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Geological evolution of the Southern Philippines

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Abstract: The Philippines is a collage of geologic terranes of disparate origin, including at least one continental fragment. It has been characterized as an arc aggregate by Karig (1975).

Tectonically, a two-fold division has long been recognised, a NNW-SSE trending sigmoid mobile (seismic) belt being separated from a stable (aseismic) region around the Sulu Sea in the southwest (Gervasio, 1966). The mobile belt is margined, both to east and west, by discontinuous subduction zones and it seems that a similar situation has existed through much of Cenozoic time, the locus of subduction expanding, contracting and "flipping" across the zone.

In the southern Philippines an ancient arc crust has been dated as Cretaceous at Cebu and evidently extends at least into Bohol and central Mindanao. By late Eocene times it is thought that an east-dipping subduction zone existed on the west side of the ancestral Philippine islands, with a magmatic arc extending from east Panay through southwest Negros, probably into the Cotabato area of southern Mindanao.

Emplacement of an ophiolite in western Panay is thought to have taken place around Late Oligocene times and may have been related to impingement of the Palawan–Busuanga microcontinent on the western side of the Panay–Negros arc. It is considered that in the southern Philippines the focus of subduction then flipped to the east side where westward subduction of oceanic crust occurred beneath the central Mindanao–Sangihe arc (Cardwell *et al.*, 1980).

NW-SE trending transcurrent faulting in Negros and Cotabato (southern Mindanao) may be related to the opening of the Sulu and Celebes seas (Oligocene to Miocene). These movements apparently caused the Cotabato block to be displaced southeastwards, along the "Mindanao lineament" (Gervasio, 1966) across the axis of the central Mindanao arc. Recurvature of the Sarangani Peninsula may be part of the same process. Continuing westward subduction beneath the Sangihe-central Mindanao arc in the Pliocene, however, produced a line of volcanoes, with a median rift valley superimposed upon the NW-SE Cotabato trend.

East Mindanao is a northward extension of the Talaud arc of Indonesia which lies above a subduction zone opposed and in the process of collision with that of Sangihe (Cardwell *et al.*, 1980). It was concluded by these workers that in Mindanao the collision was substantially complete by the Late Miocene. The obliquity of the collision has led to the generation of the Philippine (transcurrent) fault whilst most of the subsequent westward translation of the Philippine Plate has been taken up in the Pliocene—Recent Philippine Trench.

The present writer believes (Burton, 1983), however, that part of the continuing post-collision plate convergence has been accommodated by rejuvenation of the Negros Trench and development of the Cotabato Trench on the west side of the mobile zone, evidently with related volcanism in Negros and possibly also in Zamboanga (west Mindanao).

GENERAL GEOLOGY

The Philippine Islands are mainly composed of Cenozoic rocks (largely volcanic and sedimentary plus a number of quartz-diorite plutons of limited extent). All of the major islands, however, include a "basement", much of which seems to be Cretaceous but which includes rocks ranging in age at least from the Permian up to the Eocene (Fig. 1). Ophiolitic bodies of various dimensions are widely distributed, hinting at a complex structural history.

Modern enquiry into the tectonic evolution of the Philippines begins with Gervasio's (1966) division of the archipelago into a NNE-SSW trending mobile (seismic) belt in the east and a stable (aseismic) region to the SW, around the Sulu Sea. A faulted contact (the "Apo Fracture Zone") was postulated between these two tectonic provinces by De Boer and his colleagues (1980) but Hamilton (1979), Cardwell et al. (1980) and Acharya and Aggarwal (1980) believe rather in an east-dipping subduction zone here, interrupted by the Palawan and Sulu–Zambonaga arcs (Fig. 1). The northern, major, part of this discontinuous Benioff system comprises the Manila Trench. Cardwell and his co-workers (1980) designated the two southern, shorter and shallow sections as the Negros Trench (after Hamilton, 1979) and Cotabato Trench.

The east side of Gervasio's mobile zone is also bordered by a subduction system—more continuous and opposed in dip to that in the west. The major portion of this constitutes the Philippine Trench which, in the Philippine Deep, east of Samar and northern Mindanao attains a depth of 11,518 m. In this vicinity, earthquakes have been recorded down to some 200 km. The feature is some 1400 km long, extending from 3° to 15°N. Northwards from the Philippine Deep sector, the maximum depth of recorded earthquakes decreases to less than 100 km at the northern end of the seismic zone.

It appears that a transform fault separates the Philippine Trench from the East Luzon Trench farther north, wherein the seismic zone is at an even shallower level, reaching a maximum depth of 85 km.

An attractive hypothesis for the origin of the Philippine Islands was proposed by Ben–Avraham and Uyeda (1973) and Ben–Avraham (1978). These workers said that in the Cretaceous the Philippine Archipelago di not aexist and in this area the Pacific Ocean (Kula Plate) was then spreading in a NNW-ly direction from the Kula–Pacific spreading ridge, and possibly from the Philippine ridge. Transform faults are presumed to have paràllelled the spreading direction.

When the spreading direction of the Pacific changed to WNW in Eocene times (43 Ma–Wilson, 1973) subduction zones are thought to have been generated on the sites of some of the transforms (e.g. Kyushu–Palau Ridge and the Philippine Islands).

According to seismic contours adduced by Hamilton (1979) and by Cardwell *et al.* (1980), the subduction zones on either side of the Philippines appear to be converging at depth (Fig. 2). They are probably dual expressions of one fundamental feature (?a former transform) anchored in the mantle. If this interpretation is correct, then it would appear to invalidate much of the massive rotation of the Philippine Islands postulated from palaeomagnetic results by De Boer *et al.* (1980), and Fuller *et al.* (1983) and also proposed by Holloway (1981).

