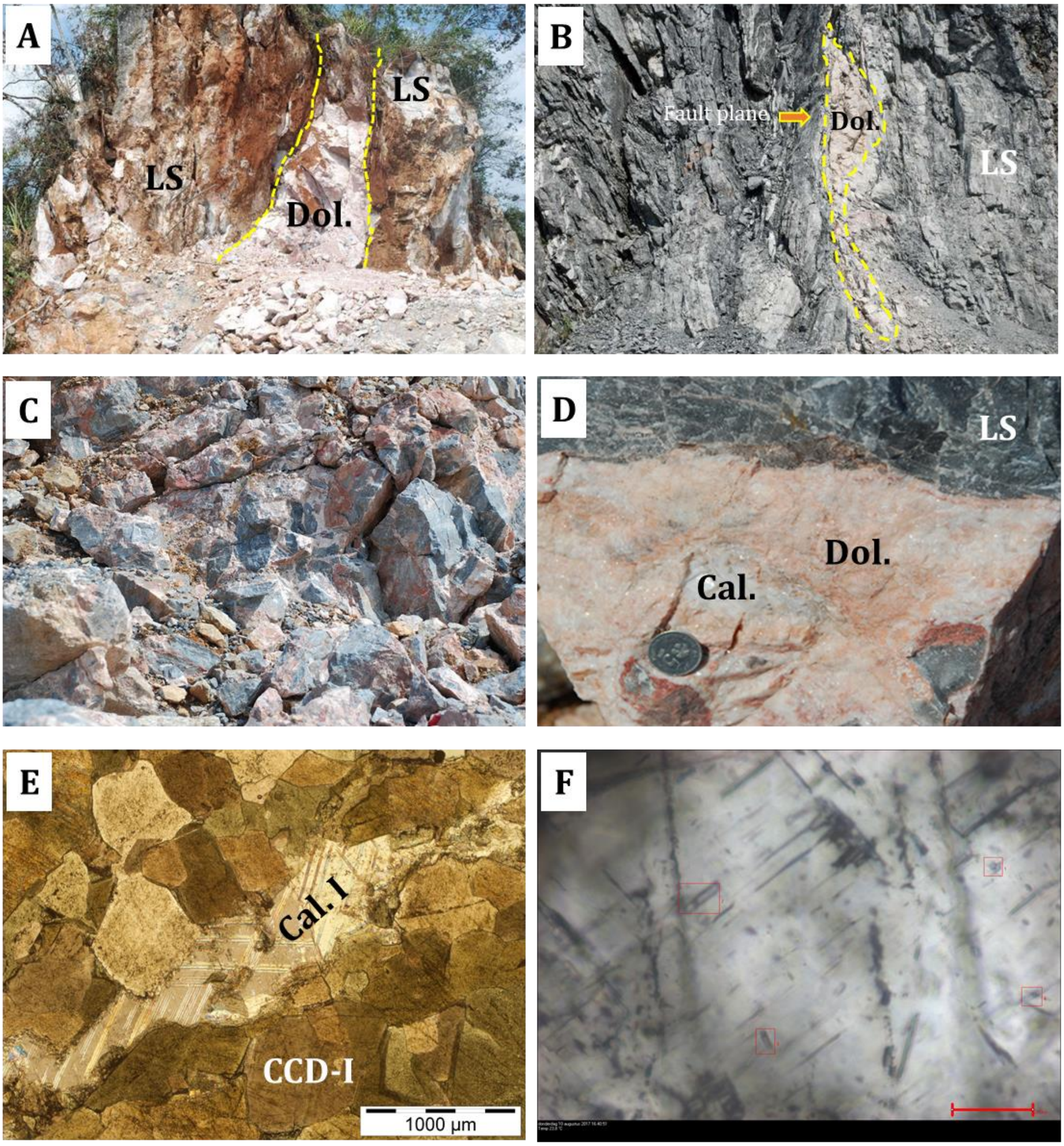
Affiliations: **1** Department of Earth Sciences, Quiad-i-Azam University, 45320 Islamabad (PAKISTAN)
2 SE-Asia Carbonate Research Laboratory, Universiti Teknologi PETRONAS, 31750 Seri Iskandar (MALAYSIA)
3 Department of Geosciences, Universiti Teknologi PETRONAS, 31750 Seri Iskandar (MALAYSIA)

Contacts: mshah@qau.edu.pk, m.poppelreiter@shell.com, askury_akadir@utp.edu.my, choong.meng@utp.edu.my

Abstract:

In the present studies, dolomite in association with haematite ore represent typical MVT deposits in the Paleozoic Kinta Valley Limestone, in the Perak state of peninsular Malaysia. Geologically, Paleozoic limestone is surrounded by two Triassic granite intrusions (Main Range to the east and the Kledang Range to the west), whereas dominant fracture sets are striking NW-SE and ENE-WSW, and indicating a rough E-W compression. In addition, shear and tension faults are widespread in the study area, where these are oriented parallel to the strikes of the beds (i.e., towards north). Field observations indicate that dolomite bodies are mostly associated with N-S oriented faults in the recrystallized Kinta Valley limestone (Figs. A&B). Intense brecciation is evident from the occurrence of limestone clasts in the dolomite cement. Dolomite cement mostly consisted of white, pink and purple colored dolomite, whereas replacive dolomite exhibited dark grey color (Fig. C). The host limestone shows initial phase of replacive dolomitization along the walls of the fracture/fault, whereas late stage dolomite cementation fill up the open spaces. Coarse crystalline, well developed calcite formed the late stage of diagenesis. Brecciated clasts of the host limestone in dolomite and calcite cements indicate the intensity of upwelling fluids (Figs. C&D). Petrographic studies revealed coarse crystalline, interlocking, saddle type of dolomite cement. In addition, replacive dolomite also exhibit rather close crystal packing (Fig. E). Isotopic studies indicate depleted oxygen signatures of various dolomite and calcite phases and hence confirm high temperature of their formation. In addition, host limestone interacted with these high temperature fluids and exhibited depleted oxygen values (Fig. G). Furthermore, fluid inclusion studies (Fig. F) indicate initial stage of dolomitization (Th= 120-170C), whereas late stage dolomitization showed high temperature of homogenization (Th= 200-290C). Salinity of the dolomitizing fluids (16-24% eq. NaCl) exhibit high values as compared to normal sea-water signatures.

Based on the above-mentioned data, it is concluded that the studied dolomite bodies are of hydrothermal origin and resulted resulted from hot and deep-seated MVT fluids and may be associated with the Triassic granitic intrusions.



