



Editorial

Evolution of fore-arc and back-arc sedimentary basins with focus on the Japan subduction system and its analogues



1. Introduction

The International Lithosphere Program (ILP) seeks to elucidate the nature, dynamics, origin and evolution of the lithosphere through international, multidisciplinary geoscience research projects and coordinating committees (Cloetingh and Negendank, 2010). The focus of the Task Force VI Sedimentary Basins activities is to foster collaborations between academia, research institutes and industry in all domains relevant for the understanding of sedimentary basins, from regional to nano-scale, from the deep earth to near surface processes (e.g., Roure et al., 2010, 2013). In this activity, it is important to develop and validate novel concepts of sedimentary basin evolution and topography building by incorporating geological/geophysical datasets and methodologies applied to worldwide natural laboratories (Cloetingh et al., 2011; Cloetingh and Willett, 2013; Matenco and Andriessen, 2013). The Task Force aims to understand and predict the processes that control the formation and evolution of the coupled orogens and sedimentary basins system through integration of field studies, analytical techniques and numerical/analogue modelling. At the same time, the Task Force aims to promote research in the domain of sedimentary basins evolution and quantitative tectonics for the study of mountain building and the subsequent extensional collapse, and their quantitative implications for vertical motions on different temporal and spatial scales (Gibson et al., 2015; Matenco et al., 2016; Roure, 2008; Seranne et al., 2015). The implications of tectonics on basin fluids (fluid-flow and rock-fluid interactions) are important to understand and predict geo-resources (e.g., Nader, 2016). Important is to initiate innovative research lines in linking the evolution of sedimentary systems by integrating cross-disciplinary expertise with a focus on integrated sedimentary basins and orogenic evolution. The key is to strengthen the synergy between academic research and applied industry in large (inter)national interdisciplinary research networks able to tackle complex problems at integrated system level.

Formation and evolution of mountain chains is intimately related to the mechanics of subduction and, ultimately, of collision. This mechanics has a direct impact and can be quantified by analysing the deformation in the fore-arc and back-arc domains, as well as the exhumation of the orogenic core. A significant number of observation and modelling studies are readily available in analysing the orogenic mechanics in various subduction-collisional settings (e.g., Burov, 2007; Duretz and Gerya, 2013; Erdos et al., 2015; Sizova et al., 2014). These studies suggested that mechanics of subduction can be derived and are associated with a fine interplay between accretion in the fore-arc and coeval deformation in the back-arc, where the latter show time-variable transitions

from extension to contraction intimately related with the coupling of tectonic plates and evolution of subducted slabs (e.g., Jolivet et al., 2015; Menant et al., 2016). This mechanics is controlled by many parameters, such as the inherited rheology, the geometry of former passive margins, subduction-related magmatism or *syn*-tectonic sedimentation, with a direct impact in the formation and evolution of the associated sedimentary basins (e.g., Cloetingh and Ziegler, 2007; Matenco and Andriessen, 2013). Other observation and modelling studies have inferred that rheological contrasts and slab advance/retreat may drive an overall migration of deformation and associated exhumation with time (e.g., Vogt et al., 2017). Such processes are quantified by tectonic and exhumation studies on long time scales or by recent short-term observations such as seismicity, crustal movements by GPS or active evolution of landforms. In this context, the change from high-convergence to slab retreat during shortening is less understood in terms of mechanics, in particular the linking observations with processes across temporal or spatial scales (e.g., Matenco et al., 2016).

In this context, the subduction of the Pacific plate and Izu-Bonin arc beneath the Japanese islands together with the Sea of Japan back arc basin are a world-class laboratory where the high-density of observations, ranging from seismicity to deep imaging by active or passive experiments, is outstanding (Ishiyama et al., 2013, 2016; Matsubara and Obara, 2011; Sato, 1994; Sato et al., 2005). These studies have resulted in major understanding of how subduction modifies the overriding plate by fractionation, accretion, and tectonic deformation including orogeny, back arc spreading, basin formation, or intraplate shear-zone initiation. Interesting is the quantification of the link between deep and shallow processes in sedimentary basins from subduction environments and related analogues.

