Docking and post-docking tectonics in the southern Philippines

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Docking and post-docking escape tectonics in the southern Philippines

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Abstract: The structure of the Philippine archipelago results from the juxtaposition, between the Late Miocene and the present, of a volcanic belt against fragments of the Eurasian margin and associated marginal basins. The southern Philippines offers the opportunity of studying the mechanics of the deformation from active contraction to a more complex post-docking setting. The docking period is characterized by a compression which began during the early Late Miocene in the central Philippines and has been recently studied in the island of Mindanao. There, deformation initiated in the Late Miocene–Early Pliocene on a NW-trending wrench zone, and continued until the Late Pliocene with thrusting on west-verging flats and ramps within the arc and east-verging thrusts within the Sangihe forearc. This deformation is still active to the south in the Molucca Sea. The post-docking period began in the Early Pleistocene in northern Mindanao and is represented by a new geodynamic framework with a paired subduction zone and strike-slip fault. However, convergence is still active in the Manila and the Negros trenches, although the Philippine fault is not offset. Large wrench faults, which reactivate the ramp faults of the collision stage, transfer strain from the Philippine fault to the Manila and Negros trenches. These observations imply active intra-arc extension and fragmentation within the Philippine mobile belt.

The Philippine archipelago is composed of fragments of the Eurasian margin, which have been rifted away from mainland Eurasia (Fig. 1), and a large volcanic belt, referred to hereafter as the Philippine arc, whose history is linked to that of the Philippine plate. The juxtaposition of the Philippine arc against the margin occurred during the late Neogene but in detail varies from north to south. The tectonic features of the collision include strike-slip faults and thrust tectonics. The post-collision setting involves two subduction zones of opposite polarity which define beween them a varied assemblage of continental, older volcanic and oceanic crust fragments upon which the active volcanic arcs are built (Cardwell *et al.* 1980; Lewis & Hayes 1984; Fig. 1).

The intra-oceanic belt is built upon an Eocene–Oligocene volcanic arc and is in tectonic contact with the Eurasian margin by means of subduction zones in front of the marginal basins and by means of collision zones in front of the continental fragments. The subduction zones are arched toward the marginal basins and anchored at the collision zones (Fig. 1). The collision zones are from north to south: the Taiwan area (Davis *et al.* 1983; Barrier 1985; Pelletier *et al.* 1985), the Mindoro–Panay collision zone (Rangin *et al.* 1985; Marchadier & Rangin 1990), and the Mindanao collision zone (Moore & Silver 1983; Hawkins *et al.* 1985; Mitchell *et al.* 1986; Pubellier *et al.* 1991, 1994). The re-entry zones within the belt imply active convergence at the Manila, Negros, and Sulu trenches. However, the Philippine fault does not respect such geometry. The elongated Philippine mobile belt is traversed by the 1200 km long left-lateral Philippine fault which roughly parallels the Philippine trench (Willis 1937; Allen 1962; Aurelio *et al.* 1991; Barrier *et al.* 1991). It has been demonstrated that the onset of movement on the Philippine fault post-dates the arc–continent collision in the northern Philippines (Pinet & Stephan 1990; Ringenbach 1992), in the central Philippines (Aurelio *et al.* 1991; Aurelio 1992), and in Mindanao (Pubellier *et al.* 1991, 1994; Quebral *et al.* 1995).

In addition, active extensional tectonics have been documented in various parts of the Philippines (Fig. 1). Several basins have been described in the island of Luzon, some of which are not directly linked with motion along the the Philippine fault. Some extensional lineaments, such as the Macolod Corridor (Fig. 1), are still controversial. Extension also occurs in the Visayas (central Philippines) controlled by faults which parallel the fold axes.

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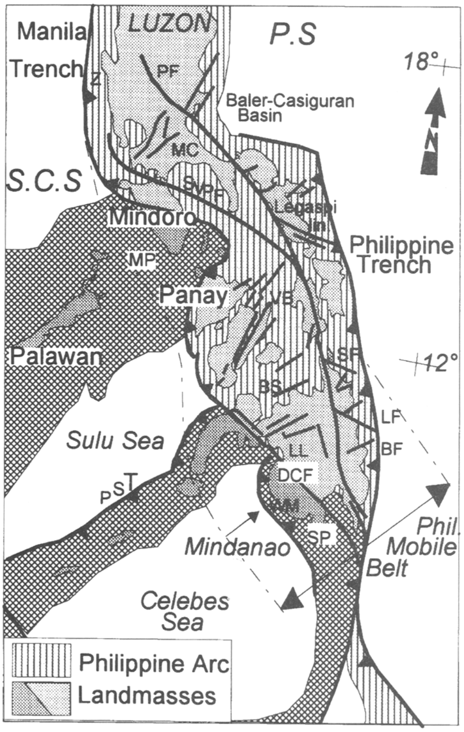

Fig. 1. Geodynamic setting of the plate boundary between the Philippine arc and the Eurasian margin, and major extensional zones of the Philippine Mobile Belt. Map distinguishes kinds of faults (thick lines for subduction and strike-slip, thin lines for normal faults) and nature of lithosphere (see key). Lithosphere is classified as continental margin (cross-hatching), intra-oceanic volcanic arc (fine stipple) or marginal basin floored by oceanic crust (blank). Labelled tectonic units are: West Mindanao continental block (WM), Palawan continental block (PB), Palawan–Sulu trenches (PST), Sulu arc continental block (SA), SVPF; Sibuyan–Verde Passage fault (SVPF), Daguma Cotabato fault (DCF), Saranggani Peninsula block (SP), Zambales Massif block of oceanic crust material (Z). South China Sea (SCS), Philippine Sea Basin (PSB), Siargao fault (SF), Lianga fault (LF), Bislig fault (BF), Macolod Corridor (MC), Visayan basins (VB), Bohol Sea (BS), Lanao Lake (LL).

A recent marine survey also indicated an active basin floored with oceanic crust SE of Marinduque (Sarewitz & Lewis 1991).

