Bull. Soc. géol. Fr., 2003, t. 174, n° 6, pp. 561-584

Volume spécial
Géodynamique de l'Asie du Sud-Est

The building of pericratonic mountain ranges : structural and kinematic constraints applied to GIS-based reconstructions of SE Asia

MANUEL PUBELLIER[1], FREDERIC EGO[1], NICOLAS CHAMOT-ROOKE[1] and CLAUDE RANGIN[1,2]

Key words. – Southeast Asia, Kinematic reconstructions, Convergence, Peri-cratonic mountain range.

Abstract. – Southeast Asia represents a valuable playground for studying the mechanisms of supra subduction mountain building. Fast relative plate velocities induce rapid geodynamic changes, so that the parameters for the convergence can be constrained, whereas the recently inactivated systems are still accessible. We make use of the GPS-controlled motion of major plates together with that of smaller units within the deformed belts, to explore the Neogene evolution of SE Asia. We present simplified synthetic sections for the structural control, and used GIS-based reconstructions to support the relative location of the plates and distances between them, so that at a given time, location of units can be confronted to the tectonic observations.

Pericratonic mountain ranges are the result of long lasting convergence which was responsible for both the fragmentation of continental landmasses by the opening of marginal basins, and the shortening of these supra subduction units, which ultimately jammed them back against the motherland, or transferred them to the neighbouring plate. Because the obliquity of the convergence generated strain partitioning, new paired trench and strike-slip systems are created, moving blocks further away from the locus of accretion, so that continental or oceanic fragments may be chopped, transported and eventually severely sheared during final docking. We present simplified cross sections of the margins of the SE Asian regions prior and after the accretions of blocks and reconstructions at 2, 4, 6, 10, 15 and 20 Ma.

L'édification des chaînes péricratoniques, contraintes structurales et cinématiques appliquées aux reconstructions de l'Asie du SE sur SIG

Mots-clés. – SE Asiatique, Reconstructions cinématiques, Convergence, Chaîne de montagne péricratonique, SIG.

Résumé. – Le SE asiatique est un chantier qui permet d'étudier la formation des chaînes de montagnes situées au dessus des zones de subduction à différents stades de leur évolution. Dans ces régions, la cinématique des plaques est extrêmement rapide, souvent de l'ordre de 10 cm/an, et la convergence engendre l'ouverture, elle aussi rapide, de bassins marginaux qui fragmentent sous forme de lanières les masses continentales. Les fragments ainsi séparés comportent donc un substratum généralement constitué de matériel correspondant à des ophiolites de supra subduction (arc, avant-arc, arrière-arc) ainsi que des reliques de croûte continentale. Ce type de mécanisme aboutit à la formation de plaques étirées qui peuvent être soit de nature océanique comme pour la plaque Philippine [Karig, 1975] formée de bassins arrière-arcs ouverts à l'Eocène (Bassin ouest-philippin), puis à l'Oligo-Miocène (bassin de Parece Vela/Shikoku), et au Pliocène (bassin des Mariannes) [Le Pichon *et al.*, 1975] ; bassin de Damar [Hinschberger, 2001]), soit de nature continentale comme dans le cas des marges Australienne et Eurasiatique [Rangin et Pubellier, 1990 ; Rangin *et al.,* 1990] (fig. 1). Dans ce dernier cas, la configuration résultante est celle d'une marge étirée à la façon d'un éventail depuis le Paléocène jusqu'au Miocène moyen. Ce mécanisme génère des bassins diachrones ouverts vers l'est, avec un propagateur vers le sud-ouest comme cela est visible dans l'ouest de la mer de Chine [Huchon *et al.,* 1998], et est déduit pour la mer des Célèbes et son prolongement dans le détroit de Makassar [Moss and Chambers, 1999]. Cet étirement prenait lui-même la suite de l'écroulement gravitaire de la chaîne Yenshanienne depuis le Crétacé supérieur, qui marquait la fin d'un processus similaire d'accrétion de blocs gondwaniens au cours du Mésozoïque [Metcalfe, 1996 ; Sewell *et al.,* 2000]. L'ensemble du bloc de la Sonde, avec ses bassins marginaux est soumis à un raccourcissement depuis le début du Miocène [Rangin *et al.,* 1990], les bassins marginaux rentrant en subduction, et certains blocs basculés de la marge passive étant en cours d'accostage contre la marge continentale. De même que l'ouverture des bassins s'était effectuée de manière diachrone, le serrage des bassins s'effectue lui aussi de façon diachrone.

Les mécanismes actifs de convergence par subduction et les blocages sont maintenant bien connus, la précision des récepteurs GPS, et surtout la répétition des mesures depuis près de dix ans permettant de bien contraindre les déplacements instantanés. Nous avons utilisé principalement les vecteurs GPS du programme GEODYSSEA [Michel *et al.*, 2001]. Parallèlement, les études de tomographie sismique imagent des anomalies positives de vitesse dans le manteau pouvant indiquer des lithosphères subductées. C'est le cas de la proto mer de Chine Sud, parallèle à l'actuelle mer de Chine du Sud et probablement de géométrie similaire, maintenant disparue par subduction [Rangin *et al.,* 1999b ; Prouteau *et al.,* 2001]. Dans cet article, les mouvements déduits du GPS ont été utilisés comme base cinématique jusqu'à l'âge de la dernière déformation marquante, pour chaque bloc des ceintures déformées. L'évolution des marges a été revue de manière globale sur l'ensemble de l'Asie du SE, de façon à présenter des coupes structurales synthétiques,

[1]Laboratoire de Géologie, Ecole Normale Supérieure-CNRS, UMR8538, F-75231, Paris, France, Tel : (33)144322258, Fax : (33)144322000, email : Manuel.Pubellier@ens.fr
[2]Actuellement : Collège de France, Géodynamique, Bât. Laennec, Europole méditerranéen de l'Arbois, BP 80, 13545 Aix-en-Provence cedex 4.
Manuscrit déposé le 17 juillet 2002 ; accepté après révision le 26 juin 2003.

avant et après raccourcissement (fig. 3 à 10). Ces coupes montrent que l'arrivée des blocs continentaux dans les zones de subduction entraîne un blocage, puis le plus souvent un saut de subduction qui intègre le bloc à la marge en créant une déformation de la plaque supérieure [Dominguez *et al.,* 1998 ; Pubellier *et al.,* 1999 ; Von Huene *et al.,* 1995 ; Ranero *et al.,* 2000].

Une base de données sur l'Asie du Sud-est est utilisée dans les reconstructions, mais seulement une partie est représentée sur les planches 1 à 6 (topographie-bathymétrie, principales failles). La base complète comprend aussi bien les failles actives et anciennes, que la topographie des chaînes de montagnes, la morphologie des fonds sous-marins, la gravimétrie à l'air libre, les vecteurs de déplacement GPS en différents points à partir du calcul du meilleur pôle eulerien correspondant au mouvement de chaque bloc, les épaisseurs des sédiments dans les bassins, ou encore la localisation des profils sismiques utilisés. L'utilisation d'un système d'information géographique permet de restituer les déplacements des plaques ou des micro-blocs crustaux, soit à l'aide des vitesses angulaires, soit de façon interactive. Cette démarche permet de choisir entre plusieurs hypothèses géologiques en gardant une cohérence d'ensemble. Les paléo-distances géodésiques entre les blocs peuvent être mesurées, et les chaînes de montagnes comme Taïwan ou la Chaîne centrale de Nouvelle Guinée ont été étirées pour retrouver l'espace qu'elles occupaient vraisemblablement avant leur formation. Dans les reconstructions, la profondeur des bassins correspond aux valeurs actuelles, et n'a pas été restaurée en fonction du temps. Enfin, nous n'avons pas étendu les reconstructions à l'Himalaya et au Tibet, les mouvements verticaux étant trop importants. Les reconstructions effectuées à 2, 4, 6, 10, 15 et 20 Ma (planches 1 à 6) montrent que les parties continentales des plaques Sunda et Australie ; (SU/AU) s'éloignent l'une de l'autre, alors que la plaque philippine continue de "brosser" la plaque de la Sonde [Rangin *et al.,* 1990], en transportant vers l'ouest des fragments formés au nord de la plaque australienne. Il s'agit donc d'un article qui présente une généralisation de processus géodynamiques de fonctionnement des marges actives, et dont le but est de donner une image cohérente de l'accrétion de blocs aux bordures des continents, et qui a nécessité des choix dans les options souvent débattues de l'évolution au deuxième ordre de secteurs d'importance locale.

INTRODUCTION

Subduction zones and collisional orogenic belts are features which result from plate convergence. In most mountain ranges, geologists find remnants of sheared continental slivers together with relicts of dismembered supra subduction ophiolites including calc-alkaline volcanic arc series, crustal terranes and melanges. This suggests that they underwent a pre-collisional evolution involving a subduction-accretion history. The accretion to the active margin of blocks of various origins predates the contact between the main continental landmasses, and is in most cases responsible for deformation of the upper plate and the formation of mountain belts sitting above the subduction zone. As in the case of the Andes or the North American cordilleras during the Mesozoic, most of the mountains in SE Asia have formed in this way, and more recent volcanic edifices nowadays crosscut the deformed units. We propose in this paper to briefly review the processes and consequences of the formation of such pericratonic mountain ranges, using schematic sections of the deformed belts in various key areas of SE Asia. We then explore the instantaneous and finite kinematics of SE Asia, in order to apply convergence parameters to GIS-based reconstructions of this region during the Neogene.

What happens when subduction works properly ?

In the western Pacific Marianna-type subduction zones, characterised by low coupling due to an asthenospheric flow opposite to the direction of subduction [Uyeda and Kanamori, 1979 ; Ricard *et al.,* 1991], local extension occurs in the upper plate, resulting into arc-splitting and eventually evolving toward the development of a marginal basin floored with oceanic crust (fig. 2, section 1). Although this case example is shown with an upper plate of oceanic nature, the concept applies to continental plates. This way, several basins have opened in the midst of the Eurasian margin since the early Tertiary. Most of them opened with a N-S or NNW-SSE direction. The mechanism of opening has for long been a matter of discussion. It had been proposed for example that the South China Sea opened as a side effect of the extrusion of Indochina [Tapponnier *et al.,* 1986 ; Briais *et al.,* 1993]. It is likely that the gravity controlled trench pull of the Sunda subduction is responsible for the rifting and spreading of the basins opened in the Sunda Plate, and similar trench pull due to the subduction of the Proto South China Sea south of Palawan to explain the South China Sea opening [Rangin *et al.,* 1990].

Almost all basins have opened diachronously in a fan shape pattern on the eastern side of the Sunda / southern China blocks. The first one was the Proto South China Sea which rifted from the late Cretaceous on the edge of the Yienshanian orogen. Limited sea floor spreading, if any, occurred in the early Eocene. Thus, we do not follow the older hypothesis of a wide Proto South China Sea with a large rotation of Borneo [McCabe and Cole, 1989].

The Celebes Sea opened in the Middle Eocene (47 Ma), followed by the South China Sea in the Oligocene (33-15 Ma) and the Sulu Sea in late early Miocene (18 Ma). A mechanism of opening of these basins is proposed, by comparison with the western South China Sea, where a propagator has been identified, mapped and modelled [Huchon *et al.,* 2000]. We likewise assume a similar evolution for the Makassar basin as a propagator of the Celebes Sea. We also assume an identical process for the narrow section of the Sulu Sea now shortened in Sabah and for the Proto South China Sea.

Similar evolution may be found in New Guinea which is a critical area to understand the geodynamic evolution of Southeast Asia. The northern Australia margin has been rifted since the Triassic, with at least two marginal basins different in age, both of which formed in back-arc setting. The older basin opened between the middle Jurassic and early Cretaceous. The New Guinea Ophiolite is a remnant of this basin. The obduction started by 40 Ma and the final emplacement on the Australian margin took place by 30 Ma

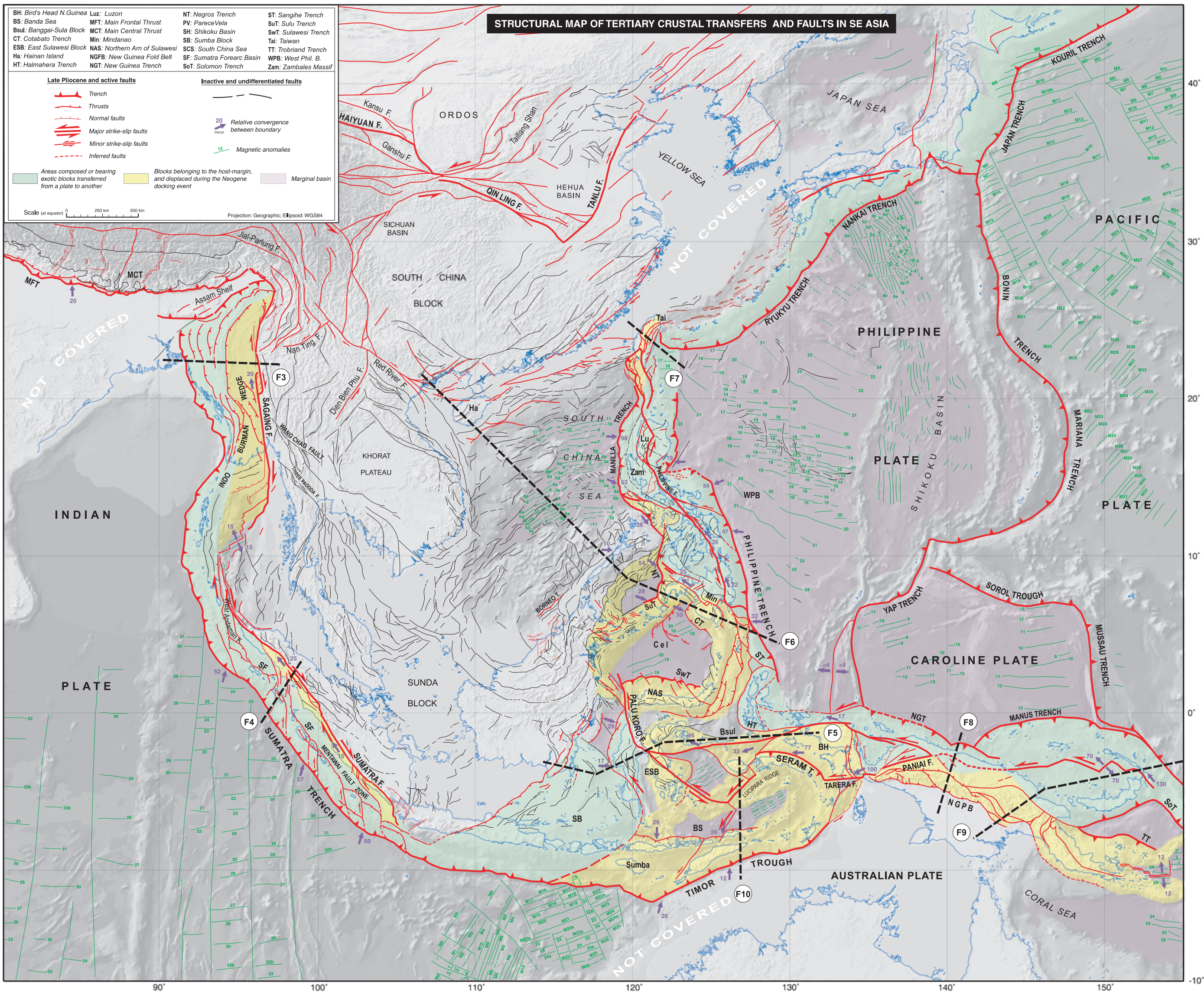


FIG. 1. – Schematic structural map of the SE Asian region showing the major fault zones responsible for motions of discrete blocks or sliver plates during the Neogene. Also indicated are the exotic blocks transferred from a plate to another (green colour), and blocks belonging to the host-margin but having been displaced during the last docking event (yellow colour). Location of schematic cross sections of figures 3 to 10 is indicated. Black arrows represent the relative motion at block boundaries. Thick red lines are active or Pliocene faults. Thin black lines are for older undifferentiated faults. Abbreviations for the structural units mentioned in text are as follows: BH: Bird's Head of New Guinea, BS: Banda Sea, Bsul: Banggai-Sula Block, Cel: Celebes Sea, CT: Cotabato Trench, ESB: East Sulawesi block, Ha: Hainan island, HT: Halmahera Trench, Luz Luzon, MFT: Main Frontal Thrust, Min: Mindanao, NAS: Northern Arn of Sulawesi, NGFB: New Guinea Fold Belt, NT: Negros Trench PV-SH: Parece Vela/Shikoku Basin, SB: Sumba Block, SCS South China Sea, SF: Sumatra Forearc Basin, SoT: Solomon Trench, ST: Sangihe Trench, SuT: Sulu Trench, SwT: Sulawesi Trench, Tai: Taiwan, WPB: West Philippine Basin, Zam: Zambales massif,

FIG. 1. – *Carte structurale schématique de la région du SE Asiatique montrant les principales failles responsables des déplacements de lanières ou blocs crustaux. Certains, dits exotiques, ont été transférés d'une plaque à une autre (vert). D'autres (en jaune) appartenant à la marge (sub-autochtones) ont été déplacés au long de la marge pendant la convergence oblique. Les grands traits représentent le tracé des coupes schématiques (figures 3 à 10). Les flèches noires représentent le mouvement sur les limites de blocs, les lignes rouges épaisses sont les failles pliocènes ou actives, et les lignes fines en noir représentent les failles plus anciennes. Abréviations pour les termes géo-structuraux : voir légende en anglais.*

[Monnier *et al.,* 1999 ; Permana, 1998]. The younger basin was active during the Oligocene to Middle Miocene and was obducted in the early Pliocene [Monnier *et al.,* 1999].

Reconstructing the extent of the marginal basins is fundamental to understand the geodynamic evolution. For the New Guinea region, a new Eocene-Oligocene plate tectonic evolution is proposed, with the assumption that the Australian plate extended on a considerable distance with oceanic crust north of the Australian craton [Pubellier *et al.,* 2003]. That crust was then subducted when Australia began its steady northward drift in the early Eocene. Therefore the part of the Philippine Sea plate carrying the Taiwan-Philippine arc to its present location may have been in contact with the New Guinea ophiolites. It may have been involved in the deformation and obduction of the Philippine Sea plate itself.