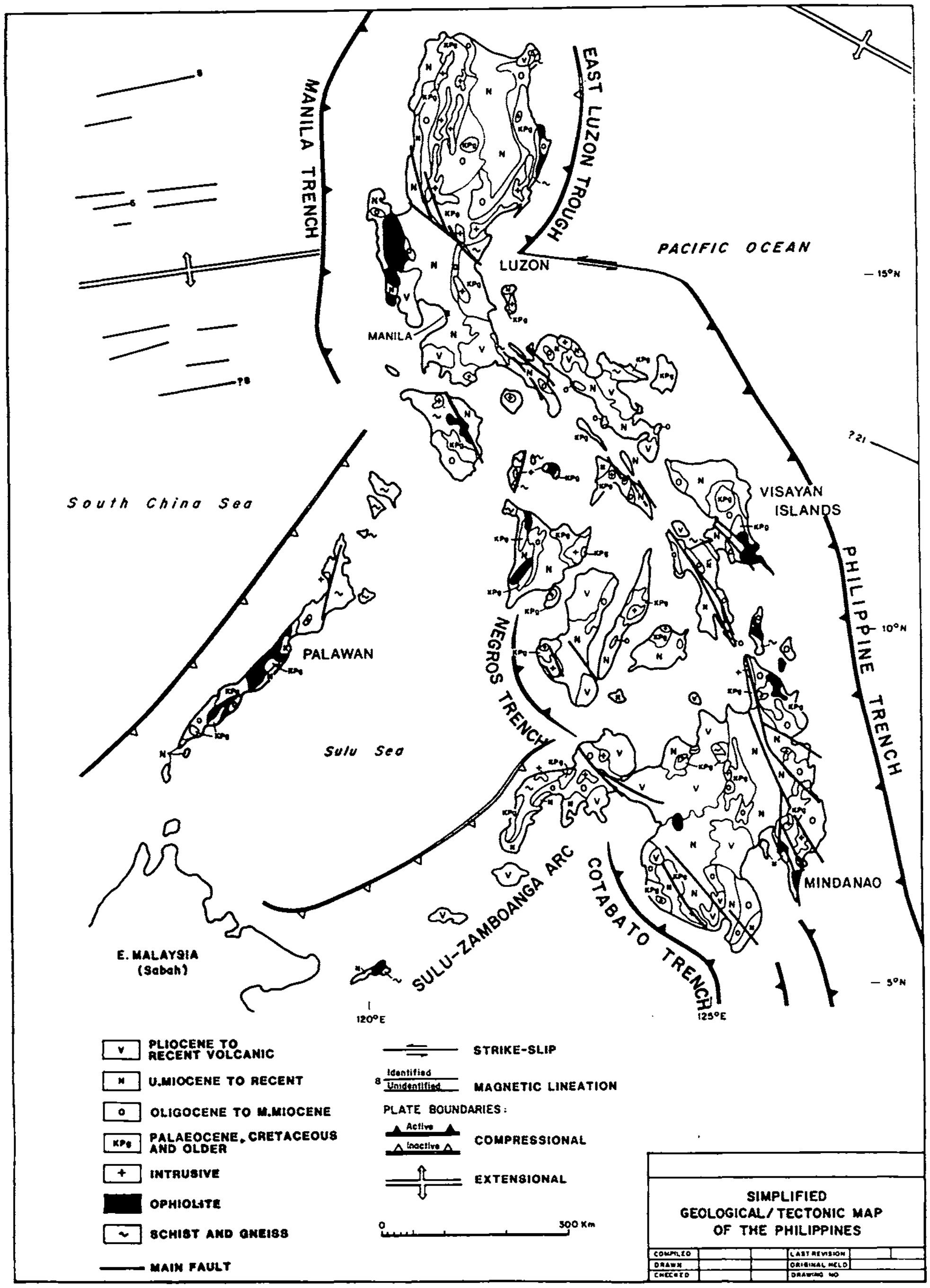

Fig. 1. Simplified geological/tectonic map of the Philippines (Based on Philippine Bureau of Mines and Geosciences, 1982).