In this paper, the deformation associated with the docking of the Philippine arc is distinguished from that associated with the post-docking setting. It is shown that most of this late deformation is extensional on the basis of field and an escape model is proposed for the deformation of the mobile belt of the Philippines (Fig. 2).

The docking phase

The Neogene collisional setting involves large strike-slip fault zones (Karig *et al.* 1986; Sarewitz & Karig 1986), and local collision zones (Holloway 1982; Bachman *et al.* 1983; Haeck & Karig 1985; Hawkins *et al.* 1985; Rangin *et al.* 1985; Marchadier & Rangin 1990; Pinet & Stephan 1990; Pubellier *et al.* 1991), depending on whether the Philippine arc was in contact with a continental fragment or oceanic crust. In Mindanao, wrenching began at the Late Miocene–Early Pliocene boundary as a NW trending wrench zone, and extended untill the Late Pliocene with movement on west-verging flats and ramps within the arc and east-verging thrusts within the Sangihe forearc.

Mindanao: wrenching and thrust tectonics

No detailed investigation of collision tectonics has previously been conducted in Mindanao because the recognition and the dating of the tectonic elements is complex and the access is difficult. In addition, Miocene compressional features (Fig. 2) were overprinted by Pleistocene to recent extension and wrenching. A synthesis of the results of the recent tectonics is compiled on the neotectonic map of Mindanao (Pubellier *et al.* 1993; simplified as Fig. 2).

Deformation began by the latest Miocene in western Mindanao and is marked by wrench faulting and folding (Fig. 3, top). The westernmost part of Mindanao (west Cotabato Basin and Illana Bay) underwent deformation on parallel NW-trending fault-bounded elongated pressure ridges. These ridges are known from seismic lines (Fig. 3, bottom) and their surface geometry was deduced from drainage anomaly mapping (Deffontaines *et al.* 1993; Pubellier *et al.* 1994). Some lie along the eastern flank of the Daguma Ridge near Lake Sebu or emerge from the Quaternary sediments of the basin (Roxas Ranges). Synthetic cross-sections drawn from a compilation of unpublished seismic lines by Letouzey *et al.* (1987) show that Pliocene reflectors unconformably overlie these structures, which are associated with west-dipping low angle faults. Their '*en echelon*' geometry also suggests a strike-slip environment which affected Upper Miocene to Lower Pliocene strata (Pubellier *et al.* 1991). The largest of these ridges is buried and known from drilling and seismic lines only (unpublished PNOC report 1986). Seismic lines show NW–SE faults with jogs resulting from a combination of reverse and strike-slip faults trending NW. Correlation of seismic lines show these structures to be at 90°to the basement reverse faults, and to connect with the Flecha Peninsula of northern Zamboanga. Reflection seismic data (Fig. 3)

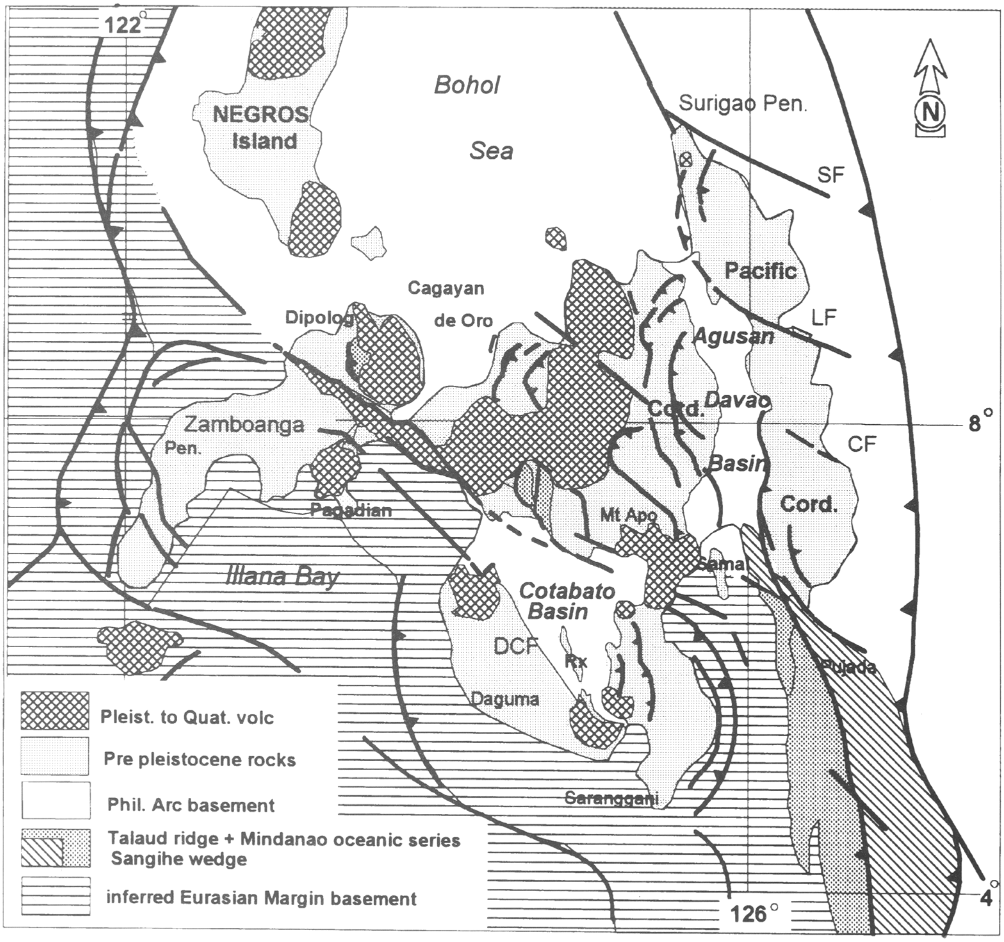

Fig. 2. Structural sketch map of the Neogene compressional features of Mindanao island prior to the Pleistocene.

indicate that the deformation is sealed by thick Pliocene and possibly uppermost Miocene sediments. In the field, the Opol Formation, whose base is dated as uppermost Miocene (NN11) by nannoplankton (C. Muller, pers. comm. 1994), is unconformable on the basement, although substantially uplifted and affected by more recent (Late Pliocene) open folds.

