ACCADEMIA NAZIONALE DEI LINCEI

CONVEGNO LINCEO

BIRTH OF A NEW OCEAN IN THE RED SEA, DANAKIL AND EAST AFRICA REGION

25-26 MARCH 2026

ABSTRACT

Comitato ordinatore: Enrico BONATTI (Linceo, Istituto di Scienze Marine – CNR), Marco LIGI (Linceo, Istituto di Scienze Marine – CNR), Giulio Armando OTTONELLO (Linceo, Università di Genova).

PROGRAMME

The formation of a new ocean through the separation of continental lithospheric blocks is one of the fundamental geological processes predicted by the theory of Plate Tectonics and the hypothesis of Continental Drift. Today, this process is observable in the region of the Red Sea and the Horn of Africa (Afar, East African Rift), where the Arabian plate is separating from the African plate. There is no other geological scenario of equal significance that so clearly demonstrates the importance of interdisciplinary collaboration for a deeper understanding of such major phenomena.

In recent years, numerous studies in geodesy, seismology, geophysics, tectonics, magmatism, petrology, and geochemistry have taken shape in this region, contributing to an increasingly detailed and precise understanding of the ongoing processes. We propose a conference at the Accademia dei Lincei to bring together experts from various scientific disciplines, with the aim of reviewing the results achieved so far, analyzing the synergies between different areas of research, and outlining the prospects for future developments on this critical issue for the Earth Sciences.

The goal of the conference is to provide a space for discussion among leading national and international experts, address open scientific challenges, and stimulate new reflections in a strictly academic context.

Wednesday, 25th March

10.00 Enrico BONATTI (Linceo, Istituto di Scienze Marine – CNR): *Brief introduction to the Meeting*

10.20 Attila BALAZS (ETH-Zurich): *Tectonic and magmatic evolution of rifted margins and oceanic spreading: inferences from thermo-mechanical modelling*

11.00 Coffee Break

11.30 Luca LUPI (Società Geografica Pontederese): *The Danakil Region*

12.10 Giacomo CORTI (Istituto di Geoscienze e Georisorse, CNR): *Rift propagation, abandonment, migration and the complex volcano-tectonic evolution of the Southern Main Ethiopian Rift*

12.50 Break

14.00 Carolina PAGLI (Università di Pisa): *Deep magma underpressure and connectivity drive large dyke intrusions*

14.40 Derek KEIR (Università di Firenze): *Along rift variations in style of extension in Afar*

15.20 Carlo DOGLIONI (Vicepresidente dell'Accademia Nazionale dei Lincei): *Welcome on behalf of the Accademia dei Lincei – Why is an ocean born?*

16.00 Coffee break

16.30 Neil C. MITCHELL (University of Manchester): *Nubia-Arabia separation: clues from oceanic spreading fabric and seismic receiver function results*

17.10 Alessio SANFILIPPO (Università di Pavia): *Recurring signature of Proterozoic mantle in Arabian magmatism*

Thursday, 26th March

10.00 Marco LIGI (Linceo, Istituto di Scienze Marine – CNR): *Parting continents: Lower-crustal intrusions delayed continental rupture in the Red Sea*

10.40 Froukje VAN DER ZWAN (KAUST): *Activity, distribution, and biodiversity of hydrothermal vent sites in the Red Sea*

11.20 Coffee break

11.50 Jamie CONNOLLY (ETH, Zurich): Thermobarometry as an inverse problem with incomplete information

12.30 Giulio Armando OTTONELLO (Linceo, Università di Genova): *The engine: ab-initio assisted petrology*

13.10 *Conclusions*

ROMA - PALAZZO CORSINI - VIA DELLA LUNGARA, 10
Segreteria del convegno: convegni@lincei.it – http://www.lincei.it

Tutte le informazioni per partecipare al convegno sono disponibili su:
https://www.lincei.it/it/manifestazioni/birth-new-ocean-red-sea-danakil-and-east-africa-region

Per partecipare in presenza al convegno è necessaria l'iscrizione online
Fino alle ore 10 è possibile l'accesso anche da Lungotevere della Farnesina, 10
I lavori potranno essere seguiti dal pubblico anche in streaming

Tectonic and magmatic evolution of rifted margins and oceanic spreading: inferences from thermo-mechanical modelling

Attila BALAZS (ETH-Zurich)

The formation of new ocean basins results from complex interactions between tectonics, magmatism, lithospheric rheology, and surface processes during continental rifting and subsequent oceanic spreading. Quantifying how these processes interact to control rift segmentation, magma generation, and transform fault development remains challenging due to their strongly non-linear feedbacks.