2. Contents of this special issue

The 10th workshop of the ILP Task Force on Sedimentary Basins that took place from 5 to 9 October 2015 in Tokyo, Japan. The workshop has provided an active platform of dialogue among researchers studying basin fill, those investigating deeper basin structure, and those developing numerical and analogue models of basin processes. Several key contributions have analysed the structure and physical properties of basins as well as the underlying crust and mantle, examining also the interactions between deep earth and surface processes, and their implications for basin dynamics. This has resulted in a novel comparison between the high resolution observational data available in the study of the Japanese fore arc/back arc domain coupled with oceanic and island-arc active

subduction domains and their worldwide analogues in the SE Asia and Mediterranean domains (Fig. 1). This has resulted in several new contributions presented in this volume that aims at linking the high-resolution observations and processes of the Japanese arc, fore arc and back arc domains with their worldwide analogue equivalents to understand the link between subduction accretion and erosion with back arc opening and closure, influence of triple junction in subduction systems and their impact on sedimentary basins formation and evolution. Several selected contributions on the evolution of the Japan orogenic system, the associated basins and their worldwide analogues, as well as comparisons with processes taking place on other systems, such as passive continental margins are combined with contributions studying their world-wide past and present analogues. The proposed table of contents reflects a wide variety of contributions linking the deep Earth with surface processes, encompassing temporal (from long-term to present-day) and spatial (from local to regional) timescales, as well as the implications in terms of basin dynamics and geo-resources.

2.1. Understanding the Japan arc and its lateral prolongation - from the back-arc to the subduction system

Topics of contributions dealing with Japan arc focus on ongoing tectonic processes and associated sedimentary records, spanning from the Japan back-arc basin (1–3 in Fig. 1, Van Horne et al., 2017–in this volume; Ishiyama et al., 2017–in this volume; Kashubin et al., 2017–in this volume), accretionary prism (4–6 in Fig. 1, Chiyonobu et al., 2017–in this volume; Kamiya et al., 2017–in this volume; Yamamoto et al., 2017–in this volume), the forearc basin (7 in Fig. 1, Toki et al., 2017–in this volume), and the overall Moho structures beneath the Japan arc system (8 in Fig. 1, Matsubara et al., 2017–in this volume).

To derive outstanding questions focusing major further research, Van Horne et al. (2017–in this volume) reviewed existing geophysical and geological studies, tectonic setting and models of late Cenozoic evolution of the Sea of Japan back-arc system. This includes a discussion on the mechanics of back-arc opening (pull-apart versus trench-roll-back), the dynamics of interacting plates (temporal evolution of the

Philippine Sea plate), the origin of the anomalously thick oceanic crust of Sea of Japan (e.g. Yamato basin), and possible influences of far field forces (India-Asia collision). Based on new multi-scale seismic reflection data, Ishiyama et al. (2017–in this volume) analyses the structural evolution of the failed back-arc rifts in the Sea of Japan and its importance for the mechanics of associated active tectonics and seismicity. The study demonstrates that ~5 km thick syn- and post-rift Neogene sediments are underlain by pre-Neogene basement characterized by high velocity anomalies and crustal thrust wedges adjacent to the rift axis. These findings demonstrate that the mechanical contrast between these pre-rift continental crustal wedges and the high velocity lower crust caused by mafic intrusions during rifting controlled the style of the post-rift compressional deformation. These results are important for the construction of seismic source fault models for tsunamis and seismic hazard estimations. New critical deep seismic constraints on the evolution of the Sea of Okhotsk are presented in the study of Kashubin et al. (2017–in this volume). The study of Vp/Vs ratio in combination with P-wave velocities obtained from available deep seismic studies allow the discrimination of the crustal composition. The analysis of P and S waves obtained from a recently acquired multi-component data with ocean bottom seismometers (OBS) along a 1700 km long north–south profile allow the interpretation of a widely distributed 2–3 km thick felsic layer that infers a continental crustal origin highly affected by stretching during basin opening.

In the study of the accretionary prism, Chiyonobu et al. (2017–in this volume) investigated calcareous nannofossil biostratigraphy of the Middle to Late Miocene trench-slope succession in the southern Boso Peninsula. These trench-slope sediments are structurally and unconformably overlying the Early Miocene Hota accretionary complex deposited below the carbonate compensation depth. The results provide important chronological constraints on the timing of accretion and showed that the accretionary system developed in Middle Miocene to Pliocene times. Kamiya et al. (2017–in this volume) conducted a multidisciplinary study on the Neogene forearc basin deposits exposed in the Boso peninsula. The paleothermal analyses by estimating vitrinite reflectance values (Ro) of older (Miura Group) and younger (Kazusa Group) forearc basin units

