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Tectogene Hypothesis Applied To The Pre-Tertiary Of Sabah And The Philippines

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Abstract: Sabah (North Borneo) is correlated with the Philippines in a pre-Tertiary arcuate tectogene-geosyncline system. The high grade banded amphibolite gneisses and the banded ultrabasic rocks of both countries are characteristic of and are confined to narrow tectogene zones.

The tectogene system has provided an orthogeosynclinal environment for the deposition of the Cretaceous-Eocene Chert-Spilite Formation, which was, in part, metamorphosed to greenschist facies during the declining revolutionary phase of the tectogene-geosyncline development.

The pre-Chert-Spilite Formation rocks, though generally of a higher grade of metamorphism, have not acted as a basement, but have acquired the same style of folding as the overlying geosynclinal rocks.

The tectogene system now occupies prominent arcuate geanticlinal welts, forming island arcs, which characterise the western margins of the Pacific Ocean.

INTRODUCTION

The pre-Tertiary of both Sabah (North Borneo) and the Philippines may be broadly subdivided into (Philippines, 1963; Kirk, 1965; Wilson, 1965; Gervasio, 1966b):

1. a so-called 'basement complex' composed of a variety of rocks characterised by amphibolites and gneisses, generally regarded as being Jurassic or older.
2. a sequence of transgressive flysch rocks of Cretaceous-Eocene age, characterised by a greywacke-shale sequence, intercalated with spilites and cherts (the Chert-Spilite Formation of Sabah).
3. ultrabasic and basic intrusive rocks, probably of Cretaceous-Palaeocene age, predominantly of peridotites and gabbros.

These broad similarities of the pre-Tertiary geology in the two neighbouring countries have prompted several attempts at correlation, notably by Reinhard and Wenk (1951) and Fitch (1953, 1963). Reinhard and Wenk (1951) clearly recognised the existence of a 'basement complex' of amphibolites and gneisses in Sabah (then North Borneo) and compiled a map showing the similarities of the geology between the two countries. Their analysis of the pre-Tertiary of the region is very similar to that which is now generally accepted (Wilson, 1965).

Fitch (1953, 1955) caused a regression in the understanding of the pre-Tertiary by failing to recognise the extensive occurrence of regionally metamorphosed rocks in Sabah. High grade banded amphibolites (Dhonau and Hutchison, 1966) were identified and mapped by him (Fitch, 1955) as layered igneous rocks. In fact, he particularly commented that metamorphic rocks were practically non-existent. Accordingly, the pre-Tetiary aspects of his correlation of Sabah with the Philippines (Fitch, 1953) are now only of historic value.

Since the recognition of a distinct metamorphic complex in Sabah (Kirk, 1964, 1965; Wilson, 1965), the pre-Tertiary similarities between the two countries are now much more apparent. The present correlation results from detailed mapping of an area of pre-Tertiary rocks in Sabah (Dhonau and Hutchison, 1966; Hutchison and Dhonau, in manuscript; Hutchison, 1966), followed by a review of the more recent publications on Philippine geology. The comparison, is mainly limited to the pre-Tertiary.

THE 'BASEMENT COMPLEX'

A. In Sabah

The 'basement complex' is referred to as the 'Crystalline Basement' (Wilson, 1965; Kirk, 1964, 1965). Kirk (1965) has described it as consisting of "granodiorite, diorite and gabbro, migmatite, amphibolite, hornblende gneiss, hornfels and schist". In fact, most of what has been described as 'diorite' and 'gabbro' by Kirk (1964, 1965) can be more accurately described as banded hornblende gneiss. The existence of hornfels is also in doubt, since Dhonau and Hutchison (1966) have shown that the hornfels of Kirk (1962) is in fact amphibolite of the greenschist facies, showing poorly developed foliation.

The only authors to confidently appreciate the distinction between hornblende gneiss and diorite, gabbro, etc. were Reinhard and Wenk (1951) and Dhonau and Hutchison (1966). Reinhard and Wenk (1951, p. 11) described the (basement) rocks as consisting principally of hornblende schists, chlorite-epidote schists, amphibolites and plagioclase-epidote-hornblende gneisses. In particular they noted that "a characteristic feature is the almost complete absence of biotite and the scanty occurrence of muscovite".

Dhonau and Hutchison (1966) have described the (basement) rocks of the Darvel Bay area in remarkably similar terms—amphibolite gneisses, amphibolites, often epidote-bearing. The grade of metamorphism ranges from greenschist to hornblende granulite facies, but the majority can be ascribed to the almandine amphibolite facies. The rocks are typically banded and are characterised by a style of broad folding; in the Darvel Bay area, the fold axes lie parallel to the island chains (Dhonau and Hutchison, 1966). There is a prominent lineation of the amphibole crystals sub-parallel to the fold axes. At least two periods of folding and metamorphism are involved because the foliation of the amphibolite gneisses (Silumpat Gneiss) is folded (Dhonau and Hutchison, 1966).

