International Workshop

Tethys Dynamics

08-09 Oct 2018 Beijing, China

ABSTRACTS BOOK

Institute of Geology and Geophysics,
Chinese Academy of Sciences

About the workshop

The primary aim of the workshop is to bring scientists in various disciplines together to review the state-of-the-art scientific questions on the dynamics of the Tethyan realm. Detailed program has been proposed, with 19 oral talks in three sections, grouping into observation of deep structure, reconstruction and evolution of major plates, and dynamics of the Tethyan realm. After the talks, there will be an open discussion about current challenges and potential tasks of future observations and modeling in the Tethyan realm.

Sponsors

This workshop is supported by State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS), the Tethyan Geodynamics Major Research Plan of National Natural Science Foundation of China, the International Partnership Program of the Chinese Academy of Sciences and the National Committee of China for International Lithosphere Program (CNC-SCL/ILP).

Program

08:30-08:35 Welcome opening

(**WU Fuyuan, Director of IGGCAS**)

Overview of Tethys, 8:25-10:00, Chair: ZHAO Liang--Auditorium, 2nd Floor, Building D3, IGGCAS

08:35-09:00 WAN Bo:

Can subduction drive the evolution of the whole Tethys?

09:00-09:30 LI Zhengxiang:

Was the Tethys ocean a legacy of the Nuna and Rodinia superoceans?—a new perspective from the point of supercontinent-superocean cycles

09:30-10:00 FACCENNA Claudio:

A mantle conveyor belt beneath the Tethyan orogeny

Break

Continental collision dynamics,10:20-12:20, Chair: CHEN Ling--Auditorium, 2nd Floor, Building D3, IGGCAS

10:20-10:50 HU Xiumian:

Two-stage evolution of the Himalayan collisional orogen and its comparison to the Alps

10:50-11:20 van HINSBERGEN Douwe:

Reconstructing Greater India: paleogeographic, kinematic, and geodynamic perspectives

11:20-11:50 LIAO Jie:

Geodynamical numeric modeling on continental collision and deep subduction

Break

Continental collision dynamics,
13:30-17:20, Chair: LIU Chuanzhou,
CHEN Yi--Auditorium, 2nd Floor, Building D3, IGGCAS

13:30-14:00 YUAN Xiaohui:
Seismic imaging of subduction of continental crust beneath the Pamir

14:00-14:30 GUO Xiaoyu:
Deep-seated lithospheric geometry in revealing collapse of the Tibetan Plateau

14:30-15:00 GUILLOT Stephane:
Importance of soft metasomatised lithosphere for the growth of the Tibet Plateau

Break

15:20-15:50 MALUSA Marco:
The Alpine segment of the Tethyan belt: linking geology, geophysics and numerical modeling

15:50-16:20 PAUL Anne:
The CIFALPS and AlpArray seismic experiments in the Alps: new data, new images, new models

16:20-16:50 LIU Lijun:
Geodynanmics behind the evolving continental cratons

16:50-17:20 GESSNER Klaus:
Continental geodynamics and Earth resources formation – a West Australian perspective

Subduction dyanmics,08:30-11:50,
Chair: LI Yang--Auditorium, 2nd Floor, Building D3, IGGCAS

08:30-09:00 HUISMANS Ritske:
Dynamics of orogens and rifted margins: Insights from 2D and 3D forward numerical modelling

09:00-09:30 HALL Robert:
High-temperature peridotite contacts, Iran and Banda, Indonesia: subduction-related?

09:30-10:00 PARLAK Osman:
Rapid cooling history of a Neotethyan ophiolite: evidence for contemporaneous subduction initiation and metamorphic sole formation

Break

10:20-10:50 YUAN Huaiyu:
Crustal structure beneath coastal northwestern Australia: seismic signature from paleo collision to modern rifting

10:50-11:20 van HINSBERGEN Douwe:
Plume-induced subduction initiation across the Cretaceous Neotethyan ocean?

11:20-11:50 HALL Robert:
Subduction initiation: observations of how subduction begins

day 1: LI Zheng-Xiang and colleagues from the Earth Dynamics Research Group

The Institute for Geoscience Research (TIGeR), School of Earth and Planetary Sciences, Curtin University, GPO Box U1987, WA 6845, Australia

Was the Tethys ocean a legacy of the Nuna and Rodinia superoceans? — a new perspective from the point of supercontinent-superocean cycles

The Tethyan ocean is commonly accepted as the "eastwards-opening triangular oceanic embayment" started from the formation of the supercontinent Pangaea at mid-Carboniferous (e.g., Sengör, 1985). Here I present a synthesis in which the Tethyan ocean, or the Tethys, was actually what remained of a superocean that first formed during the final assembly of the Mesoproterozoic supercontinent Nuna some 1.6 billion years ago as part of the supercontinent cycle.