By the end of the Pliocene, deformation was more intense in central Mindanao. It is marked by folds axes and thrusts whose orientation varies from N–S to ENE (080°), which die out along-strike as they branch into NW-trending faults (Figs 2 & 4). South and west of Cagayan de Oro city, overturned folds and large thrusts have brought the metamorphics and the ultramafic complex with its overlying arc series onto upper Oligocene or Lower Miocene foraminifera-bearing limestones. The Opol Formation, dated at its base as uppermost Miocene (NN11, Pubellier *et al.* 1991), is unconformable on these structures. The northern part of the Cotabato Basin also includes two narrow ranges (north of Pigkawayan) composed of peridotites, pillows and radiolarites where similar structural observations were made (Figs 2 & 4). The folds are sealed by a sequence of rocks including columnar basalt flows and thick tuffs, which have yielded K–Ar ages of 2 Ma (Sajona *et al.* 1993). This papwe therefore separates a NW–SE strip (Fig. 4) with very few outcrops sandwiched between the Philippine arc and the continental margin on which the Sangihe forearc rests. This central strip is interpreted as a zone of wrench deformation along-strike from the Molucca Sea collision complex, deduced from the bathymetry observed during the MODEC cruise (Rangin *et al.* 1995), and

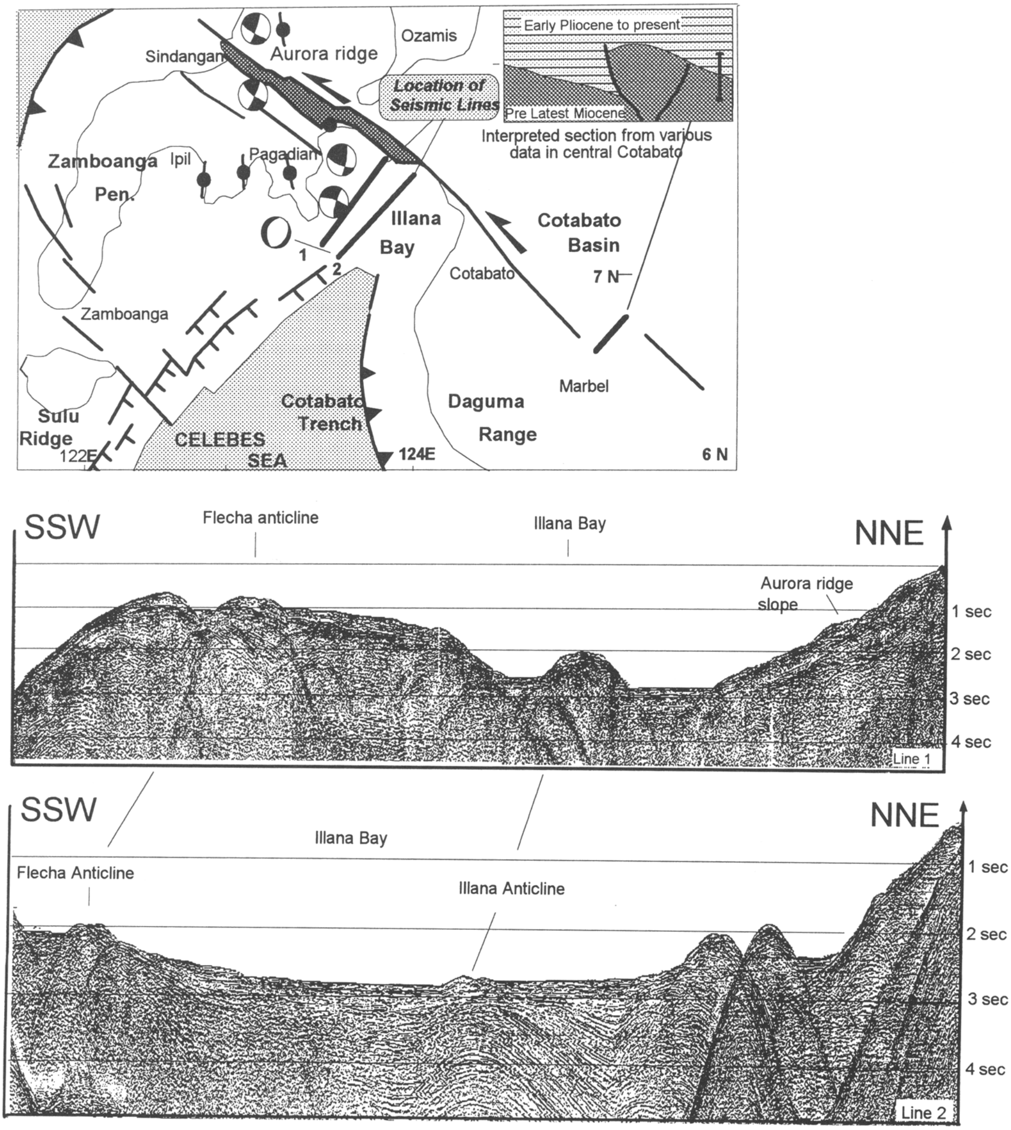

Fig. 3. Structural map of western Mindanao and seismic lines within the Illana Bay. Similar features in the Cotabato basin are deduced from Letouzey *et al.* (1987) and drainage anomalies (Pubellier *et al.* (1994). Upper map also shows the Aurora ridge (dark pattern), σ_3 values from fault slip analyses in Pleistocene sediments and focal mechanisms from shallow earthquakes.

with rare outcrops of ophiolites and melanges in central Mindanao (Fig. 2).