The metamorphic facies series (Miyashiro, 1961) is characterised in Sabah by the following calciferous amphiboles (Hutchison and Dhonau, in manuscript):

1. Greenschist facies: actinolite
2. Amphibolite facies: { blue-green hornblende / green-brown hornblende }
3. Granulite facies: brown hornblende, often clouded

Garnet-wollastonite calc-silicate layers also occur in the basement rocks (Kirk, 1964).

Chemically, the amphibolites and amphibolite gneisses of the basement may be considered to be meta-gabbro or meta-basalt (Hutchison and Dhonau, in manuscript).

Age

Kirk (1965) gave the age as Jurassic or older. This deduction is supported by the following radiometric determinations on metamorphic minerals or on minerals in syntectonic magmatic rocks. All determinations are by the potassium-argon method by the Age Determination Unit of Overseas Geological Surveys (Snelling, 1964, 1965; Anon, 1966).

1. Biotite from a biotite-rich zone in a hornblende hornfels (amphibolite) at the margin of a granite vein.

   Locality: Litog Klikog Kiri Valley, a tributary of the Segama River, lying northwest of Darvel Bay. N.B. 10852 O.G.S. 63.21.

   Age 160 ± 8 m.y. (Kirk, 1964).

2. Biotite from tonalite which is intrusive into the amphibolite.

   Locality: Litog Klikog Kiri Valley. O.G.S. 64.46.

   Age 150 ± 6 m.y. (Snelling, 1965).

3. Whole rock analysis of a fine-grained lineated amphibolite.

   Locality: Adal Island, Darvel Bay. J1166 O.G.S. 65.126.

   Age 140 ± 20 m.y. (Dhonau and Hutchison, 1966).

4. Hornblende from amphibolite gneiss (Silumpat Gneiss).

   Locality: N.E. Silumpat Island, Darvel Bay. J1060 O.G.S. 65.120.

   Age 101 ± 15 m.y. (Dhonau and Hutchison, 1966).

The above radiometric evidence strongly suggests that the last major orogenic development and metamorphism was Jurassic. But these potassium-argon dates may have failed to penetrate the "metamorphic veil" (Amstrong, 1966), as is to be expected in the zone of high grade metamorphism of an orogenic region. It can, therefore, be confidently said that the rocks of the 'Crystalline Basement' are at least Jurassic, and are probably much older.

B. In the Philippines

The (basement) complex generally consists of:

(a) a lower structural zone of basic amphibolite and amphibolite gneiss, meta-spilite, sometimes with associated quartzo-feldspathic mica-amphibolite schist, generally raised to the amphibolite facies of regional metamorphism (Gervasio, 1966b), and

(b) an upper structural zone of chlorite-epidote mica schists, phyllites and slate with associated marble and thin alternating beds of metagray-wacke, phyllite, slates generally raised to the greenschist facies of regional metamorphism (Gervasio, 1966b). Intrusive rocks include granite, adamellite, granodiorite and quartz-diorite (Gervasio, 1966a).

The basement rocks are products of more than one orogenic cycle and overlapping schistosities in some localities indicate at least two periods of regional metamorphism (Gervasio, 1966a).

The basement rocks are broadly folded, although narrow, closely-folded zones broken by upthrusts are common. Their structures are roughly parallel to the existing topography of the achipelago except in Palawan where part of the structure apparently trends oblique by 45° to the axis of the island (Gervasio, 1966a).

Age

None of the (basement) rocks has been radiometrically dated. Some stratigraphic control does, however, exist and the ages shown in Table 1 are based on the following information from Gervasio (1966b):

1. The 'basement' rocks in Mindoro are discordantly overlain by conglomerates which contain the lamellibranches *Daonella (?)* and *Monotis (?)*. If the fossil identification is valid, then the basement here is pre-Triassic.
2. The 'basement' rocks in north Palawan are discordantly overlain by Triassic (?) to Jurassic greywacke-shale-chert deposits.
3. Fusulinids in limestone which is thought to belong to the upper zone of the basement' in Carabao island are presumed to be Permian.
4. A *cyathopsid* coral in Mindoro probably indicates that some of the basement' is Carboniferous, though the fossil is not in place.

It seems justified to consider that the 'basement' rocks are at least Jurassic, and may well extend downwards to the Carboniferous.

THE CHERT-SPILITE FORMATION

A. In Sabah

The 'basement' is overlain unconformably by a transgressive sequence of geosynclinal deposits, essentially spilitic and basaltic lavas and pyroclastic rocks, and more rarely keratophyre lava, associated with chert, greywacke, shales and limestone (Kirk, 1965).