The supercontinent cycle of episodic assembly and breakup of almost all continents on Earth is commonly considered the longest period variation to affect mantle convection(Anderson, 1982; Bleeker, 2003; Li and Zhong, 2009; Zhong et al., 2007).However, global zircon Hf isotopic signatures and seawater Sr isotope ratios suggest the existence of a cycle twice the duration of the supercontinent cycle (Spencer et al., 2013). We propose here that since ~2 billion years ago the superocean surrounding a supercontinent, as well as the circum-supercontinent subduction girdle, survive every second supercontinent cycle. We suggest that supercontinents assemble alternatingly through dominantly extroversion(Murphy and Nance, 2003) (the previous supercontinent turned inside-out through the destruction of the Panthalassa-type superocean) after a more complete breakup, and dominantly introversion (survival of the superocean) after an incomplete breakup of the previous supercontinent, giving rise to the two harmonic cycles. A global analysis suggests that the Nuna superocean appeared to have survived the Rodinia supercontinent cycle, bet got consumed during the assembly of Pangea, with the Tethyan ocean being what remained of that ancient superocean after Pangea's assembly. This residual of an ancient superocean finally got completely consumed by the closure of the Neotethys during India's collision with Eurasia on way to form the next supercontinent Amasia (Hoffman, 1997).

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day 1: FACCENNA Claudio

Claudio Faccenna

Mantle conveyor beneath the Tethyan collisional belt

Collisional belts are generated by the arrival of continental lithosphere into a subduction zone. The Tethyan suture from the Bitlis to the Himalayas is a prime example where the Arabian and Indian plates collided with Eurasia during the Cenozoic. While the kinematics of this process are well established, its dynamics are more uncertain. India and Arabia intriguingly keep advancing, in spite of large collisional resisting forces, and in the absence of a substantial, upper mantle slab driving force at present-day. We perform global mantle circulation computations to test the role of deep mantle flow as a driving force for the kinematics of the Tethyan collisional belt, evaluating different boundary conditions and mantle density distributions as inferred from seismic tomography or slab models. Our results show that mantle drag exerted on the base of the lithosphere by a large-scale, convective "conveyor belt" with an active upwelling component is likely the main cause for the ongoing indentation of the Indian and Arabian plates into Eurasia.

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day 1: HU Xiumian

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Two-stage evolution of the Himalayan collisional orogen and its comparison to the Alps

According to our recent research of stratigraphy, sedimentology, basin analysis, tectonic, combined with the previous studies of structure geological, geophysical and magmatic rocks, metamorphic rocks, themochronology in region, we suggest that the Himalayan orogen experienced two stages of evolution after the initial India-Asian continent collision. During the first stage (~60-40 Ma), it happened the continental crust (northern Indian) subduction dragged by the oceanic crsust (Neo-Tethys) subduction. In the upper plate (southern Lhasa block), the magmatism widely occurs, characterized by the Linzizong volcanic succession and Gangdese batholith. The forearc basin, collisional suture zone, southern syncollisional basins and the trench basin developed in the early stage were filling contionuosly and transited into the shallow marine sedimetation in the later stage. During the second stage (< 40 Ma), it developed a new continental crust subduction along the Himalayan front (MCT, MBT, MFT). This stage is characterized by the development of massive thrust nappe in the Himalayan front, thin-skinned tectonic shorten of Tethys Himalayan, high temperature and high pressure metamorphism of Great Himalayan and leucogranite induced by crust remelting, and the Great Counter Thrust developed in the Himalayan region leading to the rise of the spelendid Hiamlayan Moutains. At this time, the plateau has been basically formed, it developed the north-south rift and potash-rich volcanism the interior plateau, strike-slip and escape structures in eastern Tibet, as well as the extensive thrust belt and foreland basin around the plateau.

Compared with the Himalayan orogen, the Alpine orogen did not develop the oceanic subduction as the first stage of the Himalayan orogen and generally lacked the syncollisional magmatism. Our recent results indicate that the provenance of the deep-water deposits represented by the Eocene Annot sandstone in southeastern France is not sourced from the orogenic belt, so it cannot represent the early Apine orogen, the underfilled northern Alps peripheral foreland basin system should be re-examined.

The northern Alps peripheral foreland basin began to develop when the European plate began to compress with the Adriatic plate at ~30-32 Ma. Simultaneously, the Ligurian-Piemout oceanic crust subducted, followed by the European continental crust subduction. As the subduction and retreat of the southern edge of the Adriatic slab, the Alpine metamorphic rocks exhumed to form the majestic Alpine mountains.

The Himalayan continental collision orogen is distinct from the Alpine continental collision orogen by the early oceanic crust subduction, so they may represent two types of continental collision orogen.