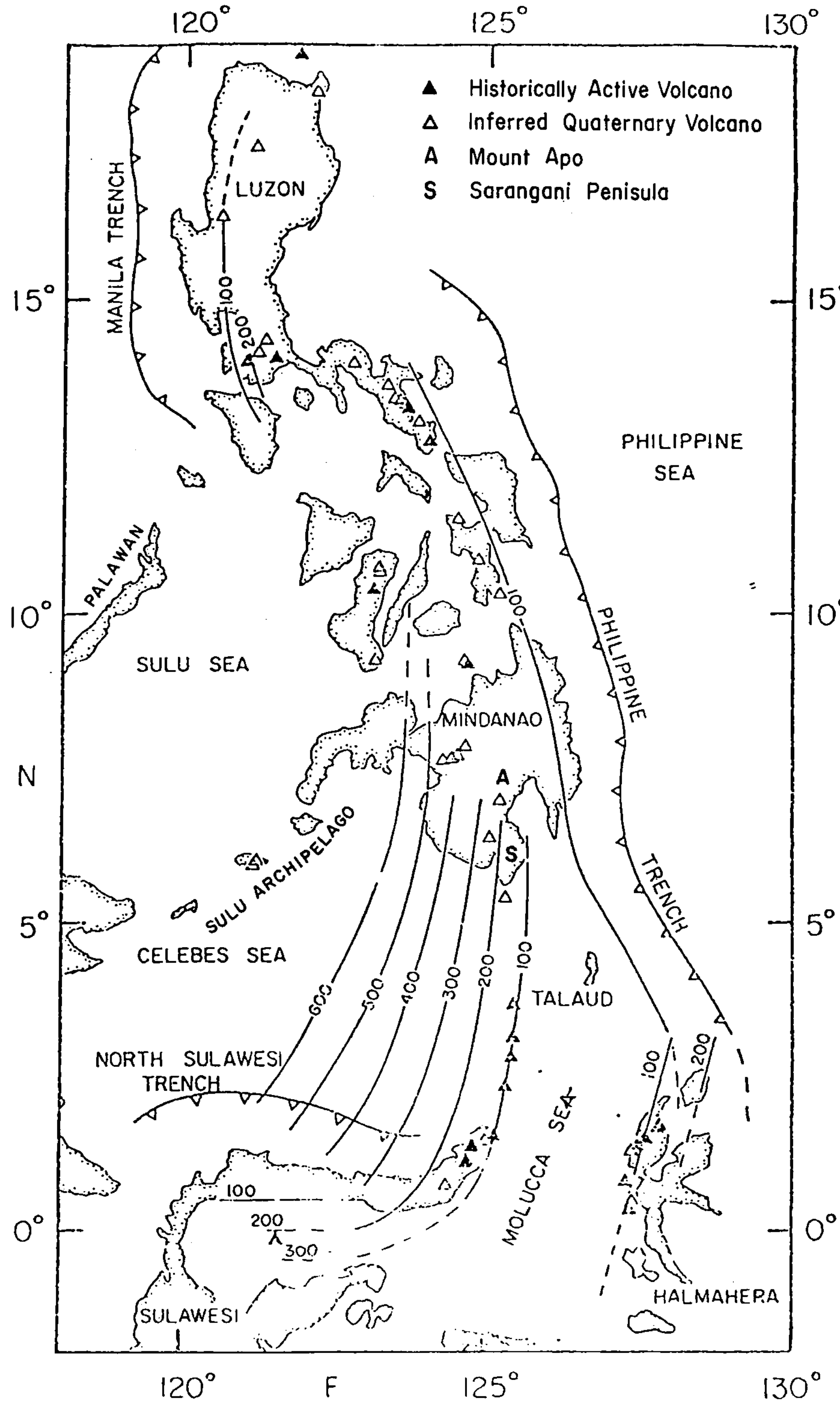

Fig. 2. Depth contours (km) to the tops of inclined seismic zones—Philippines, after Cardwell *et al.* (1980). Showing the convergence at depth of the eastern (west-dipping) and western (east-dipping) subduction zones.

It is, however, interesting to note that the two confronting subduction directions seem to reflect, or be reflected by, opposite horizontal rotations of crustal masses on either side of the Philippines, as indicated by palaeomagnetic data.

Both the Philippine Sea Basin, to the east of the archipelago, and part, at least, of Luzon seem to have originated far to the south. Phase-shifting of magnetic anomalies suggests that the West Philippine Basin has drifted north about 15°–20° and rotated some 50°–70° clockwise since 35–40 Ma (Shih, 1980). Preliminary results from the Angat ophiolite (terrane 5 on Fig. 3) point to a similar history (Fuller *et al.*, 1983). Farther west, the cordilleran region of north Luzon shows northward translation prior to the Early Miocene and counter-clockwise rotation, predominantly since mid-Miocene time. The Zambales ophiolite of NW Luzon appears to have experienced northward movement from equatorial latitudes and a stronger counter-clockwise rotation since the Eocene (Fuller *et al.*, 1983).

It thus seems that the Philippine Islands are situated above a zone where counter-rotating mantle currents converge. Palaeomagnetic results imply that these mantle currents have a horizontal (northward) component (i.e. the axes of rotation are inclined to the south). As detailed below, there is also some indication that the activity of the opposed subduction zones is largely periodic and alternating, although partially overlapping, in time.

Karig (1983) has introduced to the Philippines the concept of geologic terranes and sutures. He recognized a minimum of seven terranes in the northern Philippines and by applying the same principles to the central and southern parts of the country, a further 13 are proposed here (Fig. 3)—a total which may be amended by further work. Two of Karig's terranes (his Mindoro metamorphic terrane and the North Palawan—Calamian terrane) are here regarded as different portions of the same unit (No. 7 in Fig. 3). United Nations Development Program and Philippine Bureau of Mines and Geosciences (1983, p.33) geologists are in accord with this interpretation. At the same time, the Isabela ophiolite (No. 2) of NE Luzon is introduced as an additional terrane, maintaining the northern Philippine inventory at seven.

The Verde Passage suture of Karig (1983), separating terrane 8 from 3, 4, and 5 (Fig. 3) trends WNW and is paralleled by a major structure cutting across the island of Mindanao and bordered by terranes 13 and 17 to the southwest and 12, 18 and 19 to the northeast. This marked feature was recognised by Gervasio (1966, p. 69) who described it as *"a linear depression characterized by an intensely crushed zone, rows of volcanic plugs and small cones, and numerous sheared small lenses of peridotites"*. He also reported numerous high-angle thrust faults along this *"Mindanao Lineament"* which does not seem to have been widely accepted, possibly because it cuts across the structural grain of Mindanao. This, of course, is a prime characteristic of a terrane suture and it will be shown below that the Mindanao Lineament plays such a role.

The Verde Passage suture, the Mindanao Lineament and a number of other structural features (Fig. 3) parallel the WNW (Eocene and later) spreading direction of the Pacific Ocean and are thought to have their origin in ocean-floor transforms.

