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Observations on the geology of the porphyry copper sub-province of southwest Negros, Philippines

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Abstract: The Philippines porphyry copper province includes a number of widely-separated sub-provinces, one of which is that of southwest Negros in the southwestern Visayas region. As in most, perhaps all other sub-provinces, porphyry mineralization here is related to late differentiates of a dioritic to quartz dioritic batholiths emplaced in possibly consanguinous andesitic volcanic rocks of island arc facies. At the present state of knowledge, southwest Negros seems to be distinguished from other Philippines porphyry sub-provinces by a number of geological criteria. Salient amongst these are:-

1) An apparent (K Ar) Late Eocene to Oligocene age of the mineralized intrusive rocks.

2) Greater amounts of molybdenum than other Philippine porphyries, with lesser amounts of gold.

3) An atypical distribution of copper mineralization. The Sipalay orebody is the second largest in the Philippines and probably contains over one billion (10^9) tons of ore. The next biggest deposit is around one quarter of this size whilst all other known occurrences appear to be considerably smaller.

4) A marked NW-SE structural grain which has controlled both the emplacement of the intrusives and the disposition of the mineralization.

5) Offshore the sub-province is bordered by a sedimentary (forearc?) basin beyond which is the short, arcuate Negros Trench. Despite appearances these may be resurgent and or aborted features unconnected with the generation of the copper porphyries.

Southwest Negros is thought to represent a fault-determined block of basement which has been subjected to extensive peneplanation, burial and later (? Pliocene) uplift by some 500 m.

INTRODUCTION

The Republic of the Philippines ranks seventh or eight amongst the world's producers (c 300,000 tonnes of metal in 1981). Most of this copper is derived from mineralization of porphyry type distributed throughout the *mobile belt* of the country from northern Luzon to southeastern Mindanao, a distance of some 1250 kilometres. Productive prophyry copper deposits may be grouped into six sub-provinces whilst porphyry-type mineralization has been identified in some four or five others (Fig. 1). This widespread distribution is more remarkable since the archipelago is thought to represent an agglomerated island arc composed of fragments of lihosphere accreted from various sources and at various times (Karig, 1975).

The age of the associated plutons seems to vary from Cretaceous in Cebu (Walther *et al.*, 1981) to Late Miocene in SE Mindanao (Wolfe, 1973) but the geological setting