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day 1: VAN HINSBERGEN Douwe

Reconstructing Greater India: Paleogeographic, kinematic, and geodynamic perspectives

At the heart of a successful geodynamic or paleoclimatic analysis lies a plate and orogen- kinematic or paleogeographic reconstruction. I will present a kinematic reconstruction of Greater India and Tibet, using a reconstruction protocol based on the following datasets: (1) marine magnetic anomalies and fracture zones in the modern oceans; (2) structural geology and paleomagnetic rotations and (3) paleolatitude estimates from deformed belts, and (4) seismic tomographic constraints on subducted lithosphere remnants. Data from sediment provenance, volcanism, or biogeography do not quantify motions and are best interpreted in the light of kinematic reconstructions rather than vice versa. This protocol constrains a width of continental Greater India prior to ~120 Ma of ~800 km, and show 1000-1200 km of Cenozoic intra-Asian shortening, not supporting or requiring significantly greater values. These restorations combined with well-constrained India-Asia convergence rates would predict an Early Miocene Tibetan Himalaya-Lhasa collision, which is clearly inconsistent with sediment provenance and metamorphic arguments for 58±2 Ma collision. Such early collision then necessitates the opening of an up to 2500 km wide Greater India ocean Basin since 120 Ma, consistent with volcanic evidence for Early Cretaceous rifting along the Himalaya, which subducted entirely without accretion, as is default in circum-Pacific subduction zones such as below the Andes. Eocene sediments on India argued to derive from the Tibetan Himalaya are then more likely derived from the Paleogene obduction-induced orogen of Pakistan and Afghanistan unrelated to the India-Asia collision. Using this kinematic restoration, I explain the delay between 58 Ma collision and a 50 Ma onset of dramatic Indian plate motion deceleration by the resistance of the GIB against lower mantle subduction. Subsequent filling of the upper mantle led to slab overturning and advance demonstrated in seismic tomography, inducing oceanic flat slab subduction, Tibetan plateau growth and arrest of arc volcanism. Associated increase in frictional plate contact area, slab bending, and upper plate thickening likely triggered the Indian deceleration. Continental collision only significantly contributed to Tibetan evolution since ~30-20 Ma.

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day 1: LIAO Jie

Jie Liao, Rui Qi, Rui Gao
School of Earth Sciences and Engineering, Sun Yat-Sen University

Geodynamical numeric modeling on continental collision and deep continental subduction

The Hindu Kush–Pamir orogenic system at the northwestern end of the Himalayan orogen offers a rare opportunity to explore the development of two opposing continental subduction zones. This orogenic system hosts several striking tectonic features (e.g., Burtman and Molnar, 1993; Kufner et al., 2016), including (1) opposite dipping continental slabs: the north-dipping slab of Indian origin beneath the Hindu Kush and the south-dipping slab of Asian origin beneath the Pamir; (2) dramatically different slab steepness and subduction depth (the Hindu Kush subducted slab in the south is much steeper (80°) and deeper (>500 km) than the Pamir slab (45° and >300 km) in the north); (3) curved orogenic belt in the Pamir; (4) and numerous intermediate-depth earthquakes (at depths between 50 and 300 km) occurred underneath this orogenic system.
Using three-dimensional geodynamical numeric modeling, we simulated opposing continental collision and subduction zones. Although general setups are used in our models, they capture the first-order features of the Hindu Kush–Pamir orogenic system. Besides, model results reveal two interesting features: (1) upper continental crust does not subduct, but shortens and thickens in shallow depth, promoting middle-depth crustal flow; (2) lower continental crust subducts with lithospheric mantle, favoring deep continental subduction (Liao et al., 2017).

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day 1: YUAN Xiaohui

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Seismic imaging of subduction of continental crust beneath the Pamir

Exhumation of ultra-high pressure metamorphic rocks testifies that the continental crust can subduct to significant depth into the mantle despite its buoyancy. However, direct observation of ongoing subduction of continental crust is rare. The Pamir is regarded as a possible place of active continental subduction because of the intermediate-depth seismicity, crustal xenoliths and estimates of crustal shortening versus convergence rates. The Pamir and Hindu Kush mountain ranges are located northwest of Tibet, where the Indian plate indents deeply into Asia. This region of intense deformation and frequent large and destructive earthquakes is underlain by a deep seismic zone, whose origin and significance has been debated by generations of Earth scientists. Starting in 2008, the GFZ and partners in the region undertook several seismological campaigns. As one of the scientific outcomes, a subducted Eurasian continental crust has been observed beneath the Pamir by different methods, including receiver functions, local earthquake tomography, attenuation tomography and guided waves. The subducted crust is characterized by a southerly dipping low-velocity zone (LVZ) with a thickness of 10-15 km. The LVZ accurately follows the intermiediate-depth seismic zone extending from 50 km depth near the base of the crust to more than 150 km depth with a dip angle increasing to subvertical. Our observations imply that the complete arcuate intermediate depth seismic zone beneath the Pamir traces a slab of subducting Eurasian continental lower crust.