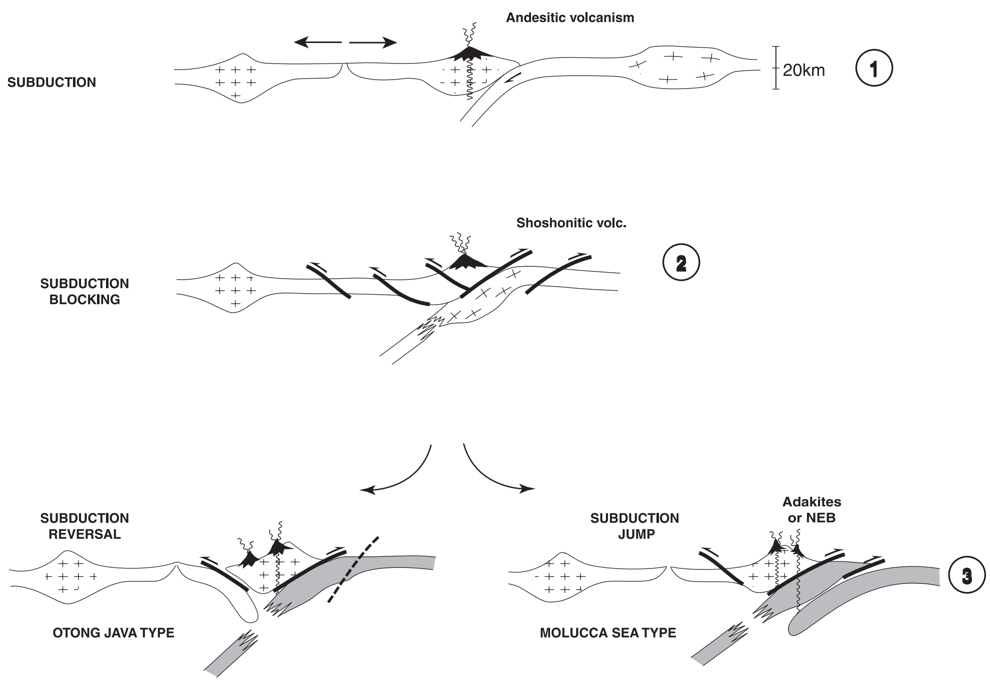


FIG. 2. – Sketch of various possible evolution of active margin when a crustal-scale asperity enters a subduction zone ;
FIG. 2. – *Scénarios possibles d'évolution d'une marge active lors de l'entrée dans la fosse d'une aspérité de taille régionale.*

What happens when subduction does not work properly ?

Asperities entering a subduction zone will try their best to subduct (fig. 2, section 2 and 3). Volcanic edifices had been proved to subduct into the trenches of Costa Rica, only leaving scars into the accretionary wedge and occasionally a bulge of the upper wedge [Dominguez *et al.,* 1998 ; Von Huene *et al.,* 1995 ; Ranero *et al.,* 2000]. Similar observations have been done in the eastern Mediterranean [von Huene *et al.,* 1997 ; Chamot-Rooke *et al.*, 2004] and in the Ryu-Kyu Trench [Lallemand *et al.,* 1992]. Larger volcanic edifices such as the Daiishi-Kashima volcano suffered slicing by normal faults which facilitated its introduction into the Japan Trench [Lallemand *et al.*, 1989]. Similarly, a large continental plate like India is capable of subducting beneath Eurasia since the Eocene over several hundreds of kilometres, having only slowed down its velocity from 80 to 40 mm/yr, but creating the uplift over a considerable surface of the crust in Tibet. In between these two extremes, the blocks of intermediate sizes (~100 km), regardless of their nature (oceanic, continental) seem to be responsible for drastic changes along the margin (fig. 2). The introduction of such a block does not seem neither to stop nor to affect the plate convergence. The block is jammed into the trench over several tens of kilometres and cannot subduct deeper because of its buoyancy. In the Molucca Sea and Mindanao Island, ongoing convergence generated shortening of the forearc basin, the back-thrusting of the upper crust of the accreted block and ultimately a jump of the subduction zone along which the convergence resumed [Pubellier *et al.,* 1996, 1999]. In this docking process, blocking of the first subduction creates slab detachment of the down-going slab. There are evidences in the southern Philippines suggesting that the remnant of oceanic lithosphere attached to the accreted block is underplated, and uplifted together with the upper plate. The uplift may be responsible for crustal melting by adiabatic decompression, resulting in effusion of adakitic or/and Nb-enriched basalts [NEB, Maury *et al.,* 1996].

The new subduction being in most cases oblique, we observe the onset of a classical system of paired subduction (Philippine Trench) and strike-slip fault (Philippine Fault), [Quebral *et al.,* 1996], which partition the oblique convergence vector [Fitch, 1972 ; Jarrard, 1986 ; McCaffrey, 1991]. The fault zone which parallels the new subduction zone (e.g. Philippine Fault in this case) drags along a sliver of the previously accreted block, and the newly formed volcanic arc runs approximately along the strike-slip fault zone.

Therefore, the docking of blocks of moderate size will actually create a large deformed belt at the edge of the continent. This belt would extend from the back-arc area of the upper plate to the new subduction zone and integrate the deformed crust of the accreted block.

Overview of the configuration of SE Asia : cratons and deformed mobile belts

Southeast Asia represents a valuable playground for studying the mechanisms of supra-subduction mountain building. Fast relative plate velocities induced rapid geodynamic changes, so that the parameters for the convergence can be constrained, whereas the recently inactivated systems are still accessible.

We have examined information from the major tectonic systems located at the boundary of the major plates involved in a large triple junction (fig. 1) ; namely the Philippine (which we associate hereafter with the Caroline plate), the Sunda and the Australian plates since the early Tertiary. These include the Philippine arc which formed on the Philippine Sea plate, and the southern extension of this belt, which has been either obducted on the northern margin of the Australian continent, or jammed within the various crustal pieces of the central part of Indonesia. Various marginal basins, trapped within this convergent triple plate junction, are presently consumed by active subduction zones (fig. 1). These include the West Philippine basin, the oldest marginal basin of the Philippine Sea plate (PH), the Molucca, South China, Celebes and the Sulu seas. The convergent plate boundaries and their associated strike-slip fault zones delineate a wide active seismotectonic zone corresponding to the Philippine Mobile Belt (PMB) to the north and the triple junction area to the south. In addition, local indenters like the northern salient of the Australian plate or the Banggai-Sula micro-continent have induced tectonic escape of blocks controlled by fast rate strike-slip faults such as the Paniai Fault zone in Irian Jaya (9 cm/y) or the Palu Koro Fault (4.5 cm/y) respectively [Bellier *et al.*, 1991 ; Walpersdorf *et al.,* 1998 ; Pubellier and Ego, 2002 ; Stevens *et al.,* 2002].

One striking tectonic feature of these regions is the association of paired subduction and strike-slip faults, behind which extensional setting generally prevails. The obliquity of the convergence, which creates a decoupling of the convergence vector above the subduction zone is responsible for this partitioning of the strain [Fitch, 1972 ; Jarrard, 1986 ; McCaffrey, 1991, 1996]. Therefore, portions of the volcanic arcs have or are in the process of separating from that plate and are scattered across the mobile belts developed between Taiwan and New Guinea.

DEFORMATION AT ACTIVE MARGINS IN SE ASIA

An overview of the structure of the deformed margins of SE Asia is presented in several schematic sections around the Sunda block and the northern Australia margin. The most deformed area is in the complex triple junction between Sunda, Australia and the Pacific. Each of the areas discussed hereafter, results from a post Cretaceous geological evolution involving several subduction and accretion events. These sections show generally one or more accreted crustal fragments and a wider deformation zone which extends far into the continental (upper) plate.

West Sunda : Andaman-Burma (fig. 3)

This region links up to the northern and the eastern branches of the Alpine-Himalayan orogenic belt and extends to the south in the Andaman-Nicobar archipelago and further south in the Sunda margin along Sumatra. The accreted fragment is the Indo-Burma block which was rifted away from India by the opening of the Bengal Gulf, an appendix of the Meso-Tethys in the Mid-Cretaceous times [Metcalfe, 1996, 1999]. The sections of figure 3 show a Burma block or western Burma block, which docked against the Sunda margin prior to the deposition of the Eocene series of the Central Burma basins [Rangin *et al.,* 1999c]. The fossil plate is nowadays buried beneath the thick sedimentary cover. It is assumed that subduction jumped to the west and absorbed the oceanic crust of the Bengal basin ever since.

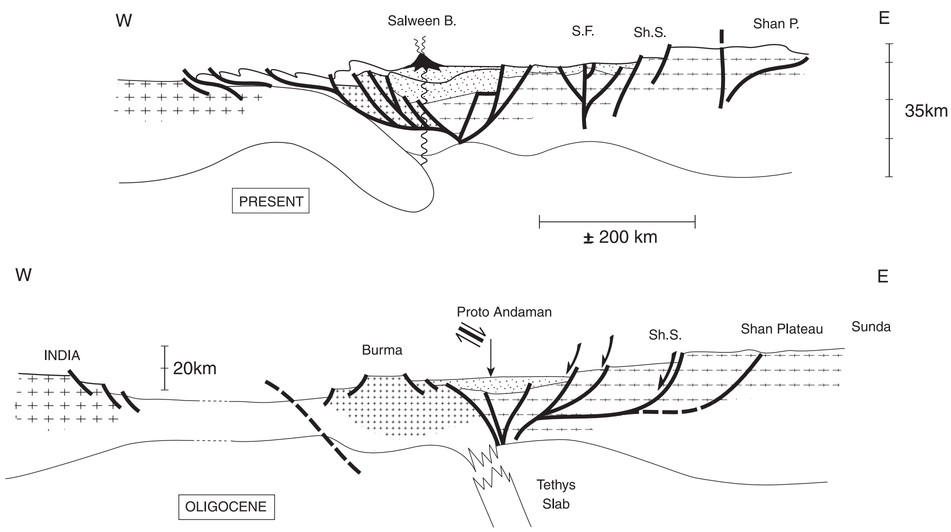


FIG. 3 to 10. – Simplified crustal cross-sections in SE Asia showing the major structures and the blocks which have been accreted or displaced at the convergent margins during the Neogene. Approximate relative crustal thickness is respected but that of superficial units, vertical offsets along faults or thickness of sedimentary units and dip of faults have been exaggerated in order to ease visualization. For each section, a pre-docking reconstruction (bottom) and a Present day section (top) are presented, with the exception of the South China Sea/Philippines where shortening of the margin is only at an early stage. Location of figures is as follows: 3 – Western Sunda: Andaman Sea and Myanmar, 4 – Sumatra and Mentawai islands, 5 – SE Borneo, Sulawesi and Banda Sea, 6 – Eastern Sunda-Southern Philippines, 7 – Taiwan, 8 – NW Australia-Irian Jaya, 9 – New Guinea and Northern Australia, 10 – Timor and Northwest Australia.

FIG. 3 à 10. – *Coupes crustales schématiques de la région du SE Asiatique montrant les principales structures ainsi que les blocs crustaux ayant été soit accretés à la marge, soit déplacés au long de la marge pendant la convergence oblique. Les épaisseurs crustales sont approximativement respectées, mais les rejets sur les failles normales et inverses ainsi que les épaisseurs sédimentaires ont été exagérés pour aider la visualisation. Pour chacune de ces coupes, un stade pré-accrétion et post-accrétion (actuel) est présenté, à l'exception de la figure 6 considérée comme n'ayant pas encore été raccourcie. La localisation des coupes est comme suit : 3 – W Sunda : mer d'Andaman et Myanmar, 4 – Sumatra et les îles Mentawai, 5 – SE Bornéo, Sulawesi et mer de Banda, 6 – E Sunda-S Philippines, 7 – Taïwan, 8 – NW Australie-Irian Jaya, 9 – Nouvelle Guinée et N Australie, 10 – Timor et NW Australie.*

From West to East, Precambrian metamorphics belonging to the Indian plate [Acharyya, 1986] extend into the Assam shelf where Cretaceous to early Tertiary sediments were deposited. The shelf is underthrust by the Indo-Burma Range which is composed of a western belt (Eocene flysch series which form the present-day accretionary wedge), and a more internal metamorphic and ophiolitic belt (Naga ophiolite) which may represent relicts of the previous Tethys ocean. The Central Burma basins were deposited on a former suture which separates the Indo-Burma block from the Shan Plateau described below. The basins were deposited from the Eocene to the Quaternary [Acharyya, 1986]. The suture (Myitkyina and Mandalay Ophiolite and the Mogok Metamorphic Belt**)** separates this wedge from more internal units. It is composed of serpentinites, gabbro, amphibolites and basalt. Locally trachytic volcanics have also been described [Acharyya 1986]. The ultramafic rocks occur within an assemblage of chlorite-schist, actinolite schist, glaucophan-garnet epidote schist, kyanite schist and graphite schist, with occasional jadeite-albite-bearing veins. Mitchell [1993] interpreted this metamorphic belt as a northward continuation of the Sumatra-western Myanmar late Cretaceous active margin. The part of the section which belongs to Sunda plate comprises the east Myanmar highlands, Shan Plateau and peninsular Myanmar-Thai-Malaysia. The Mogok belt passes eastward into the structurally complex Shan Scarps, with west dipping Cambrian to early Cretaceous rocks. In Shan Plateau the base of the Cambrian to early Cretaceous succession lies unconformably on the late Proterozoic turbidite. The Shan Scarp and plateau successions are considered to be a part of Asian plate since the late Triassic or early Jurassic [Mitchell, 1992, 1993].

Therefore, the east Sunda margin grew from accretion of Gondwanian blocks (Burma/eastern India) in the early Tertiary prior to a recent (Pliocene) dispersion due to the incipient Andaman/Sagaing Fault zone and the opening of the Andaman Sea.

Sumatra (fig. 4)

The crustal nature of the Sumatra margin (fig. 4) has been much debated with issues concerning the extent of the accretionary wedge and the presence of ultramafic rocks along the Sumatra forearc [Moore and Karig, 1980 ; Pubellier *et al.,* 1992 ; Samuel and Harbury, 1996]. In northern Sumatra, ophiolites constitute one of the two main units of the Woyla group [Cameron *et al.,* 1980]. The whole assemblage had been attributed to an old accretionary wedge which would have integrated the ophiolitic fragments of the Indian Ocean mostly composed of melanges and spilitic lavas [Moore and Karig, 1980 ; Wajzer *et al.,* 1991 ; Barber, 2000]. However petrographic and geochemical data for these rocks are lacking. Being separated from the Indian Ocean by a coastal Permian arc assemblage, they might represent fragments of a previous and more internal Tethyan basin. These rocks mostly present in the peridotites and "melanges" basement of Nias and Simelue islands may as well be interpreted as part of the Sunda margin onto which slivers of the Tethys were obducted in the early Tertiary [Pubellier *et al.,* 1992]. The rocks are unconformably overlain by thick clastic and limestone series bearing ages ranging from late Paleocene-early Eocene to early Miocene [Pubellier *et al.,* 1992] or from Oligocene to early Miocene [Samuel *et al.,* 1997]. This series forms part of a stratigraphically continuous sedimentary succession which may have deposited in a set of NW trending half-grabens formed during an extensional/transtensional phase.

The section of figure 4 represents the composite Woyla terrane which was accreted against the Sunda margin and presently composes the basement of the Sumatra forearc and the Mentawai islands. The grabens which existed on the accreted terrane [Samuel and Harbury, 1996 ; Samuel *et al.,* 1997] were inverted and shortened in the Middle Miocene, giving the aspect of an old and partly buried wedge [Schlüter *et al.,* 2002].

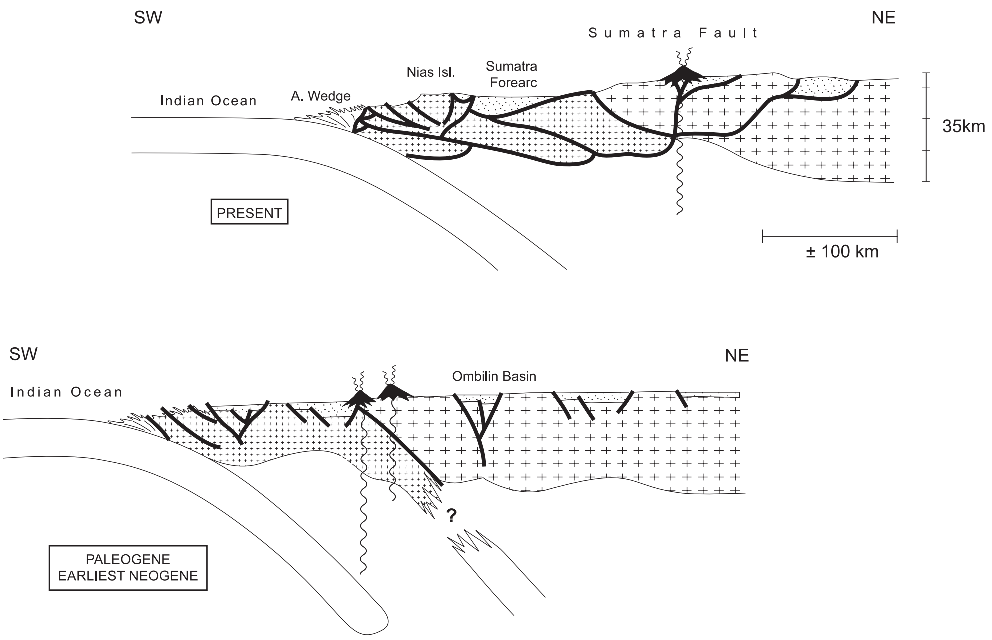


FIG. 4 (voir légende p. 565; *explanation p. 565*)

SE Borneo-Sulawesi-Banda (fig. 5)

Most authors accept the accretion of blocks of Gondwanian origin to the Sundaland margin during the Cretaceous and the early Tertiary [Audley Charles *et al.,* 1972 ; Hamilton, 1979 ; Hutchison, 1987, 1989 ; Metcalfe, 1996, 1999]. Some paleo-reconstructions [Rangin and Pubellier 1990 ; Rangin *et al.,* 1990] simplify this accretion history by a Paleocene collision of a large composite block (Sumba block). This collision marked by a Paleocene to early Eocene unconformity, is known from Sumatra (see previous section) to central Java [Ketner *et al.,* 1976]. The SE part of Borneo constitutes the continental core against which the various blocks were accreted since the late Cretaceous. Two early tectonic events during Albian-Cenomanian and late Paleocene to early Eocene times are recorded in SE Borneo [Pubellier *et al.,* 1998 ; Wakita, 2000]. Structural data show that these events are characterized by a HT which does not affect Senonian series [Yuwono *et al.,* 1988], and is followed by LT compressional structures which are in turn sealed by the Eocene sediments.

Because the accretion history of the Sulawesi region was long-lasting and complex, we present a section around the Oligocene so that the late Mesozoic early Tertiary history was completed. This part of the Sunda margin was composed of a thick continental crust because of underplated crustal blocks derived from Gondwana beneath SE Borneo and Laut Island (fig. 5). The eastern Sunda margin was in that sense similar to the margin of the South China block thickened by accretion of exotic blocks during the Yenshanian orogen by the late Cretaceous. The Central Sulawesi metamorphics (intermediate high pressure conditions) belong to the same subduction system in the early Cretaceous [Parkinson, 1998 ; Syafri, 2000].