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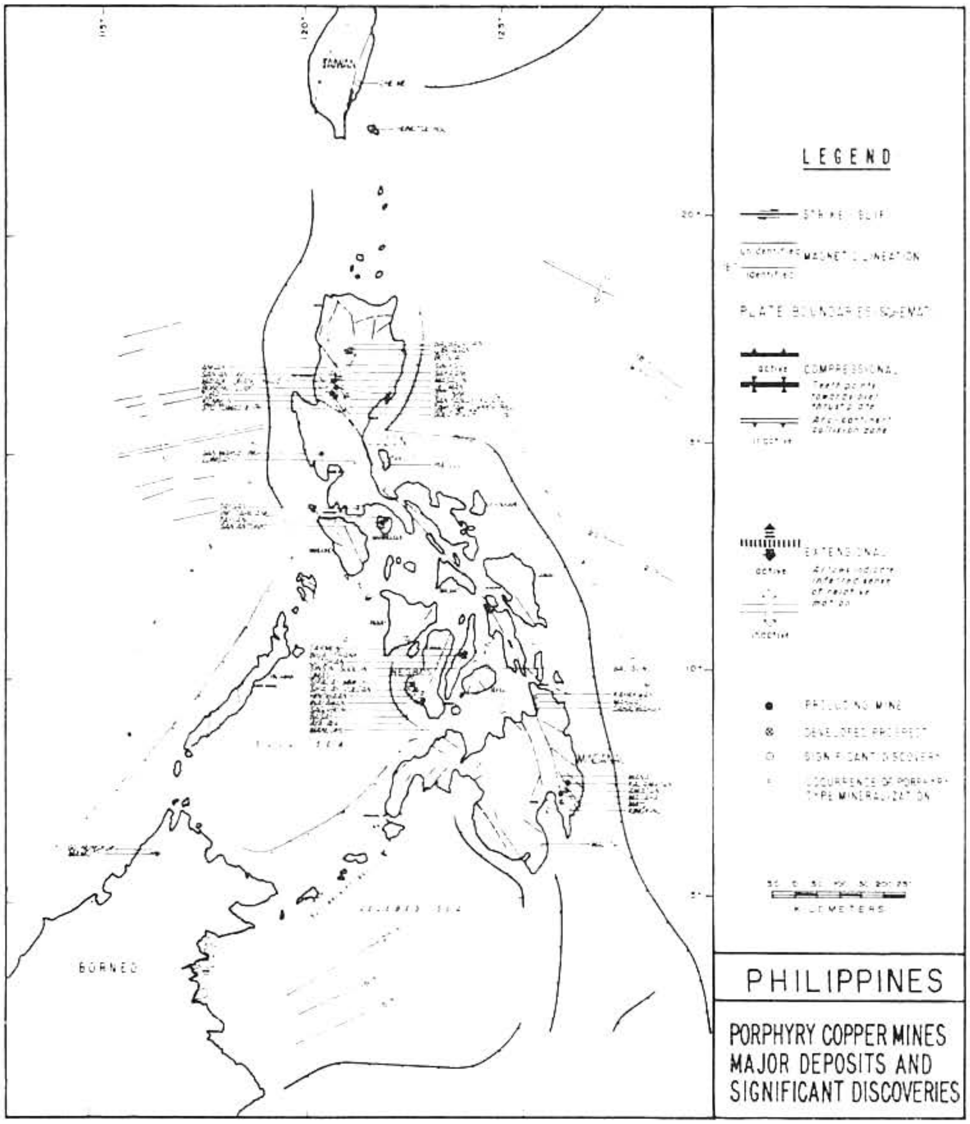


Fig. 1. Philippines showing porphyry copper mineralization: mines, major deposits and significant discoveries.

normally comprises an andesitic metavolcanic terrain of island arc facies, intruded by possibly consanguinous dioritic to quartz dioritic batholiths, the mineralization being associated with late-stage differentiates of the batholith.

In the southwest Negros sub-province, the Sipalay deposit was located in 1936 (although it was not immediately recognized as a porphyry). This discovery has inspired geological exploration in the surrounding area and numerous spot investigations have been made by the Philippine Bureau of Mines and the local mining industry. Geotechnical information on the entire island, so far as it was available to the Bureau, was summarized in their Report of Investigation No. 95 (Bureau of Mines, 1978). Recognizing the economic importance of the area, regional survey of SW Negros was undertaken by the Bureau from 1976 to 1978 and the principal findings set out in their Technical Information Series Publication No. 4–79, accompanied by a geological map at 1:500,000 scale (Castillo & Escalada, 1979). This work is still continuing and draft maps at 1:50,000 were produced in in 1980. These latter maps form the basis of the geologic map appended hereto but which has been considerably amended by information obtained from prospecting activity and from the writer's own discontinuous observations during the course of the past 6 years.

In SW Negros, Castillo and Escalada (1979) recognise 12 rock units of formation status which include two major Neogene limestone developments. To accommodate current widely varying levels of knowledge, the writer prefers to work with units of group status. It has been acknowledged that the two Neogene limestones may be of identical lithology and can only be separated in northern Negros because of the fortuitous discovery of an angular unconformity between them (Melendres and Barnes, 1957, p. 24). These two limestones are therefore grouped together here. It is recognised that this is an over-simplification but it does emphasize that the principal product of the Neogene in this area is a massive development of calcareous rock. On the other hand, because of their economic importance, various differentiates of the Pagatban Diorite have been separately identified.