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day 1: GUO Xiaoyu

Xiaoyu Guo1, Rui Gao1, Junmeng Zhao2
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Deep-seated lithospheric geometry in revealing collapse of the Tibetan Plateau

Abstract

The Tibetan Plateau's enigmatic collapse, which was indicated based on extensional faulting in the interior of the plateau and large eastward-directed strike-slipfaults, has inspired intensive geologic inquiry and debate. Interaction of the subducting Indian plate with the overlying Asian lithosphere is one factor that may be affecting the plateau. A more detailed image of the subducting Indian plate can help constrain its role, but regional high-resolution seismic data have not been widely available at a relevant scale. Here we present an integrated interpretation based on two types of seismic datasets: (1) two N-S oriented deep seismic-reflection profiles that cross the Yarlung-Zangbo suture, and (2) two E-W receiver function profiles that cross the Xainza-Dingjye and Nyima-Tingri rifts, respectively. These images reveal different crustal-scale structures in the dominant collision zone between the western and central regions, as well as distinctly offset Moho discontinuities across the N-S trending rift grabens in southern Tibet. These crustal variations, combined with previous tomographic studies in Tibet, outline an easterly tilt of the subducting Indian slab, along which crust-mantle decoupling occurred. Together with the spatio-temporal distribution of synchronous potassium-rich volcanics exposed within the grabens in southern Tibet, this offset Moho structure beneath the grabens lends support to the hypothesis that eastward steepening of the subducting Indian slab was accompanied by slab tearing beneath each north-south striking rift. This overall crustal geometric variation suggests a stepwise flattening of the torn Indian slab from west to the east, a process that brought easterly migration of gravitational instability to the overriding Tibetan crust that drove collapse of the Tibetan Plateau once gravitational instability reached a critical level to the east.

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day 1: GUILLOT Stephane

ISTerre, Université Grenoble Alpes, CNRS
France

Importance of soft metasomatised lithosphere for the growth of the Tibet Plateau

Stéphane Guillot

How and when the Tibetan plateau growth occurred remains a puzzling question and more specifically, addressing the role of rheology and the mechanical behaviour of the continental lithosphere in convergent context. Several reasons can explain the difficulty to constrain the lithospheric processes responsible to the Tibet building. First the internal structure of the Tibet plateau is hidden beneath an upper crustal lid without direct access to the deep part of the crust and even less the upper mantle. Second the numerous available seismological data especially for the upper mantle are ambiguous and interpreted in non-consistent ways. Third, the timing of Tibetan growth is also controversial, with either a building of the plateau during the collision from south to north or the existence of a proto-Tibetan plateau before the collision.

Based on the considered rheological model of the lithosphere, some authors argue that the crust and the upper mantle are weak ("jelly sandwich" model) enhancing the homogeneous thickening of the Tibetan lithosphere followed by delamination of the lithospheric root. The advantage of this model is to explain the low P-waves anomaly and shallow lithosphere asthenosphere boundary (LAB) observed beneath Central Tibet as reflecting asthenospheric mantle replacing the lithospheric mantle. However, this model imposes a major phase of uplift of the Tibet plateau and a widespread magmatism, ca. 20 Ma after the initial collision, which is not observed. Based on the location of most Tibetan earthquakes in the upper crust, the second class of model proposed that the strength of the Tibetan lithosphere is located mainly in its upper crust ("crème-brulée" model). While several models focus on the relative importance of the underthrusting of the Indian plate beneath Tibet, following the qualitative first cross-section of Tibet (Argand, 1924). Other models suggest that the southern Asian lithosphere is strong enough to allow the India/Eurasia convergence forces to be transmitted north of the plateau, enhancing northern Asian lithosphere subduction. Those models have the advantages to explain:

(1) the localisation of the diachronous Tibetan magmatism along reactivated suture zones, (2) the seismological evidence of continental underthrusting of the Indian lithosphere beneath South Tibet and Asian lithosphere beneath North Tibet and (3) the high altitude of the southern and central parts of the Tibetan plateau soon after the India-Asia collision. Analogue modelling of subduction at lithospheric plate scale, show that a continental indenter (Indian plate) generates horizontal forces transmitted far enough from the collision front to trigger the so-called southward "collisional subduction" of Asian lithosphere beneath Tibet and favours the formation of a wide plateau. However, these second series of models cannot simply explain the low velocity P-waves anomaly in Central Tibet.