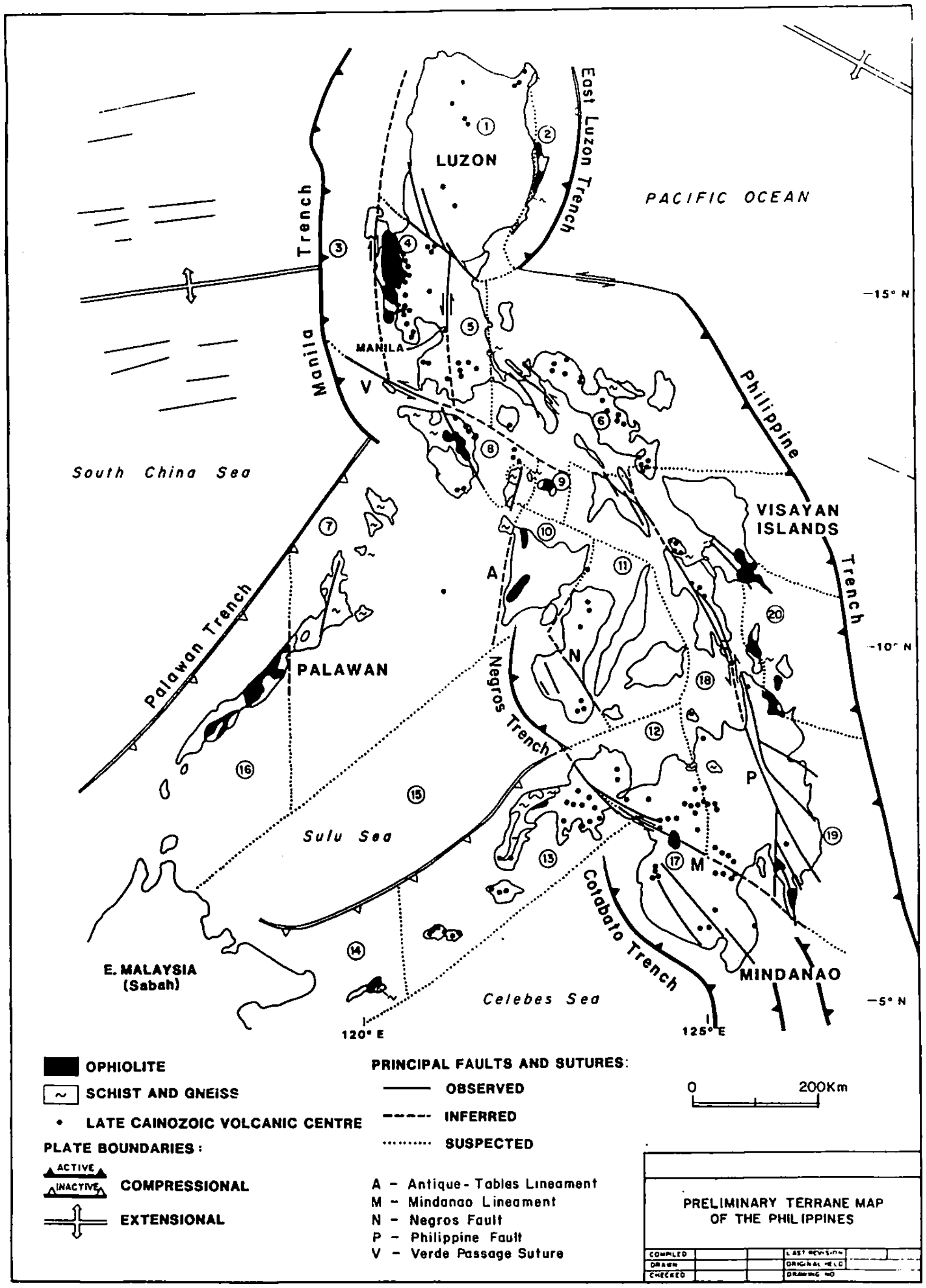

Fig. 3. Preliminary terrane map of the Philippines Terranes (terrains) presently identified are as follows:-

1. North Luzon
2. Isabela ophiolite
3. West Luzon accretionary prism (Karig, 1983)
4. Zambales ophiolite
5. Angat ophiolite (Karig, 1983)
6. East Luzon metamorphic belt (Karig, 1983).
7. North Palawan—West Mindoro (Palawan–Busuanga microcontinent, Palawan block, North Palawan–Calamian etc.)
8. East Mindoro
9. Sibuyan ophiolite
10. Panay–S.W. Negros
11. North Negros–Cebu–Bohol
12. Lanao–Bukidnon
13. SW Zamboanga–Jolo
14. Tawi Tawi–Sibutu
15. Inner Sulu Sea (Irwing, 1951)
16. South Palawan ophiolite
17. Cotabato
18. Central Mindanao–West Leyte–Masbate
19. East Mindanao-Samar (Cardwell *et al.*, 1980)
20. Surigao ophiolite

GEOLOGIC HISTORY

As pointed out by Wolfe (1984), Ben-Avraham and Uyeda (1973) and Ben-Avraham (1978) are not strictly correct in saying that the Philippine Islands did not exist in the Cretaceous. Cores of metamorphic and ophiolitic rocks, some indicated to be Cretaceous, others assumed to be so, occur within most of the terranes recognised here. These cores may be fragments of a pre-existing landmass or island arc distintegrated by the Eocene change in ocean-floor spreading direction or by other processes.

Predating these Cretaceous (and possibly older) inliers are restricted occurrences of Palaeozoic strata, confined to the so-called stable zone around the Sulu Sea. Permian limestone has been proven in place in Palawan (Gervasio, 1971) and in Carabao Island, Romblon (Andal, 1966) and fossiliferous Carboniferous argillite occurs as float in Mindoro (Easton & Melendres, 1963). Ancient schists underlie the Permian outcrops and similar metamorphic rocks occur in the Zamboanga peninsula of western Mindanao.