STRATIGRAPHY

The stratigraphy column evolved here for SW Negros (see fig. 2) reads as follows:-

Age	Rock-stratigraphic Unit
Quaternary	Alluvium, colluvium, volcanic ash & flows
Miocene-Pliocene	Talave limestone
? Miocene	Calaogao tuff
? Oligocene-? Miocene	Tabu formation
? Oligocene	Dacite porphyry
? Oligocene	Quartz porphyry
? Oligocene	Diorite porphyry
Late Eocene-Oligocene	Pagatban diorite
Late Eocene-Oligocene	Gabbro
Eocene	Isio limestone
? Cretaceous-? Palaeogene	Basak formation

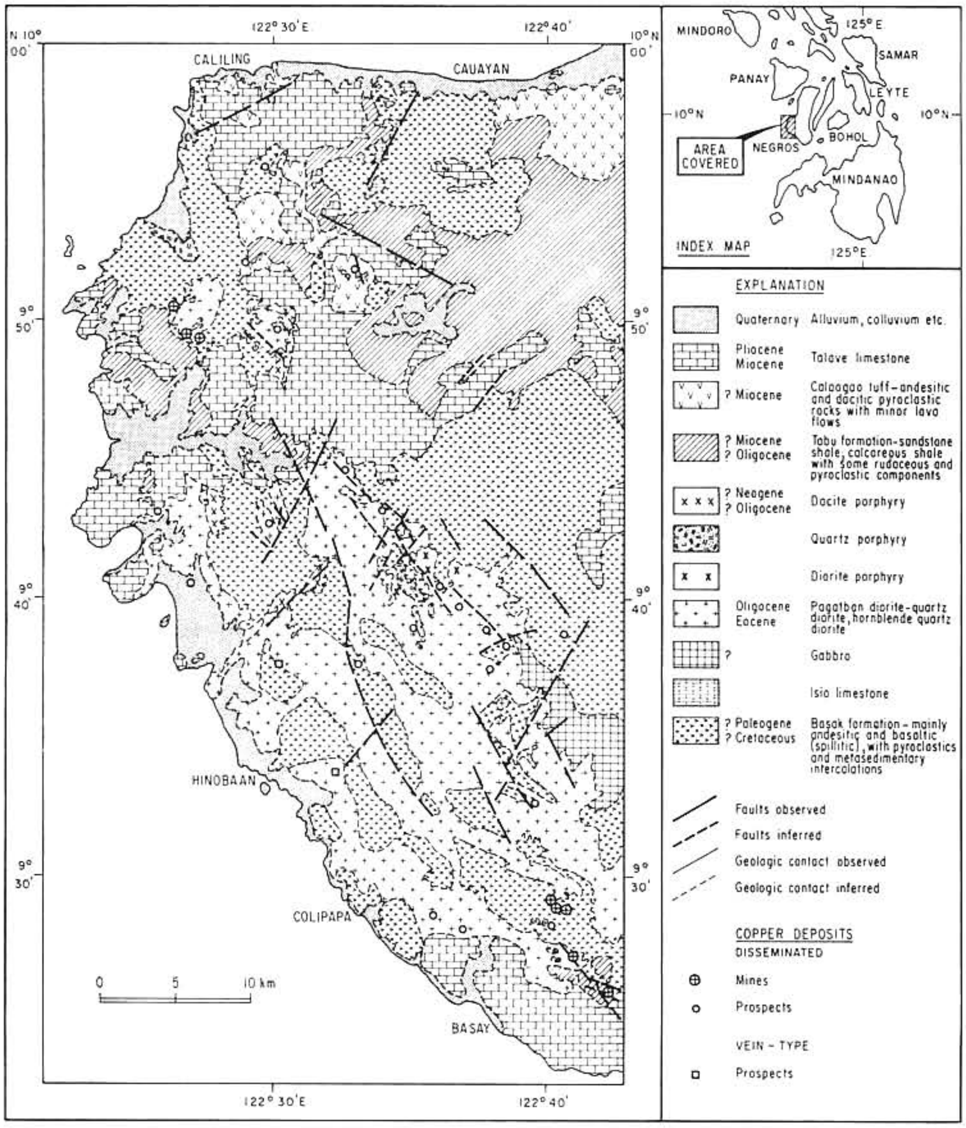


Fig. 2. Southwest Negros, compilation geological map.