Ramp faults are associated with this event, the largest of which is the 50 km long left-lateral Tagoloan fault (Figs. 2 & 4), SE of Cagayan de Oro, but several others appear on Landsat images. The Tagoloan fault affects affects the Upper Miocene to at least Upper Pliocene clastic Opol Formation overlying serpentinized peridotites. The fault is capped by 50 m of columnar basalts. The flows were not dated in this area but samples from the huge volcanic field of central Mindanao yield ages of 0.4 Ma and younger (Sajona *et al.* 1993) and the volcanic ridge of northern Zamboanga is intercalated with lower Pleistocene (NN19) marine sediments. It is suggested that the wrench tectonic phase was coeval with the thrusting in northern Mindanao and is of late Pliocene age. The most

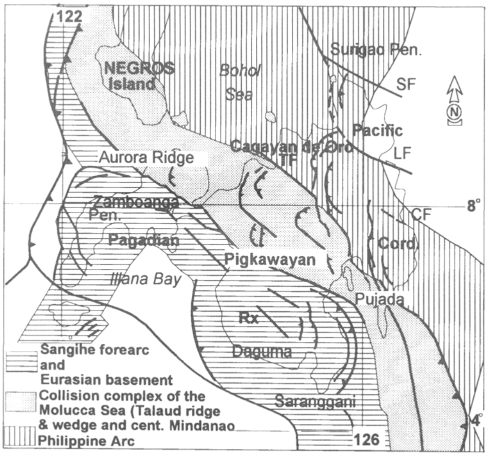

Fig. 4. Schematic map of the structural units of the transfer zone during the Pliocene. Folds and thrusts are east-verging in the Sangihe forearc and the margin (SW), and are west-verging in the Philippine arc (horizontal pattern) and the central strip (dark pattern). The central strip is interpreted as the extension of the Molucca Sea collision complex deduced from the bathymetry of the MODEC cruise (Rangin *et al.* 1995) and with scarce outcrops of ophiolites and melanges in central Mindanao.

accurate dating of this Late Pliocene compressional event comes from shallow marine sediments of the Agusan-Davao basin in eastern Mindanao. There, tight 050° to 070°-trending folds affect Middle Pliocene (NN15) to Upper Pliocene (NN16) clays and greywackes. These folds are sealed by Upper Pleistocene (NN20–21) sediments (Quebral *et al.* 1995). To the west, the basin rests on the eastern side of the Central Cordillera, which in an assymetric west-verging thrust-anticline.

In the southern part of eastern Mindanao, serial seismic lines onland and offshore of Davao Gulf (Quebral *et al.* 1995; Rangin *et al.* 1995) show the ridges to be very young asymmetrical anticlines, most of them being bounded on the eastern side by reverse faults. Unconformable reflectors overlying the folds are rare except for locally seismically transparent detrital fans eroded by channels. These anticlinal structures are very tight east and north of Samal island which is formed by the emergence of such a ridge.

Only the southwestern part of Mindanao shows a difference in tectonic style because duplexes are thrust to the east (Fig. 4). The most remarkable structure is the Saranggani Peninsula which is an anticline cored with middle Miocene limestone underlying a thick unit of volcanic and volcaniclastic upper Miocene rocks (whole rock K–Ar dating, Pubellier *et al.* 1991). This series is overlain by a sandy and marly unit whose base is of lower Pliocene age and whose upper section includes upper Pleistocene sediments. This again indicates that the beginning of the deformation began by the Late Miocene–Early Pliocene boundary. According to Quebral *et al.* (1995), the Pujada Peninsula at the southernmost end of the Pacific Cordillera, is one of these east-verging thrusts. These interpretations were later confirmed by the MODEC cruise (Rangin *et al.* 1995).

Luzon: Middle Miocene compression

Coarse upper Oligocene–lower Miocene clastic sediments (Klondyke Formation) are interpreted to have come from mass wasting along the arc and are covered by upper Lower Miocene to lower Middle Miocene platform limestones. This is interpreted to record a tectonic event related to the early accretion of the Philippine arc against the Eurasian margin with sedimentary detritus carried as far as Ta'iwan (Florendo 1994; Pelletier *et al.* 1985). The tectonic features of this event are folds, thrusts, and poorly understood strike-slip faults in the Philippine arc as in Catanduanes island (Geary & Kay 1989) or in the Zambales massif (westernmost Luzon; Hawkins & Evans 1983; Karig 1983). Stratigraphic evidence of strike-slip motion is found within upper Middle Miocene rocks (Maleterre *et al.* 1988; Pinet & Stephan 1990). However, these faults reactivated previous structures that controlled sedimentation during the Oligocene. This contraction, which involved wrenching, was closely followed by a renewal of volcanic activity attributed to the present Manila trench (Defant *et al.* 1990). The second arc started activity by the late Middle Miocene and its products are clearly recorded in sedimentary basins (Ilocos and Cagayan basins) on both sides of the Cordillera (Pinet & Stephan 1990).

NE Visayas and central Visayas: Late Miocene–Early Pliocene accretion

The Visayan archipelago in the central Philippines (Fig. 1) is composed of a Cretaceous to Palaeogene ultramafic, metasedimentary and Eocene to middle Oligocene volcanic and plutonic basement (Irving 1950; Gervasio 1966). Most important is the presence of an unconformity at the middle and upper Miocene boundary (9 Ma; Rangin *et al.* 1991). This unconformity is typical of the central Philippines; it is known in Palawan (Fricaud 1984), and Panay-Mindoro (Rangin *et al.* 1985; Marchadier & Rangin 1990). It was also found in oil wells in the Bantayan graben NW of Cebu. The upper Miocene–Pliocene calcareous Carcar Formation is unconformable on older rocks, although moderately folded.

Fault set analyses in Bondoc, Masbate and Leyte indicate that stress tensors correspondingly shifted from a collision-related direction to a strike-slip-related one between the latest Miocene to the Pliocene (Aurelio *et al.* 1991; Aurelio 1992). This shift in tectonic regime is best manifested in Bondoc Peninsula, where collisional σ_1 orientations are generally N–S (incompatible with left-lateral motion along the Philippine Fault) while the Philippine Fault s1 orientations are between 050 and 080°. It should however be noted that traces of older strike-slip faults can be found in the region, the most conspicuous of which are in Mariduque island (Fig. 5). Here, a NNW–SSE trending left-lateral fault affects Middle Miocene sedimentary formations but is sealed by Plio-Pleistocene formations. Furthermore, a Quaternary volcano built on the southern tip of the island does not appear to be truncated by the strike-slip fault (Aurelio 1992).