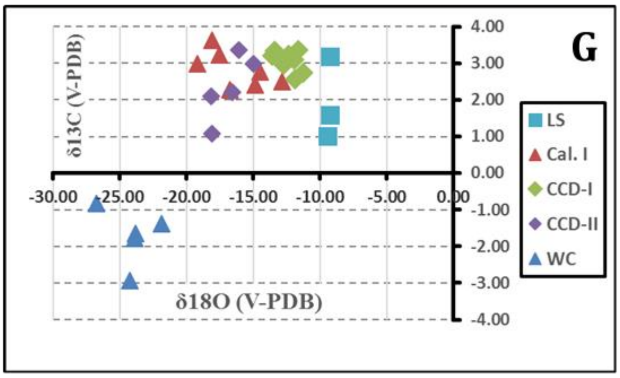


Fig. 1 (A&B): Panoramic value of the dolomite bodies in the host limestone. **(C)** Limestone brecciated clasts are observed in the outcrop showing intense deformation due to upwelling of the dolomitizing fluids. **(D)** Off-white colored calcite filling open spaces within dolomite and exhibit post-dolomite stage, whereas dolomite in contact with limestone indicate fracture fillings. **(E)** PPL photomicrograph showing twinned calcite fracture within medium crystalline dolomite (CCD-I). **(F)** Photomicrograph showing fluid inclusions within calcite cement. **(G)** O/C stable isotope signatures of the selected samples.

Topic 6: Rock-fluids interactions in sedimentary basins

Poster preference

Title: New insights on closed system dolomite recrystallization processes from clumped isotope (Δ_{47}) thermometry and Laser Ablation U-Pb chronometry - Arab Fm. reservoirs (UAE)

Authors: Morad, D.[1], Gasparrini, M.[2], Mangenot, X.[2,3], Gerdes, A.[4], Bonifacie, M.[3], Morad, S.[5], Hellevang, H.[1], Nader, F.H.[2], Al Darmaki, F.[6], Bin Ishaq, W.[6]

Affiliations:
1 University of Oslo, Norway ;
2 IFP Energies nouvelles, Rueil-Malmaison, France;
3 IPGP, Paris, France ;
4 Goethe Universität Frankfurt, Germany
5 Petroleum Intitute, Abu Dhabi, UAE
6. Abu Dhabi Gas Development Co. Ltd. (Al Hosn Gas), Abu Dhabi, UAE

Contacts: d.j.morad@geo.uio.no; marta.gasparrini@ifpen.fr;

Dolostones of the Arab Fm. (Arabian Gulf) are among the largest oil and gas reservoirs in the world. Diagenesis of these reservoirs has been studied (e.g. Swart et al., 2005; Morad et al., 2012; Nader et al. 2013, Morad et al., submitted), though uncertainties still exist on how these dolomites, and related intercrystalline pores, formed. The combined application of novel techniques like clumped isotope (Δ_{47}) thermometry and laser ablation U-Pb chronometry (Gasparrini et al., in press) could bring new light in understanding the origin and distribution of heterogeneities in such dolomitic reservoirs.

It has been suggested (Swart et al. 2005, Morad et al. 2012; Nader et al., 2013) that the dolomites from the Arab Fm. formed in the Upper Jurassic (~150-154 Ma) during major syn-sedimentary to early diagenetic processes (i.e. sabkha-evaporative and seepage-reflux dolomitization models), at surface temperature conditions. However, oxygen isotope data ($\delta^{18}O_{carb}$) suggest that some of the dolomites formed (or were reset during burial) at relatively high temperatures (Morad et al., 2012). Recently, Swart et al. (2016) conducted a clumped isotope study on the Arab Fm. dolomites from the Ghawar field (Saudi Arabia). They recorded temperatures between 25 and 125 °C for the dolomites and $\delta^{18}O_{fluid}$ of the parent fluids between 0 and 8 ‰ (SMOW), pointing rather towards a local resetting of the original sedimentary signature by basinal fluids. Interestingly, the reset dolomites seem to correspond to the highly porous and permeable zones of the reservoir (super-K zones).

Here, a detailed diagenetic study has been conducted on the Upper Jurassic Arab Fm. from a gas anticline field onshore Abu Dhabi (Morad et al., submitted). Variable porosity-permeability values were recorded in similar dolomitized facies, suggesting that the reservoir properties are not only linked to the original depositional heterogeneities. Additionally, a spread in the $\delta^{18}O_{carb}$ values of the dolomites (-1 to -4,5 ‰; PDB), suggests that processes, other than early dolomitization from marine Late Jurassic fluids, have affected the reservoir units. The samples also display variable textures at the microscopic scale, going from tight dolomicrite to coarser dolomite crystal mosaics with better reservoir properties.

Clumped isotope (Δ_{47}) data for 15 dolomite samples of this field indicate that the dolomites record temperatures in the range 43-82 (±6) °C. Also the lowest temperatures are too high for carbonates that precipitated from seawater, even under arid climate conditions and in very restricted environments.

Laser ablation U-Pb chronology on 7 of these 15 dolomite samples indicate two populations with ages of about 130-135 Ma (Late Jurassic) and 92-96 Ma (Late Cretaceous), respectively (Fig. 1). Both populations are too young compared to depositional age and suggest a reset of the dolomite system by multiple events.

The data overall suggest a selective recrystallization of some portions of the dolomitic reservoirs by high temperature fluids during burial. They also suggest that the recrystallization affected the dolomites at different moments of the basin evolution (~130-135 and ~92-96 Ma) and was not a continuous process.

The data also indicate that the recrystallization occurred in a closed system: the process was driven by the same dolomite pore-fluids evolving during fluid-rock interaction through time. The temperature-$\delta^{18}O_{fluid}$ data from the studied field share similarities with those from the Gahwar field (Swart et al. 2016), suggesting that the dolomite recrystallization process occurred in a similar manner in reservoirs far from each other (i.e. at basin scale), thus allowing conceptual scenarios to be drawn, which could be extrapolated to reservoirs of the Arab Fm. located in other areas of the Arabian platform.