A widespread extension followed the Paleocene-early Eocene shortening. It is responsible for the opening of the oil-bearing basins of the Sunda margin during the Oligocene.

The next shortening event took place during the Middle Oligocene and is difficult to detect since it does not clearly affect the interior of the Sunda margin. It is marked by the obduction of ophiolite onto the East Sulawesi terrane ; a block which was part of the actively dismantling Australian margin. The obduction would thus be coeval with the obduction of the ophiolites of Irian Jaya (western Papua) which were emplaced in the Middle Oligocene [Pigram and Symonds, 1991 ; Permana, 1998 ; Monnier *et al.,* 2000]. The whole assemblage was later transported to the Sunda Plate [Pubellier *et al.,* 2003]. The final accretion episode occurred from the Middle Miocene to the Present with the accretion of the Sula block to the East Sulawesi block [Kundig, 1956 ; Syafri, 2000] (fig. 5). The effects of this event were also described in western Sulawesi and to the Makassar basin where thin-skinned decollement are observed [Bergman *et al.,* 1996]. On the section of figure 5, the Sula block is separated from the largest Australian fragment, the Bird's Head block, by the Sorong Fault zone.

Eastern Sunda : southern Philippine (fig. 6)

The East Sunda margin (fig. 6) and the Philippine Sea plate have been converging obliquely since the beginning of the Tertiary. The East Sunda margin is composed of drifted fragments of the Chinese continental margin. They are namely the Macclesfield Bank, the Reed Bank, Palawan Island, Cagayan Ridge, Zamboanga Peninsula, and part of the north arm of Sulawesi [Holloway, 1982 ; Rangin *et al.,* 1990], separated by marginal basins which are the South China Sea, the Sulu Sea and the Celebes Sea. Another of these basins, the Proto South China Sea has entirely disappeared into a fossil subduction zone SE of Palawan Island. Spreading occurred by the early-middle Eocene time in the proto South China Sea, by the middle Eocene time in the Celebes basin, by the middle Oligocene time in the South China Sea, and by the early Miocene time in the Sulu Sea. The opening of these basins is a result of long-lasting roll-back associated stretching behind the subduction of Sunda trench, which existed since Triassic times. The schematic cross section (fig. 6) is presented only for the Present, considering that the shortening of the margin is only at an early stage of its evolution. Since the early Miocene – or possibly the late Oligocene in Sulawesi [Villeneuve *et al.,* 1998] – this active margin which extended much further toward the north served as a collector for all the asperities carried by the Philippine plate, and the traces of the docking

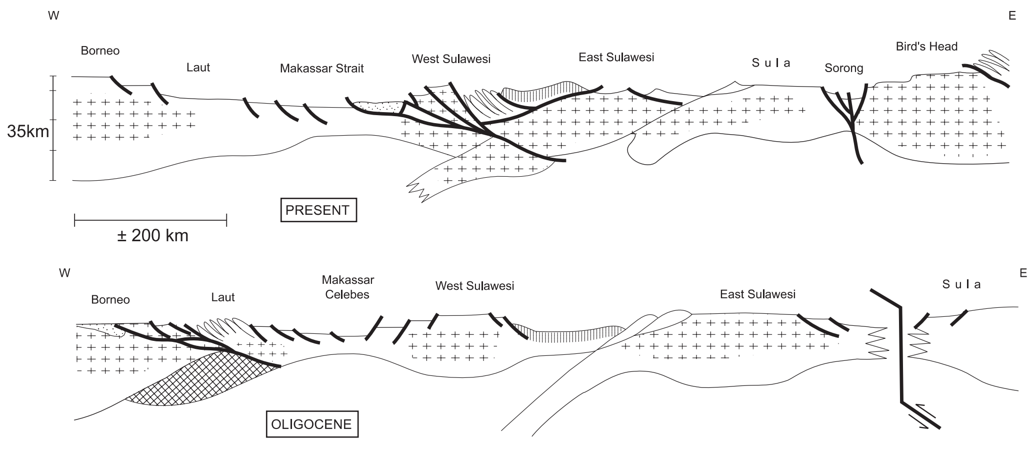


FIG. 5 (voir légende p. 565; *explanation p. 565*)

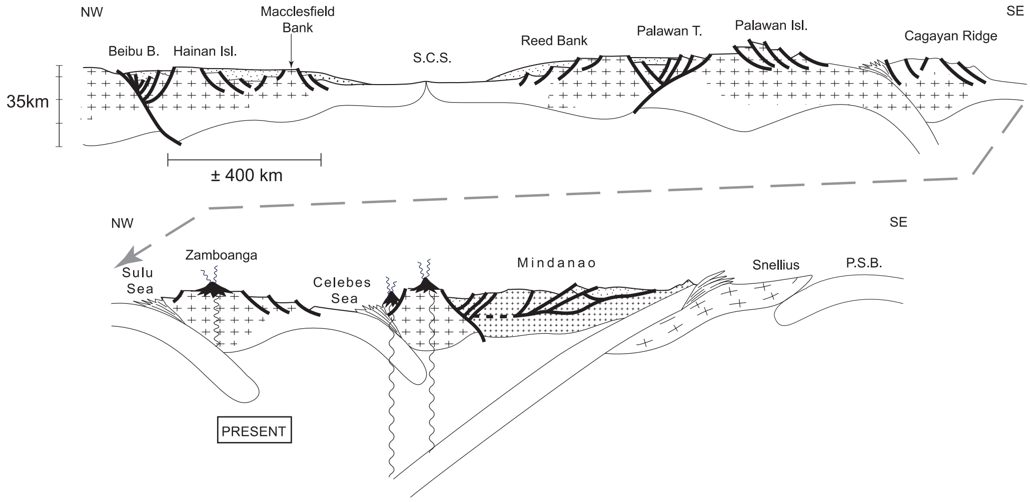


FIG. 6 (voir légende p. 565; *explanation p. 565*)

are found everywhere along the deformed plate boundary [Rangin *et al.,* 1985 ; McCabe and Almasco, 1985 ; Pubellier *et al.,* 1996]. The reconstructions illustrate a southward migration of the docking, which reached the southern island of Mindanao in the Pliocene [Quebral *et al.,* 1996 ; Pubellier *et al.,* 1991, 1999]. Relics of the ocean that existed between the margin of the Philippine Sea plate (Philippine arc) and the Eurasian margin were not found. After the docking and following the evolution proposed on plates 2 and 3 (subduction blocking), the subduction jumped to the opposite (eastward) side of the Philippine archipelago, and is accompanied by a large strike-slip fault : the Philippine Fault. The last accreted block is the Snellius Plateau ; an element of the Philippine Sea plate, which is in the process of blocking the Sangihe subduction zone [Lallemand *et al.,* 1998 ; Pubellier *et al.,* 1999 ; Bader *et al.,* 1999]. Hence, the convergence rate is fast and varies along the Philippine Trench from 8 cm/yr in the north to 10 cm/yr in the south. Part of the convergence however is accommodated in the Sangihe Trench, the Cotabato Trench, and in the Negros Trench, via a large NW-SE left-lateral fault which dissects Mindanao obliquely: the Cotabato Fault [Pubellier *et al.,* 1994, 1996 ; Rangin *et al.,* 2000].

Taiwan (fig. 7)

Taiwan is a case example of arc/continent subduction where the Luzon volcanic arc overrides the continental shelf of the China margin (fig. 7) [Lallemand and Tsien, 1997]. The result is a crustal wedge involving thin-skin tectonics of the platform sediments. The crustal shortening began by the latest Miocene around 5 Ma [Ho, 1986], by the time subduction volcanism vanished. We do not know exactly the nature of the crust disappeared by subduction beneath Taiwan. The existence of subducted thinned continental crust cannot be ruled out because of the existence of olistostromes associated with the beginning of deformation which exist in older Middle Miocene series [Pelletier and Stephan, 1986], indicating that topographic structures were actively deformed. The structure could as well be an earlier exotic block [Lu and Malavieille, 1992], or a structure belonging to the margin [Hsü and Sibuet, 1995]. Some of the faults of the wedge (e.g. Lishan fault) show indicators of reactivation. They may be former normal faults of the South China Sea margin. The oceanic domain that has been subducted into the Manila Trench is imaged by seismic tomography [Rangin *et al.,* 1999b], and corresponds to the easternmost South China Sea, or a relict of the Proto South China Sea [Sibuet *et al.,* 2002].

On the upper plate, the forearc domain and part of the Luzon arc has probably disappeared into the subduction zone [Chemenda *et al.,* 1997], bringing the volcanic chain against the metamorphosed platform series, from Paleozoic to Miocene, being only separated by the narrow elongated Longitudinal Valley. The deformed area in Taiwan is thus composed of both an accreted intra-oceanic or composite island arc terrane and reactivated structures crustal elements of the Chinese continental margin.

New Guinea and N. Australia (fig. 8 and 9)

We have limited information about the nature of the crust that existed north of the present New Guinea Island. In western New Guinea Island, early works ascribed a single origin to the ophiolite of northern Irian Jaya (fig. 8), and the ones of the Central Range [Dow *et al.,* 1988 ; Pigram and Symonds, 1991]. Later, the two ophiolitic bodies were distinguished by dating and geochemistry [Girardeau *et al.,* 1994 ; Monnier *et al.,* 1999, 2000]. In northern New Guinea, the continental crust stacked by thin-skin tectonics in the Pliocene is overthrust by a large piece of Mesozoic oceanic crust (New Guinea Ophiolite). There are discrepancies in age between the ophiolites of Irian Jaya (Jurassic) and those of PNG (late Cretaceous-Paleocene), which may have been connected, with the Coral Sea basin at that time [Pigram and Symonds, 1991].

During the Mesozoic, a succession of basins developed along the northern margin of Australia, probably similarly to what happened to the east of Australia in the late Cretaceous and Paleogene [e.g. Yan and Kroenke, 1993]. Subsequently, fragments of these basins were incorporated to the New Guinea Central Range. However, the geodynamic set-

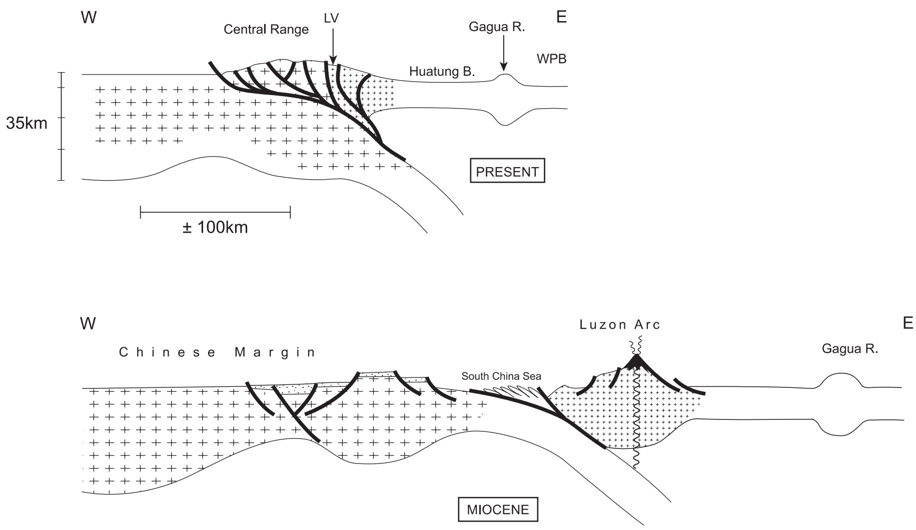


FIG. 7 (voir légende p. 565; *explanation p. 565*)

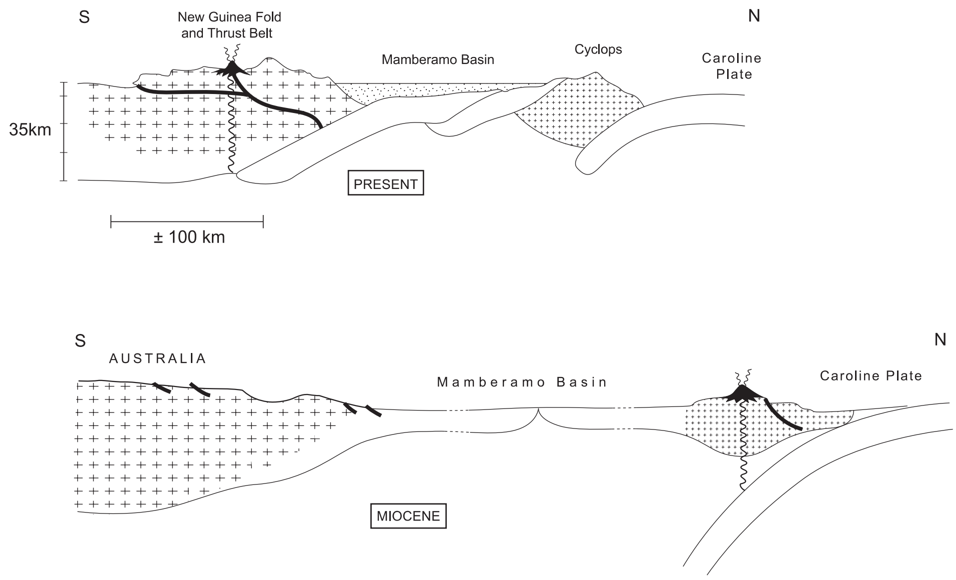


FIG. 8 (voir légende p. 565; *explanation p. 565*)

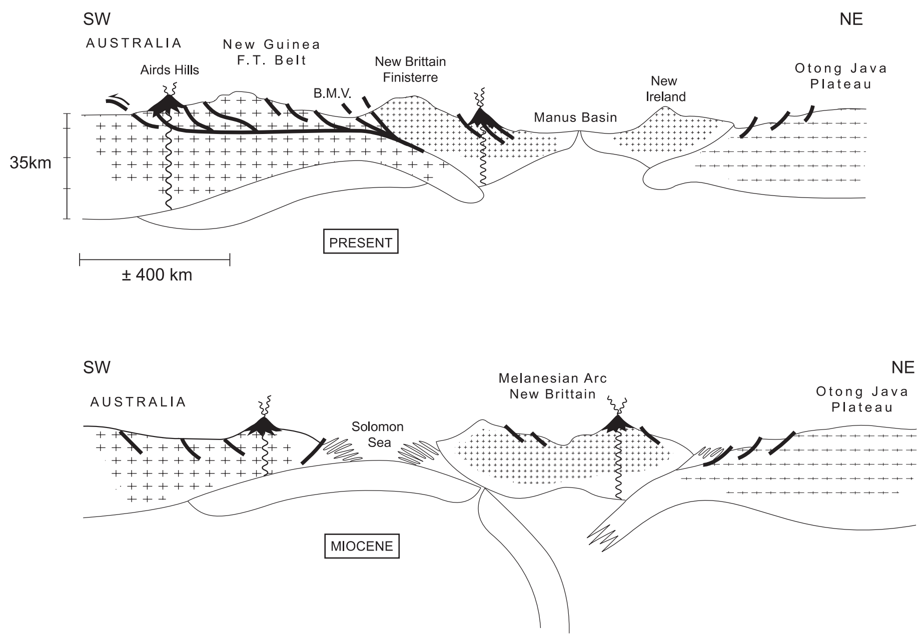


FIG. 9 (voir légende p. 565; *explanation p. 565*)

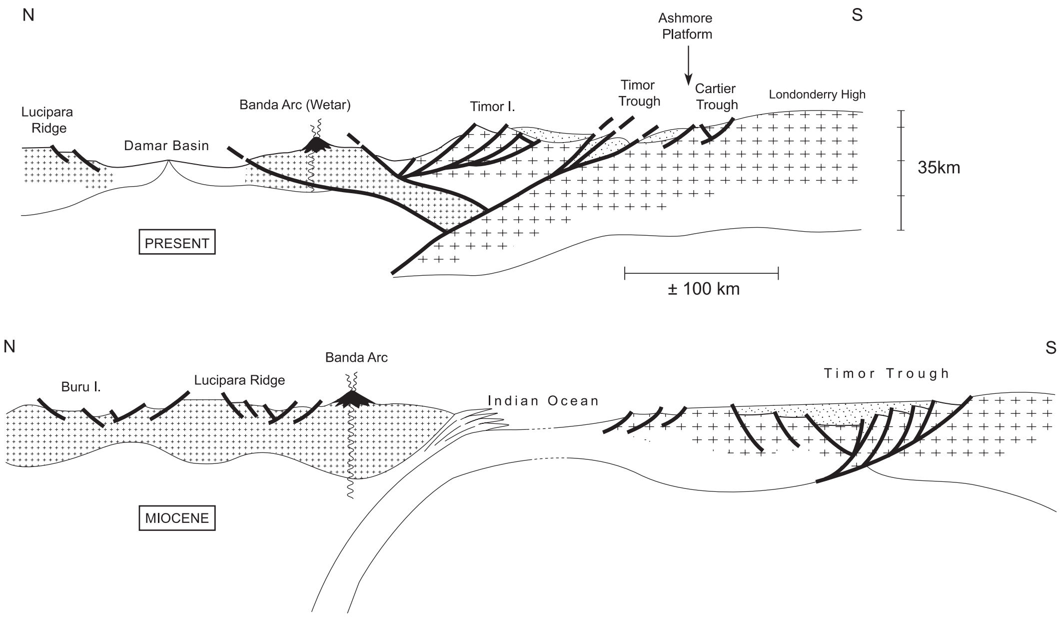


FIG. 10 (voir légende p. 565; *explanation p. 565*)

ting of these basins is poorly known since they are located at the boundary between the volcanic active margin developed at the eastern side of Australia and the rifted-passive margin basins of NW and western Australia. According to the results presented here, the northern margin is the edge of a back-arc basin, which developed during the Jurassic and the early Cretaceous [Pubellier *et al.,* 2003]. Since the beginning of the Tertiary, a wrenching component prevailed so that the northern edge of the craton has been sliced off and transported toward the west [Silver *et al.,* 1985 ; Rangin *et al.,* 1990 ; Hall, 1996, 1998].