Following Hamilton (1977), Mascle and Biscarrat (1978) and others, Holloway (1981) divided the island of Palawan into two blocks, of disparate origin, on either side of the north-trending Ulugan (Bay) Fault. Re-examination of the record, however, reveals more parallels than dissimilarities between the northern and southern parts of the island (Philippine Bureau of Mines and Geosciences, 1982, pp. 22–28). Like the north, the south has a basement of Carboniferous (?), Permian and Triassic strata and exhibits rocks of continental facies in the Middle Tertiary. The ophiolite which is characteristic of the southern part of the island also occurs in the north and it seems that basically Palawan is a single geologic unit and that the Ulugan Bay Fault is of limited importance (in Fig. 3 it has been shown as approximately limiting the extent of the overthrust ophiolite terrane, No. 16, from the autochthon, No. 7).

Holloway believed that northern Palawan originated on the margin of China and was transported south during the (north-south) opening of the South China Sea, dated by Taylor and Hayes (1980) at 32 to 17 Ma. It appears likely, however, that both the Palawan Trench to the NW of the island and the ophiolite on the island pre-date this spreading activity.

The Palawan ophiolite is variously estimated to be Late Cretaceous and Late Eocene by the Philippine B.M.G. (1982) and is said to be overlain by Late Oligocene to Early Miocene limestone. U.N.D.P./Philippine B.M.G. geologists (1983) have recently suggested, however, that this ophiolite represents the slab which became detached in the west Panay subduction zone in the Early Oligocene.

The SE-dipping Palawan Trench comprises an accretionary basin of Early to Middle Miocene strata resting on an imbricate wedge. The older portion of the Miocene rocks are deformed with the wedge and it is concluded that subduction continued well into Miocene time (Hamilton, 1979, p. 112). It is reasonable to relate the Palawan ophiolite to this subduction system and it is suggested (C.C.O.P./I.O.C., 1980) that the ophiolite represents the non-volcanic arc of an Eocene subduction complex.

Palawan Island and the Palawan Trench are, of course, also disposed at an acute angle to the N-S China Sea spreading. The author therefore proposes that these features are related in origin to an earlier spreading phase of the China Sea, with a spreading axis parallel to the NE-SW grain of the Sulu Sea structural elements, as postulated by Taylor and Hayes (1980).

By this interpretation, the 32–17 Ma spreading phase would have resulted in oblique subduction of China Sea crust into the Palawan Trench. It seems likely that this later spreading system was delimited to the east by one or more transform faults which affected the northward transport of the Zambales and Angat ophiolites of central Luzon, as set forth by Karig (1983). Subduction in the Palawan Trench may have been terminated by the arrival there of the non-subductible Reed Bank, as concluded by Holloway (1981).

Farther to the east, in the central Visayan Islands of Cebu and Bohol (terrane 11 in Fig. 3) Cretaceous rocks are exposed and seem to be prolonged southwards in the Lanao–Bukidnon highland of Mindanao (terrane 12). On the west side of the Cebu–Bohol basement, a Cenozoic subduction system was recognized in SW Negros and Panay (terrane 10) by Hamilton (1979). This complex was thought to be complete, including a trench, outer arc (melange), fore arc basin (outer arc basin) and volcanic arc as shown in Fig. 4. In fact, Hamilton's interpretation proves to be an over-simplification and the tectonic elements here appear to have evolved as follows. Hamilton's volcanic arc, probably dating from the Eocene, was established in SW Negros (Basak formation—Philippine B.M.G., 1982) and eastern Panay (Sibala formation—Capistrano, 1953). This feature is thought to have been continued south into the Cotabato area of SW Mindanao (terrane 17 on Fig. 3), which may have then been contiguous with Negros and Panay (see below). A pattern of major NW-trending and minor Ne-trending wrench faults was then developed (Burton, 1983).

Diorite plutons were emplaced in this arc. Early in the Oliogocene, as dated by radiometry in SW Negros (reported in Burton, 1983) and superjacent limestone in Panay (Florendo, 1982). The magmatic arc then "jumped" to the Antique Cordillera of eastern Panay, the site of Hamilton's "melange" belt (U.N.D.P. and Philippine B.M.G., 1983).

Collision of the North Palawan—West Mindoro continental fragment (terrane 7 in Fig. 3) with the west-facing Panay–SW Negros subduction system (terrane 10) has been proposed by several investigators including Mascle and Biscarrat (1978), Hamilton (1979) and McCabe and others (1982). The latest and best-supported view is that this event is of Middle Miocene date (U.N.D.P. and Philippine B.M.G., 1983). Evidently this collision played an important role in the evolution of the central Philippines, with the following results:-

(a) Generation of a suture zone between these two terranes along the approximate trace of the Antique–Tablas lineament (Gervasio, 1966) following the western margin of Panay. It is not certain whether the lineament pre-dates the suturing. Departures of the two features may be a result of the original complexities of the terrane margins. The parallels between the