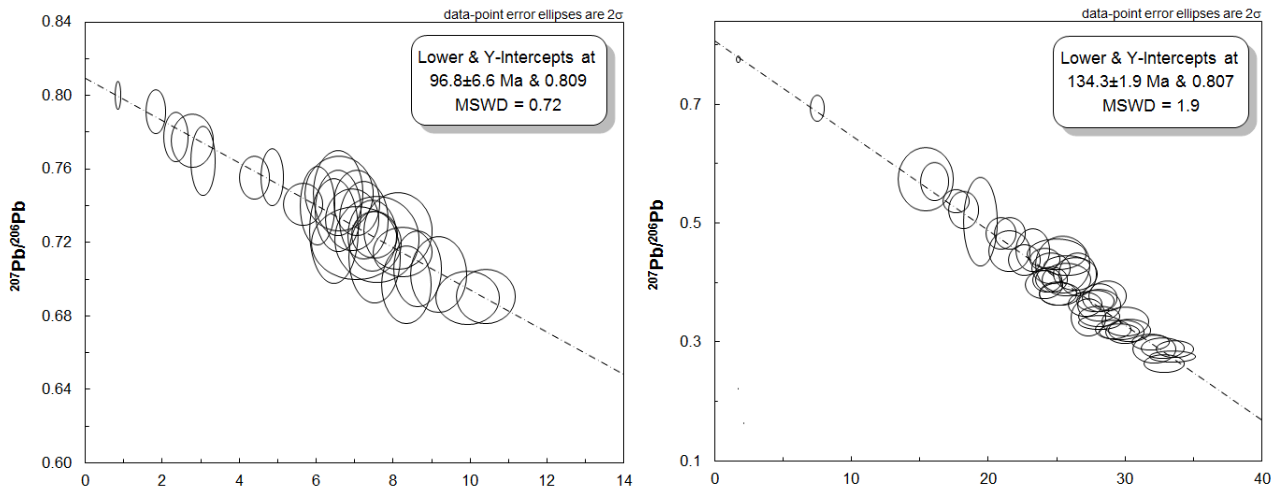


***Figure 1**: Tera-Wasserburg diagrams (^{238}U-^{206}Pb - $^{235}U/^{206}Pb$) illustrating the isochrones reconstructed for two dolomite samples and indicating absolute ages of recrystallization at 96.8 Ma (left) and 134.3 Ma (right), respectively.*

The major implication for oil and gas industry is that the reservoir properties changed through time due to burial recrystallization of the original early dolomites and that they are not only controlled by the origin and distribution of precursor facies and depositional environments.

In order to build realistic reservoir models and better predict the distribution of the more porous-permeable zones in such dolomitic reservoirs, a research approach given by two complementary tasks seems to be needed:
1) Characterize the events of early dolomite recrystallization by applying advanced analytical techniques (i.e. Δ_{47} thermometry and U-Pb chronometry) which overcome the limits normally encountered in establishing the diagenetic evolution of fine crystalline carbonate reservoirs (Gasparrini et al., in press);
2) Implement the characterization data from such advanced diagenesis study in reservoir modelling approaches (e.g. geostatistics; Gasparrini et al., 2017), aiming to simulate the distribution of heterogeneities due to mutual interactions of facies and diagenesis, by including also the effects of dolomite recrystallization.

References

- Gasparrini, M., López-Cilla, I., Blázquez-Fernández, S., Rosales, I., Lerat, O., Martín-Chivelet, J., Doligez, B., 2017. A multidisciplinary modeling approach to asses facies-dolomitization-porosity interdependence in a Lower Cretaceous platform (northern Spain). In: MacNeil, A.J., Lonnee, J., Wood, R. (eds), *Characterization and modeling of carbonate reservoirs*. *SEPM Special Publication*, 109. SEPM (Society for Sedimentary Geology), Tulsa, Oklahoma. DOI: 10.2110/sepmsp.109.07
- Gasparrini, M., Mangenot, X., Montano, D., Bonifacie, M., Gerdes, A., Rouchon, V., Della Porta, G., in press (this conference). Innovative approaches of carbonate diagenesis quantification (Δ_{47} thermometry - U/Pb chronometry) - towards appraisal in geological modeling. *ILP2017 Sedimentary Basins*, 29th October – 2nd November, Limassol (Cyprus).
- Morad, S., Al-Aasm, I.S., Nader, F.H., Ceriani, A., Gasparrini, M., Mansurbeg, H., 2012. Impact of diagenesis on the spatial and temporal distribution of reservoir quality in the Jurassic Arab D and C members, offshore Abu Dhabi oilfield, United Arab Emirates. *GeoArabia*, 17(3): 17-56.
- Morad, D., Nader, F.H., Gasparrini, M., Marchionda, E., Hellevang, H., submitted. Comparison of diagenetic and reservoir quality evolution between the anticline crest and flank of a carbonate gas reservoir, Upper Jurassic Arab Fm., United Arab Emirates (UAE). *Sedimentary Geology.*
- Nader, F.H., De Boever, E., Gasparrini, M., Liberati, M., Dumont, C., Ceriani, M., Morad, S., Lerat, O., Doligez, B., 2013. Quantification of diagenesis impacts on reservoir properties of the Jurassic Arab D and C members (offshore, U.A.E). *Geofluids*, 13(2): 204-220.
- Swart, P.K., Cantrell, D.L., Westphal, H., Handford, C.R., Kendall, C.G., 2005. Origin of dolomite in the Arab-D reservoir from the Ghawar field, Saudi Arabia: Evidence from petrographic and geochemical constraints. *Journal of Sedimentary Research*, 75: 476-491.
- Swart, P.K., Cantrell, D.L., Arienzo, M.M., Murray, S.T., 2016. Evidence for high temperature and ^{18}O enriched fluids in the Arab-D of the Ghawar Field, Saudi Arabia. *Sedimentology*, 63(6): 1739–1752.

~~Poster~~ / Talk preference (please delete one, or show no preference)

Integrated approach for tectono-sedimentary basin analysis of the Levant (East-Mediterranean region): Implications on petroleum potentials and exploration de-risking of frontier basins.

Nader, FH

IFP Energies nouvelles, Geosciences Division, Georesources Department, France
Contact: fadi-henri.nader@ifpen.fr

More than 60 trillion cubic feet (Tcf) of natural gas were recently discovered offshore Israel, Cyprus and Egypt. The Lebanese government has set a first offshore licensing round this year (2017) and announced gross amounts of gas between 30 and 95.5Tcf, yet to be discovered. These developments clearly make out of the East-Mediterranean region very exciting for future exploration and a proven world-class, frontier deepwater gas province. New discoveries resulted in new plays and prospects, such as Zohr carbonate supergiant gas field (30 Tcf), while un-explored areas, such as the Lebanese offshore, may yield additional surprises. Still, the Levant Basin is characterized by a lack of data, a complex geodynamic history, diverse sediments fairways, and ultimately high exploration costs.

This contribution is based on the current geological understanding of the Levant Basin that was achieved by several academic and industry-based research projects since 2011. From crustal modelling and geodynamics to seismic interpretations (structural geology and stratigraphy), geochemical analyses of source rocks and petroleum systems modelling. A considerable weatlth of knowledge has been made available and the most important lesson is the integrated approach that was devised. Here lies, the take home message of the present contribution: integrated approach for characterization and numerical modelling helps in better assessing petroleum potentials of a frontier basin and allows exploration de-risking.

The type and architecture of the underlying crust have major implications on the formation and deformation of sedimentary basins and their thermal history. This latter issue is fundamental for the maturation of source rocks and expulsion of hydrocarbons. For the Levant Basin, the fact that the crust underlying the basin is very much thinned (attenuated continental crust) compared to the relatively thicker crust below the margins, plays an important role in the deformation styles and petroleum systems. Source to sink basin-infilling is also associated to geodynamics and precisely the tectono-stratigraphic evolution. Hence, the tilting and emergence of Afro-Arabia Plate in the Oligocene and the advent of the Levant Fracture in the Miocene controlled the major clastic sources infilling the East-Mediterranean basins. Paleo-highs, resulting from the tectonic deformation and/or sea-level variations promoted the deposition of carbonates.