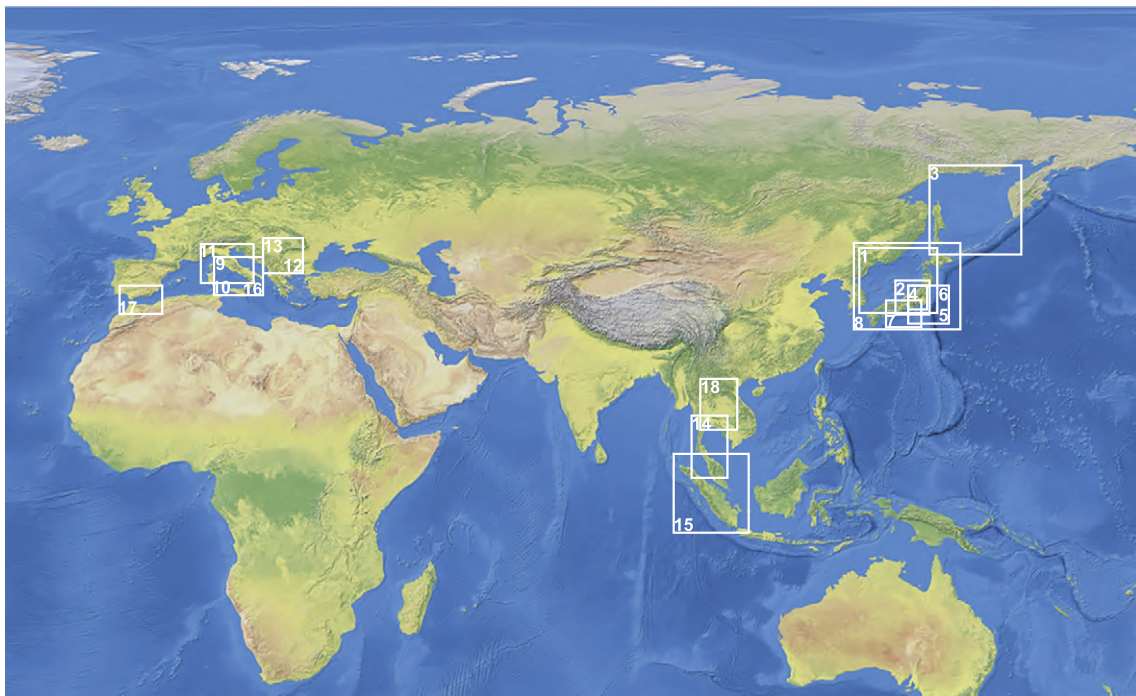


Fig. 1. Localization map of the regions and areas that are described in the articles included in this Special Issue of Tectonophysics. The numbers refer to the papers order in the table of contents: 1 - Van Horne et al.; 2 - Ishiyama et al.; 3 - Kashubin et al.; 4 - Chiyonobu et al.; 5 - Kamiya et al.; 6 - Yamamoto et al.; 7 - Toki et al.; 8 - Matsubara et al.; 9 - Milia et al. (a); 10 - Milia et al. (b); 11 - Gueydan et al.; 12 - Erak et al.; 13 - Stojadinovic et al.; 14 - Sautter et al.; 15 - Berglar et al.; 16 - Milia et al. (c); 17 - Capella et al.; 18 - Arboit et al.

combined with geoenvironmental consolidation experiments showed significant differences beneath and above separating unconformity, which reflect temporal changes of the tectonic evolution and the development of the trench-slope system. Furthermore, Yamamoto et al. (2017—in this volume) investigated maximum paleo-temperature data derived from new vitrinite reflectance data to provide constraints on the geothermal structure of the Miura-Boso plate subduction margin. The results show that higher maximum paleo-temperatures are restricted to the western part of the early Miocene Hota accretionary complex, indicating a spatial difference in the accumulated amount of fault slip on the out-of-sequence thrust, potentially associated with the Izu–Bonin Island Arc collision. This is significantly different from the overlying, less deformed sedimentary sequences, suggesting lower maximum burial depth. Contrastingly, maximum paleo-temperatures obtained for tectonic blocks hosted by the neighbouring Mineoka ophiolite complex are much higher, indicating exhumation from depths of 3–5 km.

Toki et al. (this volume) revealed vertical profiles of chloride ion concentration, oxygen and hydrogen isotopic ratios in pore fluids of sediments obtained by the IODP drilled cores in the southern Kumano Basin, Pleistocene forearc basin of the Nankai subduction zone, southwestern Japan. They revealed significant roles of diffusion and advection of freshwater from methane hydrate dissolution, to explain a very low rate of upward fluid advection compared to other accretionary prisms, resulting from tectonic compaction and recent fault activity.