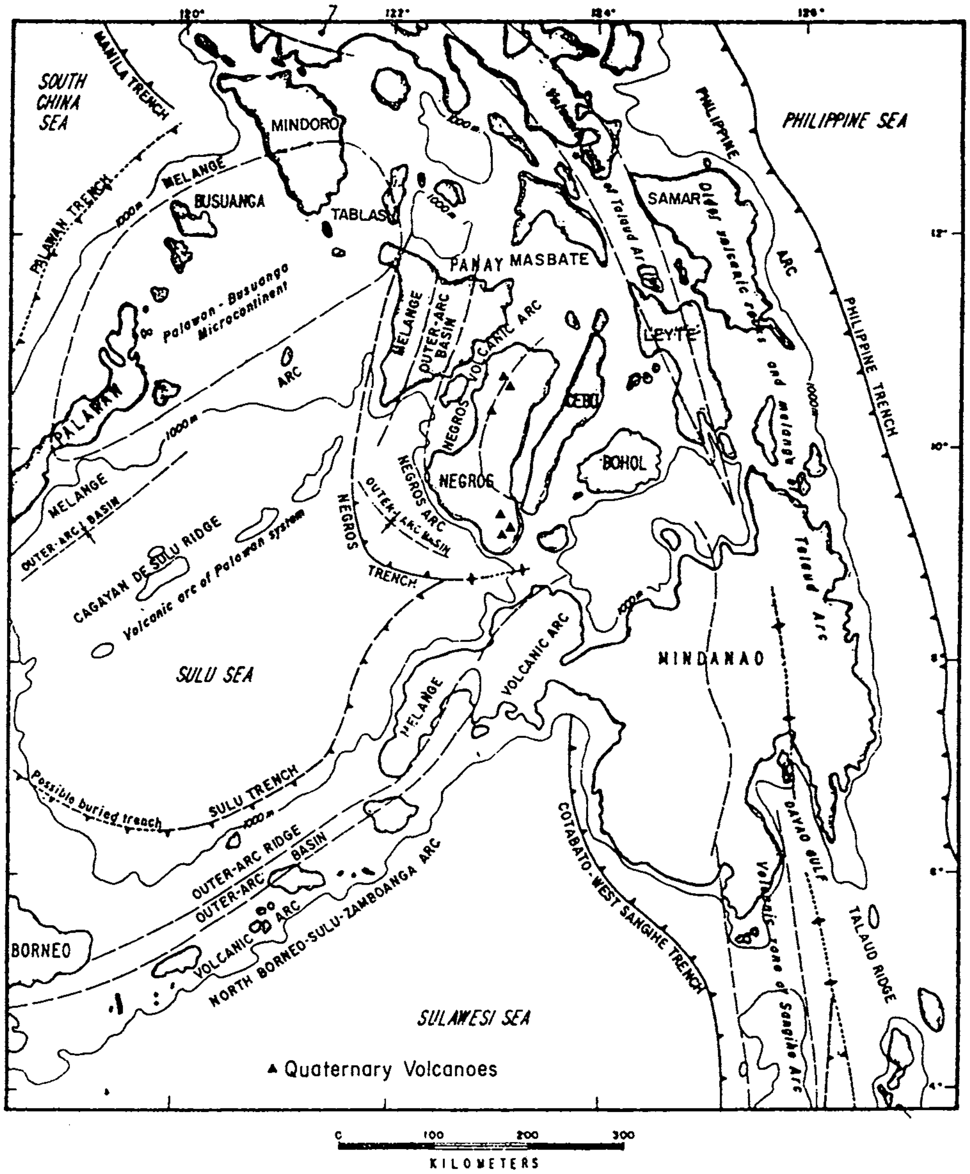

Fig. 4. Central and southern Philippines—tectonic elements. After Hamilton (1979).

geology of Tablas Island, abutting the lineament in the north, and SW Negros suggest that this structure has also been the locus of transcurrent movement.

(b) Formation or consolidation of a terrane boundary along the Negros Fault (Fig. 3), the main component of the SW Negros wrench fault system. This fault delimits the Panay–SW Negros terrane against North Negros–Cebu–Bohol (terrane 11).

(c) Clockwise rotation by some 20 degrees of the island of Panay (McCabe *et al.*, 1982) The Antique–Tablas lineament may have been similarly displaced.

(d) "Flipping" of the subduction zone from the west side of the Visayas to a new location some 200–300 km to the east.

A still-active subduction zone in the Sangihe Islands of Indonesia is traceable in the seismic record of the southern Philippines, although subduction seems to have virtually ceased here (Seno and Kurita, 1978; Hamilton, 1979; Cardwell *et al.*, 1980). This appears to be the re-sited Benioff referred to at (d) above. It plunges from the vicinity of the Agusan–Davao Trough in eastern Mindanao to a depth of 680 km beneath the western part of the island (Fig. 2). The volcanic arc of the Central Mindanao Cordillora has been shown to be genetically related to this subduction system. Although seismic evidence does not prove to this subduction system. Although seismic evidence does not prove the extension of this Benioff zone north of Bohol (Cardwell *et al.*, 1980) it is considered by the author that geological correlations are sufficiently strong to justify prolonging the volcanic arc terrane (No. 18 in Fig. 3) into western Leyte and possibly as far north as Masbate Island.

If a mean subduction rate beneath Mindanao of 5 cm/yr is assumed, then according to the depth attained, the subduction zone must be at least some 14.5 Ma old, a reading which supports Hamilton's (1979) contention that westward subduction in the Sangihe arc commenced at least by early Middle Miocene times (c. 14 Ma.) and which seems to be confirmed by the inferred appearance of a belt of volcanoes in the central Visayan region around 14–18 Ma ago (Mueller *et al.*, 1980).

As a physiographic feature, the Central Cordillera of Mindanao can be traced meridionally across the island for some 390 km. It is characterized by a median valley with which, apart from the central 150 km, are associated youthful to sub-mature stratovolcanoes, including Mount Apo, the highest peak in the Philippines (2954 m). Mount Apo is actually part of a volcanic complex, elongated WNW and it marks a discordance in the geological success and the structure of the cordillera, as noted by Gervasio (1966). The north-south grain of the country rocks north of Apo is not seen to the south where the volcanic chain (Apo–Parker Range) and the median valley continue across NW-SE striking strata pertaining to the southwestern bulge of Mindanao (the Cotabato terrane, terrane 27 on Fig. 3).

