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Phanerozoic growth of Asia: Geodynamic processes and evolution

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A B S T R A C T

Accretion processes often obscured in mountain belts can be documented with great detail in SE Asia where these have taken place during the Tertiary. The resulting configuration showing accreted continental strips and tectonised wedges is illustrated by the Tethysides jammed between the northern Laurasian cratons (Baltica and Siberia) and Gondwanian cratons (Africa, Arabia, India and Australia). Eurasia increased progressively in size due to the amalgamation of crustal and sedimentary belts. At places where the processes are documented in the recent times, they can be included within a "collision factory" which displays the opening of basins by rifting and sea floor spreading within the upper plate, until they undergo a process of shortening, both stages being subduction-controlled. In SE Asia the early stages are illustrated in the eastern Sunda arc where the subduction of the Sunda Trench is blocked in Sumba and Timor region, and flipped into the Flores Trough in less than 2 My. The incipient shortening is at present taking place in the Pliocene Damar basins. Another stage, where half of the upper plate basin has disappeared, is documented in the Celebes Sea. The examples of deformation being transferred further inland exist in the northern Celebes Sea and the Makassar Basin. The next important stage is the complete consumption of the marginal basin where both margins collide and the accretionary wedge is thrust over the margin, as illustrated in NW Borneo and Palawan. Each of these stages is responsible for a single short-lived tectonic event, the succession of several events composes an orogen which may last for over 10 My. These events predate the arrival of the conjugate margin of the large ocean, which marks the beginning of continental subduction as observed in the Himalaya–Tibet region.

These examples show that the closure is generally diachronous through time as illustrated in the Philippines. We observe that the ophiolite obducted in such context is generally of back-arc origin (upper plate) rather than the relict of the vanishing large ocean which is rarely preserved. In the Philippines, once the crust is accreted the subduction zone progressively moved southward until its present position. We propose that the lithospheric mantle of the accreted block is delaminated and rolls back in a continuous manner, whereas the crust is deformed and accreted.

1. Introduction

1.1. The Tethysides

The whole of Eastern Eurasia is involved in a global convergence of plates since the beginning of the Phanerozoic times. The area covered by the present day Eurasian plate is composed of cratons that have formed prior to the Phanerozoic and have since then acted as large jaws which crushed smaller continental fragments together with relicts of former oceanic domains. Among these domains were the Paleotethys and the Tethys oceans which both acted as zippers that opened toward the west.

As a result, the most prominent collision belt of the world: the Tethyan belt is located between a group of major continental blocks composed of Africa–Arabia–India in the south and Baltic–Siberian blocks in the north. Between these blocks undeformed during the Phanerozoic is an apparently complex system of microblocks and tectonic belts (Fig. 1). This assemblage is narrow in southern Europe and remarkably wide in Eastern Asia. The global understanding of the evolution of this area exists and many reconstructions at small scale have been performed (Metcalfe, 1996, 1999; Hall, 1998, 2002). On the other hand the geological history of each local area in western Tethys (Lee and Lawver, 1985; Stampfli and Borel, 2004), or South East Asia (Audley-Charles et al., 1988; Pubellier et al., 2003; Harris, 2003a,b) has been generally documented and mapped. Geological maps at the scale of Eurasia illustrate the mean age of the main geological entities, but do not allow a clear correlation of the tectonic belts during the Phanerozoic and cannot help to understand the evolution trough time.

In order to understand the global accretion tectonics which formed the Asian continent, one needs to accept that the exact

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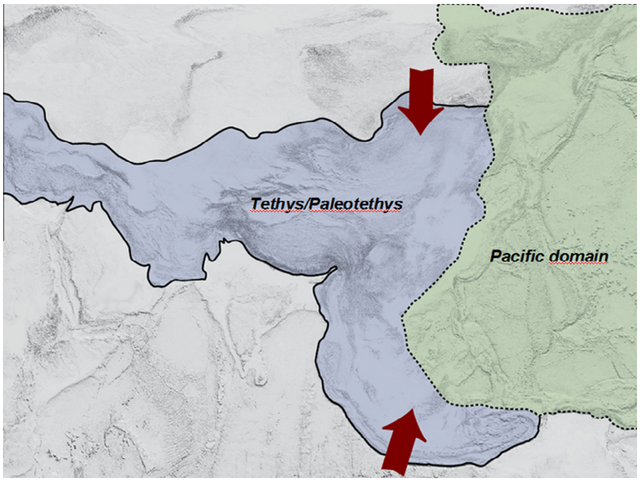

Fig. 1. The tectonic belts including continental fragments from the Mediterranean to the SE Asian regions. The central part of the map represents the Tethyan realm which developed to the south of an earlier Early Paleozoic "Caledonian" and Late Paleozoic "Variscan" entity. This mega structure is narrower to the west in the Mediterranean region and becomes wider in Eastern Asia between Siberia and Australia. The various cratons structured prior to the Late Proterozoic are represented in grey colour. Modified from the Structural Map of Eastern Eurasia published by CGMW (Pubellier, 2008).

age of the block juxtaposition is often debated and that this docking may be diachronous along large belts. Then the litho-stratigraphic units may be separated into crustal blocks - often of continental nature but also of mafic oceanic plateau or volcanic arc affinity - which have been jammed into the tectonic belts, and wedges which are composed of packages of sedimentary rocks that have undergone intense deformation during the shortening stages. These wedges have been studied for decades by geologists with varying tectonic concepts, which tried to depict the evolution of sedimentary and crustal rocks undergoing varying degrees of deformation and metamorphism.