Recently the calc-alcaline ultra-K volcanism widespread on Tibet has been interpreted as an evidence of an upper mantle fully metasomatized beneath Tibet. This is confirmed by the recent discovery of carbonatitic lavas and phlogopite bearing peridotite xenoliths in South According to these data, we recalculated the P and S-waves velocities of a carbonate and phlogopite bearing peridotite along a normal geotherm and showed that the calculated P and S waves-velocities reproduce the seismic anomaly observed beneath Central Tibet. Consequently, we proposed that the low P-wave anomaly beneath Tibet is the expression of a metasomatised lithosphere rather than a thermal anomaly or a thinned lithosphere. We numerically demonstrated that a soft metasomatised lithosphere beneath central Tibet (1) facilitates a shallow continental subduction (2) induces the ultra-K magmatism and (3) participates to the thickening of the Tibetan crust.

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day 1: MALUSA Marco

Marco G. Malusà
Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy (marco.malusa@unimib.it)

The Alpine segment of the Tethyan belt: linking geology, geophysics and numerical modeling

The Cenozoic evolution of the Alpine segment of the Tethyan belt has been recently re-assessed thanks to new constraints provided by geophysical investigations (CIFALPS experiment, Zhao et al., 2015, 2016a). This presentation summarizes the main results of the CIFALPS experiment in the southern Western Alps and in the broader Alpine region. New insights provided by geophysical imaging include: (i) evidence of down-dip and along-strike continuity of the Alpine slab (Zhao et al., 2016b) in the region where slab breakoff was first proposed (von Blanckenburg and Davies, 1995); evidence of mantle-wedge exhumation associated with exhumation of continental (ultra)high-pressure rocks (Solarino et al., 2018) in the region where coesite in continental units was first described (Chopin, 1984); (iii) evidence of active strike-slip faulting in the mantle atop the Alpine slab (Malusà et al., 2017); (iv) evidence of an active asthenospheric counterflow beneath the external zones of the Alps, likely triggered by Apenninic slab rollback, which may have favored the topographic uplift of the highest Alpine peaks (Salimbeni et al., 2018). The geologic interpretations of CIFALPS results are independently validated by thermomechanical numerical models (Liao et al. 2018a,b) that underline analogies between the Alps and eastern Papua New Guinea, in the easternmost part of the Tethyan belt (Malusà et al., 2015).

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day 1: PAUL Anne

Anne PAUL, Université Grenoble Alpes, CNRS, IRD, IFSTTAR, ISTerre, Grenoble 38041, France

The CIFALPS and AlpArray seismic experiments in the Alps : new data, new images, new models

with : Liang Zhao [2], Stéphane Guillot [1], Marco Malusá [3], Stefano Solarino [4], Yang Lu [1], Chao Lyu [2], Simone Salimbeni [4], Silvia Pondrelli [4], Stéphane Schwartz [1], Thierry Dumont [1], Helle Pedersen [1], Xiaobing Xu [2], C. Aubert [1].

[1] ISTerre, Université Grenoble Alpes, France ; [2] IGGCAS, Beijing, China ; [3] University Milano-Bicocca, Milan, Italy ; [4] Istituto Nazionale di Geofisica e Vulcanologia, Genoa, Bologna, Italy.

Since 2012, the Alpine belt and its surroundings have been the focus of a number of passive seismic experiments including CIFALPS (China-Italy-France Alps seismic transect), AlpArray, EASI (Eastern Alpine seismic investigation) etc. This data recording effort on the most emblematic mountain belt is unprecedented since the controlled-source seismic experiments of the 80’s and 90’s (ECORS-CROP in France and Italy; NFP-20 in Switzerland; TRANSALP in the E-Alps; GeoFrance-3D in France). This group of seismic experiments combines the AlpArray seismic network and its broad scale, homogeneous coverage (50 km) of the greater alpine region with regional experiments of smaller extent but higher spatial resolution along transects across the belt (Cifalps, Cifalps-2, EASI) or in 2-D arrays (Swath-D of the 4D-MB German project). Their results have renewed and will renew our knowledge and understanding of the deep structures and processes in the crust and upper mantle beneath the Alps, and complement the wealth of available geological data to build new geodynamic models of the mountain belt.

I will review the seismic tomography results of the Cifalps team on the first transect across the southwestern Alps from the Rhône Valley (France) to the Po plain (Italy). Then, I will discuss the implications of the recent results obtained by Lu et al. on the crustal and uppermost mantle structure of the Alps using ambient noise tomography.