Here we present results from systematic three-dimensional magmatic thermo-mechanical numerical models[1] coupled with surface processes to investigate the transition from continental rifting to oceanic spreading and transform fault formation.

Our simulations show that slow extension, limited erosion and sedimentation, and lower mantle temperatures favour magma-poor margins characterized by mantle exhumation and the development of stable transform fault systems with deep magma-starved valleys. In contrast, faster divergence, inherited mantle weaknesses, and enhanced surface processes promote increased mantle melting, rift magmatism, and the formation of spreading centres, producing magma-rich oceanic crust.

Oblique rifting[2] promotes strain partitioning and along-strike segmentation that controls the distribution of crustal melting and the location of continental break-up. When rift evolution involves segmented rift systems, continental crustal slivers may become entrapped within the evolving shear zones that later develop into oceanic transform faults, allowing fragments of continental lithosphere to be emplaced far from the continental margins[3].

These results provide new insights into the processes governing the birth of ocean basins, with implications for the evolving Red Sea–Afar–East African rift system.

References

1 Balázs A., Gerya T. 2024. Modelling the contrasting tectonic and magmatic evolution of rifted and transform margins and subsequent oceanic spreading. Tectonophysics, 889, 230446.

2 Oravecz E. Balázs A., Gerya T., Fodor L. 2025. Syn-rift magmatism and oceanic spreading initiation controlled by rift obliquity: Insights from 3D coupled thermo-mechanical and surface processes modeling. JGR-Solid Earth, 130, e2025JB031142

3 Balázs A., Gerya T., Tari G. 2025. Continental slivers in oceanic transform faults determined by rift inheritance. Nature Geoscience 18, 1303-1310.

The Danakil Region

Luca LUPI (Società Geografica Pontederese)

Nella prima parte dell’intervento sono fornite informazioni a carattere generale sull’origine e le differenze dei termini “Afar” e “Dancalia” ed il loro utilizzo in letteratura storica e scientifica; sono descritti brevemente i processi tettonici che caratterizzano l’Africa Orientale e la geografia dell’area e dei suoi ambienti; è spiegato come si pensa che i grandi fenomeni geologici siano stati il motore dei cambiamenti che hanno originato il processo di ominazione; sono fornite brevi informazioni sul popolo Afar che vive nella regione.

Nella seconda parte si evidenzia, molto sinteticamente, quali siano stati i contributi scientifici italiani nell’esplorazione e nello studio della intera regione Afar dal XX° secolo fino ad oggi, dimostrando quanto fruttuosa e continuativa sia stata la ricerca, soprattutto in campo geologico e paleontologico.

Infine, si descrive brevemente le fasi della recente spedizione vulcanologica organizzata a gennaio 2026 per studiare l’eruzione esplosiva “anomala” del vulcano Hayli Gubbi del 23 novembre 2025, centro eruttivo del massiccio dell’Erta Ale nel nord della Dancalia.

***

The first part of the presentation provides general information on the origin and differences between the terms "Afar" and "Danakil," and their use in historical and scientific literature. The tectonic processes that characterize East Africa and the geography of the area and its environments are briefly described. It explains how major geological phenomena are thought to have driven the changes that led to stages of human evolution. Brief information is provided on the Afar people who live in the region.

The second part briefly highlights the Italian scientific contributions to the exploration and study of the entire Afar region from the 20th century to the present day, demonstrating how fruitful and continuous research has been, especially in the geological and paleontological fields.

Finally, we briefly describe the phases of the recent volcanological expedition organized in January 2026 to study the "anomalous" explosive eruption of the Hayli Gubbi volcano on 23 November 2025, the eruptive center of the Erta Ale massif in northern Danakil.