Meta-dolerite sills and cross-cutting sheets in the Silumpat Gneiss (Dhonau and Hutchison, 1966) and in the ultrabasic rocks very likely are contemporaneous with the Chert-Spilite Formation.

M.Y. AGO		AGE (KULP, 1961)	SABAH: DARVEL BAY REGION	SABAH: SEGAMA VALLEY	SABAH: BANGGI ISLAND	GRADE OF METAMORPHISM	PHILIPPINES: SOUTHERN PALAWAN	PHILIPPINES: NORTHERN PALAWAN	PHILIPPINES: MINDORO	PHILIPPINES: WEST VISAYAS & N.W. MINDANAO	PHILIPPINES: ZAMBOANGA & COTABATO
50	CENOZOIC	PLIOCENE MIOCENE OLIGOCENE EOCENE				NON-METAMORPHIC					
100	CENOZOIC / MESOZOIC	PALEOCENE CRETACEOUS	META-DOLERITE DIKES META-SPILITE, SPILITE, CHERT, GREYWACKE, SHALE •	LIMESTONE * SERPENTINITE SPILITE CHERT	BASIC PILLOW LAVA, DOLERITE, SILLS & DIKES LARGER GABBRO MASSES, CHERT & QUARTZITE	GREENSCHIST FACIES: GENERALLY NON-FOLIATED	DIABASE DIKES * ULTRAMAFIC COMPLEX SPILITE, GREYWACKE CHERT, SHALE	? ?	PERIDOTITES * SPILITES, CHERT GREYWACKE ARKOSE	PERIDOTITES * MINOR LIMESTONE SPILITES, CHERT GREYWACKE	PERIDOTITES * SPILITES, CHERT GREYWACKE
	MESOZOIC		ULTRAMAFIC COMPLEX •	ULTRAMAFIC COMPLEX	ULTRAMAFIC COMPLEX						
150 200	MESOZOIC	JURASSIC TRIASSIC	BANDED AMPHIBOLITE (Metabasite) GNEISSES & AMPHIBOLITES (Silumpat Gneiss)	GRANITE & TONALITE • • AMPHIBOLITE AMPHIBOLITE GNEISS MIGMATITE SOME CALC-SILICATE	HORNBLENDE SCHIST & GNEISS, CHLORITE ACTINOLITE SCHIST & SCHISTOSE EPIDOSITE & ULTRABASIC ROCKS	ESSENTIALLY FOLIATED OR SCHISTOSE	META-GREYWACKE ARKOSE, PHYLLITE SLATE, QUARTZITE	DIORITE STOCK * CHERT, SPILITE, GREYWACKE, ARKOSE PHYLLITE, SLATE, QUARTZITE	GREYWACKE, SHALE META-GREYWACKE, PHYLLITE, SLATE, META-CONGLOMERATE	GREYWACKE, SPILITE, CHERT, SHALE, CONGLOMERATE	DIORITE SILLS * GREYWACKE, CHERT META-ARKOSE WACKES, SHALES
250	PALAEOZOIC	PERMIAN				ESSENTIALLY FOLIATED OR SCHISTOSE	? ? QUARTZ-FELDSPAR-MICA-SCHIST	GRANITE STOCK + DACITE-ANDESITE TUFF META-GREYWACKE, ARKOSE, PHYLLITE, SLATE, QUARTZ-FELDSPAR-MICA-SCHIST	QUARTZ-DIORITE STOCK * META-GREYWACKE, PHYLLITE, SLATE, MARBLE, QUARTZ-FELDSPAR-MICA-AMPHIBOLE SCHIST	DACITE RHYOLITE * A LIMESTONE LENS, GREYWACKE, PHYLLITE SLATE, QUARTZ-FELDSPAR-MICA-AMPHIBOLE SCHIST GLAUCOPHANE	GARNET GRANITE STOCK * PHYLLITE, SLATE, CHLORITE-MICA-EPIDOTE SCHIST, QUARTZ-FELDSPAR-MICA-AMPHIBOLE SCHIST
300 350 400	PALAEOZOIC	CARBONIFEROUS DEVONIAN				AMPHIBOLITE FACIES with LOCALISED HORNBLENDE GRANULITE SUB-FACIES	? ?	META-SPILITE ? BASIC AMPHIBOLITE SCHIST	META-GABBRO * WITH POSSIBLY PERIDOTITE. META-SPILITE, MICA-CHLORITE-AMPHIBOLE-SCHIST BASIC AMPHIBOLITE SCHIST	BASIC AMPHIBOLITE SCHIST	META-GABBRO * BASIC AMPHIBOLITE SCHIST

• RADIOMETRIC AGE DETERMINATION + POST OROGENIC * SYNOROGENIC INTRUSIVE

Table 1. Correlation chart of Sabah and Philippine pre-Tertiary geology.