The post-docking phase: Late Pliocene to Present strike-slip, extension and escape

In contrast, and with the exception of the active thrusts described in Zamboanga and in NW Mindoro, most of the active deformation of the Philippine Mobile Belt is presently extensional and strike-slip (Fig. 1). Rather than a classical post-orogenic collapse in the sense of Dewey (1988), the extensional features observed seem closely linked to the tectonic setting of oblique convergence and the geometry of the suture zone. In addition to the pull-apart basins associated with the Philippine fault, two fabrics are observed in the the active grabens on either side of the Philippine fault. A set of extensional basins situated within the strip between the Philippine fault and the Philippine trench is attributed to a process referred to hereafter as a post-docking dispersion since it removes fragments of the Philippine arc (Figs 6 & 7). On the other hand, grabens located in the middle of the Philippine arc seem to be controlled by the subduction zones in front of the marginal basins to the west, which generate differential displacements inside the belt, a process referred to hereafter as lithospheric escape.

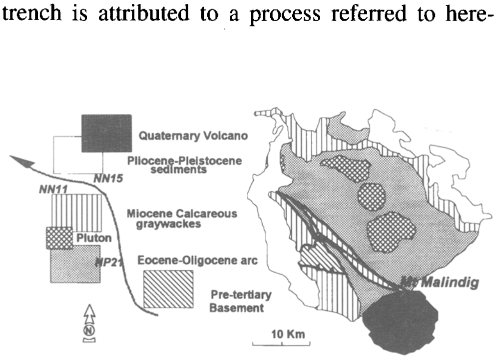

Fig. 5. Structural map of Marinduque island showing the Late Miocene left-lateral wrench fault zone (modified from Aurelio 1992).

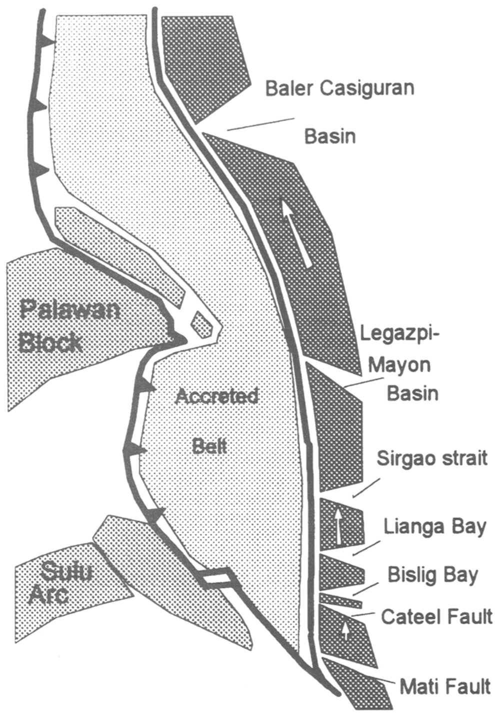

Fig. 6. Sketch diagram showing the dispersion of the tectonic sliver between the Philippine fault and the Philippine trench, as a result of the southward migration of the trench–fault pair.

Post-docking dispersion

Dispersion between the Philippine fault and the Philippine trench (Figs 6 & 7) results from the oblique convergence along the trench and the southward propagating trench–fault system. Strike-slip motion along the Philippine fault separated and defined a strip of volcanic material between the the Philippine fault and the trench (Barrier *et al.* 1991). Field data show that the fault is older in the northern Philippines (Pinet & Stephan 1990) than it is in the central (Aurelio *et al.* 1991; Aurelio 1992) and the southern Philippines (Quebral *et al.* 1995). This implies that the total offset of the fault increases from south to north in the manner

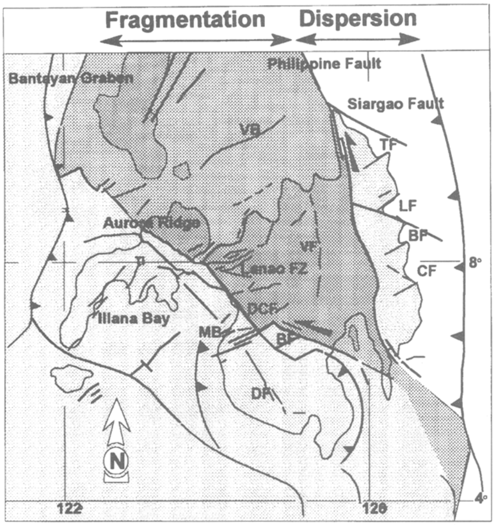

Fig. 7. Simplified map of the major post-early Pleistocene extensional faults of Mindanao and the two main strike-slip fault zones, with labels. Light pattern for the Eurasian margin and dark pattern for the accreted Philippine arc undergoing dispersion and fragmentation (see text). Visayan basins (VB), Tandag fault (TF), Lianga fault (LF), Bislig fault (BF), Cateel fault (CF), Daguma fault (DF), Cotabato fault (DCF), Valencia (East Cotabato fault, VF).

described by McCaffrey (1992) for the forearc of Sumatra. Differential displacement of discrete blocks due to a southward decrease in the total displacement along the Philippine fault accounts for extension in the region (Fig. 6).

Lianga and Bislig Bays in Mindanao

The northern Pacific Cordillera (Figs 1, 2 & 7) is considered to be a large ramp anticline guided along its southern limit by the NNW–SSE Lianga fault. During the early deformation which affected upper Pliocene (NN15–16) rocks, the Lianga fault acted as a left-lateral strike-slip fault. However, truncation of the northern Pacific Cordillera by the Philippine fault and its subsequent northward strike-slip displacement resulted in the reactivation of the Lianga fault as a normal fault (Fig. 7). The youngest slickensides observed in upper Pleistocene (NN20–21) marls therefore correspond to normal faulting. A NNE–SSW structural fabric, observed throughout the Pacific Cordillera, strongly influences the coastline of eastern Mindanao (Bislig, Cateel Bays, Fig. 7). Bislig Bay, for example, is interpreted as a half-graben. Sediments along its northern coast dip gently towards the bay; whereas its southern coastline is controlled by a major NNE–SSW escarpment which exposes the Oligocene volcanic basement of the cordillera. Between the Lianga fault and Bislig Bay is a carbonate platform whose morphology is interrupted by normal faults expressed as north-facing escarpments with NNE–SSW and NNW–SSE segments which affect rocks as young as Late Pleistocene.