Figures 8 and 9 show two sections in western (Irian Jaya) and eastern (PNG ; Papua New Guinea) New Guinea Island, both at Miocene and Present times. Deformation in New Guinea results from the blocking of the subduction that existed north of Australia, possibly by the arrival into the trench of large asperities such as the ridge which separated the Pacific and the New Guinea plate [Hall, 1996] or the edge of the Philippine Sea plate [Pubellier *et al.,* 2003]. This early stage is not represented on the sections. Similarly, the Neogene shortening began when the Otong Java Plateau, the world's largest oceanic plateau, entered the Melanesian trench and forced the subduction to shift to the opposite side of the Melanesian arc [Yan and Kroenke, 1993 ; Wells, 1989]. The deformation extends southwards to the active front of the Fold-and-Thrust Belt where 100 km of shortening is absorbed [Hill, 1991] (fig. 9). However, most of the material involved in the crustal wedge comes from the Australian plate (fig. 8). The new Brittain-Finisterre volcanic arc may also have originated from the Australian Plate prior to the formation of the Solomon Sea. Therefore, the accreted material may not strictly be considered as exotic, but as fragments rifted away from the margin and later incorporated back to it [Pigram and Symonds, 1991 ; Struckmeyer *et al.,* 1993]. In the midst of the accreted terrane, about 4 Ma ago, the Manus basin opened, triggered by the important wrench component of the convergence. A similar tectonic evolution may account for the Irian Jaya section where another marginal basin developed in the Neogene (Oligocene to Middle Miocene) [Monnier *et al.,* 1999]. This basin has been partially shortened in the early Pliocene and the deformation is still active today [Puntodewo *et al.,* 1994 ; Mc Caffrey, 1996 ; Pubellier and Ego, 2002].

Timor-NW Australia (fig. 10)

Timor is also a case example of continental subduction, where the geodynamic setting is well constrained [Hamilton, 1979 ; Audley-Charles, 1986]. After completion of the subduction of NE corner of the Indian oceanic crust by the Pliocene, the continental margin of Australia was subducted to a depth over 100 km beneath the Banda arc (fig. 10). Structures inherited from the rifting phase during the Triassic and early Jurassic found in the Timor Trough have been inverted during the late Miocene with south-verging thrusts [Audley-Charles *et al.,* 1988 ; Hughes *et al.,* 1996]. To the opposite (northward) side, Timor Island is thrust onto the Timor Trough toward the south, whereas other thrusts north of the Banda arc nowadays account for the incipient subduction reversal in the Neogene Damar basin, north of the Banda arc [Silver *et al.,* 1983 ; Honthaas *et al.,* 1998 ; Hinschberger *et al.,* 2001]. Most of the shortening between Australia and Sunda nowadays takes place along this new convergent boundary, implying that a fragment of the Sunda plate, the Banda arc is presently integrated to the Australian plate [Genrich *et al.,* 1996 ; Rangin *et al.,* 1999a]. Such a system with opposite verging thrusts creates a wedge that can be imaged by deep seismic profiles [Richardson and Blundell, 1996]. In the core of the wedge, the present Timor Island is composed of thrusts sheets with melanges [Barber, 1981]. Timor therefore shows a structure with island arc crust sandwiched between slivers of continental crust.

THE RECONSTRUCTIONS

Methodology

Many attempts to reconstruct the complex setting of SE Asia have been performed by various authors since the 80s' [Rangin *et al.,* 1990 ; Daly *et al.,* 1991 ; Lee and Lawver, 1994 ; Hall, 1996, 1998]. However, these reconstructions were based on simple shapes, such as coastlines, basic geological entities (e.g. magnetic anomalies). In this paper, we have more constraints on the geometry and the displacement of blocks, compared to previous models, because we keep graphic elements included in the shapes (Present topography and bathymetry), so that areas are filled and any rotation has to account for accretion or consumption of crustal material (fig. 11).

The stages chosen for reconstructions (tables available on http://www.geologie.ens.fr/~pubellie) concern only the period of time where reliable kinematic constraints (GPS, seismicity, magnetic anomalies when identified), or geologic events (onset or cessation of volcanism controlled by paleontological or isotopic datings) are available. The 20 Ma stage has less control but gives an insight of the SE Asian basins just before mid-Miocene inversion. We firstly extracted all the geological information necessary for understanding the past geodynamic setting from the database. We used a GIS-based system on which developments have been made in order to rotate interactively all elements integrated in the database (bathymetry and topography, tectonic elements, magnetic anomalies, location of samples or wells, isopachs of sediments...) included inside the fence boundary of a given plate or microblock. However, for the sake of readability, we only present maps showing the major fault zones, the topography and the bathymetry. The rotations are actually performed on a sphere tangent to the ellipsoid WGS84 at the location of the Euler poles, plotted with accuracy. As a result, for large rotation, a small modification of the elevation may be observed on the 3D files. Computed relative motion between blocks and/or plates boundaries is basically from NUVEL 1A and the Sundaland/Eurasia motion is from the GEODYSSEA geodetic data [Michel *et al.,* 2001]. In addition, mountain ranges were stretched back to their original size prior to shortening by a similar operation. Finally, geodetic distances can be measured also with great accuracy on the restored plate/microblock configuration.

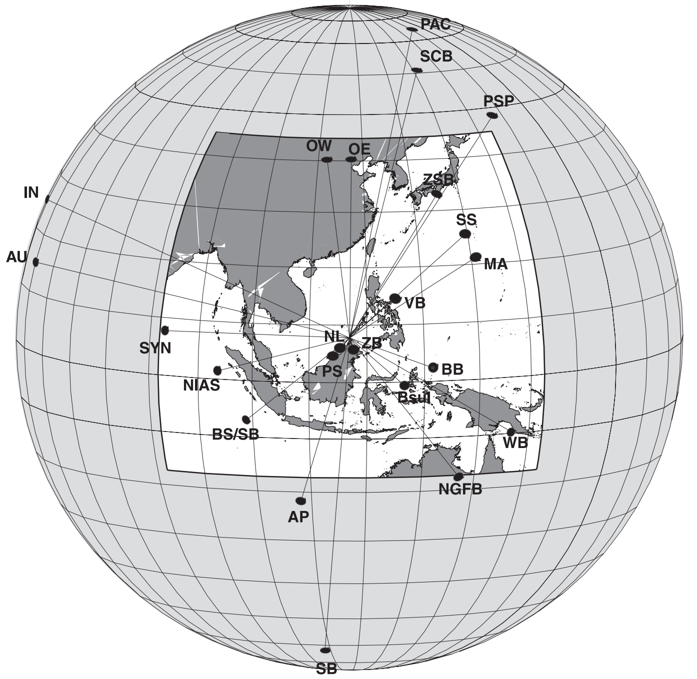


FIG. 11. – Graphic representation of the different euler poles used for the reconstruction. Poles are given with reference to varying stable plates. For example, IN/EU indicate the euler pole for the rotation of the Indian plate (IN), with respect to stable Eurasia (EU). Pac: Pacific, SCB: South China block, PSP: Philippine Sea plate, OW: Ordos West, OE: Ordos East, ZSB: Zenisu block, SS: Sumatra sliver, MA: Marianna arc, VB: Visayas block ZB: Zambales block, BB: Burma block, WB: Woodlark basin, NGFB: New Guinea fold belt, SB: Sunda block, BS: Banda Sea, NIAS: Banda, Nias, Simeleu block, Bsul: Banggai-Sula block, PS: Philippine sliver, NEL, North East Luzon, SYN: syntaxis, AU: Australia, IN: India.

FIG. 11. – Représentation graphique des différents pôles eulériens utilisés dans les reconstructions. Les pôles sont donnés par rapports à différentes plaques fixes. Par exemple IN/EU indique le pôle eulerien de la rotation de la plaque indienne par rapport à la plaque eurasiatique.

Kinematic parameters and options used for the evolution of the major plates

Since the middle Paleogene, the tectonic development of Southeast Asia has been controlled largely by the rapid convergence between the Eurasia-Sunda, Pacific-Philippine Sea and Indo-Australia plates (fig. 11). Between the major plates, development of volcanic arcs and back-arc basins have occurred, sometimes at fast rates. The instantaneous relative motion between the major plates as well as between smaller crustal fragments or internal deformation within blocks or belts can often be accessed by spatial geodesy. For SE Asia, we used the recent Geodyssea results, based on data from two GPS measurement campaigns in December 1994 and April 1996, which gave us the possibility to evaluate the relative motions across the main tectonic boundaries with a precision inferior to 5 mm/yr [Simons, 1999] when the results are directly derived from adjacent measurements [Rangin *et al.,* 1999a]. Some of these motions can be compared to those deduced from moment tensors of earthquakes [Beaudouin *et al.,* 2003], finite motion along the transcurrent faults deduced from offsets of dated geological object, and to the motion predicted from slip vectors. For example a good control of the present kinematics of the Philippine Sea plate is given by Seno *et al.* [1993]. We did not take into account a possible reorientation of the Pacific plate motion between 3 and 6 Ma [Wessel and Kroenke, 2000]. The reconstructions are based on several basic ideas, some of which have been discussed in the previous section.

1) The Eurasian margin has been stretched on its eastern and southern side by the rollback of the Indian plate, opening a variety of marginal basins since the early Tertiary ; the Proto South China Sea, the Celebes Sea, the South China Sea, the Sulu and the Japan seas, and more recently the South Banda (Damar basin) Sea.

2) The Australian margin underwent a similar evolution in a more oblique environment. The basins which opened the Papuan basin in the Jurassic and the Coral Sea in the late Cretaceous are the Solomon Sea in the Eocene, the Mamberramo basin in the Oligocene-Miocene and the Woodlark and Manus basins in the Pliocene.

3) These marginal basins were shortened after the Eocene (Australian basins) due to the convergence with the

nascent Philippine Sea plate, and since the early Miocene for the Eurasian plate, because of the docking of the continental fragments originated from the Australian plate.

4) During the Neogene shortening, the very oblique motion between the Australian and the Pacific-Philippine plates induced important wrench motion which-sliced off the advancing Australian plate and ejected fragments toward the Eurasian plate. Hence, in addition to the accretion of blocks coming from the south since the Cretaceous, we observe starting from the Neogene continental and island arc blocks coming from the E or the SSE (Banggai-Sula, East Sulawesi, Buton, Bird's Head, and the Philippine arc including Halmahera).

5) The evolution of the western edge of Sunda during the Tertiary is basically controlled by the India-Eurasia convergence which induced a large wrench system.

The motion of the major plates are not significantly different from those from other models, but some differences exist with respect to second order large regional blocks.

The 2 Ma step (plate 1)

The reconstruction at 2 Ma is based almost entirely on GPS data. Among the new data used is the kinematics of Sunda margin and surrounding areas [Chamot-Rooke *et al.,* 1998 ; Michel *et al.,* 2001]. Most of the SE Asian Region is undergoing convergence so that the striking aspect of the map is the increase of the surface occupied by seas, particularly along the western side of the Philippine Sea basin and the Molucca Sea. Another important point is the active clockwise rotation of the Sunda block relative to stable Eurasia. This rotation also leaves a relict of small motion relative to the South China block, which leads to minor right lateral strike-slip motion along both the Red River Fault and the China margin. This has been taken into account but do not show well on the small scale maps, because of small angular velocities. A large amount of material has been subducted in the Ryukyu and Nankai trenches. Similarly, large parts of the Pacific and the Indian ocean have disappeared into the Marianna and the Japan trenches, and the Sunda Trench respectively. The Marianna basin opens in a back-arc position [Le Pichon *et al.,* 1975]. The Philippine Sea plate is rotating clockwise, and the collision in Taiwan is progressing. East of Taiwan, rifting occurs in the Okinawa Trough, by means of en echelon grabens. This system terminates in Japan along the MTL. In the Philippine Mobile Belt, shortening is observed in both the southern and the northern Philippines. The Philippine Fault begins to develop between these two compressional ends. To the south, the Snellius Plateau (a part of the Molucca Sea) enters the Sangihe subduction zone and is underplated at the base of the Sangihe forearc basin [Moore and Silver, 1983 ; Pubellier *et al.,* 1999]. In the Central Indonesia triple junction, subduction has occurred along the Seram and Halmahera trenches, and the rotation of Sulawesi was accommodated by wrenching along the Palu Koro Fault and subduction into the Sulawesi Trench. Shortening is present in Central Sulawesi and part of it is transferred into the Makassar basin [Bergmann *et al.,* 1996].

Shortening is no longer dominant in the New Guinea fold-and-thrust belt, except in the eastern part, where subduction takes place into the New Britain Trench, and in the Trobrian Trough. The rest of the fold-and-thrust belt connects to the Tarera Fault zone and the Seram Trough in the east. The Sorong Fault Zone and Bird's Head escapes as individual blocks along the Paniai Fault zone.

To the south of the Sunda Plate, the 2 Ma step is also marked by the onset of the right-lateral Great Sumatra Fault zone [Bellier *et al.,* 1991], following a major compression in the arc-forearc area [Matson and Moore, 1992]. The Sunda Strait opens at its extremity [Huchon and Le Pichon, 1984 ; Diament *et al.,* 1990]. This system connects to the West Andaman Fault zone and Andaman spreading center further north. Some relicts of deformation are observed in some places in the Mentawai forearc basin [McCaffrey, 1991 ; Malod *et al.,* 1993]. The Andaman pull-apart basin connects with the Sagaing Fault that terminates in the vicinity of the Himalayan Syntaxis in the north. However, wrench motion still exists along the front of the wedge [Nielsen *et al.,* 2002]. This individualizes a discrete Andaman block. The frontal thrust of the Himalaya is active. The South China block surrounded by active faults with historical seismicity has moved in a direction close to that of Indochina, and at a slightly higher velocity according to geodetic data, leaving a minute right-lateral slip along the Red River Fault.

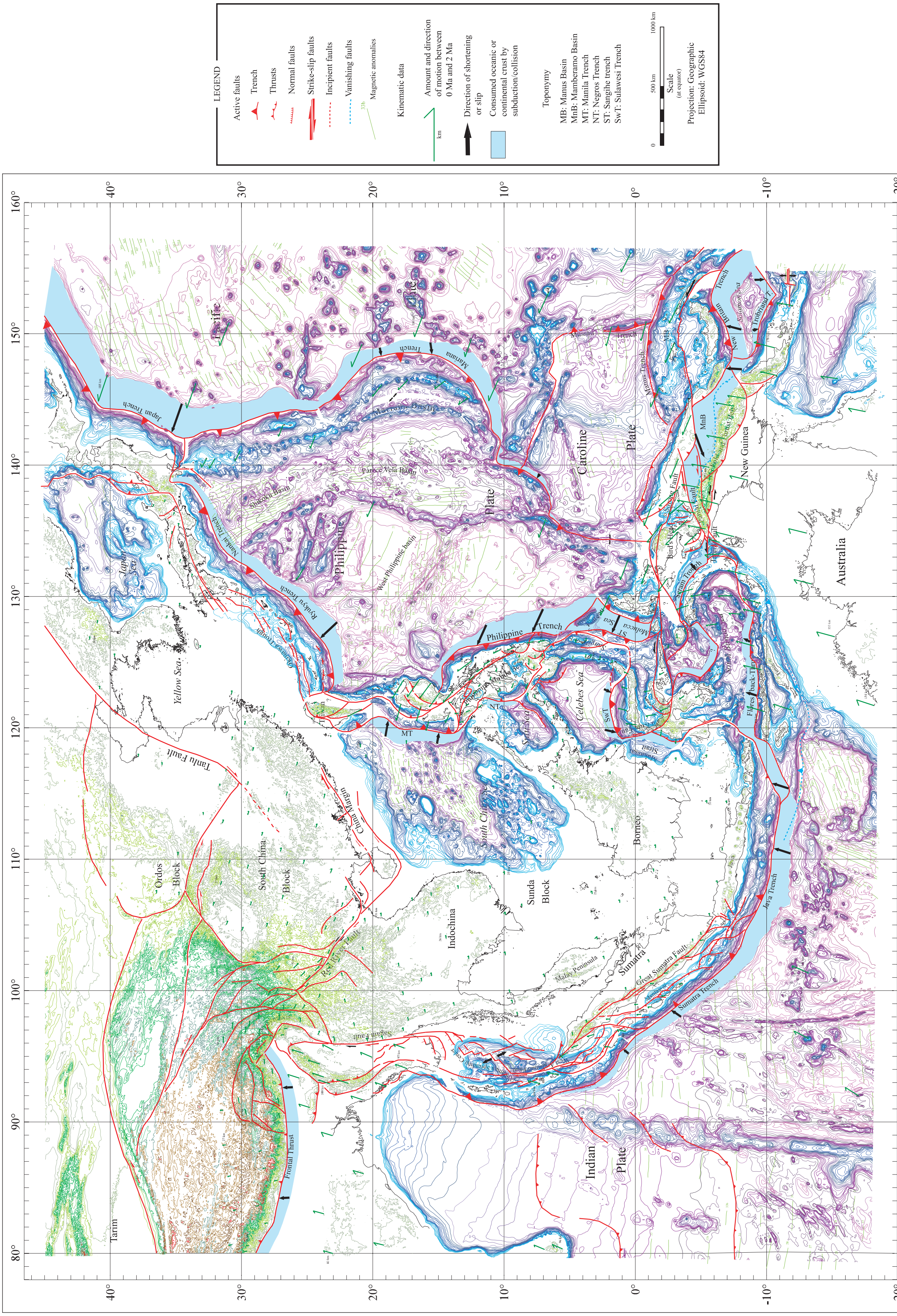
The 4 Ma step (plate 2)

In the eastern Sunda region, the Philippine Sea plate is further away from the Sunda block, encroaching the Sunda margin only in the northern Philippines [Rangin *et al.,* 1991] and the southern Philippines [Pubellier *et al.,* 1996], and in Taiwan [Ho, 1986]. In spite of these local zones of shortening, the Philippine Fault and Philippine Trench just initiated in the central part of the Philippine Archipelago [Quebral *et al.,* 1996], and the Philippine Mobile Belt was moving together with the Philippine Sea basin. Subduction was active on both sides of the Molucca Sea [Silver and Moore, 1978]. Spreading and incipient rifting occurred and was restored in the Marianna basin [Le Pichon *et al.,* 1975] and Okinawa Trough respectively [Sibuet *et al.,* 2002].