The rocks of this formation are patchily metamorphosed, and are locally characterised by epidote and actinolite-bearing spilites (Kirk, 1962). The grade of metamorphism has been more precisely defined in the Darvel Bay area by Hutchison and Dhonan (in manuscript) as the quartz-albite-biotite subfacies of the greenschist facies. Koopmans (1968) has also noted that most of the spilites in the Darvel Bay and Semporna region have been raised to the greenchist facies of regional metamorphism. Some of the spilites are foliated and others apparently lack foliation (Dhonau and Hutchison, 1966); but those without foliation are actinolite-rich and contain clouded plagioclase, which Poldervaart and Gilkey (1954) have shown indicates metamorphism.

Rocks of this formation are more extensive in outcrop than the 'basement' rocks, but where they are associated with 'basement' rocks, they appear also to have suffered regional metamorphism, albeit of a lower grade.

In the Darvel Bay area, Dhonau and Hutchison (1966) have shown that rocks which can be ascribed to this formation are folded together with the so-called 'basement' rocks.

Age

The age of the Chert-Spilite Formation is well established by pelagic foraminifera as ranging from Upper Cretaceous to Eocene (Kirk, 1962).

B. In the Philippines

The most widely exposed sequence of early geosynclinal rocks consists of spilites, greywacke associated with chert and minor limestones, and basic lava flows (Gervasio, 1966a). Generally the formation may be described as an extensive (compared with the 'basement' rocks) greywacke-shale sequence intercalated with spilites, associated with tuffaceous clastics.

The rocks are commonly, but patchily, metamorphosed to greenschist facies (Philippines, 1963, Gervasio, 1966b).

There is strong angular unconformity between the Cretaceous spilite-flysch strata and the 'basement' rocks (Gervasio, 1966b). The rocks are usually folded, and sometimes severely crumpled (Gervasio, 1966a).

Age

The associated limestones are dated by fossils as Upper Cretaceous (Gervasio, 1966a).

THE ULTRABASIC AND BASIC INTRUSIVE ROCKS

A. In Sabah

There are two closely associated groups of intrusive rocks—(a) peridotite which is normally serpentinised, with sparse occurrence of dunite and pyroxenite, and (b) gabbro, olivine gabbro, hornblende gabbro, diorite, dolerite and troctolite (Kirk, 1965). Layering occurs sporadically, but is somewhat disturbed (Wilson, 1964; Hutchison and Dhonau, in manuscript). A foliation occurs in the Darvel