Matsubara et al. (this volume) presented a new method of mapping the Moho using a 3D seismic tomography model constructed using a dense seismic network (Hi-net) by searching zones of high velocity gradient. The mapping of the residual between isovelocity surfaces of 7.0 km/s and 7.5 km/s resulted in the observation of areas where such residual is small, the separation between the surfaces is narrow, and the velocity gradient is high. This showed that Moho is best constrained where the isovelocity surfaces are close together. The obtained Moho map beneath Japan is comparable with existing regional Moho models obtained from controlled source seismic investigations. This has provided new insights on the structural evolution of the Japanese islands, including the opening of the Sea of Japan back-arc, on-going arc–arc collisions at the Hidaka and Izu collision zones, ongoing back-arc extension in Kyushu, and a possible failed back-arc extensional event of Mesozoic age.

2.2. Worldwide analogue systems

The second part of the volume analyses worldwide analogues of subduction and collisional systems from extensional back-arcs to fore-arcs, collisional systems and thrust belts. The analysed natural examples span from the Mediterranean to the SE Asia systems.

In a series of two contributions Milia et al. (this volume-a, b) studies the evolution of the Tyrrhenian back-arc domain and the inferences for the evolution of the Ionian subduction system. The first study (Milia et al., this volume-a) analyses the mode of extension of the Vavilov fossil back-arc basin located between Sardinia margin to the west and Campania margin to the east (9 in Fig. 1) by the means of recent geological and geophysical data constraining the crustal/sedimentary structure and the tectonic evolution of both central deeper and marginal parts of the basin. The results demonstrate that the apex part of the basin corresponds to a sediment-balanced basin, with a sedimentary infill recording the episodes of basin evolution, while the distal part is characterized by localized volcanic activity and a thin sedimentary succession that covers exhumed mantle. These observations demonstrate an initial pure shear mechanics followed by simple shear associated with supra-detachment basins and mantle exhumation. The second contribution (Milia et al., this volume-b) combines the analysis of a recent seismic tomography model and geological data in the Tyrrhenian Sea (10 in Fig. 1) to understand the relationship between the subducting lower plate and the tectonic evolution of the sedimentary basins formed on the upper plate. The results show a system of linked sedimentary basins formed over a narrow deformation zone bounded by transform

faults associate with poly-phase extension in the upper plate and a major change in extension during the Pleistocene, which infer a kinematic link with the development of a major STEP zone along the northern margin of the Ionian slab. The study of Gueydan et al. (this volume) analyses the key location of Corsica during the Alpine subduction and collision and the post-dating opening of the Western Mediterranean back-arc system (11 in Fig. 1). The study shows three main stage of extension starting with the Oligocene times that are correlated with periods of marked slab roll-back in the Apennines resulting in the formation of the Liguro-Provençal and Tyrrhenian back-arc basins. Two contributions are providing key constraints for the collisional and back-arc evolution of the Dinarides of Serbia (12–13 in Fig. 1). The study of Erak et al. (this volume) analyses the evolution of the key locality of Jastrebac Mountains located near the pole of Neogene rotation during the formation of the SE prolongation of the Pannonian back-arc system. By combining field kinematics with low temperature thermochronology and dating of pluton emplacement, the results demonstrate that a Late Cretaceous–Paleogene period of contraction and nappe stacking was subsequently followed by the formation of an extensional detachment starting in the latest Oligocene times that evolved gradually throughout the entire Miocene. It demonstrates that extensional zones situated near the pole of extensional-driven rotation favour late stage truncations and migration of extension in a hanging-wall direction, while directions of tectonic transport show significant differences in short distances across the strike of major structures. The low-temperature thermochronology provenance study of Stojadinovic et al. (this volume) demonstrates rapid Late Cretaceous sedimentation in the trench and forearc basin overlying the upper European tectonic plate, sourced predominantly from a subduction-related magmatic arc. This was followed by a novel stage of Middle–Late Eocene exhumation driven by continued continental collision that had larger effects than previously thought and by Late Oligocene–Miocene exhumation of the former lower Adriatic plate along extensional detachments reactivating the inherited collisional contact along the entire Dinarides margin. The study demonstrates short lag times between exhumation and re-deposition in the Dinarides, whereas the upper tectonic plate is significantly exhumed only during the final stages of collision. In the SE Asia, the study of Sautter et al. (this volume) of the Malay Peninsula segment separating the Andaman/Malacca basins in the west from the Thai/Malay basins in the east (14 in Fig. 1) demonstrates the reactivation by extension of major inherited structural discontinuities from the previous orogenic evolution. The study shows that rifted basins resemble N–S en-echelon structures along large NW–SE shear bands where the extension is accommodated by large low angle normal faults. On the flanks, the deep Andaman, Malay and Pattani basins overlain weaker crust inherited from Gondwana-derived continental blocks, while narrow elongated basins in the centre of the region underwent relatively lower amounts of extension.