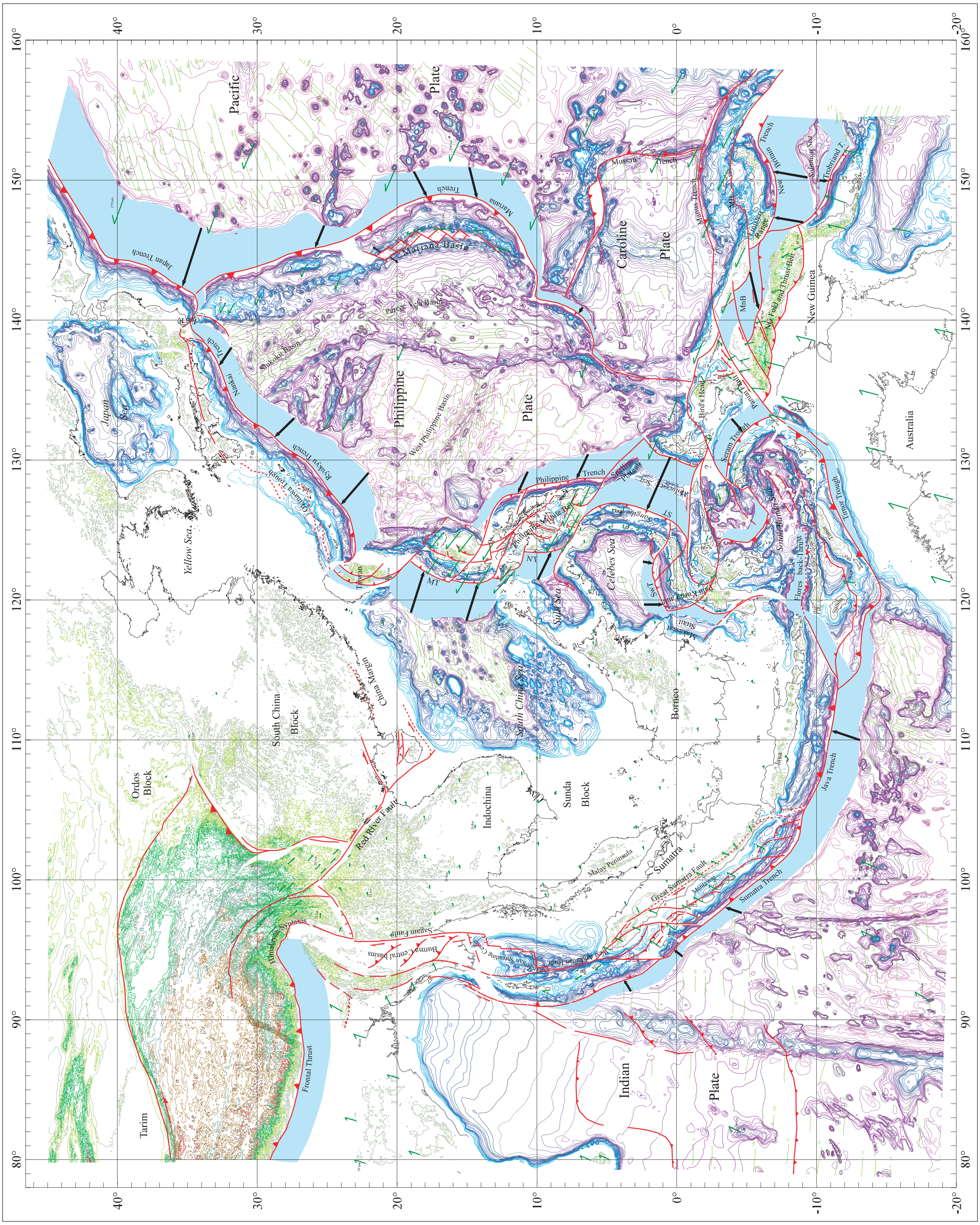
The Australian continental margin began to enter the New Britain subduction zone and was then underthrust be-

PLATES 1 to 6. – Reconstructions of the SE Asian region from 20 Ma to Present. Plate 1 : 2 Ma, plate 2 : 4 Ma ; plate 3 : 6 Ma, plate 4 : 10 Ma, plate 5 : 15 Ma ; plate 6 : 20 Ma. Contours with colour code indicate the elevation at Present and have no value at the reconstructed stages other than showing surfaces where geological information exist. Blue areas represent crust having disappeared into subduction zones. Red lines represent the major faults active between the stage of the reconstruction and the previous one. Green arrows represent the motion of a point from its position to its next position in the younger stage. The black arrows illustrate the finite motion of several points. All reconstructions are with reference to stable Eurasia.

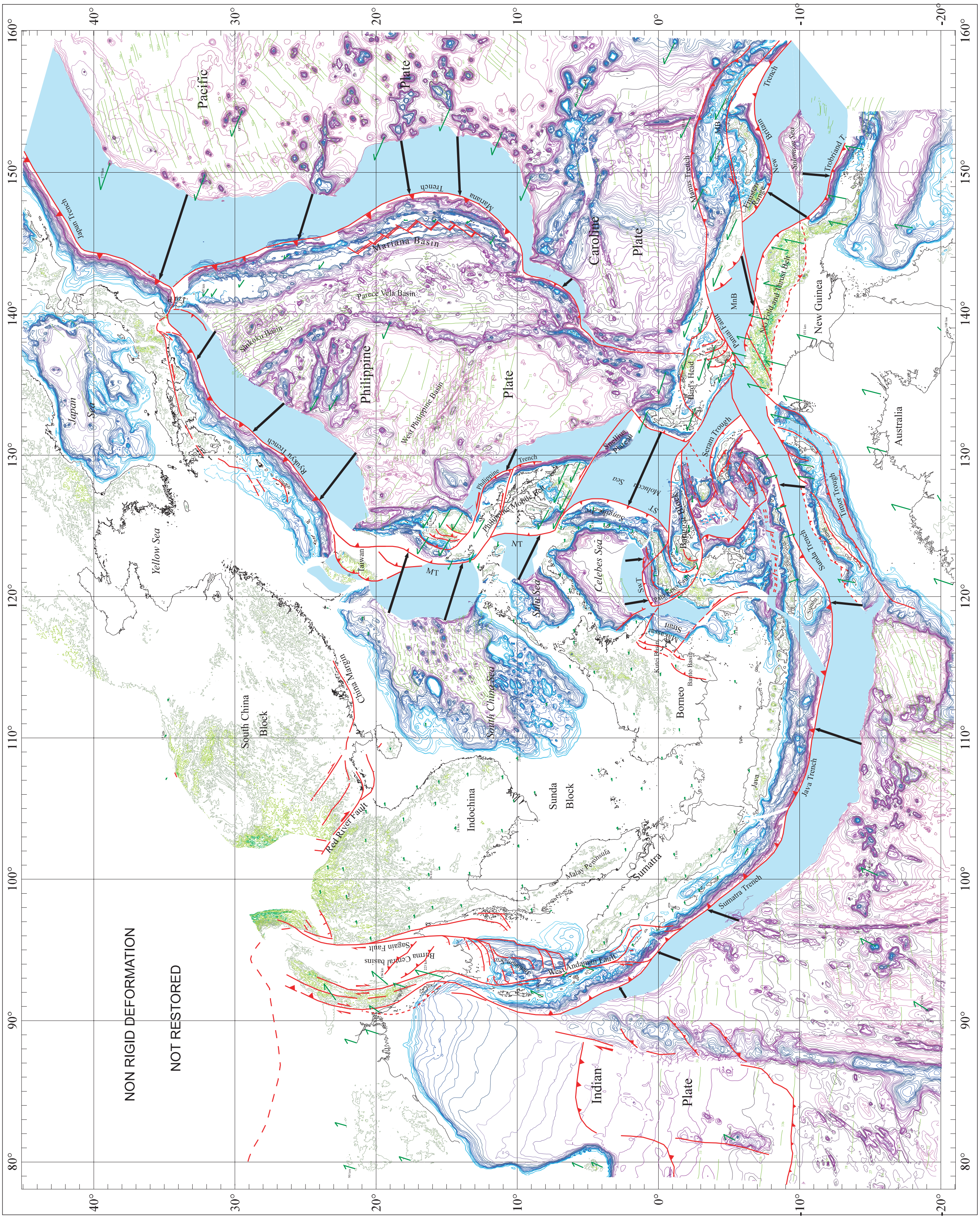
PL. 1 à 6. – *Reconstructions de la région du SE Asiatique de 20 Ma à l'Actuel. Planche 1 : 2 Ma, planche 2 : 4 Ma, planche 3 : 6 Ma, planche 4 : 10 Ma, planche 5 : 15 Ma, planche 6 : 20 Ma. Les courbes de niveau sont associées à un code de couleurs, mais ne sont qu'indicatives ; la topographie/bathymétrie n'ayant pas été restaurée. Ces courbes n'indiquent donc que les zones affleurantes ou des informations géologiques peuvent être obtenues. Les zones bleues représentent les surfaces disparues dans les zones de subductions. Les lignes rouges représentent les failles actives entre le stade de la reconstruction et le stade précédent. Les flèches vertes représentent le déplacement d'un point entre sa position et celle du stade précédent. Les flèches noires représentent le déplacement fini. Les reconstructions sont faites par rapport à l'Eurasie stable.*


LEGEND
Active faults
Trench
Thrusts
Normal faults
Strike-slip faults
Incipient faults
Vanishing faults
Magnetic anomalies
Kinematic data
Amount and direction of motion between 0 Ma and 2 Ma
Direction of shortening or slip
Consumed oceanic or continental crust by subduction/collision
Toponymy
MB: Manus Basin
MnB: Mamberamo Basin
MT: Manila Trench
NT: Negros Trench
ST: Sangihe trench
SwT: Sulawesi Trench
0
500 km
1000 km
Scale (at equator)
Projection: Geographic
Ellipsoid: WGS84
Pacific
Japan Trench
Japan Sea
Nankai Trench
Mariana Trench
Mariana Basin
Parece Vela Basin
Shikoku Basin
Philippine
Plate
West Philippine basin
Ryukyu Trench
Okinawa Trough
Caroline
Plate
New Guinea
Australia
Philippine Trench
Celebes Sea
Flores back-thrust
Java Trench
Sumatra Trench
Great Sumatra Fault
Sumatra
Malay Peninsula
Borneo
Sunda Block
Indochina
South China Sea
South China Block
Ordos Block
Yellow Sea
Tanlu Fault
Red River Fault
Sagain Fault
Frontal Thrust
Tarim
Indian Plate
MT
NT
ST
SwT
MB
MnB
Banda Sea
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
-10°
-20°

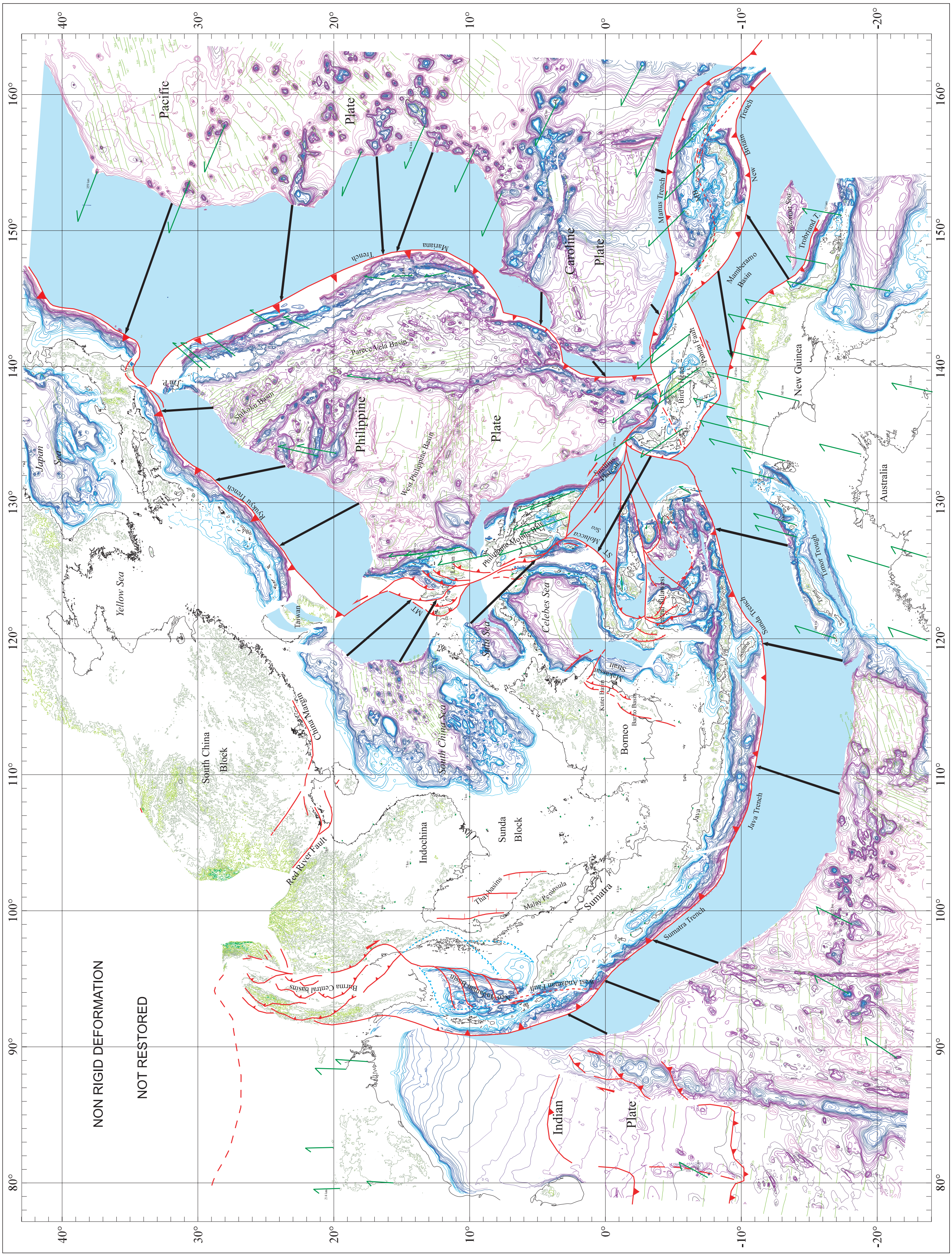
pl. 1 : 2 Ma


Pacific
Plate
Philippine
Plate
Caroline
Plate
Indian
Plate
Australia
New Guinea
Japan Trench
Mariana Trench
Mariana Basin
Parece Vela Basin
West Philippine Basin
Shikoku Basin
Nankai Trench
Ryukyu Trench
Okinawa Trough
Japan Sea
Yellow Sea
Philippine Trench
Celebes Sea
Sulu Sea
South China Sea
South China Block
Ordos Block
Tarim
Frontal Thrust
Himalayan Syntaxis
Red River Fault
Indochina
Sunda Block
Borneo
Malay Peninsula
Sumatra
Great Sumatra Fault
Sumatra Trench
Java Trench
Java
Flores
Timor Trough
Seram Trench
Bird's Head
Manus Trench
Mussau Trench
New Britain Trench
Trobriand T.
Taiwan
Sagaing Fault
Burma Central basins
Makassar Strait
MnB
Mentawai
Banda Sea
Molucca Sea
Sangihe
Finisterre Range
New Guinea Fold and Thrust Belt
Philippine Mobile Belt
Tarakan Basin
80°
90°
100°
110°
120°
130°
140°
150°
160°
40°
30°
20°
10°
0°
-10°
-20°

pl. 2 : 4 Ma

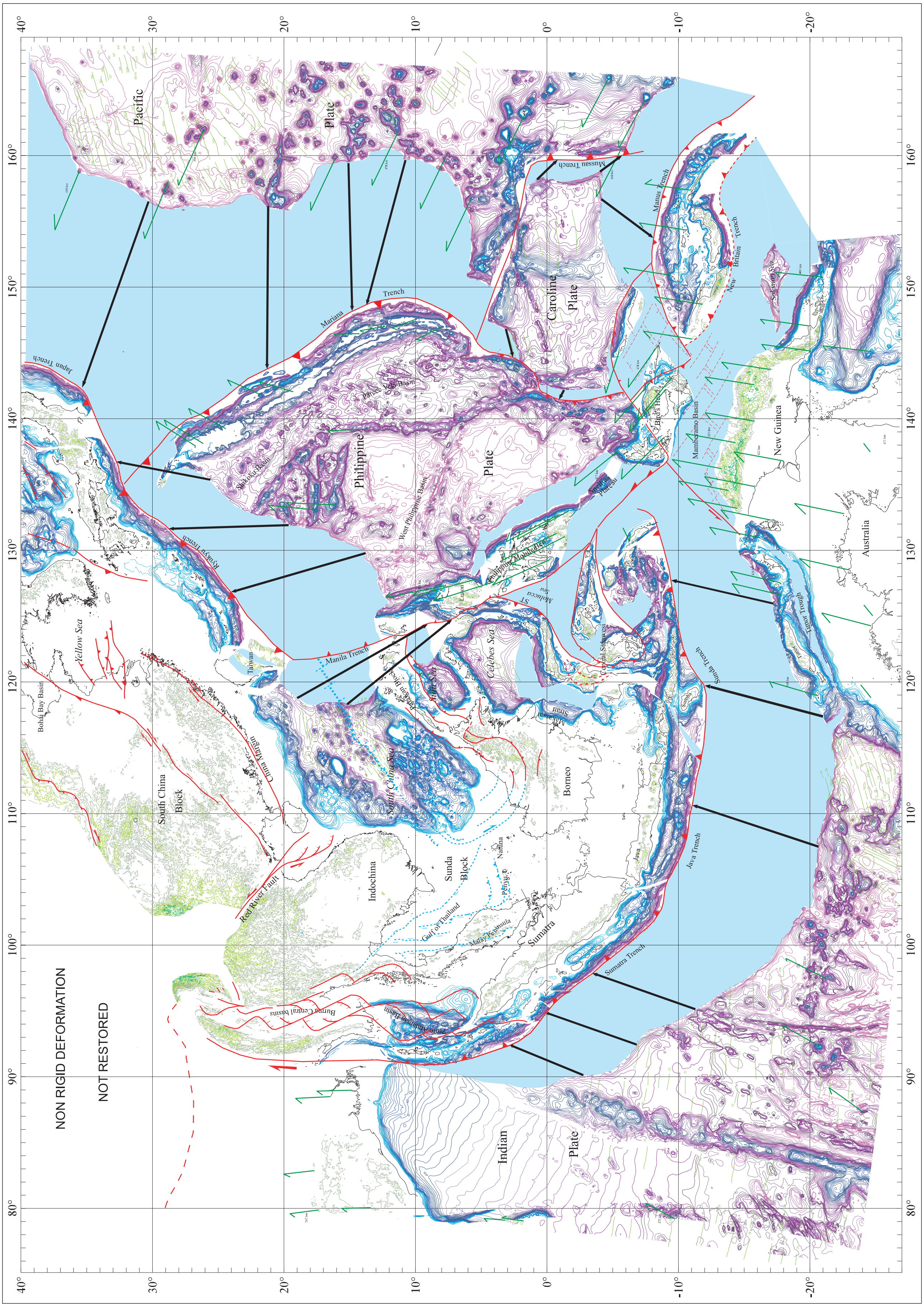

NON RIGID DEFORMATION
NOT RESTORED
Pacific
Plate
Philippine
Plate
Caroline
Plate
Indian
Plate
Australia
New Guinea
Borneo
Sunda
Block
Indochina
South China
Block
Japan
Sea
Yellow Sea
Japan Trench
Ryukyu Trench
Mariana Trench
Mariana Basin
Parece Vela Basin
Shikoku Basin
West Philippine Basin
Taiwan
MT
NT
Sulu Sea
Celebes Sea
Molucca Sea
South China Sea
China Margin
Red River Fault
Sagain Fault
Burma Central basins
West Andaman Fault
Sumatra Trench
Sumatra
Malay Peninsula
Java
Java Trench
Sunda Trench
Timor Trough
Seram Trough
Manus Trench
Solomon Sea
Trobriand T.
New Britain Trench
MnB
Banggai
Makassar Strait
Kutei Basin
Barito Basin
Philippine Mobile Belt
Philippine Trench
Sorong
Birds Head
ST
SwT
Solomon
160°
150°
140°
130°
120°
110°
100°
90°
80°
40°
30°
20°
10°
0°
-10°
-20°