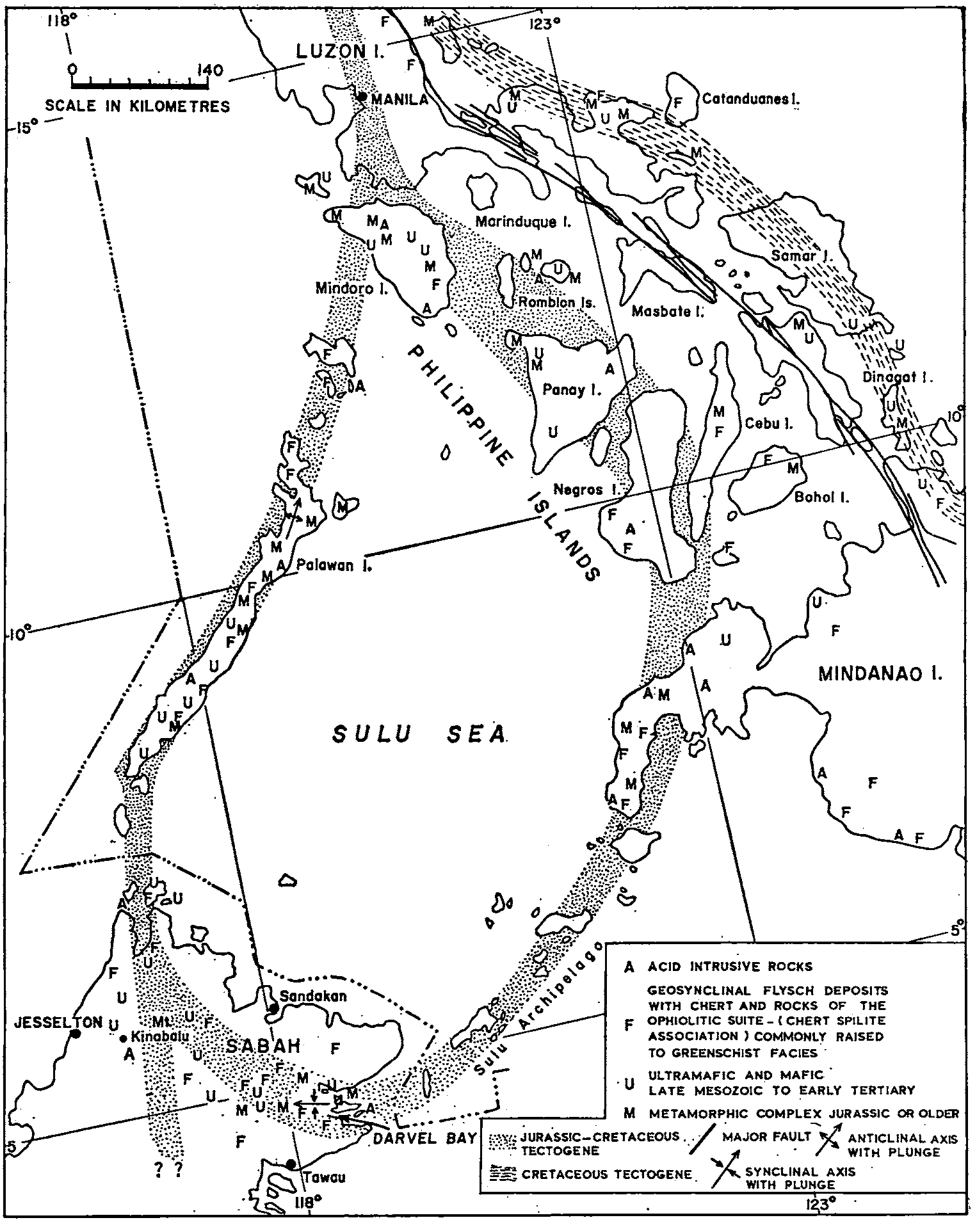

Fig. 1. Map showing the correlation of pre-Tertiary geology of eastern Sabah and the Philippines. The shaded arcuate zones represent the tectogene axes.

Bay ultrabasic rocks which has been interpreted to be metamorphic and related to the metamorphism of the 'basement' rocks (Dhonau and Hutchison, 1966). The peridotites and dunites are characterised by rather rounded crystals with a finer-grained matrix. This feature, together with the absence of any metamorphic aureole, has led Dhonau and Hutchison (1966) to believe that the intrusion was in the form of a crystal mush in a minimum of liquid. However the 'magma' still retained some assimilative power, because transformed blocks of gneiss are locally found in the peridotite where it is in close contact with the gneiss (Hutchison and Dhonau, in manuscript).

In places, the ultrabasic rocks have suffered intense shearing and serpentinisation. Ultrabasic bodies are commonly bounded by shear zones or faults.

Age

Indefinite, but presumed to be Cretaceous to early Tertiary by Kirk (1965). Taken by Dhonau and Hutchison (1966) to be pre-Chert-Spilite Formation and to have been intruded during the late stage of orogenesis of the 'basement' rocks, and accordingly approximately of Cretaceous age. However the fact that some ultrabasic masses are layered while others are not, strongly suggests that not all ultrabasic intrusion were emplaced in the same tectonic environment.

B. In the Philippines

The rocks are predominantly peridotites, associated with late gabbro and diabase dykes (Philippines, 1963). The peridotites generally occur as lenticular bodies in chains approximately along the 'basement' belts (Fig. 1). They have no distinct intrusive contacts and are bounded by shear zones or faults. They are largely serpentinised (Gervasio, 1966a).

The largest mass is the Zambales peridotite-gabbro complex (Wilson, 1964) which shows complex compositional zoning and foliation as well as cross-cutting dykes (Gervasio, 1966a). Wilson (1964) noted the close similarity between the ultrabasic rocks of Sabah and the Philippines, in particular their common tendency to be banded and foliated.

Age

Presumed to be Cretaceous-Eocene and to coincide closely in age with the spilite-chert-greywacke sequence of flysch geosynclinal rocks (Philippines, 1963, Gervasio, 1966b).

GENERAL CORRELATION

The Chert-Spilite Formation of Sabah correlates excellently from the point of view of age, lithology, and metamorphism with a similar rock sequence in the Philippines (Table 1). This similarity has been fully discussed by Fitch (1953, 1963).

There is likewise a close similarity between the ultrabasic and basic intrusives of the two neighbouring countries.

The 'basement' rocks are of similar complexity, containing in both cases a lower structural zone, predominantly of metabasites, of almandine amphibolite facies (Table 1).