Petroleum exploration and production endeavors generate huge amounts of data, which can be well used for academic research to improve knowledge and numerical tools. Integrated workflows – similar to the ones presented here – result in reducing uncertainties and efficient processing of data and results. Finally, collaborative ventures between academic and industry-based groups yield rewarding outcomes in well-timed framework.

Mesozoic clastics in Cyprus : an exhaustive sedimentologic and petrographic study may lead to refine eastern mediterranean paleogeographic reconstructions.

Christian BLANPIED[1], Ludovic MOCOCHAIN[1], Sidonie REVILLON[2], Jean-Michel KLUSKA[3], and Etienne DELOULE[4]

[1]UPMC, Paris, [2]SEDISOR, Brest, [3]TOTAL, Pau, [4]CRPG, Nancy.

Paleogeographic and geodynamic reconstructions prior to the Tertiary in the Mediterranean remains problematic even if this tethysian domain is the site of extensive work for many decades. This is in part due to the large uncertainties concerning the postulated ages of not proven oceanic crust and the timing of mesozoic events.

Lower Cretaceous clastic series derived from the African or Arabian hinterland are well known onshore in the coastal areas in the northern part of Africa and in the Levant region. They are not reported from the series described from the complex folded, accretionary wedges constituting the neotethysian terranes in the Anatolian, Tauride and northern Syrian domains. In between these two geologic entities, in the actual offshore of the central and eastern Mediterranean, they have only been penetrated in a few petroleum wells.

In Cyprus, a series of clastics composing part of the allochthonous Mamonia complex, and termed the Akamas sandstone, are attributed a Lower Cretaceous age. The composition of this sandstone, its possible local or long distance sources are succinctly presented based on recent petrographic analysis, (U-Pb Zr geochronology and Sr-Nd).

In Cyprus also, the Triassic carbonate and clastic series rich in plant remains poses a similar problem of provenance and reliable correlation with the Levant and eastern Mediterranean onshore series.

Based on this recent preliminary petrographic results, different provenance hypotheses are discussed. In order to test them, further systematic sediments and petrographic approaches coupled with isotopic and mineralogy studies are proposed. This will in turn contribute to refine at least locally the actual proposed paleogeographic reconstructions.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Talk preference

Title: Eratosthenes Seamount; The evolution of an isolated carbonate platform at a major plate boundary (offshore Cyprus)

Authors: **N. Papadimitriou[1, 2]**, C. Gorini[2], FDeschamps[1], and A.Tassy[2]

Affiliations: [1] Georesources Department, Geosciences Division, IFP Energies Nouvelles (France)

[2] ISTEP, UMR 7193, UPMC, F-75005 Paris (France)

Contacts: papsalokin@gmail.com;nikolaos.papadimitriou@ifp.fr

The Eratosthenes Seamount is described as a 5-km thick isolated carbonate platform, which is adjacent to the deep marine facies of the Levant Basin. In general, the isolated carbonate buildups are attractive exploration targets, and such statement has been confirmed with the most recent discovery of light oil in the Lower Cretaceous platform south of Eratosthenes Seamount. However, understanding the stratigraphic architecture of isolate carbonate platforms from seismic data have been proven to be difficult.

The objective of this contribution is to present a model of the onset and the demise of the an isolated carbonate platform in the Eastern Mediterranean (i.e., the Eratosthenes carbonate platform). During this study, we applied seismic stratigraphy concepts to better understand the tectonostratigraphy, the sedimentary architecture and morphology of the Eratosthenes carbonate platform from the Jurassic to the present day. The evolution of the Eratosthenes isolated platform partly resembles the Egyptian margin and could be compared to other ancient and modern isolated carbonate platforms. The onset of the carbonate factory is marked by a post-rift Jurassic retrograding and aggrading lower seismic unit characterised by rapid lateral shifts in seismic facies interpreted by successions of mounds. The upper unit is aggrading and characterised by prograding clinoforms that is interpreted as shoals. This unit is topped by an erosional surface described in Egypt and Lebanon at the limit between Jurassic and Cretaceous. This succession is followed by a

Cretaceous aggrading carbonate platform characterised by different seismic facies interpreted as forereef breccia, buildups and lagoonal facies.

Similar to the neighbour margins Late Cretaceous carbonate platforms at Eratosthenes vicinity were drowned during the Coniacian. During the Cenozoic, both the Eratosthenes Seamount and the Levant Basin became part of a foreland basin along the Cyprus arc zone as a result of the collision of the African and Eurasian plates. Late Cretaceous and Eocene deep-water carbonates were covered by shallow carbonates pinnacles during the Miocene. At that period the basin is characterised by chaotic seismic facies interpreted by mass transport deposits events strongly related to the geodynamic activity. These events are also described onshore Cyprus and are Tortonian in age.

Crustal structure across the Cyprus arc plate boundary from the Eratosthenes Seamount to south Turkey from an amphibian wide-angle seismic profile

Mechie, J.[1], Feld, C.[1], Hübscher, C.[2], Hall, J.[3], Nicolaides, S.[4], Gurbuz, C.[5], Bauer, K.[1], Louden, K.[6], Weber, M.H.[1,7]

1 Deutsches GeoForschungsZentrum - GFZ, Telegrafenberg, 14473 Potsdam, Germany.
2 Institute of Geophysics, University of Hamburg, Bundesstraße 55, 20146 Hamburg, Germany.
3 Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL A1B 3X5 Canada.
4 Geological Survey Department, Lefkosia (Nicosia), Republic of Cyprus.
5 Department of Geophysics, Boğaziçi University, Istanbul, Turkey.
6 Department of Oceanography, Dalhousie University, Halifax, NS, B3H 4J1 Canada.
7 University of Potsdam, Institute of Earth and Environmental Science, 14478 Potsdam-Golm, Germany.