This major discontinuity evidently coincides with the main, northern arm of the Mindanao Lineament recognized by Gervasio (1966, p. 69). This feature was described from the proximal end of the Zamboanga peninsula where it comprises an intensely crushed zone, rows of volcanic plugs and small cones numerous small sheared lenses of peridotites, high angle thrust faults and tight folds. To the southeast, the lineament was seen to split, one branch passing southeastwards along the northern foot of the Cotabato Highland (parallel to, and almost on strike with the Negros Fault) whilst the more northerly arm trends ESE through the Makaturin and Apo volcanoes. The name Mindanao Lineament is here principally restricted to this main, northern branch. It has received scant attention from most workers, but is here re-instated as a major transcurrent feature, constituting an important terrane boundary and a significant element in regional tectonic evolution.

From the disposition of geological outcrops, the Mindanao Lineament appears to have effected some 25 km of left-lateral offset of the ?Pliocene volcanic rocks of the Apo–Talomo volcanic complex (Fig. 1). Northwestward convergence of Cotabato fold axes with this lineament on its SW side also indicate sinistral displacement. Evidently strike-slip movement has amputated the southern end of the Central Mindanao–West Leyte–Masbate terrane (No. 18) and replaced it with the Cotabato terrane (No. 17). Since the volcanoes of the Apo–Parker Range are a continuation of the Central Cordilleran volcanoes and cut across the Cotabato structural trend, they are evidently of later genesis and the Cotabato terrane must have assumed its position athwart the cordilleras trend prior to the last phase of volcanism, believed to be Pliocene to Recent. The recurved nature of the Sarangani Peninsula (Fig. 4), evidently part of the Cotabato terrane, may result from collision with the (now displaced) southern extension of the Central Mindanao–West Leyte–Masbate terrane.

As noted above, like the Verde Passage Suture of Karig (1983), the Mindanao Lineament parallels the post-Late Eocene spreading direction of the Pacific Ocean and may have originated as a sea-floor transform. It could be a continuation of the parallel transform fault postulated by Moore and Silver (1983) as separating the southern end of the East Mindanao arc (the author's terrane 19) from the Snellius Ridge—Halmahera arc to the SE.

The cross-sections drawn by Cardwell *et al.* (1980) show that the volcanoes of the Mindanao Central Cordillera are directly related to the ancient underlying deep subduction zone, which is presumably anchored in the mantle. It is therefore deduced that the central Mindanao subduction complex has acted as an autochthon and that most of the relative movement along the Mindanao Lineament was affected by southeastward translation of the Cotabato terrane.

Any investigation of the source of the Cotabato terrane is hampered by limited knowledge of the terrane itself. It seems clear from the foregoing exposition, however, that this crustal block originated to the northwest of its present location. In this direction, the closest geological parallel with the Cotabato Highlands appears to be the rather well-studied Iloilo Basin of Central Panay. In both areas a basement, including ophiolite, of uncertain age is overlain by a mainly sedimentary succession of possible Oligocene to Quaternary date, in which the volcanic component is more apparent to the west (Philippine B.M.G., 1982).

If this correlation is valid, horizontal translation of some 400 km would be involved. Such major movement would be closely related to the origin of the Sulu Sea, which is also, unfortunately, rather obscure.

What appears to be a recently-defunct subduction trench (the Sulu Trench) lies along the SE border of the Sulu Sea (Figs. 1, 3). No magnetic lineaments or former spreading ridge have been detected in the Sulu basin, although heat flow is high (Mascle and Biscarrat, 1978). Geological similarities along the island arcs to NW and SE, together with its rectangular form, however, may mean that the Sulu Sea has generated by some kind of spreading process. Holloway (1981) was also of this opinion. This spreading could have been restricted to crustal extention.

Both the Palawan and Zamboanga–Sulu arcs show a general progression from ancient continental metamorphic rocks with minor dioritic intrusions in the NE passing SW-wards to ophiolite with Neogene cover (Fig. 1). It is suggested here that the two arcs may have formerly been contiguous along their length and have subsequently been separated by some 450 km or orthogonal sea-floor spreading. This would imply transcurrent faulting on the NE and SW margins. Since a NW-SE wrench fault system is well-developed to the NE in SW Negros, it is conceivable that appropriate displacement occurred on these faults and/or along the line of the parallel Negros Trench. It could also be that some of the movement was taken up by the Antique—Tablas Lineament before this was rotated, with Panay, to its present alignment. Thick sedimentary cover obscures the nature of the SW border of the Sulu Sea (Mascle and Biscarrat, 1978).

The proposed displacement, with a rotational component introduced by the divergence of the Mindanao Lineament from the trend of the Negros Trench, could also have taken the Cotabato block from a position south of Panay to its present location.

Although the (east-facing) Sangihe arc is still active in Indonesia, in the Philippines, its continuation on the east side of the Central Mindanao–West Leyte–Masbate terrane is extinct. This circumstance has been ascribed by Hamilton (1979) and by Cardwell *et al.* (1980) to the impingement upon it of the west-facing Talaud–East Mindanao arc (the author's East Mindanao–Samar terrane) which also still exhibits active subduction to the south of Mindanao. Cardwell *et al.* (1980) believed that the arc collision was complete by the Late Miocene in Mindanao, whilst Moore and Silver (1983) thought it pre-dated 10 Ma.