The dating of the 'basement' in Sabah is based on radiometric ages of metamorphic minerals and of igneous minerals in syntectonic intrusions. However, as explained by Dhonau and Hutchison (1966), these dates represent only an upper limit, and presumably indicate only the very latest orogenic phase in a complex tectonic development. Such an interpretation is further supported by Armstrong's (1966) "metamorphic veil" concept. Accordingly the real ages for the 'basement' rocks of Sabah are very probably significantly greater than those shown in Table 1.

The ages shown against the 'basement' rocks of the Philippines have been taken from Gervasio (1966b), but they are somewhat tentative in view of the rather imperfect palaeontological evidence. Accordingly the Philippine subdivisions (Table 1) may well be subsequently modified in the light of more refined palaeontological evidence.

It is only reasonable to presume, however, that the broad similarities of a high grade lower structural zone and a greenschist facies upper zone indicates that the 'basement' rocks of both countries have been evolved in the same orogen, and that the age discrepancies shown in Table 1 are not real, since the dating of each neighbouring country is differently based.

Gervasio (1966a, b) concludes that rocks of the 'basement' complex underlie large areas of the South China Sea and everywhere underlie the Sulu Sea, in an area which he calls the 'Philippine Stable Region' (Gervasio, 1966a). This concept of an extensive basement of metamorphic rocks, akin to a shield area, upon which all younger rocks were deposited with a strong unconformity, appears also to be greatly favoured by Sabah geologists (Wilson, 1965; Kirk, H.J.C. and Wilford, G.E., personal communications).

This basement concept of Philippine and Sabah geologists is invalidated by the following three impossible requirements:

i. That this large shield area of high grade metamorphic rocks has foundered extensively but irregularly in places to depths in excess of 5,000 metres below sea level, for example in the Sulu Sea along the north-west coast of the Zamboanga peninsula, while only about 25 to 30 miles away, it appears on the land surface, and under most of the Sulu Sea and the South China Sea it must occur at comparatively shallow depths.

ii. That this large shield-like ancient metamorphic terrain has had superimposed upon it the pronounced arcuate pattern of younger ultrabasic and acid intrusions, and volcanic extrusions of the chert-spilite association. This prominent arcuate pattern results in the arcuate shapes of the island arcs along which the ultrabasic rocks occur associated with the younger chert-spilite rocks and the older 'basement' rocks.

    Nowhere else in the world can shield areas be found cut by younger arcuate plutonic and volcanic arcuate structures. Tuzo Wilson (1959) has shown that primary arcs cannot rest upon basement of more ancient rocks.

iii. That the Chert-Spilite Formation and other post—'basement' rocks are not generally derived from the 'basement' rocks (Stauffer, 1968). There is furthermore no evidence of a tectonic unconformity between the Chert-Spilite Formation rocks and the underlying 'basement' rocks; both have been folded together and metamorphosed together in the same tectonic zone (Dhonau and Hutchison, 1966).

Since the basement concept cannot be reconciled with these three fundamental difficulties, the following hypothesis is offered as an alternative.

TECTOGENE HYPOTHESIS

The essence of the hypothesis is that so-called 'basement' complexes of both Sabah and the Philippines do not represent a pre-Chert-Spilite Formation metamorphic basement, but represent a sequence of rocks which have been folded and metamorphosed in the root zone, or tectogene, beneath the main Chert-Spilite Formation geosyncline (see Hess, 1948; Umbgrove, 1942, Wyllie, 1965; for a discussion and definition of this terminology) (fig. 2).

The metabasites of the 'basement complex' are possibly older in that they may well represent oceanic basalts of the lower crust, which were metamorphosed in the tectogene. Outside of the tectogene, it is envisaged that the unmetamorphosed equivalents of these metabasites still persist. Hence the term 'basement' is confusing. The revolutionary development of the tectogene-geosyncline system caused simultaneous concordant folding and metamorphism of the lower levels of the overlying Chert-Splite Formation. Being of a higher tectonic level, these rocks have been raised only to greenchist facies.

The geosynclinal and tectogene evolution is schematically outlined in fig. 2. A convection cell descending below part of the crust leads to downwarping of the lower crustal layers causing subsidence of the surface to form a geosyncline.

While rocks of the Cretaceous-Eocene Chert-Spilite Formation were being deposited, downbuckling of the lower crust caused a phase change of the basalts to peridotite, resulting in further contraction and accelerated downwarping (Wyllie, 1965). Hence the rocks of the Chert-Spilite Formation may be described as extensive and transgressive when compared with the geographical distribution of the underlying tectogene rocks.

The accelerated downwarping resulted in rapid accumulation of geosynclinal sediments, folding, heating resulting from the accumulated radioactivity in the geosynclinal pile, metamorphism and faulting (fig. 2).