jimmy@gfz-potsdam.de

In 2010, project CoCoCo (incipient COntinent-COntinent COllision) recorded a 650 km long amphibian N-S wide-angle seismic profile, extending from the Anatolian plateau across southern Turkey and Cyprus to just south of the Eratosthenes Seamount (ESM). The aim of the project was to reveal the impact of the transition from subduction to continent-continent collision of Africa with Eurasia. Arrival picking, finite-differences ray-tracing and inversion of the offshore and on-offshore data produced a tomographic model across southern Cyprus, the accretionary wedge and the ESM. Beneath the ESM, the Moho occurs at 32-35 km depth and compressional (P) wave velocities lie mainly between 5.5 and 6.5 km/s (Fig. 1). This supports the view that the ESM comprises continental crust (Feld et al. 2017). Picked secondary seismic phases were used to invert for a shallow reflector beneath the ESM. The reflector is located at 8-9 km depth at the northern and southern ends of the ESM. Directly beneath the ESM the reflector rises up to 3.5 km depth. The geometry of the reflector corresponds to the 5.5 km/s P-wave velocity isoline and agrees with the general observation that the upper low-velocity layers (< 4.8 km/s) thicken to the north and south of the ESM. Therefore this modelled reflector probably represents the boundary between the sedimentary layers and the upper crystalline crust beneath the ESM. South of the ESM (625-650 km offset), the presence of a thickened low velocity layer (< 4.8 km/s) in the upper 10 - 12 km, higher velocities in the lower crust and the decreasing Moho depth to about 28 km are indicators for a possible transition towards oceanic crust. The northern boundary of the ESM is considered to represent a Mesozoic NNW–SSE oriented transform margin. North of the ESM (450-525 km offset), the Moho depth is about 37 km and increasing beneath Cyprus and higher P-wave velocities of 6-5-7.0 km/s are observed at depths greater than 15 km. The accretionary wedge is represented by a triangle shaped low velocity zone (P-wave velocities lower than 5.5 km/s) north of the ESM. It has a north dipping lower surface, starting at the trench of the Cyprus arc, at an offset of 512 km. It reaches a depth of 15 km at its northern end and extends above the northward subducting plate with a total width of ~37 km. A high velocity zone (7.6-8.0 km/s) beneath Cyprus is interpreted as the ophiolite sequence of the Troodos complex on Cyprus. The high velocity zone is located at 5-12 km depth and extends offshore south of Cyprus (up to 470 km offset).

Land shots in Turkey, also recorded on Cyprus, gravity data and geological and previous seismic investigations allow to derive a layered velocity model beneath Anatolia and the northern part of Cyprus (Fig. 1). Beneath the Central Anatolian Crystalline Complex (CAAC) and the Taurides block, the upper and lower crusts show large lateral changes in velocity structure and thickness. Lateral velocity changes in the sediments are up to 0.7-0.8 km/s and in the upper and lower crusts below the sediments up to 0.3 km/s. A Moho depth of 38 km occurs at the northern end of the profile, increasing southward to 45 km in combination with an upper mantle P-wave velocity of 7.8 km/s (Feld et al. 2017). A high velocity block of 7.5 km/s which probably corresponds to the ophiolite complex occurs beneath northern Cyprus. This block extends to the northern coast of Cyprus and disappears north of the coast. This is interpreted as the northern end of the Troodos ophiolite complex. A subducting plate has been modelled with two reflected phases recorded by the Cyprus stations. The dip of the upper boundary is less than the dip of the lower boundary (Moho). Thus, the wide-angle seismic and gravity data provide detailed insights into the 2-D geometry and velocity structures associated with the Cyprus Arc collision zone.

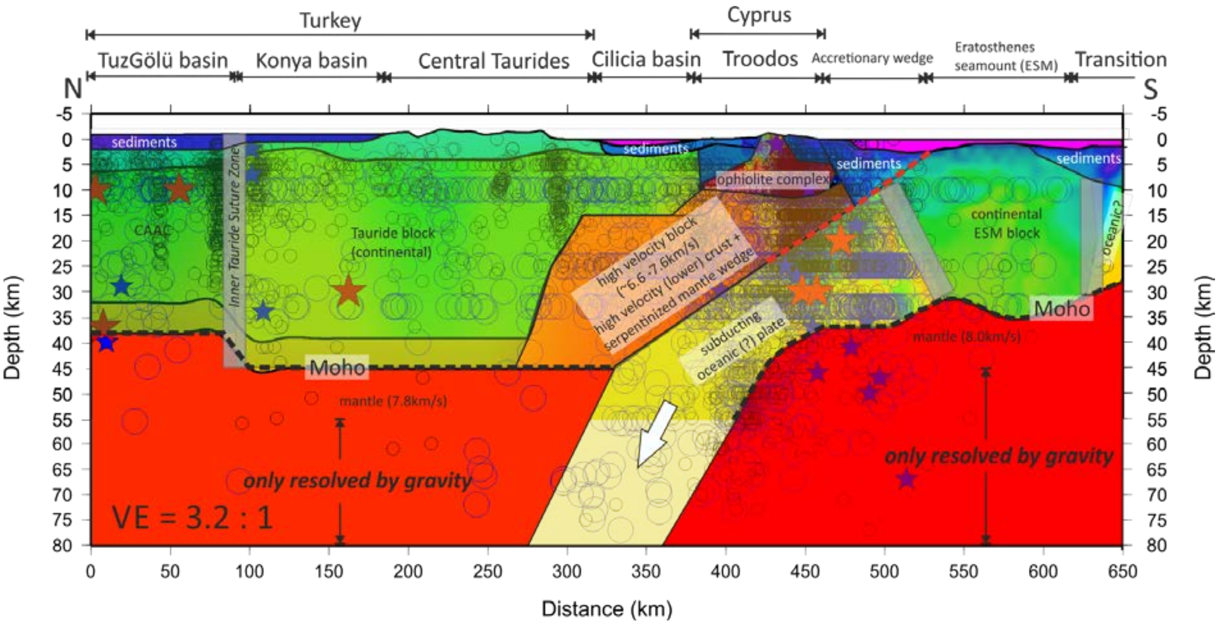


Figure 1. Transect across the Cyprus arc plate boundary between the northernmost unit of Africa, the Eratosthenes seamount, and Eurasia, represented from south to north by Cyprus, including the Troodos ophiolite, the Cilicia basin, the Taurides and the Central Anatolian Crystalline Complex (CAAC). Circles and stars show the seismicity distribution (from NEIC (USGS), Kandilli Observatory and Earthquake Research Institute (Turkey) and Geological Survey Department, Republic of Cyprus). Blue and red stars show earthquakes with magnitudes >4.5 and >5.0 respectively.

The velocity structure beneath the Troodos ophiolite suggests that it was most probably obducted onto a rifted, thinned continental margin. North of the continental Eratosthenes seamount (ESM), the subducting African plate can be traced with seismic reflections, also using the line-drawing migration method (Bauer et al. 2013), and refractions beneath the accretionary wedge and the Troodos ophiolite to about 60 km depth (Fig. 1). The ESM with a crustal thickness of 27-34 km and low crustal P-wave velocities (Welford et al. 2015, Feld et al. 2017), lies beneath about 1 km of water. This is probably due to the fact that the ESM is being held down by the northwards subducting plate to the north and possible oceanic crust to the south.