pl. 3 : 6 Ma

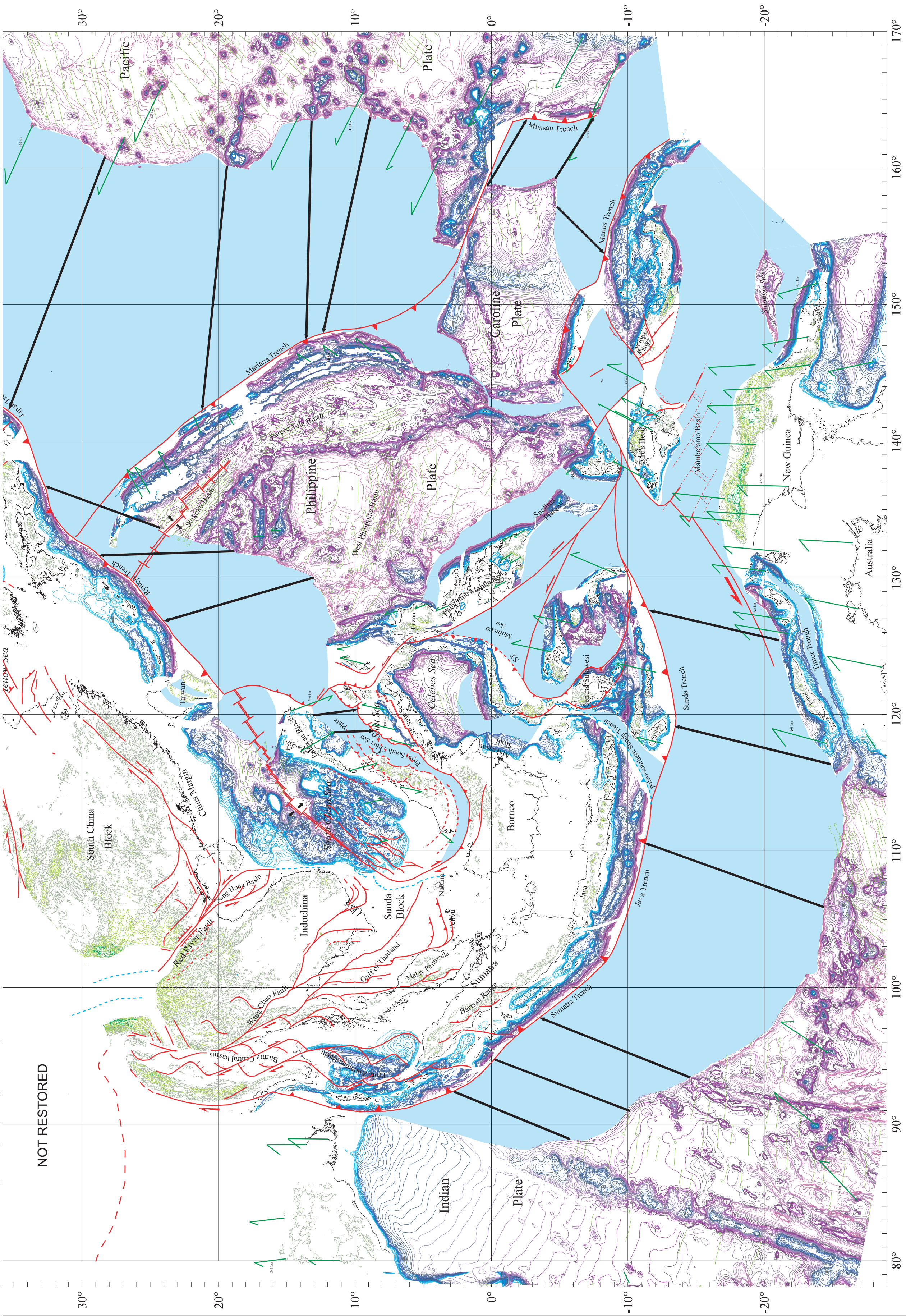


NON RIGID DEFORMATION
NOT RESTORED
Pacific
Plate
Philippine
Plate
Caroline
Plate
Indian
Plate
Mariana
Trench
Parece Vela Basin
Shikoku Basin
West Philippine Basin
Ryukyu Trench
Japan
Sea
Yellow Sea
Taiwan
South China
Block
China Margin
Red River Fault
South China Sea
Sulu Sea
Celebes Sea
Molucca
Sea
Makassar
Strait
Borneo
Indochina
Sunda
Block
Malay Peninsula
Thai basins
Sumatra
Java
Java Trench
Sumatra Trench
Sunda Trench
West Andaman Fault
Burma Central basins
Manus Trench
New Britain Trench
Mamberamo
Basin
New Guinea
Timor Trough
Australia

pl. 4 : 10 Ma


Pacific
Plate
Philippine
Plate
Caroline
Plate
Indian
Plate
Mariana
Trench
Japan Trench
Ryukyu Trench
Manila Trench
Mussau Trench
Manus Trench
New Britain Trench
Sunda Trench
Java Trench
Sumatra Trench
Timor Trough
Shikoku Basin
Parece Vela Basin
West Philippine Basin
South China Sea
Celebes Sea
Yellow Sea
Bohai Bay Basin
Taiwan
South China
Block
Indochina
Sunda
Block
Borneo
Sumatra
Gulf of Thailand
Malay Peninsula
Red River Fault
New Guinea
Australia
NON RIGID DEFORMATION
NOT RESTORED

pl. 5 : 15 Ma


Pacific
Plate
Mussau Trench
Manus Trench
Caroline
Plate
Mariana Trench
Parece Vela Basin
Shikoku Basin
Philippine
Plate
West Philippine Basin
Ryukyu Trench
Philippine Mobile Belt
Molucca Sea
Celebes Sea
Central Sulawesi
Sunda Trench
Bird's Head
Mamberamo Basin
New Guinea
Australia
Timor Trough
Solomon Sea
Taiwan
South China Block
South China Sea
Sulu Sea
Borneo
Sunda Block
Indochina
Song Hong Basin
Red River Fault
Gulf of Thailand
Malay Peninsula
Natuna
Java
Java Trench
Sumatra
Sumatra Trench
Barisan Range
Wang Chao Fault
Burma Central basins
NOT RESTORED
Indian
Plate

pl. 6 : 20 Ma

neath the Finisterre Range, and further SW, the fold-and-thrust belt of New Guinea developed where 100 km of shortening may have taken place [Hill, 1991]. Strain partitioning occurred at Manus Trench and the Manus basin started to open. Strike slip motion was active along the Sorong Fault [Dow and Sukamto, 1984]. Westward the northward drift of Australian Plate produced the collision between the Banda arc and the Timor block. This initiated the closure of the Timor Trough and the initiation of the Flores back-thrust which is still active today [Silver *et al.,* 1983 ; Genrich *et al.,* 1996], over a newly formed back-arc basin floored with anomaly-bearing oceanic crust [Hinschberger *et al.,* 2001].

The whole forearc of Sumatra underwent a major phase of compression-transpression leading to the back-thrusting of the outer arc ridge onto the forearc basin [Matson and Moore, 1992]. The Barisan Range underwent also a major compressive phase in Sumatra Island in the late Pliocene [Bennet *et al.,* 1981]. From now on, the forearc will appear more rigid, and the deformation will be localized on the Great Sumatra Fault. Further north, the spreading in the modern Andaman Sea is beginning [Chamot-Rooke *et al.,* 2001].

The 6 Ma step (plate 3)

To the eastern side, the end of the Miocene corresponds to a climax in the collision of exotic blocks and plates against the Sunda plate. Collision of the Philippine arc and the Eurasian continental margin started in Taiwan, and further NE in Central Japan (Izu Peninsula) with the imbrication of the Tanzawa ophiolites and formation of the intraplate Zenisu Ridge in the Philippine Sea plate. Marianna basin was in rifting stage. The northern part of the Philippines was still sweeping off the edge of the Palawan block at this time, resulting in the shortening and uplift of the Central Cordillera of Luzon [Loevenbruck *et al.,* 2002]. Strike-slip was the main mechanism in the southern Philippines with the activity of a transform fault zone between the Sangihe and the Cotabato subduction zones [Pubellier *et al.,* 1996]. In the triple junction area, the indentation of the Banggai block toward the west is coeval with the beginning of the clockwise rotation of the North arm of Sulawesi along the Palu-Koro Fault, and the initiation of the Celebes subduction zone. Deformation is transferred laterally in Borneo where inversion in the Kutei and Barito basins is observed [Ott, 1987 ; Moss and Chambers, 1999].

The northward drift of the Australian plate initiated the deformation front and fault-and-thrust belt in Irian Jaya [Pigram and Symonds, 1991], in Papua New Guinea [Crowhurst *et al.,* 1996], and the collision of Timor [Karig *et al.,* 1987 ; Charlton, 1989 ; Hughes *et al.,* 1996] in the west that closed the pathway that existed between the Indian and the Pacific oceans. Shortening started in the Timor Trough [Hughes *et al.,* 1996]. Toward the rear side of the range, the probably composite Mamberramo-Sepik-Solomon basin was in the process of closing [Monnier *et al.,* 1999] and the Bird's Head was beginning to escape the advancing Australian Craton [Pubellier and Ego, 2002].

Along the western margin of Sunda, the rifting is well marked in the Andaman Sea and associated with the initiation of dextral motion along the Sagaing Fault [Bertrand *et al.,* 1998] and the rift borders. To the north of the Sunda plate, the deformation associated with the left-lateral motion of the Red River Fault is sealed [Rangin *et al.,* 1995], and the RRF possibly started to move in a dextral sense.

The 10 Ma step (plate 4)

Between 7 and 10 Ma ago, the initiation of compressional and transpressional intraplate deformations started in the Indian Plate marking the incipient separation between the Indian and Australian plates [Royer and Sandwell, 1989]. This period corresponds to deformation in various places around the Sunda block, which probably started its clockwise rotation [Chamot-Rooke *et al.,* 2001]. The Philippine Sea plate encroached the rifted blocks of the Sunda plate. As a result, thrusts formed in Luzon (Northern Philippines) and a shear zone developed in the south (Mindoro, Panai). Further south, rifting occurred in the Thai basins. In the south, continental subduction and obduction occurred in Central Sulawesi. This early late Miocene time was a period of relative quiescence for the south of the Sunda plate. Along the western margin of Sunda plate, rifting in the modern Andaman basin initiated [Curray *et al.,* 1979 ; Polochan and Racey, 1994] and was accommodated laterally by transpression along the Three Pagodas Fault. At the same time, the Burma basins were inverted in Central Myanmar, and the West Andaman Fault motion initiated in the south [Rangin *et al.,* 1999c]. Further East in the New Guinea region, the Solomon Sea started to be consumed in the Trobriand Trough, and shortening was beginning in the Mamberamo basin.

The 15 Ma step (plate 5)

The Middle Miocene was a period of major shortening in the eastern Eurasian margin (the Sunda plate was not individualized yet). Within the Eurasian plate, complete subduction of the Proto South China Sea was completed and the Cagayan Ridge was sutured with the Palawan block forming a major crustal accretionary wedge that extends to the SW in Borneo [Rangin *et al.,* 1985, 1989, 1991]. Spreading in the South China Sea and SE Sulu Sea was interrupted [Briais *et al.,* 1993]. However, the Philippine Sea plate was still migrating northward [Ali and Hall, 1995] and incipient subduction is recorded along the Manila Trench [Maury *et al.,* 1998].

In Sulawesi, a major event reflects the collision of the East Sulawesi block with the southeastern corner of the Eurasian margin [Villeneuve *et al.,* 1998, 2000], and the deformation extended as far as SE Borneo in the Meratus Range. An unconformity sealing broad folds and thrusts exists in the northern Mentawai Island, however most of the deformation recorded in the western Eurasian margin was along the edge of the Shan Plateau. This event has been documented by the youngest ages obtained in ductile structures from Myanmar to Yunnan [Leloup *et al.,* 1995 ; Bertrand *et al.,* 1999]. In Myanmar, the deformation has been interpreted as extension along pull-apart basins [Rangin *et al.,* 1999c], and continues toward the south in a Proto-Andaman basin, while dextral transcurrent motions in the Gulf of Thailand and inversion in Penyu and West Natuna basins waned. In New Guinea, a Middle Miocene unconformity is recorded in the Mamberramo basin, but no noticeable deformation exists onland. However, subduction of the Solomon Sea crust started in the New Britain Trench as the Otong Java Plateau was jamming the Melanesian Trench plate [Kroenke, 1984 ; Wells, 1989].

The 20 Ma step (plate 6)

The 20 Ma step is a critical period for the western Pacific area. The spreading in the Japan Sea started by that time while it waned in the Parece Vela and Shikoku basins in the Philippine Sea plate. The free boundaries that existed previously along the eastward and southward margins of Eurasia, are then affected by the docking of the northern margin of Australia to the south and the Philippine arc to the east. Within the Eurasian margin, the SE Sulu Sea opened in response to the SE dipping subduction of the Proto South China Sea plate beneath the Cagayan Ridge. Around 17 Ma, the Palawan-NW Borneo continental accretionary prism formed. One of the immediate consequence was a drastic reorganization of the spreading in the South China Sea (NNW-SSE instead of N-S). The opening was controlled by a trench pull caused by the subduction of the Proto South China Sea and/or the Indian Ocean, after dismantling of the Asian continent following the India-Asia collision [Tapponnier *et al.,* 1986]. Left-lateral motion along the RRF was vanishing [Leloup *et al.,* 1995]. After 20 Ma, the opening was being influenced by the early docking of Philippine fragments such as the NE Luzon or the Zambales block. The last spreading is associated with a fast propagation of the spreading centre to the SW into South Vietnamese Shelf [Huchon *et al.,* 1998]. A far consequence of this motion may be a dextral motion along the China margin and ultimately the inversion of the Yellow Sea basins. Near the triple junction of central Indonesia, the paleo-southern Sunda Trench was closed by the docking of the Sumba block [Rangin *et al.,* 1990] and subduction jumped to the south of Sumba Island.

During this period, the western edge of the Eurasian margin underwent a major phase of rifting, with the formation of pull-apart basins in Central Myanmar lowlands, and the proto-Andaman basin. In contrast, after a period of left-lateral motion that ended around 23 Ma [Lacassin *et al.,* 1997] dextral motion along N-S trending structures of the proto-Thai basins and along the Wang Chao Fault zone produced inversion in the Penyu and west Natuna basins. Incipient other inversions are observed in the Barisan Range (Sumatra), and in Yellow Sea basins. Left-lateral motion along the Red River Fault is associated with rifting in the Song Hong basin.

CONCLUSIONS

SE Asia has been constructed by successive accretion of blocks of Gondwanian origin. Continental landmasses of Central Asia have thus been composed by amalgamation of large blocks and the subsequent history of arc accretion involving subduction jumps and marginal basins consumption has been obliterated by the large collisions. During the Tertiary however, smaller blocks have docked against Eurasia and allow us to see in better condition the processes of blocks accretion. We observe that the convergence is responsible for both the opening of marginal basins, and the shortening of these supra subduction units. The crustal slivers composed of continental and island arc crust were therefore separated from the main continent, and later jammed them back against the mother plate. Because the obliquity of the convergence generated strain partitioning, new paired trench and strike-slip systems are created, moving blocks further away from the locus of accretion, and therefore, the blocks can be transferred toward the neighbouring plate. The reconstructions presented here obliged us to take into account, not only the kinematic parameters, but also the variation of space available for arc development, subduction of small basins, and lateral motion of exotic belts (e.g. Philippine Arc). Depending on the geometry of the margin, the contact points migrate together with the block motion, resulting in migration of the deformation.

Acknowledgements. – This paper is one result from a three years project conducted within the framework of a collaboration between Ecole Normale Supérieure, Conoco, Exxon, Unocal and Total-Fina-Elf, through the Deep Offshore Tectonic Studies (DOTS). Many researchers participated in the data collection. We would particularly like to thank Nguyen T. K. Hai for the synthesis on marine data, and Cindy Pubellier (IDS) for the adaptation of GIS tools for the rotations of graphic elements on the sphere. F. Mion and A. Rabaute ameliorated considerably the drafting of the maps. J. Malod and E. Silver provided very useful comments for the improvement of the manuscript. Three of the authors (NC, MP and CR) belong to the CNRS (UMR-8538).

References

ALI J.R. & HALL R. (1995). – Evolution of the boundary between the Philippine Sea Plate and Australia: paleomagnetic evidence from eastern Indonesia. – *Tectonophysics,* **251**, 251-275.

ACHARYYA S.K. (1986). – Tectono-stratigraphic history of Naga-Hills Ophiolites. *In*: Geology of Nagaland Ophiolite. – *Mem. Geol. Surv. India*, **119**, 94-103.

AUDLEY-CHARLES M.G. (1986). – Timor-Tanimbar Trough: the foreland basin of the evolving Banda Arc. *In*: P.A. ALLEN & P. HOMEWOOD Eds., Foreland basins. – International Association of Sedimentology, *Sp. Publ.*, **8**, 91-102.

AUDLEY-CHARLES M.G., BALLANTYNE P.D. & HALL R. (1988). – Mesozoic-Cenozoic rift-drift sequence of Asian fragments from Gondwanaland. – *Tectonics*, **155**, 317-330.

AUDLEY-CHARLES M.G., CATER D.J. & MILSOM D.J. (1972). – Tectonic development of eastern Indonesia in relation to Gondwanaland dispersal. – *Nature, Phys. Sci*., **239**, 35-39.

BADER A.G, PUBELLIER M, RANGIN C & DEPLUS C. (1999). – Active slivering of oceanic crust along the Molucca Ridge, (Indonesia-Philippines). – *Tectonics*, **18**, 4, 606-620.

BARBER A.J. (1981). – Structural interpretation of the island of Timor, eastern Indonesia. *In*: E.J. BARBER & S. WIRYOSUJONO Eds. The geology and tectonics of eastern Indonesia. – *GRDC Sp. Publ.*, **2**, 183-198.

BARBER A.J. (2000). – The origin of the Woyla terranes in Sumatra and the late Mesozoic evolution of the Sundaland margin. – *J. Asian Earth Sci*., **18**, 713-738.