Finaly (fig. 2c), uplift was accompanied by folding and release of peridotite magma from the mantle. Uplifted tectogene zones are characterised by the intimate association of peridotite and metamorphic rocks of variable grade (fig. 1, table 1).

Tectogene pattern

The geographical extents of the root zones of the geosyncline are shown (Fig. 1) to be typically arcute. One arc extends from West Luzon across

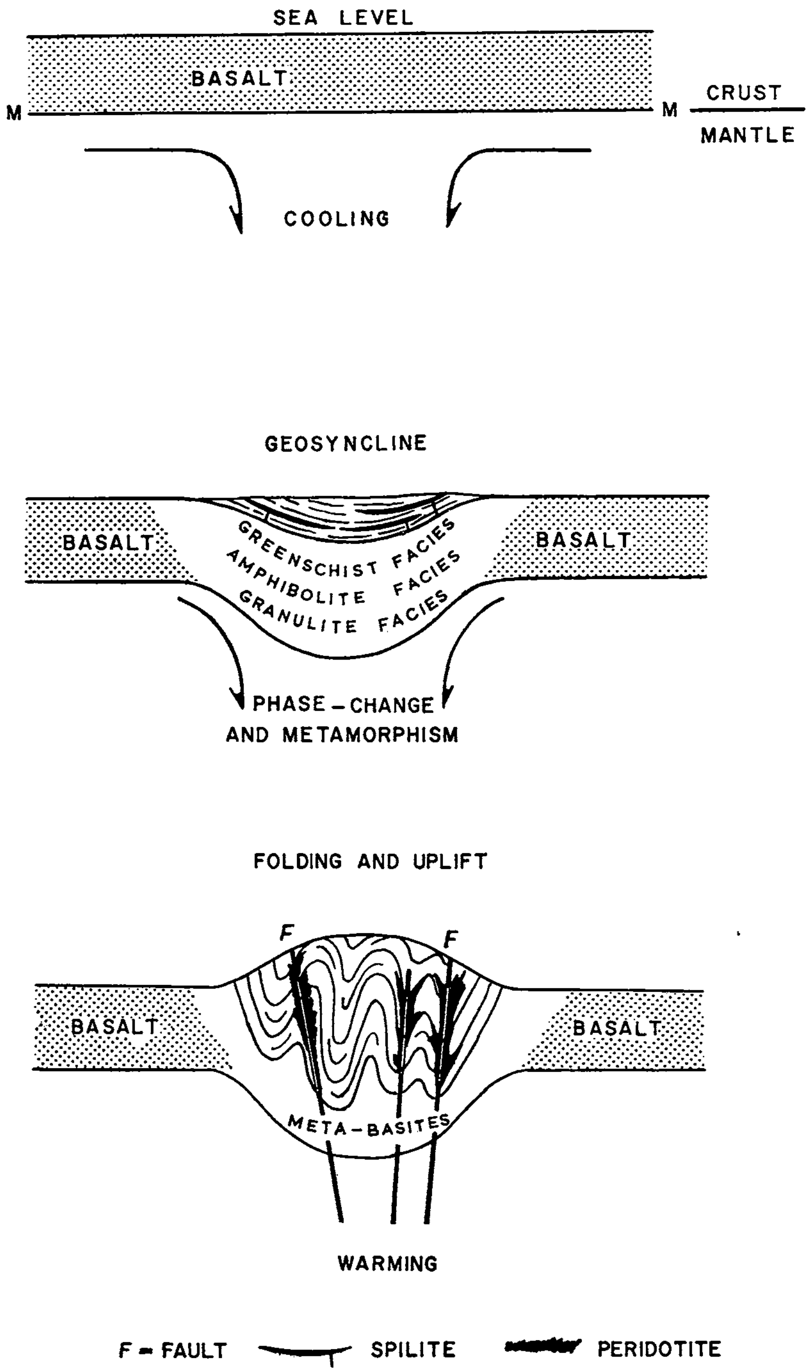

Fig. 2. Possible sequence of events in the geosyncline-tectogene system as shown in diagrammatic cross sections. A. Pre-tectogene situation. B. Tectogene downwarping causing the Chert-Spilite Formation geosyncline. C. Revolutionary phase of the orogeny causing peridotite intrusion from the mantle and uplift into a geanticlinal welt.

Palawan into Sabah and bends southwards towards Kinabalu while the other extends from Mindanao along the Sulu Archipelago to the Darvel Bay area of Sabah, from where it swings northwards. These two arcs appear to coalesce somewhere in Central Sabah and indeed they may be arms of the same structural zone. After the theory outlined in figure 2, these arcs represent the geographical distribution of the downwards direction of the circulation cell in the mantle at the beginning of the evolution of the Chert-Spilite Formation geosyncline. This early event is difficult to date, but appears to be early Mesozoic or even Upper Palaeozoic.