References

Bauer, K., Ryberg, T., Fuis, G. S., and Lüth, S., 2013. Seismic imaging of the Waltham Canyon Fault, California: Comparison of ray-theoretical and Fresnel volume prestack depth migration. Bulletin of the Seismological Society of America, 103: 340-352.
Feld, C., Mechie, J., Hübscher, C., Hall, J., Nicolaides, S., Gurbuz, C., Bauer, K., Louden, K. and Weber, M., 2017. Crustal structure of the Eratosthenes Seamount, Cyprus and S. Turkey from an amphibian wide-angle seismic profile. Tectonophysics, 700-701: 32-59, doi:10.1016/j.tecto.2017.02.003.
Welford, J.K., Hall, J., Hübscher, C., Reiche, S. and Louden, K., 2015. Crustal seismic velocity structure from Eratosthenes Seamount to Hecataeus Rise across the Cyprus Arc, eastern Mediterranean, Geophysical Journal International, 200, 933-951.

Deformation and metamorphism on the Northern Sporades: a field study from Skopelos and Alonnisos (Aegean Domain)

Talk preference

Kristof Porkolab[1], Ernst Willingshofer[1], Dimitrios Sokoutis[1,2], Iverna Creton[1], Dimitrios Kostopoulos[3]

1 Faculty of Geosciences, University of Utrecht, Budapestlaan 4, 3584CD Utrecht, Netherlands

2 University of Oslo, Department of Geosciences, PO Box 1047 Blindern, 0316 Oslo, Norway

3 Department of Mineralogy and Petrology, Greece, National and Kapodistrian University of Athens

Contact: k.porkolab@uu.nl

Extension in the Aegean region is a process driven by slab rollback since 45 Ma (e.g. Brun et al., 2016; Brun and Sokoutis, 2007). These and other studies dominantly focused on the northern Aegean/Rhodope or the Cycladic tectonic systems, yielding abundant kinematic, structural, petrologic and geochronological data to constrain their geodynamic evolution. This contrasts with the region of the Northern Sporades, which have not yet been thoroughly studied in the light of subduction-exhumation processes. In particular, a detailed kinematic and petrological analysis, the focus of this study, is missing that allows for establishing the relation between the deformation structures and mineral paragenesis on the island, and the large-scale tectonic events in the Aegean domain.

The Northern Sporades consist of three major (area ≥ 50km2) islands (Skiathos, Skopelos, and Alonnisos) and a number of smaller islands. As the first phase of exploring the structural evolution of the Northern Sporades, this work reports the results of field work performed on the island of Skopelos and Alonnisos, and aims to provide a preliminary model for the deformation history of the island group.

Skopelos and Alonissos consist from bottom to top of three structural units, which are separated by thrust contacts: the Pelagonian, the Eohellenic/Vardar suture, and the Palouki unit (Jacobshagen and Wallbrecher, 1984; Jacobshagen and Ματαράγκας, 2004; Matarangas, 1992). The age of the formations constituting these units ranges from Paleozoic to Paleogene, and all formations have been metamorphosed under lower greenschist or possibly also blueschist facies conditions (Mposkos and Liati, 1991) and experienced polyphase deformation.

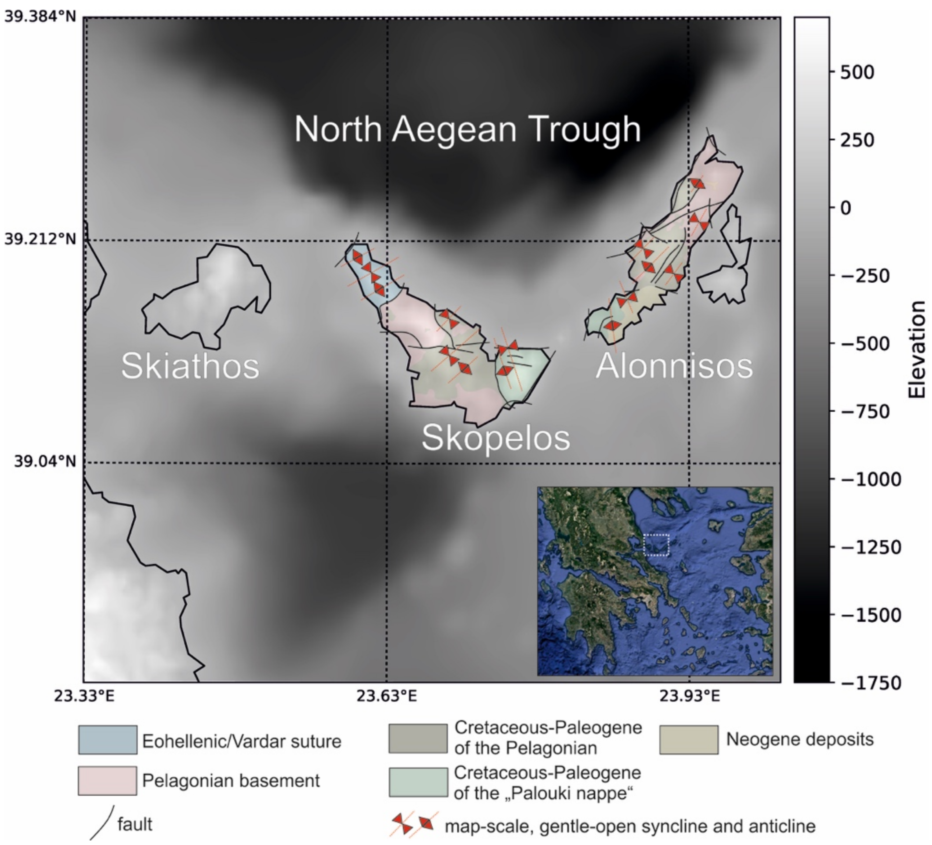


Figure 1. Regional geology of Skopelos and Alonnisos and the elevation of the surrounding region

Based on our field kinematic and structural analysis we suggest the following deformation sequence: D1 is characterized by tight to isoclinal folding (F1) and the formation of a penetrative foliation (S1), which is the axial plane cleavage to the F1 folds. S1 planes carry a stretching lineation which has a dominant NE-SW trend on Skopelos, and NW-SE trend on Alonnisos as we observe it today. The first metamorphic foliation of Al-rich metasediments contains phengite and the remnants of carpholite, which are gradually replaced by chloritoid. Geothermobarometric calculations infer HP-LT conditions for D1. Along the stretching direction top-SW sense of shear has been inferred on Skopelos, and top-NW on Alonnisos indicating the tectonic transport direction of D1 phase. The Maastrichtian-Paleogene flysch succession of Alonnisos shows a characteristic trend of NW-verging tight, asymmetric folding, which supports the idea of top-NW tectonic transport during D1 in case of Alonnisos. The second phase of deformation (D2) is defined by top-NE to E shear on Skopelos and top-SE on Alonnisos largely using the already existing S1 foliation planes and forming asymmetric boudinage - and porphyroclast structures. D2 folding (F2) entails the formation of sheath folds on Skopelos with their axes being sub-parallel to the dominantly NE-SW trending stretching lineation in zones of high strain, close-tight upright folds with NE-SW trending axes as well as recumbent folds that affected the already tilted penetrative foliation. D2 was accompanied by extensive greenschist facies overprint which erased most of the HP mineral associations from the islands. Progressive exhumation to conditions of the brittle-ductile transition resulted in semi-brittle equivalents of ductile D2 structures. The orientation of upright, gentle-to close folding is the same on both islands, as well as the orientation of conjugate kink bands. D3 phase is brittle and is defined by outcrop-to regional-scale fault (and fault-related fold) systems, which have shaped the geometry and elevation of islands and basins of the region until present days. The open-gentle upright fold population with roughly N-S trending fold axes is also folding the Miocene carbonate deposits on Alonnisos and very gently even the Pliocene conglomerate strata, thus raising the attention to a young shortening component in E-W direction which is most likely driven by the propagation of the North Anatolian Fault in the region.