BARRIER E., HUCHON P. & AURELIO M. (1991). – The Philippine Fault: A key for Philippines kinematics. – *Geology,* **19**, 32-35.

BEAUDOUIN T., BELLIER O. et SÉBRIER M. (2003). – Champs de contrainte et de déformation déduits de l'analyse des mécanismes au foyer des séismes de la région de Sulawesi (Indonésie) : implications géodynamiques. – *Bull. Soc. géol. Fr.*, **174**, 3, 305-317.

BELLIER O., SEBRIER M. & PRAMUMIJOYO S. (1991). – La grande faille de Sumatra: géométrie, cinématique et quantité de déplacement mises en évidence par l'imagerie satellitaire. – *C. R. Acad. Sci.,* Paris, **312**, II, 1219-1226.

BENNET J.D., MC.BRIDGE D., CAMERON N.R., DJUNUDDIN A., GHAZALI S.A., JEFFERY D.H., KEATS W., ROCK N.M.S., THOMPSON S.J., WHANDOYO R. (1981). – Expl. notes of geological map of the Banda-Aceh Quadrangle, Sumatra. GRDC, 1 : 25000.

BERGMAN S.C., COFIELD D.Q., TALBOT J. P., GARRARD R.A. (1996). – Tertiary tectonic and magmatic evolution of western Sulawesi and the Makassar Strait, Indonesia: evidence for a Miocene continent-continent collision. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub.,* **106**, 391-429.

BERTRAND G., RANGIN C., MAURY R., HLA MYO HTUN, BELLON H. & GUILLAUD J.P. (1998). – The Singu basalts (Myanmar): new constraints for the amount of recent offset on the Sagaing Fault. – *C. R. Acad. Sci.,* Paris, **327**, 479-484.

BERTRAND G., RANGIN C., MALUSKI H., TIN AUNG HAN, MYINT THEIN, OHN MYINT, WIN MAW & SAN LWIN (1999). – Cenozoic metamorphism along the Shan Scarp (Myanmar): evidences for ductile shear along the Sagaing Fault or the northward migration of eastern Himalayan Syntaxis ? – *Geophys. Res. Lett*. **26,** 7, 915-918.

BRIAIS A., PATRIAT P. & TAPPONNIER P. (1993). – Updated interpretation of magnetic anomalies and seafloor spreading stages in the South China Sea: implications for the Tertiary tectonics of Southeast Asia.– *J. Geophys. Res*., **98**(B4), 6299-6328.

CAMÉRON N.R., CLARKE M.C.G., ALDISS D.T., ASPDEN J.A. & DJUNUDDIN A. (1980). – The geological evolution of northern Sumatra. – *Proc. Indo. Petrol. Assoc., 9th Ann Conv*., 149-187.

CHAMOT-ROOKE N., LE PICHON X., RANGIN C., HUCHON P., PUBELLIER M., VIGNY C. & WALPERSDORF A. (1998). – Sundaland motion in a global reference frame detected from GEODYSSEA GPS measurements: implications for relative motions at its boundaries with the Australian - Indian plate and the South China block, GEODYSSEA Final Report. *In*: P. WILSON & G.W. MICHEL Eds., GFZ Scientific Technical Report, Commission of the European Community, EC. Contract CI1*CT93-0337.

CHAMOT-ROOKE N., RANGIN C. & NIELSEN C. (2001). – Timing and kinematics of Andaman basin opening. – *Eos. Trans. AGU*, **82**(20), Spring Meet. Suppl., Abstract T42B-08.

CHAMOT-ROOKE N., RANGIN C., LALLEMANT S., LAURENT O., LE PICHON X., NIELSEN C., PASCAL G. & RABAUTE A. (2004). – Active tectonics of the Mediterranean Ridge. – *Tectonics* (in press).

CHARLTON T.R. (1989). – Stratigraphic correlations accross an arc-continent collision zone, Timor and the Australian Northwest shelf. – *Austr. J. Earth Sci*., **36**, 263-274.

CHEMENDA A.I., YANG R.K., HSIEH C.H., GROHOLSKY A.L. (1997). – Evolutionary model of the Taiwan collision based on physical modelling. – *Tectonophysic*s, **274**, 1/3, 253-274.

CROWHURST P.V., HILL K.C., FOSTER D.A., BENNET A.P. (1996). – Thermochronological and geochemical constraints on the tectonic evolution of northern Papua New Guinea. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub*., **106**, 525-537.

CURRAY J.R., MOORE D.G., LAWVER L.A., EMMEL F.L., RAITT R.W., HENRY M. & KIECKHEFER R. (1979). – Tectonics of the Andaman Sea and Burma. – *AAPG Mem.,* **29,** 189-198.

DALY M.C., COOPER M.A., WILSON I., SMITH D.G., HOOPER B.G.D. (1991). – Cenozoic plate tectonics and basin evolution in Indonesia. – *Mar. Petrol. Geol*., **8**(1), 2-21.

DOW D.B. & SUKAMTO R. (1984). – Western Irian Jaya, the end product of oblique plate convergence in the late Tertiary. – *Tectonophysics*, **106**, 109-139.

DOW D.B., ROBINSON G.P., HARTONO U. & RATMAN N. (1988). – Geology of Irian Jaya. Preliminary geological report. Indonesia-Australia geological mapping project. – Geological Research and Development Centre, Indonesia in cooperation with BMR, Camberra, 298 p.

DIAMENT M., DEPLUS C., HARJONO H., LARUE M., LASSAL O., DUBOIS J. & RENARD V. (1990). – Extension in the Sunda Strait (Indonesia): a review of the Krakatau programme. – *Ocean. Acta*, **10**, 31-42.

DOMINGUEZ S., LALLEMAND S., MALAVIELLE J. & VON HUENE R. (1998). – Upper plate deformation associated with seamount subduction. – *Tectonophysics*, **293**, 207-224.

FITCH T.J. (1972). – Plate convergence transcurrent faults and internal deformation adjacent to South-East Asia and western Pacific. – *J. Geophys. Res*., **77**, 4432-4460.

GENRICH J.F., BOCK Y., MC CAFFREY R, CALAIS E., STEVEN C.W. & SUBARYA C. (1996). – Accretion of the southern Banda arc to the Australian plate margin determined by GPS measurements. – *Tectonics*, **15**, 2, 288-295.

GIRARDEAU J., PUBELLIER M. & PERMANA H. (1994). – A complete ophiolitic sequence at the Pacific-Australia plate boundary. – *EOS Transactions, Amer. Geophys. Union*, 54.

HALL R. (1996). – Reconstructing Cenozoic SE Asia. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub.,* **106**, 153-184.

HALL R. (1998). – The plate tectonics of Cenozoic SE Asia and the distribution of land and sea. *In*: R. HALL & J.D. HOLLOWAY Eds., Biogeography and geological evolution of SE Asia. – Backhuys Publishers, Leiden, The Netherlands, 99-131.

HALL R. & WILSON M.E.J. (2000). – Neogene sutures in eastern Indonesia. – *J. SE Asian Earth Sci*., **18** (6), 781-808.

HAMILTON W. (1979). – Tectonics of the Indonesian region. – *U.S. Geol. Survey. Prof. Paper*, **1078**, 345 p.

HEKI.K., MIYAZAKI S., TAKAHASHI H., KASAHARA M., KIMATA F., MIURA SATOSHI V., NIKOLAY F., IVASHCHENKO A. & AN K-D. (1999). – The Amurian plate motion and current plate kinematics in eastern Asia. – *J. Geophys. Res*., **104**(12), 29147-29155.

HILL K.C. (1991). – Structure of the Papuan Fold Belt, Papua New Guinea. – *AAPG Bull*., **75**, 857-872.

HINSHBERGER F., MALOD J., DYMENT J., HONTHAAS C., RÉHAULT J-P. & BURHANUDDIN S. (2001). – Magnetic lineations constraints for the back-arc opening of the late Neogene South Banda basin (eastern Indonesia). – *Tectonophysics,* **333**, 47-59.

HO C.S. (1986). – A synthesis of the geologic evolution of Taiwan. – *Tectonophysics*, **125**, 1-16.

HOLLOWAY N.H. (1982). – The North Palawan block, Philippines: its relation to the Asian mainland and its role in the evolution of the South China Sea. – *AAPG Bull*., **66**, 1355-1383.

HONTHAAS C., REHAULT J.P., MAURY R.C., BELLON H., HÉMOND C., MALOD J.A., CORNÉE J.J., VILLENEUVE M., COTTEN J., BURHANUDDIN S., GUILLOU H. & ARNAUD N. (1998). – A Neogene back-arc origin for the Banda basin: geochemical and geochronological constraints from the Banda Ridges (East Indonesia). – *Tectonophysics*, **298**, 297-317.

HSU S.K. & SIBUET J.C. (1995). – Is Taiwan the result of arc-continent or arc-arc collision ? – *Earth Planet. Sci. Lett*., **136**, 315-324.

HUCHON P. & LE PICHON X. (1984). – Sunda Strait and Central Sumatra Fault. – *Geology*, **12**, 668-672.

HUCHON P., NGUYEN T.N.H. & CHAMOT-ROOKE N. (1998). – Finite extension across the South Vietnam basins from 3D gravimetric modelling: relation to South China Sea kinematics. – *Mar. Petrol. Geol*., **15** (7), 619-634.

HUCHON P., NGUYEN T.N.H. & CHAMOT-ROOKE N. (2001). – Propagation of continental break-up in the south-western South China Sea. *In*: R.C.L. WILSON, R.B. WHITMARSH, B. TAYLOR & N. FROITZHEIM Eds., Non-volcanic rifting of continental margins: a comparison of evidence from land and sea. – *Geol. Soc., London, Sp. Publ.*, **187**, 31-50.

HUGHES B.D., BAXTER K., CLARCK R.A. & SNYDER D.B. (1996). – Detailed processing of seismic reflection data from the frontal part of the Timor Trough accretionary wedge, eastern Indonesia. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub*., **106**, 75-83.

HUTCHISON C. (1987). – Displaced terranes of the southwest Pacific. *In*: BEN AVRAHAM Ed., The evolution of the Pacific Ocean margins. – *Oxford Monographs on Geology and Geophysics,* **8**, 161-175.

HUTCHISON C. (1989). – Geological evolution of South-East Asia. – *Oxford Monographs on Geology and Geophysics*, **13**, 370p.

JARRARD R.D. (1986). – Terrane motion by strike-slip faulting of fore-arc slivers. – *Geology*, **14**, 780-783.

KARIG D.E. (1974). – Evolution of arc systems in the western Pacific. – *Ann. Rev. Earth Planet. Sci. Lett*., **2**, 51-75.

KARIG D.E., BARBER A.J., CHARLTON T.R., KLEMPERER S. & HUSSONG D.M. (1987). – Nature and distribution of deformation accross the Banda arc-Australian collision zone at Timor. – *Geol. Soc. Amer. Bull*., **98**, 18-32.

KETNER K.B., KASTOWO MODJO S., NAESER C.W., OBRADOVICH J.D., ROBINSON K., SUPTANDAR T. & WIKARNO (1976). – Pre-Eocene rocks of Java, Indonesia. – *J. Res. U.S. Geol. Survey*, **4** (5), 605-614.

KROENKE L.W. (1984). – Cenozoic tectonic development of the Southwest Pacific. – United Nation Economics and Social Commission for Asia and the Pacific, Commitee for Coordination and Joint Prospecting for Mineral Resources in South Pacific Offshore Areas, (CCOP-SOPAC). – *Technical Bulletin*, **6**, 122p.

KUNDIG E. (1956). – Geology and ophiolite problems of East Celebes. – Verh. Koninkl. Nederlandsch., *Geol. Mijnb.* Genoots., Geol., **16**, 210-235.

LACASSIN R., MALUSKI H., LELOUP, P.H., TAPPONNIER P., HINTHONG C., SIRIBHAKDI K., CHUAVIROJ S. & CHAROENRAVAT A. (1997). – Tertiary diachronic extrusion and deformation of western Indochina ; structural and (super 40) Ar/ (super 39) Ar evidence from NW Thailand. – *J. Geophys. Res*., **102** (5), 10,013-10,037

LALLEMAND S., CULOTTA R. & VON HUENE R. (1989). – Subduction of the Daiichi-Kashima Seamount in the Japan Trench. – *Tectonophysics*, **160**, 231-248.

LALLEMAND S., MALAVIEILLE J. & CALASSOU S. (1992). – Effects of oceanic ridge subduction on accretionary wedges: experimental modelling and marine observations. – *Tectonics*, **11**, 6, 1301-1313.

LALLEMAND S. & TSIEN H.H. (1997). – An introduction to active collision in Taiwan. – *Tectonophysics*, **274**, 1/3, 1-4.

LALLEMAND S., POPOFF M., CADET J-P., DEFFONTAINES B., BADER A.G., PUBELLIER M. & RANGIN C. (1998). – The junction between the central and southern Philippine Trench. – *J. Geophys. Res*. **103** (B1): 933-950.

LE PICHON X., FRANCHETEAU J. & SHARMAN G.F. (1975). – Rigid plate accretion in an inter arc basin: Marianna trough. – *J. Physics of the Earth*, **23**: 251-256.

LELOUP PH., LACASSIN R., TAPPONNIER P., SCHÄRER U., DALAI Z., XIAOHAN L., LIANGSHANG Z., SHAOCHENG & PHAN T.T. (1995). – The Ailao Shan-Red River shear zone (Yunnan, China), Tertiary transform boundary of Indochina. – *Tectonophysics*, **251**, (1-4), 3-84.

LEE T.Y. & LAWVER L.A. (1994). – Cenozoic plate reconstruction of the South China Sea region. – *Tectonophysics*, **235**(1-2), 149-180.

LINTHOUT K., HELMERS H. & ANDRIESSEN P.A.M. (1991). – Dextral strike-slip in central Seram and 3-4.5 Ma Rb/Sr ages in pre-Triasic metamorphics related to early Pliocene counter-clockwise rotation of the Buru-Seram microplate (E. Indonesia). – *J. SE Asian Earth Sci.,* **6**, 335-342.

LOEVENBRUCK A. (1999). – Déformation des philippines durant le dernier million d'années à partir des données GPS, de la sismicité et de la tectonique. – Mem. DEA Géodynamique et Physique de la Terre, ENS Paris, 36p + annexes.

LOEVENBRUCK A., PUBELLIER M. &. STEPHAN J.F. (2002). – The northern extension of the Philippine fault: a restraining bend within the Central Cordillera, Luzon Island, Philippines. – EGS XXVII, March 2002, Nice. – *Geophy. Res. Abstr.* **4**, EGS02-A05448.

LU C. & MALAVIEILLE J. (1992). – Oblique convergence, indentation and rotation tectonic in Taiwan mountain belt ; insights from experimental modelling. – *29th internat. Geol. Congr.*, **29**, 416, Kyoto, Japan.

MALOD J-A., KEMAL B.M., BESLIER M-O., DEPLUS C., DIAMENT M., KARTA K., MAUFFRET A., PATRIAT P., PUBELLIER M., REGNAULT H., ARITONANG P. & ZEN M.T. JR. (1993). – Déformation du bassin d'avant-arc au Nord-Ouest de Sumatra : une réponse à la subduction oblique. – *C. R. Acad. Sci.,* Paris, **316** (II), 791-797.

MATSON R.G. & MOORE G.F. (1992). – Structural influences on Neogene subsidence in the central Sumatra fore-arc basin. *In*: J.S. WATKINS & F. ZHIQIANG *et al*. Eds., Geology and geophysics of continental margin. – *AAPG Mem*., **53**, 157-181.

MAURY R.C., SAJONA F.G., PUBELLIER M., BELLON H. & DEFANT M.J. (1996). – Fusion de la croûte océanique dans les zones de subduction/collision récentes : l'exemple de Mindanao (Philippines). – *Bull. Soc. géol. Fr.*, **167**, 5, 579-595.

MAURY R.C., DEFANT M.J., BELLON H., JACQUES D., JORON J.L., MCDERMOTT F. & VIDAL. P. (1998). – Temporal and geochemical trends in northern Luzon arc lavas (Philippines): implications on metasomatic processes in the island arc mantle. – *Bull. Soc. géol. Fr.*, **169**, 69-80.

MCCABE R. & ALMASCO J.N. (1985). – Terranes of the Central Philippines. *In*: D.G. HOWELL Ed., Tectonostratigraphic terranes of the Circum Pacific Region, **1**, 421-436.

MCCABE R. & COLE J. (1989). – Speculations on the late Mesozoic and Cenozoic evolution of the Southeast Asian margin. *In*: BEN AVRAHAM Ed., The evolution of the Pacific Ocean margins. – *Oxford Monographs on Geology and Geophysics*, **8**, 143-160.

MCCAFFREY R. (1991). – Slip vectors and stretching of the Sumatran forearc. – *Geology*, **19**, 881-884.

MCCAFFREY R. (1996). – Slip partitioning at convergent plate boundaries of SE Asia. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub*., **106**, 3-18.

METCALFE I. (1996). – Pre-Cretaceous evolution of SE Asian Terranes. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub*., **106**, 97-122.

METCALFE I. (1999). – Gondwana dispersion and Asian accretion. *In*: Gondwana dispersion and Asian accretion, Final results of IGCP 321, edited by I. METCALFE. – AA Balkema Publishers, Rotterdam, 141-160.

MICHEL G.W., YU Y.Q., ZHU S.Y., REIGBER C., BECKER M., REINHART E., SIMONS W., AMBROSIUS B., VIGNY C., CHAMOT-ROOKE N., LE PICHON X., MORGON P. & MATHEUSSEN S. (2001). – Crustal motion and block behaviour in SE-Asia from GPS measurements. – *Earth Planet. Sci. Lett*., **187**(3-4), 239-244.

MITCHELL A.G.H. (1992). – Mineralization related to closure of Tethyan ocean basins in Myanmar and Thailand. – Seventh regional conference on Geology, mineral and hydrocarbon resources of Southeast Asia (GEOSEA VII), Bangkok, Thailand, Nov. 5-8, 1991. – *J. SE Asian Earth Sci*., **7**(4), 86.

MITCHELL A.H.G. (1993). – Cretaceous-Cenozoic tectonic events in the western Myanmar (Burma)-Assam region. – *J. Geol. Soc. London*, **150** (6), 1089-1102.

MONNIER C., GIRARDEAU J., PUBELLIER M., POLVÉ M. & PERMANA H. (1999). – Petrology and geochemistry of the Cyclops ophiolite (Irian Jaya – East Indonesia), Consequences for the evolution of the north Australian margin during Cenozoic. – *J. Min. Petrol*., **65**, 1-28.

MONNIER C., GIRARDEAU J., PUBELLIER M. & PERMANA H. (2000). – L'ophiolite de la Chaîne Centrale d'Irian Jaya (Indonésie): évidences pétrologiques et géochimiques pour une origine dans un bassin arrière arc. – *C. R. Acad. Sci.,* Paris, **331**, 691-699.