Rift propagation, abandonment, migration and the complex volcano-tectonic evolution of the Southern Main Ethiopian Rift

Giacomo CORTI (Istituto di Geoscienze e Georisorse, CNR)

Continental rift systems form by propagation of isolated rift segments that interact and eventually evolve into continuous zones of deformation. This process impacts many aspects of rifting including the distribution and characteristics of deformation, and the relations with the associated volcanic activity. Here I present a summary of recent data from the Ririba rift in the Southern Main Ethiopian Rift, which reveals how two major sectors of the East African rift, the Kenyan and Ethiopian rifts, interacted and evolved. These data show that the Ririba rift formed from the southward propagation of the Ethiopian rift during the Pliocene but this episode of rift propagation was short-lived and aborted close to the Pliocene-Pleistocene boundary. Analysis of the distribution of recent-active deformation supports the abandonment of laterally offset, overlapping tips of the Ethiopian and Kenyan rifts. Integration with numerical models indicates that rift abandonment resulted from progressive focusing of the tectonic and magmatic activity into an oblique, throughgoing rift zone of extension directly connecting the Ethiopian and Kenyan rifts. After rift abandonment, a recent (Late Pleistocene-Holocene) phase of volcanic activity developed in the Ririba rift and surroundings, giving rise to different, isolated volcanic fields (e.g., Dilo, Mega). This volcanism, formed long after the tectonic activity ceased, was structurally unrelated to rifting, showing alignments that cut rift-related features. Analysis of the Gravitational Potential Energy in the region indicates that variations in topography and (subordinately) crustal thickness give rise to a secondary stress field that -away from the areas of active extension- is able to control the arrangement of volcanic vents, with no influence exerted by the regional (plate motion driven) stress field. In these conditions, magmas may have exploited deep inherited lithospheric structures for their ascent to the surface, resulting in the anomalous distribution of volcanic vents observed in the Ririba rift and surroundings.

Nubia-Arabia separation: clues from oceanic spreading fabric and seismic receiver function results

Neil C. MITCHELL (University of Manchester)

Neil C. Mitchell[1], A.Y. Izzeldin[2], Ian C. F. Stewart[3]

[1]Department of Earth and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester M13 9PL, U.K., neil.mitchell@manchester.ac.uk
(https://orcid.org/0000-0002-6483-2450)

[2]Awasconrc, Gereif West, H4, Bld 376, Khartoum, POB 119, Khartoum, Sudan, awasconrc@gmail.com

[3]Stewart Geophysical Consultants Pty. Ltd, Adelaide, South Australia, Australia, stewgeop@senet.com.au

The breakup of the Arabian-Nubian (Ar-Nu) shield created the Red Sea rift, a young continental rift transitioning to an ocean basin. Different Ar-Nu plate reconstruction models have emerged, which complicate interpreting the shield geology, reconstructing motions of other plates and leave open the question of how much oceanic crust underlies parts of the sea. Uncertainty of plate reconstructions also affects how we interpret the dynamics of rifting in this basin from geophysical data. Helping to address this issue, gravity anomalies reveal an oceanic segmentation fabric that constrains the opening direction since ~10 Ma or half the total Ar-Nu movement. We derive an Euler plate reconstruction pole from that fabric and apply it to restore the configuration of Ar-Nu shield structures at ~10 Ma. With the Ar and Nu structures brought closer together, the reconstruction supports a new association of those structures across the Red Sea. That association in turn constrains the pre-breakup relative positions of the Ar-Nu shield fragments in a NW-SE sense (i.e., rift obliquity). It allows us to prioritise earlier-published total opening Euler poles that also bring these structures together. In particular, one of them was derived using the known Dead Sea Transform (DST) and Suez Rift motions, which constrain total Ar-Nu separation magnitude and direction. New Moho depth estimates further allow an assessment of how much

distributed extension has left coastal units displaced relative to plate interiors. Applying the total-opening pole, and allowing for those coastal displacements, the pre-breakup shield terranes of the two sides are brought together but with significant gaps remaining between the two sides. The results support the views that the northern Red Sea is underlain largely by stretched continental crust and that the central Red Sea is underlain by both continental and oceanic crust.