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day 1: LIU Lijun

Lijun Liu, Department of Geology, University of Illinois

Geodynamics behind the evolving continental cratons

Although the theory of plate tectonics has become the basic framework of modern geosciences, many important questions pertinent to the evolution of plates, especially that of continental cratons, remain poorly understood. On one hand, the cratonic lithosphere is considered to be tectonically stable due to presumed neutral buoyance as its depletion in basaltic composition balances its thermal density. On the other hand, cratons do demonstrate significant temporal variations including multi-km uplift/subsidence, compositional changes seen in xenoliths, as well as lithospheric-scale craton destruction. We attempt to better understand the evolution of continental lithosphere through data assimilation approaches that position all known and unknown tectonic elements into the same evolutionary model so that new knowledge could emerge through the constraining power of big data.

Two examples will be discussed. The first focuses on the southern Atlantic margins, where multiple cratons (Sao Francisco, Congo, Kalahari) experienced late Mesozoic exhumation, accompanied with flood basalts and kimberlitic flareups, coeval with Pangea separation. We first reproduced the post-100 Ma subduction history along the west coast of South America by matching both plate reconstruction and present mantle seismic structure. We then quantified lithosphere-asthenosphere deformation using the inferred mantle flow history, which reveals that the enigmatic fast upper-mantle seismic anomalies below the south Atlantic likely represent stalled lithospheric roots. We conclude that the Mesozoic plume activities triggered lower lithosphere delamination, and that the lost lithosphere has thermally grown back by now, during which the cratonic crust was sheltered from deformation by the buoyant, intact upper lithosphere. Another study locality is the western U.S., where its cratons (Wyoming & Colorado Plateau) have likely been structurally altered during the late Cretaceous-early Cenozoic Farallon flat subduction. We showed that the region experienced broad dynamic subsidence in late Cretaceous, followed by Cenozoic uplift following the trajectory of the subducting Farallon slab. However, to raise the western U.S. to its present high elevation, additional lithospheric buoyancy is required, which could result from a similar process as occurred in the southern Atlantic margins.

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day 1: GESSNER Klaus

Klaus Gessner, Geological Survey of Western Australia,
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Continental geodynamics and Earth resources formation – a West Australian perspective

The exploration for mineral resources and their extraction has been a fundamental human activity since the dawn of civilisation: Geology is everywhere – ore deposits are rare. Most deposits have been found at or near Earth's surface, often by chance or serendipity. Whereas the use and development of high-tech exploration, extraction and processing methods is of great significance, understanding how, when and where dynamic Earth systems become ore-forming systems is a difficult scientific challenge. Ore deposits often form by a complex interplay of coupled physical processes with evolving geological structure. Understanding the geodynamic and tectonic context of crustal scale hydrothermal fluid flow and magmatism can help constrain the spatial extent of heat and mass transport and therefore improve targeting success in mineral exploration. The Geological Survey of Western Australia promotes the geological assets of Western Australia, one of the World's largest and most resource-rich jurisdictions. This presentation will provide examples of how we undertake collaborative projects that systematically collect, analyze and integrate geophysical, geological and geochemical data of cratons and craton margins to reveal critical ties between lithospheric evolution and the formation of mineral and energy resources. It will be shown how this approach has led to significant reinterpretations of Archean and Proterozoic geodynamics and the nature of tectonic domains and their boundaries.

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day 2: HUISMANS Ritske

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day 2: HALL Robert

Robert Hall1, Jonathan M. Pownall2
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High-temperature peridotite contacts, Iran and Banda, Indonesia: subduction-related?

Unusual metamorphic rocks described as skarns are known from the Neyriz ophiolite region in southern Iran. Few people appear to have seen them, but almost all of those who have done so have interpreted them as the product of a high temperature contact between peridotites and marbles. This is incompatible with most ideas concerning ophiolites and their origin, and seems to be the main reason these rocks have been ignored or interpreted in other ways, for example as rodingites. I too was sceptical of the high temperature interpretation until I saw the rocks in the field and studied them, but then became convinced of their high temperature origin. Modern technology now provides the ability to show these rocks and their field relations to a wider audience, which I propose to do in this talk, which I hope will cause other sceptics to reconsider their origin and implications.
However, a high temperature contact raises the question of where and how this formed. Previous workers, especially L-E Ricou who described the field relations in some detail, all concluded an intrusive relationship was required to explain the rocks. This remains a possible but problematical scenario. However, in the past few years ultrahigh temperature metamorphic rocks have been discovered in Seram in the northern Banda Arc of Indonesia at the contacts of peridotites where they are associated with cordierite granites. Their volcanic equivalents are garnet-cordierite dacites known as ambonites. These rocks were interpreted as melts associated with metamorphic rocks and previously considered to have formed below an ophiolite and they have been described as a sub-ophiolite metamorphic sole. Careful mapping shows that they are above, not below, the peridotites which are not part of an ophiolite but represent sub-continental lithospheric mantle. Dating of these rocks has shown that they are Neogene and they are interpreted as formed during major extension associated with subduction rollback of the Banda slab during Australia-SE Asia collision. A similar extensional model for the Neyriz region could resolve the apparent incompatibility of a high temperature peridotite-marble contact and the subduction origin often suggested for the Neyriz ophiolite based on geochemical arguments.