In our view D1 structures and the remnants of HP-LT mineral associations reflect the tectonic burial and prograde metamorphism of the Pelagonian continental block during subduction. The flysch successions were deposited in the trench during Upper Cretaceous-Paleogene times and were subducted together with the subducting Pelagonian cover, which got detached form the underlying basement. In contrast, D2 records progressive and distributed extensional deformation and provides the main mechanism for exhuming the previously buried rocks. This phase of deformation was probably triggered by the southward retreat of the Hellenic trench. The huge, rougly 90° difference between Skopelos and Alonnisos in the trend of the stretching lineation and thus the inferred tectonic transport directions for subduction and exhumation infers that rotation must have taken place after the rocks were already exhumed to above the brittle-ductile transition zone. Some of the nappe contacts exposed on the islands show post-metamorphic reactivation and in our view related to the dextral displacement along the fault that borders the North Aegean Trough.

Brun, J.-P., Faccenna, C., Gueydan, F., Sokoutis, D., Philippon, M., Kydonakis, K., and Gorini, C., 2016, The two-stage Aegean extension, from localized to distributed, a result of slab rollback acceleration 1: Canadian journal of earth sciences, v. 53, no. 11, p. 1142-1157.

Brun, J.-P., and Sokoutis, D., 2007, Kinematics of the southern Rhodope core complex (North Greece): International Journal of Earth Sciences, v. 96, no. 6, p. 1079-1099.

Jacobshagen, V., and Wallbrecher, E., 1984, Pre-Neogene nappe structure and metamorphism of the North Sporades and the southern Pelion peninsula: Geological Society, London, Special Publications, v. 17, no. 1, p. 591-602.

Jacobshagen, V., and Ματαράγκας, Δ., 2004, Nappe structure of the North Sporades (Greece): on the geological evolution of Alonnisos Island: Δελτίον της Ελληνικής Γεωλογικής Εταιρίας, v. 36, no. 4, p. 1636-1642.

Matarangas, D., 1992, Geological investigation of Skopelos island, North Sporades, Greece, Forschungszentrum Jülich, Zentralbibliothek.

Mposkos, E., and Liati, A., Fe-carpholite in chloritoid-bearing metapelites–metasandstones of Skopelos Island, N. Sporades, Greece, *in* Proceedings 5th Congress of the Geological Society of Greece. Deltio tes Ellenikes Geologikes Etaireias (Bulletin of the Geological Society of Greece)1991, Volume 25, p. 55-66.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins

Talk preference

Title: A geochemical study of siliceous ferromanganese rocks of the Mamonia Complex, SW Cyprus

Authors: Loukidis D[1], Pasadakis N[2], Sotiropoulou E[2], Christanis K[3], Koulermou N[4], Alevizos G[2], Kallithrakas-Kontos N[2]

Affiliations: **1** University of Cyprus, Cyprus
2 Technical University of Crete, Greece
3 University of Patras, Greece
4 Geological Survey Department of Cyprus

Contacts: loukidis@ucy.ac.cy, pasadaki@mred.tuc.gr, evsotiropoulou@outlook.com, christan@upatras.gr, nkoulermou@gsd.moa.gov.cy, alevizos@mred.tuc.gr, nkallithrakas@isc.tuc.gr

Introduction

The Mamonia Complex comprises various groups of allochthonous Upper Triassic to Early Cretaceous geological formations. Outcrops of these formations are located mainly in southwest Cyprus (Paphos District), but also in other parts of the southern coast of the island. These consist predominantly of sedimentary rocks formed in the seabed of the Neotethys Ocean, in deep water environment west to south of the current location of Cyprus, and accreted onto the Troodos Complex from Late Campanian up until Early Eocene (Robertson 1998, Morris et al. 2015). As such, stratigraphical sections (Lapierre 1975, Robertson & Woodcock 1979) include mostly radiolarian-rich, fine-grained clastic rocks (mudstones and shales) and cherts. However, there are numerous strata of turbiditic sandstones, indicating a depositional environment relatively close to a continental margin. Moreover, several phases of volcanic activity can be traced by the basaltic lavas found in some of the geological formations of the Mamonia Complex. Anoxic events are also evident from the occurrences of organic-rich layers reported in Lapierre 1975, Robertson & Woodcock 1979 and Swarbrick & Robertson 1980, such as bituminous or carbonaceous shales and lignitic sandstones.

Geochemical testing program

This study focuses on the geochemical features of metal-rich radiolarian mudstones, siltstones and sandstones belonging to the Episkopi formation of the Ayios Photios Group, in which igneous rocks are absent. Most of the samples were collected from the area of the Ayios Photios village and date from Middle Jurassic to Early Cretaceous. The mineralogical composition of the rocks was established using XRD, while the inorganic geochemical characteristics were assessed through XRF analysis. In addition, the sulphur and total carbon contents were determined using a CHNS elemental analyzer and the hydrocarbon generation potential was studied using Rock-Eval 6 pyrolysis. Moreover, the chemistry of the lighter organic compounds was studied through gas chromatography – mass spectrometry (GC-MS) analysis of extracts (Soxhlet) in order to perform biomarker interpretation. Apart from the Rock-Eval pyrolysis, the total organic carbon (TOC) content was also estimated by running acid (HCl) digested samples through the elemental analyzer, as well as using the wet oxidation (dichromate) method.