This narrow tectogene zone has been continued through Borneo to West Sarawak, then through Malaya into Thailand and Burma by Hess (1948, 1955). However, the rock associations in any westwards extrapolation are somewhat different from those in the area of figure 1. Central Sabah, therefore, appears to be the western culmination of the peridotite-metamorphic tectogene system which extends southwestwards from the Philippines.

Ultrabasic rocks in the tectogene

Peridotites of the ultramafic magma suite occur in all alpine-type mountain systems and nowhere else (Hess, 1948). They occur in association with the formation of a tectogene and are intruded during the first great deformation and deep downbuckling of the belt, during the early stages of the formation of the overlying eugeosyncline. Later deformation of the same tectoclinal belt (zone of intense deformation of a tectogene) is not accompanied by the intrusion of peridotites (Hess, 1948), but they may be up-faulted during later thrusting. The fabric of the Darvel Bay peridotites in Sabah indicates that they were finally emplaced forcibly as a crystal differentiate in a minimum of liquid. This is consistent with the interpretations of ultrabasic rocks elsewhere (Green, 1964; Noble and Taylor, 1960). However the statement by Hess (1955) that the field geologist has "invariably drawn the conclusion that they (ultramafic rocks) appear to have been very fluid—liquid—at the time of injection" must be strongly refuted. Only a small percentage of published work on ultrabasic intrusions would support Hess's statement; the majority strongly contradict it. Intrusion as a 'cold' crystal-mush is by far the most common throughout the world to such an extent that MacKenzie (1960) made a particular point of stressing that the locality described by him in Venezuela shows a pronounced metamorphic aureole. He concludes that most other peridotite bodies appear to be re-intruded.

In the tectogene hypothesis, as applied to Sabah and the Philippines, the peridotites are initially intruded during the first great downbuckling of the tectogene, and since the pre-Chert-Spilite Formation rocks, through which these peridotites intruded, were folded and metamorphosed at this time, and later, it follows that the peridotites could not have escaped metamorphism, except for those intrusions which ended up at a high tectonic level in the overlying geosyncline. Accordingly, some signs of metamorphism should be expected in many of the peridotite bodies, especially in those closely associated with the high-grade amphibolite gneisses. Indeed, textures and structures which can be ascribed to regional metamorphism have been described from some peridotites in the region. Dhonau and Hutchison (1966) have ascribed a marginal foliation in some peridotites to regional metamorphism when the gneisses and the ultrabasic rocks were folded together.

The banding of the ultrabasic rocks, which is excellently displayed in the Zambales, bears such a strong similarity to the banding of the high grade gneisses, that at least one field geologist (Fitch, 1955) failed to recognise a metamorphic foliation and lineation. Because of the common and intimate association and frequent concordance of banded ultrabasic rocks with banded high grade gneisses, one is driven to conclude that the two fabrics are genetically related. Other writers have noted that alpine type peridotites have structures which are more akin to metamorphic than to igneous, and Thayer (1963) summarised the problem thus: "the flow structures in alpine mafic complexes are directly comparable to those often seen in other flow banded intrusives and in high-grade metamorphic rocks........... The prominent parallelism of layering with foliation and lineation is attributed to extensive flowage of largely crystalline magma during emplacement". I therefore propose that the banding of the ultrabasic rocks in the Sabah-Philippine tectogene zones does not result from a mineral separation under gravity as in high level stratiform layered bodies, but from physical separation or from metamorphic diffusion under tectonic stress in the narrow tectogene zones. Such a process would account more readily for the vertical or steep dipping nature of the banding.

There is still further evidence that the peridotites have suffered regional metamorphism: Miyashiro (1966) has ascribed the high frequency of serpentinites in tectoclinal belts to regional metamorphism, rather than to hydrothermal action accompanying later faulting. However there is no support from Sabah for his thesis that the serpentinites could represent lenticular picrite volcanics concordant with the surrounding schistose metamorphic rocks. I believe that the concordance of the schistosities is tectonic rather than stratigraphic.

Late stage of the tectogene-geosyncline

The final revolutionary development of the tectogene-geosyncline caused an uplift into and arcuate geanticlinal welts characterised by the intimate association of the high grade metamorphic rocks of the tectogene and the patchily metamorphosed Chert-Spilite Formation rocks of the overlying geosyncline.

Major faulting occurred in the now geanticlinal areas at a date which is assumed to be much later than the events already described (Wilson, 1964). This faulting, with accompanying intense shearing, has been responsible for the shapes of the islands in the island arcs and for mylonitisation and cataclasis (Dhonau and Hutchison, 1966).

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