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day 2: PARLAK Osman

RAPID COOLING HISTORY OF A NEOTETHYAN OPHIOLITE: EVIDENCE FOR CONTEMPORANEOUS SUBDUCTION INITIATION AND METAMORPHIC SOLE FORMATION

Osman Parlak[1,2], István Dunkl[3], Fatih Karaoğlan[1], Timothy M. Kusky[2,4], Chao Zhang[5], Lu Wang[2], Jürgen Koepke[5], Zeki Billor[6], Willis E. Hames[6], Emrah Şimşek[1], Gökçe Şimşek[1], Tuğçe Şimşek[1], and Selena Ezgi Öztürk[1]*

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ABSTRACT

The Beyşehir-Hoyran Nappes including Mesozoic carbonate platform rocks, deep sea sediments and ophiolite-related units, crop out extensively on the western limb of the Isparta Angle in the Central Taurides. The ophiolite-related rocks in the Beyşehir-Hoyran nappes are represented by variably serpentinized harzburgitic mantle tectonites, tectonically underlain by a subophiolitic metamorphic sole and mélange. The harzburgitic mantle tectonites and metamorphic sole were intruded by isolated dykes. The metamorphic sole rocks are represented by amphibolite, plagioclase amphibolite, plagioclase-amphibole schist and calcschist. Protoliths of the metamorphic sole are more akin to within-plate alkali basalts and associated sediments. The isolated dykes were geochemically derived mainly from tholeiitic magma and alkaline magma to a lesser extent. Five isolated dyke samples with island arc tholeiite geochemistry cutting the mantle tectonites yielded U-Pb ages ranging from 90.8±1.6 to 87.6±2.1 Ma (zircon) and 102.3±7.4 to 87.5±7.9 Ma (titanite). Seven amphibolites with ocean island alkaline basalt geochemistry yielded U-Pb ages, ranging from 91.1±2.1 to 88.85±1.0 Ma (zircon); 94.0±4.8 to 90.0±9.4 Ma (titanite) and 40Ar-39 Ar ages ranging from 93.7±0.3 to 91.4±0.4 Ma (hornblende). U-Pb and 40Ar-39Ar ages of mineral phases with different closure temperatures (~900-500 o C) from the isolated dykes and metamorphic sole rocks are almost identical and overlapping

within one standard deviation, suggesting that both the magmatic growth of oceanic crust and formation of metamorphic sole were contemporaneous and cooled very rapidly. Hence, all the data should be interpreted as the crystallization age for the ophiolite and metamorphic sole. Genesis of suprasubduction zone (SSZ) type oceanic crust, metamorphic sole and dyke emplacement within the Inner Tauride Ocean can be best explained by subduction initiation and roll-back processes during the Late Cretaceous based on petrological, geochronolgical and structural data obtained from the ophiolitic rocks of the Beyşehir-Hoyran Nappes.

Notes

day 2: YUAN Huaiyu and the CWAS team

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Crustal structure beneath coastal NW Australia: seismic signature from paleo-collision to modern rifting

CWAS Team:
Geological Survey of Western Australia: Ruth Murdie, Lucy Brisbout, Klaus Gessner, John Brett
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The coastal region of the northwest Australia, focused in this study mainly the onshore and offshore Caning Basin region, is tectonically significant owning to the role it played in shaping up the continent in the Precambrian, subsequent intracontinental rifting and basin forming in the Paleozoic, and opening of the Neotethys Ocean in the late Jurassic which has left the oldest oceanic floor (ca 155Ma, Argo Abyssal Plain) along the continent's passive margin. Key questions remain in better understanding the region's tectonic evolution through time, as well as the dynamics in early seafloor spreading and transiting from passive margin to on-going subduction (e.g., the convergence towards the Eurasia Plate further north). Fine-resolution seismic images may put tight constraints to the deep lithospheric architecture, bridge the gap left by early high-resolution studies focusing on regions shallow crust, and shed light on the associated dynamics processes.

In a collaborative project between Macquarie University, the Chinese Academy of Sciences, and the Geological Survey of Western Australia, a large-scale earthquake seismology campaign has been carried out since late 2017 in the Canning region, both onshore and offshore. So far over 70 broadband stations have been deployed. Across the Canning Basin, 60 on-going land stations connect the two ancient cratons, the Pilbara and the Kimberley with a ~15km spacing; and 11 Ocean-Bottom Seismometers extended offshore to over 4000 m deep seafloor in the Argo Abyssal Plain, covering the edge of the passive margin with ~50km spacing. The project is still under data collection, and a series of Earthquake seismic imaging techniques, including bodywave tomography, surface wave (both earthquake and ambient Nosie) tomography, and receiver functions will be used to target the whole-lithosphere volumetric velocity variations, lithospheric discontinuities and seismic anisotropy.