Northern Philippines

Several other areas in the Philippines display features which are compatible with this mechanism. The Baler–Casiguran basin (Fig. 8) is located along the southern coast of the Sierra Madre of Luzon, and was studied on the basis of seismic lines between the San Ildefonso Ridge and the Casiguran Coast by Ringenbach *et al.* (1993). The elongated graben is considered to have undergone minor right-lateral slip according to Ringenbach *et al.* (1993) and therefore to be the result of oblique rifting. However, the overall geometry on the seismic lines is consistent with a basically extentional motion. The active faulting reactivated pre-existing 050°-trending basement faults.

The Legaspi Lineament (Fig. 8) is a left-lateral strike-slip fault trending WNW–ESE in the southeastern Luzon area. It intersects both the Philippine Fault in the Ragay Gulf and the Philippine trench east of Catanduanes Island. Aside from displacing the Philippine trench left-laterally by about 40 km, its activity is demonstrated by the occurrence of earthquakes on its southeastern segment. Onshore, the Legaspi Lineament is responsible for the formation of an elongated depression represented by Lake Bato, probably situated in a local pull-apart setting in a restricted segment of the lineament. It also appears to partly control the activity of Mayon Volcano, the most active of all the Philippine volcanoes. Into the Ragay Gulf, the lineament occurs as a steeply SW-dipping fault cutting through the entirety of the sedimentary fill (seismic profile). Simultaneous activity along the Legaspi Lineament and the Philippine fault gives rise to the elongated geometry of the Ragay Gulf depression (Fig. 8).

Post-docking escape

Extensional transfer faults

The term transfer faults is used for large wrench faults which connect the collision zone or the Philippine fault to the intraplate deformation front (e.g. the Negros and Manila trenches, or the Mindoro–Panay thrusts). Geologic data and seismic

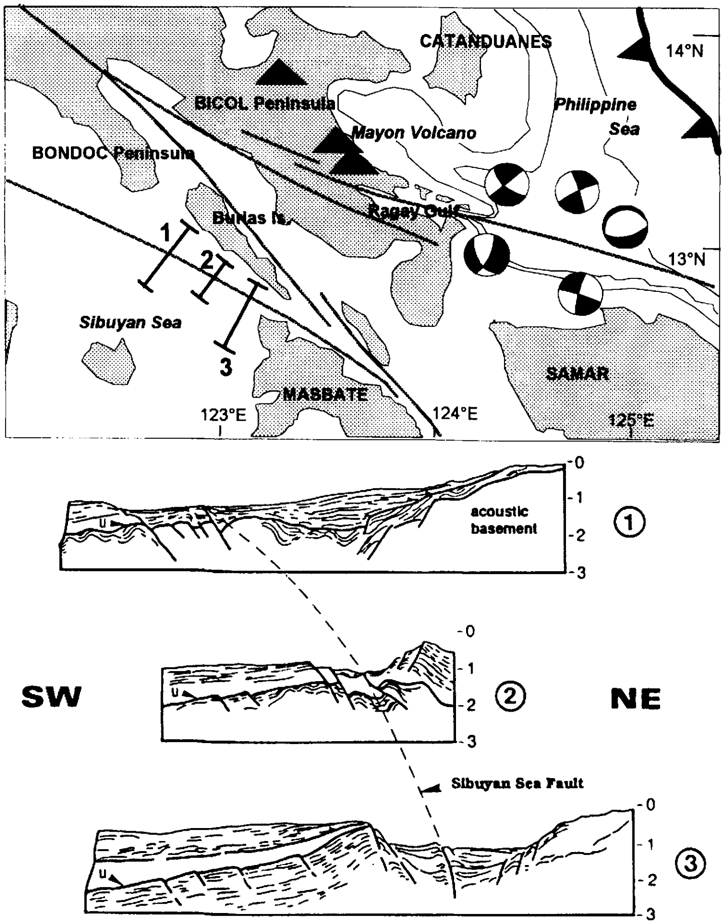

Fig. 8. Structure of the Legazpi Lineament and location of seismic lines at the termination of the Sibuyan–Verde Passage fault with major focal mechanisms.

lines across these faults reveal that an extensional component is important (Figs 1 & 7).

Cotabato fault and Aurora volcanic ridge

This ridge is located right on the suture zone and is presently an elongated bayonet-shaped horst which obliquely separates northern Illana Bay from the southern Dipolog basins. The left-lateral motion on the bordering NW faults is indicated by several focal mechanisms determined on shallow earthquakes (Fig. 3). Microtectonic studies along the Sindangan–Cotabato–Daguma lineament clearly indicate E–W compression generating left-lateral faulting. Microtectonic measurements on Pleistocene sediments and overlying basalts indicate N–S extension. E–W normal faults accommodate the strike-slip motion and have created pull-apart basins west of Aurora in northern Zamboanga.

Daguma fault

Both edges of the Cotabato Basin are fault-bounded with tilted blocks (Fig. 7). On the eastern side, a N–S diffuse fault zone exists in central Mindanao. Tilted blocks and small volcanic cones, some of them dated between 1.15 and 0.25 Ma (K–Ar), occur there and underline normal faults which are thought to reactivate the short limb of the Central Cordillera ramp anticline. On the western side, Pliocene thrust-cored folds orientated NW (N130°) along the Daguma range have been reactivated as normal faults with considerable offset southeast of Cotabato (Daguma or Tiruray fault). Some of these normal faults cross-cut the Parker volcano in southern Kudarat Province and cut the Quaternary reefal terrace south of General Santos. Although this extensional pattern can be related to backarc extension behind the Cotabato trench, the authors favour a wrench-related interpretation following the accretion.