Recurring signature of Proterozoic mantle in Arabian magmatism

Alessio SANFILIPPO[1,2] (Università di Pavia)

1- Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Italy
2- Istituto di Geoscienze e Georisorse, CNR, U.O. Pavia, Italy

The Cenozoic magmatic evolution of the Arabian Plate and the opening of the Red Sea provide a unique window into how inherited lithospheric architecture controls rift magmatism, a central issue in models of continental breakup and plume-lithosphere interaction. By integrating geochemical and isotopic data from pre-rift lavas, syn-to-post-rift volcanic fields (harrats), and mantle xenoliths, we show that the magmatic history of this region is intrinsically linked to a heterogeneous sub-continental lithospheric mantle (SCLM) stabilized during the Neoproterozoic Pan-African orogeny. The earliest stages of magmatism, which preceded the arrival of the Afar plume, already record the geochemical signature of this ancient SCLM, characterized by long-term enrichment in incompatible elements acquired during episodes of melt metasomatism in subarc environments. As rifting progressed and the Red Sea evolved toward oceanic spreading, this lithospheric signal remained pervasive but was progressively overprinted by mixing with melts derived from more depleted, relatively shallow mantle sources. Nevertheless, even within the axial trough of the Red Sea and the extensive volcanic lava fields of Saudi Arabia and Syria, the isotopic and trace-element compositions of basalts retain a persistent Proterozoic lithospheric signature, despite the increasing contribution of depleted mantle sources. Basalts alone, however, provide only a biased view of the original mantle heterogeneity, as melts preferentially sample the most fertile metasomatized domains. In this context, the physical and chemical drivers of Arabian magmatism ultimately reflect the bimodal nature of the Arabian SCLM. Hafnium (Hf) isotope systematics in mantle xenoliths reveal the local preservation of domains of extremely melt-depleted, refractory mantle formed up to 1 billion years ago. These buoyant, low-density domains may have provided a compositional buoyancy that enhanced the passive mantle upwelling induced by tectonic extension. In contrast, fertile metasomatized veins embedded within this refractory matrix acted as the primary melt source, preferentially sampled at low degrees of melting and relatively great depth. Consequently, the transition from continental rifting to sea-floor spreading in the Red Sea cannot be interpreted as a purely asthenospheric process. Rather, it partly reflects the selective recycling of a billion-year-old lithospheric mosaic, in which metasomatic processes following ancient depletion events provide the chemical fuel for magmatism generated within an overall depleted, and therefore buoyant, mantle.

Parting continents: Lower-crustal intrusions delayed continental rupture in the Red Sea

Marco LIGI (Linceo, Istituto di Scienze Marine – CNR)

Marco Ligi[1(*)], Alessio Sanfilippo[2,3], Riccardo Avanzinelli[4], Valentin Basch[2,3], Alessandro Bragagni[1,4], Alessandro Decarlis[5], Hervé Guillou[6], Sebastien Nomade[6], Najeeb Rasul[7], Luigi Vigliotti[1] & Sandro Conticelli[4,8]

[1] *Istituto di Scienze Marine, CNR, Via Gobetti 101, 40129 Bologna, Italy*

[2] *Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy*

[3] *Istituto di Geoscienze e Georisorse, CNR, Via Ferrata 1, 27100 Pavia, Italy*

[4] *Dipartimento di Scienze della Terra, Università di Firenze, Via La Pira, 4, 50121 Firenze, Italy*

[5] *Dipartimento di Fisica e Geologia, Universita' degli Studi di Perugia, Piazza Universita' 1, 06123 Perugia, Italy*

[6] *Laboratoire de Sciences du Climat et de l'Environnement, CEA, UMR 8212, UVSQ, IPSL and Université de Paris-Saclay, Gif-sur-Yvette, France*

[7] *Geological and Geophysical Research Systems, Canada*

[8] *Istituto di Geologia Ambientale e Geoingegneria, CNR, Strada Provinciale 35d, 00010, Montelibretti (RM), Italy*