1.2. Crustal fragments, sedimentary and orogenic wedges

Wedges are well known for recent events and usually incorporate the deep sea sediments of the former oceanic domains in the early stages of subduction. Then as the continental margin entered the subduction, an increasing amount of proximal sediments and even continental shelf sediments were stacked in the accretionary wedge (Wakita and Metcalfe, 2005). The latter are generally preserved in the foothills of recent or isolated orogens. Finally, in the late stages of the basin closure, the basement rocks may be also stacked in the wedge, thus exhuming metamorphosed sediments or crust of the down-going plate, together with metamorphosed sediments of the deep accretionary wedge or the subduction channel. When highly metamorphosed, these sediments represent the "cratonized rocks" of orogenic wedges and are difficult to distinguish from the old metasediments of the cratons surrounding the orogen.

Then, it is obvious that we can separate the tectonic units of Eastern Asia which represent Pacific-derived blocks and wedges now accreted in a large N–S trending belt between Eastern Siberia and New Guinea Island (Fig. 1). This belt includes the Indosinian Kolyma–Olomon system in the north which accreted continental fragments of debated size against Siberia. Relicts of melanges and ophiolites exist between the Siberia and the accreted units (Oxman, 2003; Khudoley and Prokopiev, 2007) and the deformation front propagated westward in the Verkhoyansk until the Cretaceous. The rest of the Pacific-derived belt is Late Cretaceous and Tertiary. It terminated the long lasting Mesozoic Andean-type subduction of the Yanshanian arc and extends from Kamchatka to offshore South Vietnam and Malaysia. Out of this scheme (Fig.1), the Ural Mountain belt also constitutes an exception. It stands out of the N–S continental jaws, and was formed during Cretaceous times without later reactivation, after having welded the Baltic and the Siberian blocks.

1.3. Opening and closure of marginal basins, as a product of the same subduction

However, in the case of most large tectonic belts, collisional orogeny lasted ~20 My or longer and involved the accretion of incipient back-arc or forearc oceanic crust (ophiolites), microcontinents, oceanic plateaux, and island arc systems into continental margins prior to final continent–continent collisions (Fig. 2). These discrete and short-lived accretionary events may result in slab breakoff, subduction jump and reversal, tectonic extension and

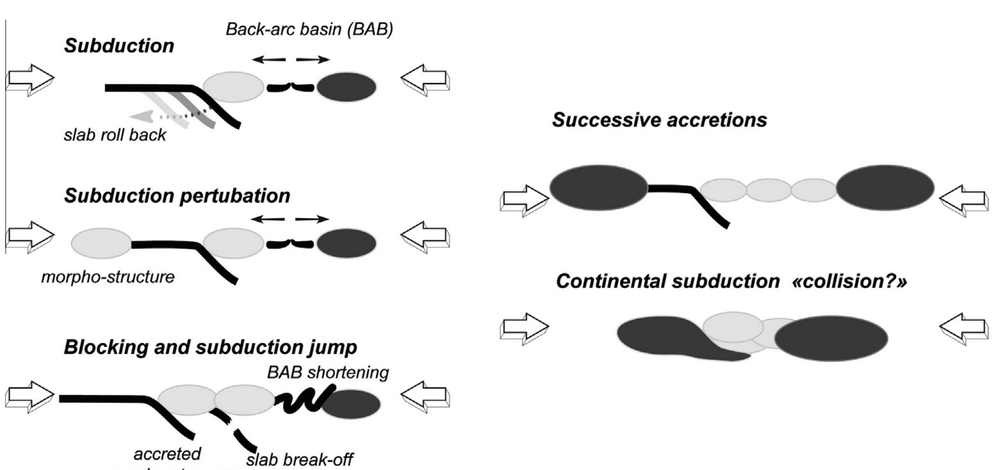

Fig. 2. Cartoon showing the simplified and generalised evolution of the accretion processes in SE Asia. (a) Subduction roll-back triggers the opening of a back-arc basin in the upper plate. (b) A crustal morphostructure (or asperity) reaches the subduction zone and generates perturbation at the plate boundary due to its thickness and buoyancy. (c) The subduction zone jumps at the receding side of the asperity creating a new plate boundary. As a result deformation takes place in the arc and the back-arc areas, whereas a slab break-off may take place. (d) This results in the accretion of crustal morphostructure and the mechanism of accretion may repeat several times; thus pushing the active subduction zone toward the oceanic domain. (e) The final stage is the subduction of the conjugate margin of the original ocean. No subduction jump can occur and continental subduction takes place.