Other occurrences in the central and northern Philippines

Gabaldon Basin (Ringenbach 1992; Ringenbach *et al.* 1993) is a Pliocene basin controlled by the Cascades fault zone which is presently associated with the Philippine fault in central Luzon (Fig. 9). The basin in its present stage is represented by fluvial deposits of Pliocene age which post-date the folded lower Miocene sediments. The present configuration is a NW–SE elongated graben bounded by listric faults as indicated by tilted terrace deposits on the basin's southern rim. This basin has been interpreted to be the result of movement at a releasing bend of the Philippine fault (Ringenbach *et al.* 1993), but it also fits well the model of an escape of the Baguio–Zambales block from a fixed Philippine fault (Fig. 10). Similar observations were made by Ringenbach (1992) in the Pantabangan–Carranglan basins which are marked by the deposition of middle Miocene sequences and presently undergo transtension as well as extension with subsidence.

Presently, the western-central Philippine area is characterized by the presence of NW-trending strike-slip faults such as the Sibuyan Sea Verde Passage faults (Fig. 8). To the south, near Masbate Island, the Sibuyan Sea fault trends WNW–ESE and cuts across the southeastern extension of the Marinduque Basin (Sibuyan Sea) filled with recent sedimentary deposits. Seismic reflection profiles clearly indicate extensional structures best exemplified by tilted blocks and graben structures. Recent activity along this fault is manifested both in terms of minor earthquakes (magnitude < 5 Mb) and variations in stress orientations in Masbate where the fault intersects the Philippine fault (Aurelio 1992).

To the NW, the Verde Passage fault trends in the same direction as the Sibuyan Sea fault as it passes between Mindoro Island and Luzon towards the Manila trench. Its termination into the trench is,

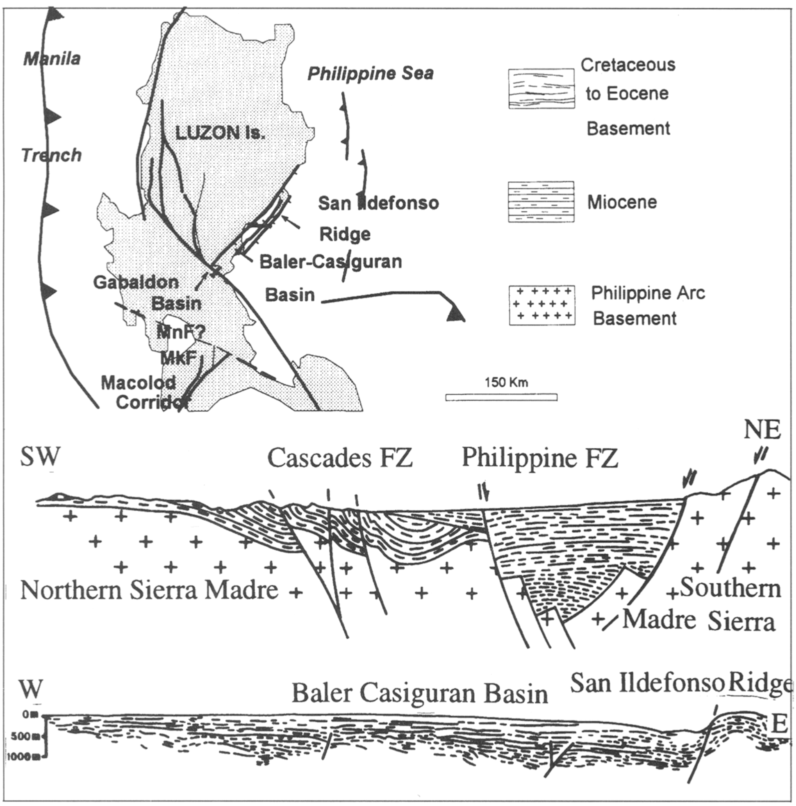

Fig. 9. Location and structure of the Baler Casiguran Basin of Luzon and the Mocalod corridor modified from Ringenbach (1992) and Wolfe & Self (1983). Manila fault (MnF), Marikina fault (MkF).

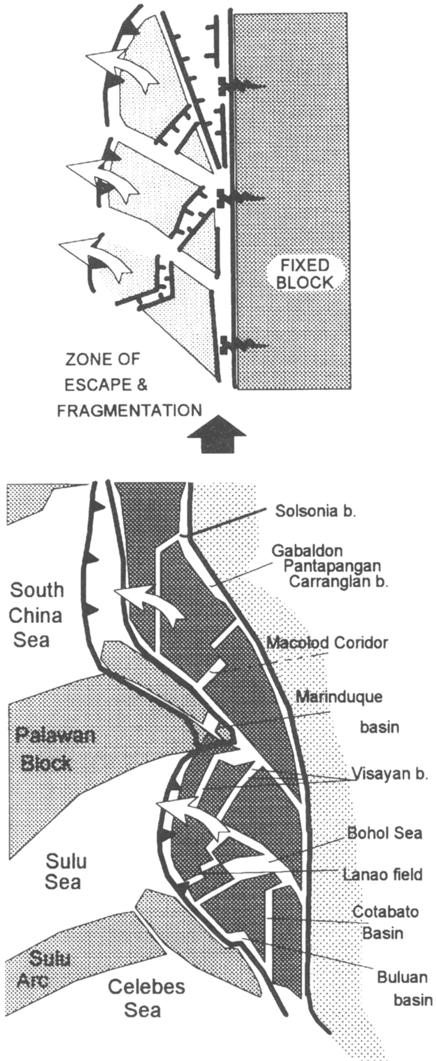

Fig. 10. Sketch diagram and map showing fragmentation and escape west of the Philippine fault due to the trench pull in front of the marginal basins.

however, unclear. It appears to die out into the accretionary prism which is well developed at this latitude as observed during the POP2 cruise (Rangin *et al.* 1988). Seismically, minor to moderate earthquakes are known to have occurred along this structure for the past 100 years (Aurelio 1992). Its connection or non-connection with the Sibuyan Sea fault, however, still remains to be understood. Bathymetrically, these two strike-slip faults are in fact linked by the Sibuyan Sea–Marinduque Basin.