North of Mindanao, there are some additional indications of southward younging of tectonic evolution. Thus the extensive andesites in axial Leyte (the Central Highland volcanics of Pilac, 1965) which are dated as Middle Miocene appear to be analogous to the massive outpourings of lava which evidently accompanied the latest stages of collision in NE Mindanao (Late Miocene to Pliocene–Santos–Ynigo, 1944; Philippine B.M.G., 1982). Similarly, post-collision strata of molasse-type with distinctive coal horizons which are mainly Late Miocene to Pliocene in Leyte.

(Pangasugan–Balahupi and Bata formations), Samar (Catbalogan formation) and NE Mindanao (Tugunan formation) seem to have an analogue in the Buyag formation, evidently of Middle to Late Miocene age, in Masbate (Philippine B.M.G., 1982). Farther south in eastern Mindanao, similar rocks range up into the Pleistocene.

With Cardwell *et al.* (1980) the author has regarded the Talaud–East Mindanao arc (the author's terrane No. 19) as continuing as far north as Samar. It may, as implied by Hamilton (1979) extend farther north and include the East Luzon Metamorphic belt of Karig (1983) but this cannot be established at the present time. Thrust upon the East Mindanao–Samar terrane is the Surigao–Dinagak–South Samar ophiolite (terrane 20 in Fig. 3). The evolution of this latter terrane is not well understood.

The junction between the Central Mindanao–West Leyte–Masbate and the East Mindanao–Samar terranes is (as was observed by Cardwell *et al.*, 1980) closely followed by the Philippine Fault system, apart from local departures consequent upon the original shape of the arcs concerned, and therefore appears to approximate to the suture between them.

It seems feasible, as both Cardwell *et al.* (1980) and Karig (1983) have suggested, that the Talaud–East Mindanao–Samar arc originated in the West Philippine Basin. Shih (1980) demonstrated that the West Philippine Basin crust started to form 59 Ma ago and that it has drifted northwards by about 15°–20– and rotated c. 50°–70° clockwise since 35–40 Ma. ago. If the easternmost arc of the Philippines did come from this area, a rotational approach, in combination with the WNW-spreading direction of the Pacific Basin would result both in diachronous collision and the sinistral strike slip displacement observed on the Philippine Fault (some 200 km according to Karig, 1983).

After collision, seismicity and volcanism persisted in the Central Mindanao–West Leyte–Masbate terrane but the continuing convergence between the Eurasian and West Philippine crustal plates was initially accommodated in two zones on either side of the Philippine mobile belt. In the west, subduction was renewed in the Negros Trench (Burton 1983) and initiated in a new feature off the SW coast of Cotabato, referred to as the Cotabato–West Sangihe Trench by Hamilton (1978) as the Celebes Trench by Acharya and Aggarwal (1980) and as the Cotabato Trench by Cardwell and his colleagues (1980).

The data presented by Cardwell *et al.* (1980) indicate that the renascent subduction zones on the Negros Trench has penetrated to a depth of almost 100 kilometres, resulting in generation of Pliocene to Recent andesitic magmas extruded to the surface in the Cuernos de Negros volcano in southern Negros, in the Canlaon, Mandalagan and Silay volcanoes in northern Negros and on Pan de Azucar and neighbouring islands offshore eastern Panay. Some of the volcanicity of northern Zamboanga in west Mindanao may also be related to this system.

The Cotabato Benioff zone has evidently only recently become active and has reached a depth of some 85 km. No volcanicity is associated with this feature.

The largest component of Pliocene to Recent convergence in the southern Philippines is taken up by the Philippine Trench system developed after collision on the east side of the East Mindanao–Samar terrane. Although seismicity extends down to almost 200 km in the East Mindanao sector, Cardwell *et al.* (1980) concluded that little or no volcanicity can be ascribed to this new subduction zone. Wolfe (personel communication), however, cites two examples of possibly related volcanic features, in NE and SE Mindanao respectively, but the present writer believes that the ancedents of both occurrences remain in doubt.

The maximum depth of earthquake acitvity in the Philippine Trench system decreases northwards. As revealed by the data accomulated by Acharya and Aggerwal (1980) and Cardwell *et al.* (1980), the seismic zone is barely 100 km deep off southern Luzon. Despite Hamilton's (1979) view of the contrary, the majestic stratovolcanoes of the Bicol peninsula cannot confidently be related to the Philippine Trench Benioff zone here. A dispersed shallow zone of earthquakes, possibly associated with the Philippine fault more directly underlies the volcanic tract and, like the volcanoes of central Leyte, those of Bicol bay be fed by conduits furnished by the fault system.

SUMMARY

It is believed that the latest stages of geological evolution of the Philippines have taken place in a situation above a descending mantle convection system between the Eurasian and West Philippine Sea crustal plates. This situation has resulted int the following process being manifest since the Oligocene:-

(a) Multiple accretion of terranes from a variety of sources, with consequent

(b) Multiple collisions of crustal (micro) plates.

(c) Multiple obduction of ophiolite.

(d) Multiple arc polarity reversals (flipping).

(e) Reactivation of defunct subduction zones.

(f) Continued seismicity and volcanism on defunct subduction zones.

(g) Volcanity both related and unrelated to subduction zones, i.e.
  (i) On sutures—Leyte volcanoes on the Philippine Fault.
  (ii) With uncertain tectonic control—e.g. Bicol volcanoes of South Luzon, Cuyo volcano of the Sulu Sea.

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Since the abstract of this article was issued as a conference pre-print (Burton, 1984) it has been observed that reference to the Philippines as a college of terranes echoes a phrase from a recent article by Karig (1983) and was probably unconsciously derived therefrom. It is hoped that this burrowing will not be regarded as plagism, but rather as a tribute to that worker who has done so much to elucidate the complexities of Philippine geology.

Discussions with John Wolfe and Robert McCabe first encouraged the writer to think of the Philippines in terms of accreted terranes.

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