The role of magmatism in continental rupture and ocean formation remains a central question in Earth Sciences. The Red Sea, where the Arabian plate is rifting from the Nubian plate, provides a unique natural laboratory to investigate the processes driving continental breakup. In this study, we examine geochemical and isotopic data from gabbros and basaltic dikes of the Tihama Asir magmatic complex, emplaced during the early stages of southern Red Sea rifting in the Late Oligocene-Early Miocene. Our results demonstrate that asthenospheric melts, influenced by Afar plume activity and extensional stresses, assimilated ancient lower continental crust before ascending into shallow magma chambers with minimal contamination from upper crustal material. The thermal and mechanical effects of rising asthenosphere weakened the lower crust, promoting its decoupling from the lithospheric mantle and enabling depth-dependent deformation. Importantly, we find that underplating and intrusion of tholeiitic melts into the thinning continental crust contributed significantly to accommodating extension, effectively re-thickening the lower crust and delaying the localization of strain necessary for continental rupture. This magmatic underplating thus prolonged the continental rifting phase and postponed the onset of steady-state seafloor spreading. Our findings provide compelling evidence that lower-crustal magmatic processes can modulate rift dynamics and challenge the traditional view that magmatism universally accelerates continental breakup.

Thermobarometry as an inverse problem with incomplete information

Jamie CONNOLLY (ETH, Zurich)

Connolly J.A.D.[1,2], and Khan D.[1]

1. Department of Earth and Planetary Science, ETH Zurich
2. Centre for Earth Sciences, IISc Bangalore

Thermobarometry is a classical inverse problem with incomplete information. Although it was originally treated by methods that did not require assumptions beyond local equilibrium, the advent of complete thermodynamic models for metamorphic rocks has made the inversion increasingly fragile. In particular, modern phase-diagram methods rely on the assumption of bulk equilibrium and unmeasured redox and volatile chemistry.
With one notable exception, Bingo-Antidote [1], thermobarometry has not been formally treated as a mathematical inverse problem. We present an algorithm for inverting for pressure, temperature, and unmeasured chemistry under either local or bulk equilibrium assumptions by minimizing the misfit between observed and predicted mineral chemistry using free energy minimization. The method is based on the inversion strategy of Khan et al. [2] and has been implemented in an open-source program MC_fit [3]. In contrast to Bingo-Antidote, the MC_fit algorithm does not require the bulk equilibrium assumption and accounts for both analytical and thermodynamic uncertainties. MC_fit also permits optimization of thermodynamic data based on field observations. MC_fit results are readily verified by back-calculation using the effective bulk chemistry generated by the inversion.

[1] Duesterhoeft E, Lanari P (2020) J Met Geol 38(5)
[2] Khan D, Liebske C, Connolly JAD (2021) Geochem Geophys Geosys 22(5)
[3] https://www.perplex.ethz.ch/mc_fit_documentation

The engine: ab-initio assisted petrology

Giulio Armando OTTONELLO (Linceo, Università di Genova)

The recent discovery that silicate melts may be treated as simple dielectrics whose static and vibrational properties may be accurately depicted through *ab-initio* procedures[1] opened new perspectives for a first principles appraisal of their thermodynamic and thermophysical properties in wide thermo-baric regimes in simple systems[2,3] and to afford the complexities of petrogenetic systems with a sound rationale. Here I present some preliminary results on CMASH (CaO-MgO-Al_2O_3-SiO_2-H_2O), a system of paramount importance in Mantle Petrogenesis. Computations confirm the importance of the *melting at the cusp* process in MORB genesis, fostered by Presnall and coworkers[4] and the astonishing precision and accuracy of Kushiro's observations on the role of H_2O[5].

1. Ottonello G, Richet P (2014) The solvation radius of silicate melts based on the solubility of noble gases and scaled particle theory. J Chem Phys 140:044506-1-9
2. Ottonello G, Richet P, Vetuschi Zuccolini M (2015) The wet solidus of silica: Predictions from the scaled particle theory and polarized continuum model. J Chem Phys 142:54503-1-9
3. Belmonte D, Ottonello G, Vetuschi Zuccolini, M (2017a) Ab-initio -assisted assessment of the $CaO-SiO_2$ system under pressure. CALPHAD 59:12-30
4. Presnall DC, Dixon JR, O'Donnell TH, Dixon, SA (1979) Generation of Mid-ocean Ridge Tholeiites. J Petrol 20:1-35
5. Kushiro I. (1969) The system Forsterite – Diopside – Silica with and without waterat hih pressures. Amer J. Sci., 267A,269-294