Findings

According to the XRD-XRF analysis, the samples collected are predominantly siliceous (SiO_2) with minimal to none clay mineral content. On the contrary, some rocks contain 5% to 12% of either muscovite or clinochlore. Siderite and pyrite were not detected and the sulphur content is negligible. Most samples had a relatively large goethite (FeOOH) content ranging from 20% to 35%, accompanied by smaller amount of manganese compounds, such as bementite, rhodochrosite, birnesite, and cryptomelane, with Mn/Fe ratios mainly in the 0.4 to 0.8 range. The organic carbon content of the specimens was low (TOC<0.5%), with the exception of the rocks containing rhodochrosite ($MnCO_3$ content around 35%). These were two Early Cretaceous fine sandstone/siltstone layers, roughly 6m stratigraphically apart, with TOC in the 0.5%-1% range. Such a combination of high content of $MnCO_3$ and FeOOH suggests that the deposition may have taken place on an organic-rich seabed slightly underneath the redox interface (Okita & Shanks 1992) or during short term oxygenation events in anoxic basin due to inflow of denser, oxygenated water masses (Huckriede & Meischner 1996). The large T_{max} and very low S2 values recorded in all samples indicate that the thermal maturity of any organic matter is very high, with most of the organic carbon being, in essence, graphitized. Biomarker interpretation pinpoints also to high maturity and marine algal-reducing depositional environment ($Pr/nC17<1.1$, $Ph/nC18<0.5$, $CPI \approx 1$).

References

Huckriede, H., & Meischner, D. (1996). Origin and environment of manganese-rich sediments within black-shale basins. *Geochimica et Cosmochimica Acta*, 60(8), 1399-1413.

Lapierre, H. (1975). *Les formations sédimentaires et éruptives des nappes de Manonia et leurs relations avec le massif du Troodos (Chypre occidentale),* Memoire No. 123, Société Géologique de France, Paris, France.

Morris, A., Robertson, A. H., Anderson, M. W. & Hodgson, E. (2016). Did the Kyrenia Range of northern Cyprus rotate with the Troodos–Hatay microplate during the tectonic evolution of the eastern Mediterranean?. *International Journal of Earth Sciences*, 105(1), 399-415.

Okita, P. M., & Shanks, W. C. (1992). Origin of stratiform sediment-hosted manganese carbonate ore deposits: Examples from Molango, Mexico, and TaoJiang, China. *Chemical geology*, 99(1-3), 139-163.

Robertson, A. H. (1998). Mesozoic-Tertiary tectonic evolution of the easternmost Mediterranean area: integration of marine and land evidence. Proceedings *of the Ocean Drilling Program, Scientific Results*, Vol. 160; Chapter 54.

Robertson, A. H. F. & Woodcock, N. H. (1979). Mamonia Complex, southwest Cyprus: Evolution and emplacement of a Mesozoic continental margin. *Geological Society of America Bulletin*, 90(7), 651-665.

Swarbrick, R. E. & Robertson, A. H. F. (1980). Revised stratigraphy of the Mesozoic rocks of southern Cyprus. *Geological Magazine*, 117(6), 547-563.

Dynamics of sedimentary basins and underlying lithosphere at plate boundaries and related analogues

ILP Task Force (VI) on Sedimentary Basins
Abstract Template

Talk preference (please delete one, or show no preference)

Title: New deep seismic data in the Eastern Mediterranean / Levant province is paramount

Authors: Schnürle P.[1], Aslanian D.[1], Moulin M.[1], and Rabineau M.[2]

Affiliations: **1** Ifremer-Géosciences Marines, Brest, France
2 IUEM-Lab. Domaines Océaniques, Brest, France

Contacts: Philippe.Schnurle@ifremer.fr

The Eastern Mediterranean is an active area of convergence between the African plate and the Aegean Anatolian micro-plate, currently undergoing a gradual and diachronic transition from subduction of oceanic crust to continental collision: oceanic crust of the last remnants of the Tethys on the northern edge of the African plate would be consumed by subduction northward below the Hellenic and Cyprus Arcs. Recently, significant gas and hydrocarbon discoveries, particularly in the Herodotus and the Levant basin, generated a growing scientific and industrial interest in this region. Therefore, this area has been the subject of many seismic imaging campaigns, complemented by sedimentological and stratigraphic studies on land. Thus, the structural scheme and understanding of the impact of major geodynamic events on the architectural evolution and the sedimentary fill of this province rose. However, the kinematic models, involving the opening and closing of the Neo-Thetys still depend largely on the determination of the nature, age and deformation of the crust forming the bedrock of these basins and many questions are still debated:
- What evidence for the presence of an ocean basin between northern Africa and Apulia?
- Can we define the extent, nature and origin of micro-continental blocks in this region?
- Are there still areas of ocean in these pools or have they been completely consumed by subduction?
- Did the basins form along a rift-type process at the opening of the Tethys?

To answer these questions, the acquisition of new deep seismic data in the Eastern Mediterranean / Levant province is paramount. In the last-decades, Ifremer has conducted world-wide successful surveys deploying its Ocean-bottom Seismometers and Seismic Land Stations pool. Today, our objective is to gather academic/industry partners together as a consortium in order to conduct such an offshore-onshore wide-angle survey of the Herodotus Basin, Eratosthenes Seamount, Levantine Basin and Margin (Figure1).

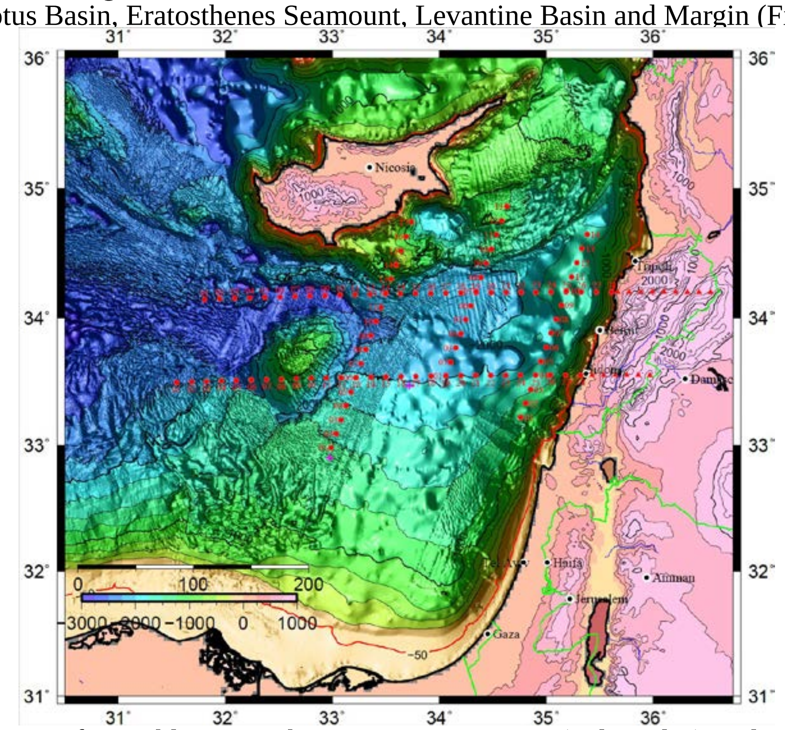


Figure 1. Location map of possible Ocean-bottom Seismometers (red circles) and Seismic Land Stations (white diamonds) deployments in the province Eastern-Mediterranean/Levant.