MOORE G.F. & KARIG D.E. (1980). – Structural geology of Nias Island, Indonesia: implication for subduction zone tectonics. – *Am. J. Sci*., **280**, 193-223.

MOORE G.F. & SILVER E.A. (1983). – Collision Processes in the Northern Molucca Sea. *In*: D.E. HAYES Ed., The tectonic and geologic evolution of Southeast Asian seas and islands. – *Geophys. Union Mon*. **27**, 360-372.

MOSS S.J. & CHAMBERS J.L.C. (1999). – Tertiary facies architecture in the Kutai Basin, Kalimantan, Indonesia. – *J. SE Asian Earth Sci*., **17**, 157-181.

NIELSEN C., CHAMOT-ROOKE N. & RANGIN C. (2002). – Partitioning at very oblique subduction zones: a comparative marine study between the Burma Trench and the western termination of the Hellenic Trench. – *EGS XXVII*, Nice, France, 21-26 April 2002.

OTOFUJI Y., SASAJIMA S., NISHIMURA S., DHARMA A. & HEHUWAT F. (1981). – Paleomagnetic evidence for clockwise rotation of the northern arm of Sulawesi, Indonesia. – *Earth Planet. Sci. Lett.,* **54**, 272-280.

OTT H.L. (1987). – The Kutei basin: A unique structural history. – *Proc. Indon. Petrol. Assoc*., **16th** Ann Conv. Bandung, 307-317.

PARKINSON C. (1998). – An outline of the petrology, structure and age of the Pompangeo Schist Complex of central Sulawesi, Indonesia. – *The Island Arc*, **7**, 231-245.

PELLETIER B. & STEPHAN J.F. (1986). – Middle Miocene obduction and Late Miocene beginning of collision registered in the Hengchun peninsula ; Geodynamic implications for the evolution of Taïwan. – *Tectonophysics*, **125**, 133-160.

PERMANA H. (1998). – Dynamique de la mise en place des ophiolites d'Irian Jaya (Indonesie). – PhD thesis of the Université de Nantes, 314p.

PIGRAM C.J. & SYMONDS P.A. (1991). – A review of the major tectonic events in the New Guinea Orogen. – *J. SE Asian Earth Sci*., **6**, 34, 307-318.

PINET N. & STEPHAN J.F. (1990). – The Philippine wrench fault system in the Ilocos Foothills, northwestern Luzon, Philippines. – *Tectonophysics,* **183**(1-4), 207-224.

POLOCHAN S. & RACEY A. (1994). – Stratigraphy of the Mergui basin, Andaman Sea: implications for petroleum exploration. – *J. Petrol. Geol*., **17**(4): 373-406.

PROUTEAU G., MAURY R., PUBELLIER M., COTTEN J., RANGIN C. & BELLON, H. (2001). – Le magmatisme post-collisionnel du Nord-Ouest de Bornéo, produit de la fusion d'un fragment lithosphérique ancré dans le manteau supérieur. – *Bull. Soc. géol. Fr.,* **172** (3), 319-332.

PUBELLIER M., QUEBRAL R., RANGIN C., DEFFONTAINES B., MÜLLER C. & BUTTERLIN J. (1991). – The Mindanao collision zone: a soft collision event within a continuous Neogene strike-slip setting. – *J. SE Asian Earth Sci.* **6**(3/4), 239-248.

PUBELLIER M., RANGIN C., CADET J-P., TJASHURI I., BUTTERLIN J. & MULLER C. (1992). – L'île de Nias, un édifice polyphasé sur la bordure interne de la fosse de la Sonde (Archipel de Mentawai, Indonésie). – *C. R. Acad. Sci.,* Paris, **315**(II), 1019-1026.

PUBELLIER M., DEFFONTAINES B., QUEBRAL R. & RANGIN C. (1994). – Drainage network analysis and tectonics of Mindanao, Southern Philippines. – *Geomorphology*, **9**, 325-342.

PUBELLIER M., QUEBRAL R., AURELIO M. & RANGIN C. (1996). – Docking and post-docking tectonics in the southern Philippines. *In*: R. HALL & D. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. Sp. Pub.*, **106**, 511-523.

PUBELLIER M., GIRARDEAU J. & TJASHURI I. (1998). – Accretion history of Borneo inferred from the polyphase structural features in the Meratus mountains, in Gondwana dispersion and Asian accretion. – Final results of IGCP 321, edited by I. METCALFE. – AA Balkema Publishers, Rotterdam, 141-160.

PUBELLIER M., BADER A.G., DEFFONTAINES B., RANGIN C. & QUEBRAL R. (1999). – Upper plate deformation induced by subduction of a volcanic arc: the Snellius Plateau (Molucca Sea, Indonesia and Mindanao Philippines). – *Tectonophysics*, **304**, 345-368.

PUBELLIER M. & EGO F. (2002). – Anatomy of an escape tectonic zone, Irian Jaya (Indonesia). – *Tectonics*, **21**, 4, 1-16

PUBELLIER M., MONNIER C. & ALI J. (2003). – Cenozoic plate interaction of the Australia and Philippine Sea plates: "hit and run" tectonics. – *Tectonophysics*, **363**, 181-199.

PUNTODEWO S.S.O., MCCAFFREY R., CALAIS E., BOCK Y., RAIS J., SUBARYA C., POEWARIARDI R., STEVENS C., GENRICH J., FAUZI ZWICK P. & WDOWINSKI S. (1994). – GPS Measurements of crustal deformation within the Pacific-Australia plate boundary zone in Irian Jaya, Indonesia. – *Tectonophysics*, **237** 141-153.

QUEBRAL R., PUBELLIER M. & RANGIN C. (1996). – The onset of movement on the Philippine fault in eastern Mindanao: a transition from a collision to strike slip environment. – *Tectonics*, **15**, 713-726.

RANERO C., VON HUENE R., FLUEH E., DUARTE M., BACA D. & MCINTOSH K. (2000). – A cross section of the convergent Pacific margin of Costa Rica. – *Tectonics*, **19**, 2, 335-357.

RANGIN C., STEPHAN J.F. & MULLER C. (1985). – Middle Oligocene oceanic crust of the South China Sea., jammed into Mindoro collision zone, Philippines. – *Geology*, **13**, 425-428.

RANGIN C., MULLER C. & PORTH H. (1989). – Neogene Geodynamic Evolution of the Visayan Region. *In*: H. PORTH & C.H. VON DANIELS Eds., On the geology and hydrocarbon prospects of the Visayan Basin, Philippines. – *Geol. Jahrb.,* vol. B., **70**, 7-28.

RANGIN C. & PUBELLIER M. (1990). – Subduction and accretion of oceanic fragments along the Eurasian margin: southern Japan-Philippine region. Some constrains for continental growth. *In*: J. AUBOUIN & J. BOURGOIS Eds., Tectonics of Circum Pacific continental margins. – VSP International Publishers, 139-164.

RANGIN C., JOLIVET L. & PUBELLIER M. (1990). – A simple model for the tectonic evolution of southeast Asia and Indonesian region for the past 43 My. – *Bull. Soc. géol. Fr.,* **8**, VI(6), 889-905.

RANGIN C., STEPHAN J.F., BUTTERLIN J., BELLON H., MULLER C., CHOROWICZ J. & BALADAD D. (1991). – Collision néogène d'arcs volcaniques dans le centre des Philippines: stratigraphie et structures de la chaîne d'Antique (île de Panay). – *Bull. Soc. géol. Fr.,* **162**(3), 465-477.

RANGIN C., KLEIN M., ROQUES D., LE PICHON X. & LE VAN TRONG (1995). – The Red River Fault system in the Tonkin gulf, Viet Nam. – *Tectonophysics*, **243**, 209-222.

RANGIN C., LE PICHON X., MAZZOTTI S., PUBELLIER M., CHAMOT-ROOKE N., AURELIO M., WALPERSDORF A. & QUEBRAL R. (1999a). – Plate convergence measured by GPS across the Sundaland/Philippine Sea Plate deformed boundary: the Philippines and eastern Indonesia. – *Geophys. J. Int*., **139**, 296-316.

RANGIN C., SPAKMAN W., PUBELLIER M. & BIJWAARD H. (1999b). – Geological and tomographic constraints on the subduction of the SE Asia marginal basins. – *Bull. Soc. géol. Fr.*, **170**, 6, 775-788.

RANGIN C., WIN MAW, SAN LWIN, WIN NAING, MOURET C., BERTRAND G. & GIAC SCIENTIFIC PARTY (1999c). – Cenozoic pull-apart basins in central Myanmar: the trace of the path of India along the western margin of Sundaland. – *Terra Abstracts*, **4**, 1, 59.

RANGIN C., PUBELLIER M., CHAMOT-ROOKE N., WALPERSDORF A., VIGNY C., LE PICHON X., AURELIO M. & QUEBRAL R. (2000). – Plate convergence measured by GPS across the Sundaland-Philippines Sea plate deformed boundary (Philippines and eastern Indonesia). – *Geophys. J. Inter*., **139**, 296-316, 2000

RICARD Y., DOGLIONI C. & SABADINI R. (1991). – Differential rotation between lithosphere and mantle, a consequence of lateral mantle viscosity variation. – *J. Geophys. Res*., **96**, 8407-8415.

RICHARDSON A.N. & BLUNDELL D.J. (1996). Continental collision in the Banda Arc. *In*: R. HALL & D.J. BLUNDELL Eds., Tectonic evolution of SE Asia. – *Geol. Soc. London Sp. Pub*., **106**, 47-60.

ROYER J.Y. & SANDWELL D.T. (1989). – Evolution of the eastern Indian Ocean since the late Cretaceous ; Constraints from Geosat Altimetry. – *J. Geophys. Res*., **94**(B10), 13,755-13,782.

SAJONA F.G., MAURY R.C., BELLON H., COTTON J. & DEFANT M. (1996). – High field strengh element enrichment of Pliocene-Pleistocene island arc basalts, Zamboanga Peninsula, western Mindanao (Philippine). – *J. Petrol.,* **3**, 693-726.

SAMUEL M.A. & HARBURY N.A. (1996). – The Mentawai fault zone and deformation of the Sumatran forearc in the Nias area. – *Geol. Soc. Sp. Publ*., **106**, 337-351.

SAMUEL M.A., HARBURY N.A., BAKRI A., BANNER F.T. & HARTONO L. (1997). – A new stratigraphy for the islands of the Sumatran forearc, Indonesia. – *J. SE Asian Earth Sci*., **15** (4-5), 339-380.

SCHLÜTER H.U, GAEDICKE CH., ROESER HA., SCHRECKENBERGER B., MEYER H. & REICHERT CH. (2002). – Tectonic features of the Sumatra-Java forearc of Indonesia: new results. – *J. SE Asian Earth Sci.* (in press).

SENO T., STEIN S.A. & GRIPP A.E. (1993). – A model for the motion of the Philippine Sea Plate consistent with NUVEL 1 and geological data. – *J. Geophys. Res*., **98**, 941-948.

SEWELL R.J. CHAN L.S., FLETCHER C.J.N., BREWER T.S. & ZHU J.C. (2000). – Isotope zonation in basement crustal blocks of southeastern China ; evidence for multiple terrane amalgamation. – *Episodes*, **23** (4), 257-261.

SIBUET J.C., HSU S.K., LE PICHON X., LE FORMAL J.P., REED D., MOORE G. & LIU C.S (2002). – East Asia plate tectonics since 15 Ma: constraints from the Taiwan region. – *Tectonophysics*, **334**, 103-134.

SILVER E.A. & MOORE J.C. (1978). – The Molucca Sea collision zone, Indonesia. – *J. Geophys. Res*. **89**, 1681-1691.

SILVER E. A., REED D., MC CAFFREY R. & JOYODIWIRYO Y. (1983). Back-arc thrusting in the in the Eastern Sunda arc, Indonesia. A consequence of arc-continent collision. – *J. Geophys. Res*, **88**, B9, 7429-7448.

SILVER E.A., GILL J.B., SCHWARTZ D. & PRASETYO H. (1985). – Evidence for a submerged and displaced continental borderland, north Banda Sea, Indonesia. – *Geology*, **13**, 687-691.

SIMONS W.J.F. (1999). – Observing plate motions in Southeast Asia: Geodetic results of the GEODYSSEA project. – *Geophys. Res. Lett*., **26**(14), 2081-2084.

STEVENS C.W., MCCAFFREY R., BOCK Y., GENRICH J.F., PUBELLIER M. & SUBARYA C. (2002). – Evidence for block rotations and basal shear in the world's fastest slipping continental shear zone in NW New Guinea. *In*: S. STEIN & J.T. FREYMUELLER Eds., Plate boundary zones. – *Geodyn. Ser*., **30**, 87-99.

STRUCKMEYER H.I.M., YEUNG M. & PIGRAM C.J. (1993). – Mesozoic to Cenozoic Plate tectonics and Palaeogeographic evolution of the New Guinea Orogen. *In*: G.J. CARMA & Z. CARMAN Eds., Petroleum Exploration in PNG. – *Proc. First PNG Petrol. Convention*, Port Moresby, 262-290.

SUTANTO (1997). – Evolution temporelle du magmatisme d'arc insulaire: géochronologie, pétrologie et géochimie des magmatismes mésozoïques et cénozoïques de Sumatra (Indonésie*)*. – Thèse de l'Université de Bretagne Occidentale, 212 p.

SYAFRI H. (2000). – Etude pétrologique et géochimique des péridotites à grenat, éclogites et roches associées des parties ouest et centrale de l'île de Sulawesi, Indonésie. – Ph.D. Thesis of the Université de Paris 6, N°7-2000, 418p.

TAPPONNIER P., PELTZER G. & ARMIJO R. (1986). – On the mechanics of the collision between India and Asia. *In*: M.P. COWARD & A.C. RIES Eds., Collision tectonics. – *Geol. Soc. Sp. Publ*., **19**, 115-157.

TAYLOR B., GOODLIFFE A.M. & MARTINEZ F. (1999). – How continents break up: Insights from Papua New Guinea. – *J. Geophys. Res.,* **104**(B4), 7497-7512.

UYEDA S. & KANAMORI H. (1979). – Back-arc opening and the mode of subduction. – *J. Geophys. Res*., **84**, 1049-1061.

VILLENEUVE M., REHAULT J.P., CORNÉE J.J., HONTHAAS C., GUNAWAN W. & GEOBANDA GROUP (1998). – Evolution géodynamique de l'Indonésie orientale, de l'Eocène au Pliocène. – *C. R. Acad. Sci.,* Paris, **327**, 291-302.

VILLENEUVE M., CORNEE J.J. & GUNAWAN W. (2000). – Continental block collision in the eastern arm of Sulawesi (Indonesia). Structure and geodynamic interpretation. – *C.R. Acad Sci.,* Paris, **330**, 371-378.

VILLENEUVE M., CORNEE J-J., GUNAWAN W., MARTINI R., TRONCHETTI G., JANIN M-C., SAINT-MARC P. & ZANINETTI L. (2001). – La succession lithostratigraphique du bloc de Banda dans la region de Kolonodale (Sulawesi central, Indonesie) ; Lithostratigraphy of the Banda Block in the Kolonodale area, central Sulawesi, Indonesia. – *Bull. Soc. géol. Fr.,* **172**(1), 59-68.

VON HUENE R., BIALAS J., FLUEH E., CROPP B., CSERNOK T., FABEL E., HOFFMANN J., EMEIS K., HOLLER P., JESCHKE G., LEANDRO M.C., PEREZ FERNANDEZ I., CHAVARRIA S., J., FLOREZ H.A., ESCOBEDO Z.D., LEON R. & BARRIOS L.O. (1995). – Morphotectonics of the Pacific convergent margin of Costa Rica. *In*: P. MANN Ed., Geologic and tectonic development of the Caribbean plate boundary in southern Central America. – *Geol. Soc. Amer. Sp. Paper*, **295**, 291-308.

VON HUENE R., RESTON T., KUKOWSKI N., DEHGHANI G.A., WEINREBE W., LE PICHON X., PASCAL G., LALLEMANT S., LE MEUR D., CHAMOT-ROOKE N., LOUCOYANNAKIS M., BABASSILAS D., NICOLICH R., CERNOBORI L., WESTBROOK G., WARNER M., TAY P.L., JONES K., LONERGAN L., DICKMANN T. & FRUEHN J. (1997). – A subducting seamount beneath the Mediterranean Ridge. – *Tectonophysics*, **271** (3-4), 249-261.

WAJZER M.R., BARBER A.J., HIDAYAT S. & SUHARSONO (1991). – Accretion, collision and strike-slip faulting: the Woyla Group as a key to the tectonic evolution of North Sumatra. – *J. SE Asian Earth Sci*. **6**(3/4), 447-461.

WAKITA K. (2000). – Cretaceous accretionary-collision complexes in Central Indonesia. – *J. SE Asian Earth Sci*., **18**, 739-749.

WALPERSDORF A., VIGNY C., SUBARYA C. &. MANURUNG P. (1998). – Monitoring of the Palu-Koro Fault (Sulawesi) by GPS. – *Geophys. Res. Lett*., **25**, 13, 2313-2316.

WANG E., BURCHFIELD B.C., ROYDEN L.H., CHEN LIANZHONG, CHEN JISHEN, LI WENXIN & CHEN ZHILIANG (1998). – Late Cenozoic Xianshuihe-Xiaojiang, Red River, and Dali fault systems of Southwestern Sichuan and central Yunna, China. – *GSA sp. Paper,* **327**, 108 p.

WELLS R.E. (1989). – Origin of the oceanic basalt basement of the Solomon Islands arc and its relationship to the Otong Java Plateau – Insight from Cenozoic plate motion. – *Tectonophysics*, **165**, 219-235.

WESSEL P. & KROENKE W. (2000). – Otong Java Plateau and late Neogene changes in Pacific plate motion. – *J. Geophys. Res*., **105**, B12, 28255-28277.

YAN C.Y. & KROENKE L.W. (1993). – A plate tectonic reconstruction of the Southwest Pacific, 0-100 Ma. – *Proc. Ocean Drill. Prog., Scientific Results*, **130**, 697-709.

YU S.B., KUO L.C., PUNONGBAYAN R.S. & RAMOS E.G. (1999). – GPS observation of crustal deformation in the Taiwan-Luzon Region. – *Geophys. Res. Lett.*, **26**(7), 923-926.

YUWONO Y.S., PRYOMARSONO S., MAURY R.C., RAMPNOUX J.P., SOERIA ATMADJA, BELLON H. & CHOTIN P. (1988). – Petrology of the Cretaceous magmatic rocks from Meratus Range, Southeast Kalimantan. – *J. SE Asian Earth Sci.,* **2**, 15-22.