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day 2: VAN HINSBERGEN Douwe

Plume-induced subduction initiation across the Cretaceous Neotethyan ocean

Despite the presence of a long-lived, northward dipping subduction zone that had existed below Eurasia since at least Jurassic time, a major, intra-oceanic subduction zone started forming within the Neotethys ocean in the Cretaceous. Relics of the upper plate of this subduction zone are found as ~96-90 Ma supra-subduction zone ophiolites from Pakistan to Oman, Syria, Cyprus, and Turkey. Current models generally assume that intra-oceanic subduction initiated with north-dipping slabs inverting a Cretaceous mid-oceanic ridge, either spontaneously or induced by an Afro-Arabian plate acceleration, or a deceleration at the northern trench due to lower mantle penetration. In this presentation, we will summarize recent paleomagnetic, kinematic, geochronologic, and petrological evidence showing that (1) subduction initiated around 105 Ma, ~10-15 Ma before upper plate extension formed supra-subduction zone ophiolites, thus showing that subduction initiation must have been induced; (2) that subduction initiated (north)westward (Oman) and (south)eastward (Turkey, Syria, Cyprus) requiring E-W compression in the Neotethys, and was associated with ~(N)W-(S)E forearc extension; (3) subduction initiated along ancient fracture zones close to the passive continental margin of Arabia and Adria, and not along a Neotethys ridge that by Cretaceous time had probably long been subducted below Eurasia; (4) a stepped intra-oceanic subduction zone may be traced from western Turkey to the Amirante ridge in the Indian ocean, from where it connects to the Mascarene oceanic basin that separated India from Madagascar. E-W contraction across the Neotethys may be explained by a counterclockwise rotation of India relative to Afro-Arabia around an Euler pole at the western end of the Mascarene basin. The bulk of this rotation post-dates the ~91 Ma arrival of the Morondova large igneous province on Madagascar and SW India. We show evidence from numerical modeling that the rise of a plume may affect plate motions already 10-15 Myr prior to plume arrival below the lithosphere, and subsequent large igneous province emplacement, and thus postulate that subduction initiation across the Neotethys resulted from a minor, 1-2° India-Arabia rotation as a surface response to plume rise.

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day 2: HALL Robert

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Subduction initiation: observations of how subduction begins

Subduction initiation is commonly identified as a major problem in plate tectonics, and said to be observable nowhere, yet in the west Pacific and eastern Indonesia there are many young subduction zones. Few modelling or theoretical studies consider these examples.

Some subduction zones, such as the Banda Arc, developed by propagation of an existing trench by tearing along a former ocean-continent boundary or existing faults. This 'solves' the problem since the earlier subducted slab provides the driving force to drag down unsubducted ocean lithosphere. Elsewhere, former transforms are suggested as sites of subduction initiation although such models are speculations based largely on geochemical arguments and dubious plate tectonic reconstructions. None of these explanations account for young subduction zones in eastern Indonesia including those in which the subducted slab is not yet at 100 km depth.

Near to Sulawesi are examples of subduction zones at different stages of development. These examples show that subduction initiated at a point, such as a corner in an ocean basin, where there were great differences in elevation between ocean floor and adjacent thickened arc or continental crust. Subduction began at the edges of ocean basins, not at former spreading centres. The age of the ocean crust appears unimportant.

In the earliest stages extension on land is linked to offshore deep water toe thrust development and detachments in the upper crust. Subsequent overthrusting and flow of arc/continent crust is associated with granitic magmatism and deeper detachments leading to depression of adjacent ocean crust. Once the loaded oceanic crust reaches depths of a few tens of kilometres, transformation to eclogite probably leads to slab pull causing the new subduction zone to grow in both directions along strike; arc magmatism may begin.

The close relationship between subduction and extension in eastern Indonesia is recorded by dramatic elevation of land, exhumation of deep crust, and spectacular subsidence of basins imaged by seismic and multibeam data. Exhumed granites and high-grade metamorphic rocks at elevations up to 3 km, separated by alluvial sediments from carbonate reefs now at depths of 2 kilometres, imply vertical movements of several kilometres in a few million years. These observations raise questions of whether subduction is driving extension or vice versa, the time required to move from no subduction to active subduction, and how these processes can be identified in the geological record.

Subduction initiation can be observed, but places where this is possible have been largely overlooked or ignored. However, some analogue models (e.g.) do resemble the development observed in eastern Indonesia, especially experiments by Lévy & Jaupart (2012) – subduction began during crustal extension at a continental margin.

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