Studies of analogue fore-arc areas show rapid evolution controlled by major tectonic episodes. Berglar et al. (this volume) analyses the accommodation of trench-parallel strain in the Sumatra oblique convergent margin, with focus on the Mentawai and Sumatran faults bounding the Mentawai forearc sliver (15 in Fig. 1). Multi-channel reflection seismic data, swath bathymetry and high resolution sub-bottom profiling demonstrate wrench faulting separating a regional strike-slip duplex forming the forearc sliver, where each composing horse comprises an individual basin of the forearc with differing subsidence and sedimentary history starting with Middle – Late Miocene times. The study of Milia et al. (this volume-c) analyses the Miocene progressive fore-arc extension in the Central Mediterranean, with special regard on the main deformation events recorded by sediments that were deposited within minor basins of the Tyrrhenian Sea (16 in Fig. 1). The results infer that coeval fore-arc extensional/transensional basins developed in the central Mediterranean during the progressive collision with the African plate and before the Tyrrhenian back-arc opening, support a geodynamic model characterized by a progressive

deformation of the fore-arc extension in the overriding plate. The study of Capella et al. (2017) analyses the effects of the change in mechanics during collision of the Rif system (17 in Fig. 1) that has resulted in the closing of the last remaining connecting corridors with the Atlantic that ultimately led to the Mediterranean Messinian Salinity Crisis. By the means of field kinematics combined with seismic interpretation, the study documents a novel evolution showing a transition from long-lived Miocene thin-skinned tectonics to thick-skinned thrusting associated with an acceleration of tectonic uplift and associated exhumation. This is related to a change in the regional plate convergence, coupled with deep lithospheric or dynamic topography processes. The study of Arboit et al. (2017) performed a quantification of the effective principal palaeostresses magnitudes during and after orogenic formation by using the Khao Khwang thrust belt in central Thailand (18 in Fig. 1) as case study. The results demonstrate a novel mechanical scenario based on the time-constrained kinematic sequence of fracturing, faulting and folding in the Saraburi carbonate Group, which allowed a quantification of principal stress magnitudes during the Indosinian orogeny and, by combination with absolute age dating, derived the amount and rate of exhumation of these carbonate formations.

3. Closing statements

The research findings presented in this volume illustrate well the close interaction between processes taking place in the fore-arc, accretionary wedge and back-arc domains, closely controlled by the mechanics of the subduction system that has a critical influence throughout the entire arc formation and subsequent continental collision. The associated sedimentary basins evolution reflects the interplay between accommodation space and sediment supply that changes rapidly with time and space in such dynamic systems. In this context, the link between tectonics and *syn*-kinematic deposition, i.e. tectonic system tracts, define the evolution of sedimentological environments and is generally less understood. Studying this link requires a sequence stratigraphic multi-scale approach that combines multi-methodological field studies with basin-wide observations, such as seismic interpretation, and integration with the evolution of the underlying lithosphere derived by geophysical observations. The current research was able to quantify the mechanisms driving the formation and evolution of system tracts and sequences at various orders of cyclicity in both orogenic forelands and in back-arc extensional or contractional basins. This is critically important in regions with high-resolution observations, such as the Japan subduction system, but is also demonstrated in the cases documented elsewhere in this volume, such as the SE Asia, Dinarides, Apennines, or the Rif orogens. The subduction dynamics controls the formation and evolution of large back-arc extensional basins from their opening to their subsequent inversion. The Sea of Japan is an active example of such a system where the earlier extensional opening and subsequent inversion was controlled by the mechanics of subduction and the collision with the Izu-Bonin arc. Similar scenarios of rapid subduction and collision with island arc are very challenging to be detected in the past evolution of other orogenic areas, but possible and required by the necessity of understanding observed orogenic variabilities. Understanding the evolution of fossil accretionary wedges and forearc basins incorporated now in exposed collisional areas is rather challenging and the Japan system offers the ideal presently active system where these processes can be directly observed and studied and their relevance can be extrapolated to other scenarios worldwide. All these observations and comparative studies demonstrate the importance of comparing and extrapolating active processes to past analogues. Understanding the evolution of associated sedimentary basins requires analysing mechanics at the scale of entire orogenic systems, while their local lateral variations create significant modifications of geometries in observed mountain chains.

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