Extension resulting from subduction at the Negros and Manila trenches

Lanao extensional field, Bohol Sea and Visayan basins

Extension almost parallel to the convergence direction was first observed by Rangin *et al.* (1989) in the central Philippines where a radial set of graben post-date the Late Miocene–Early Pliocene docking phase and tend to parallel the Negros trench (Figs 1 & 7). The basins were explored for oil (Glocke 1980) and some of them are filled with up to 6 km of Miocene to Recent sediments. Normal faults of the grabens reactivate the short limbs of the folds and affect the Pliocene to Pleistocene Carcar Formation (Rangin *et al.* 1989). The southernmost basin is the Bohol (or Mindanao) Sea which is a poorly known basin of 2.5 s reflection seismic floor with 0.5 s mean sediment thickness (Hamilton 1979). In central Mindanao, the 200 km long Lanao volcanic field is a huge plateau situated around Lanao lake. Nb-enriched calc-alkaline and potassic lava samples have been dated between 2.31 and 0.29 Ma (Sajona *et al.* 1993) in this area. Extension is marked by 20 to 50 km long arcuate normal faults (Ranneft *et al.* 1960) which appear on Landsat images and control the geometry of the lake. Although the faults do affect the volcanic aprons, the active or dormant volcanic cones are aligned in the same direction, as pointed out by Hamilton (1979). The normal faults connect with the active transtensile Cotabato fault and Aurora ridge as part of a single tectonic system with σ_3 striking N–S (Pubellier *et al.* 1994). Symmetrically, on the opposite side of the Cotabato fault, an extensional zone affects the Quaternary volcanics and the Quaternary reefal terraces of Mt Blick in the northern Daguma Range. The 050°-trending normal fault provide the structural control for the tiny Bongo island.

Macolod corridor

The Macolod Corridor (Figs 1 & 8) is a complex graben structure which has been interpreted as a pull-apart basin characterized by the occurrence of intense volcanism (Defant *et al.* 1990). However, the bounding faults are not clearly identified and the mechanism debatable (F^rster *et al.* 1988). Wolfe & Self (1983) suspected that this feature may be a link between the northwestern shelf of Palawan and the Philippine fault of central Luzon. Regardless, the distribution and abundance of volcanoes suggest lithospheric fractures striking mainly NE–SW but also NW–SE. The large Taal volcanic centre is located at the intersection of these directions. Clearly the Macolod corridor accommodates a differential displacement between the central and northern parts of Luzon, in response to forces induced between the Manila trench and colliding Benham Plateau, and the encroachment of the southern part of Luzon on the Palawan Block (Fig. 1).

Marinduque Basin

Recently, incipient sea floor spreading has been documented in the central Philippines (Sarewitz & Lewis 1991), in connection with a wrench environment. The Marinduque Basin, located east of Marinduque Island and Bondoc Peninsula, has a NW–SE bathymetric axis. Offshore data, however, suggest the presence of an E–W trending bathymetric ridge which, according to Sarewitz & Lewis (1991), might correspond to a N–S spreading axis, based upon the observation that the ridge is made up of volcanic rocks whose magnetic signature is comparable to that of rocks produced during oceanic accretion. In this model, the system, now inactive, could have operated along N–S trending strike-slip zones. Such structures are presently observed as thrust faults lining up the western edges of the Bondoc Peninsula compressive ridge, associated with the Philippine fault. In view of its location between the Sibuyan Sea fault and the Verde Passage fault, it is tempting to argue that the Marinduque Basin is an extensional relay zone between strike-slip faults.

Interpretation and discussion

One of the best recorded Tertiary tectonic events in the Philippines is the collision of the continental block of north Palawan with island arc units in the central Philippines. Manifestations of this collisional event are readily observable in the islands of northern Palawan, Mindoro, Panay and other neighboring islands (McCabe *et al.* 1983; Rangin *et al.* 1985; Mitchell *et al.* 1986), and recently mapped in Mindanao (Pubellier *et al.* 1993, 1994; Quebral *et al.* 1995). Folds and thrusts produced by this event are associated with lateral ramps striking NW–SE. It is believed that the lateral ramps are part of a large transfer zone with follows the Eurasian margin geometry and truncates the Molucca Sea (Rangin *et al.* 1995). In Mindanao, this wrench tectonic phase began at the Late Miocene–Early Pliocene boundary and lasted until the end of the Pliocene resulting in deformation of the Agusan–Davao Basin. In the northern Philippines this event is dated as Middle Miocene.

The post-docking period is now represented by a new geodynamic framework with paired subduction zones and strike-slip faults, due to continued convergence at the Manila and Negros trenches. Large transfer wrench faults (Fig. 4), which reactivate the lateral ramps of the collision stage, transfer strain from the Philippine fault to the Manila and Negros trenches. If the Philippine Mobile Belt east of the Philippine Fault is considered to be fixed on the basis that the 1200 km long Philippine fault is not offset nor disrupted by the transfer faults, it can be inferred that the western half is undergoing extension driven by slab-pull at the Manila and Negros trenches. In response to the extension, this part of the belt is fragmented and the fragments tend to escape toward the marginal basins. The escape concept, which refers to the motion of a package of rocks towards a free edge within a compressional environment, has been much described as a by-product of frontal collision (e.g. the Indochina block: Tapponnier *et al.* 1982; Davy and Cobbold 1988; or the Alps: Ratschbacher *et al.* 1991), or from the combination of movement of the Anatolian block triggered by Arabian–Eurasian convergence and extensional forces due to slab-pull at the Aegean trench (McKenzie 1972; Sengör *et al.* 1985). This paper proposes that oblique convergence along an irregular continental buttress is also a likely setting for escape of continental fragments. The escape motion affects the continental fragments dragged by the northward motion of the Philippine plate to a smaller extent.

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