Details of these rock units are given below:-

Basak formation

The oldest known rocks in SW Negros have frequently been referred to as "Metavolcanics" or "Basement Complex" and assigned a Cretaceous-Palaeocene age. These were also referred to as the Ilog formation by Santos-Ynigo and Oca (in manuscript) and it was Domingo (in manuscript) who introduced the name Basak volcanics. Castillo and Escalante (1979), whilst mentioning this name, continue to use the term *metavolcanics*. The name has, however, been adopted in the latest Philippine Bureau of Mines and Geosciences (1981) lexicon in the form Basak formation.

In that publication the type locality is said to be merely *the northeastern, southern and southwest parts of Cabanbanan area, Cauayan*. Rocks along the coastal zigzag road between Sangke and Colipapa were also assigned to the Basak formation. The author has selected a reference section here at 9°27′11″ N; 122°33′07″ E, one km. SSE of Barrio Colipapa.

The Philippine Bureau of Mines and Geosciences (1981) volume describes the Basak as *massive amygdaloidal basalt and agglomerate of basaltic to andesitic composition with intercalated tuff and thin beds of metasediments*. In fact, andesite is a dominant component of this rock unit and in the reference section cited above.

The Basak formation is similar to the metavolcanic rocks of Gumaras and eastern Panay, also known as the Sibala formation (Capistrano and Magpantay, 1958) of the Tablas altered volcanic rocks (Vallesteros and Argano, in manuscript) of Romblon and the Ubay volcanics at Bohol (Arco, 1971). All these possible correlatives are also thought to be of Cretaceous to Palaeocene date.

On his masterly *Tectonic Map of the Indonesian Region*, Hamilton (1979) represents the Basak as *Melange*. This is incorrect and the formation appears to comprise island arc volcanic rocks.

Isio Limestone

This rock unit name was evidently also introduced by Damingo (in manuscript) and adopted by subsequent workers of the Philippine Bureau of Mines. An Eocene age was cited initially, although Castillo and Escalada (1979, p. 8) report Early Miocene fossils here. The latest Philippine Bureau of Mines and Geosciences (1981, p. 98) publication states, however, that *definite Late Eocene large foraminiferal assemblages* have been found in the unit. The type locality consists of exposures along the Isio river, Isio, Cauayan in the northern part of SW Negros where well-bedded, buff-yellow to brown silty, fossiliferous limestone is found. The Isio is reported to be unconformable on metavolcanic rocks of the Basak (Castillo and Escalada, 1979).

No correlatives of the Isio limestone are known from Panay or Romblon, but it seems to correspond to the Calape limestone of Bohol (Arco, 1971).

Gabbro

A northward-thinning wedge-shaped body of gabbro trending parallel to the NW regional strike on the eastern side of the Pagatban diorite batholith was mapped by the

Philippine Bureau of Mines geologists. Its outcrop aggregates some 30 square kilometres. This rock was named as the Manlawan Gabbro by Castillo and Escalada (1979, p. 13) from good exposures in the upper course of the Manlawan River, a left-bank tributary of the Pagatban River. This body of gabbro has not been seen by the present writer but can occurrence of gabbro was found in the Manlupo creek, some 7 kilometres west of the northern end of the outcrop shown on the map.

Texturally, the gabbro is reported to range from fine to very coarse, in the latter case the pyroxene grains measuring 1 cm. Quartz was seen in some samples and a crude layering is occasionally present.

It is not known whether this rock represents a basic phase of the Pagatban diorite or whether it is component of an ophiolitic sequence, much of which may have been assimilated by the batholith to produce the hornblendic varieties of diorite. Nor is there any direct indication of age of this rock. It is presumed to be either synchronous with or (more probably) somewhat older than the Pagatban diorite.

Pagatban diorite

The term Pagatban intrusive (Castillo & Escalada, 1979) was applied to the batholith which underlies much of the western part of SW Negros and which, together with the Basak formation forms much of the basement thereof. It has also been informally referred to as the Hinobaan diorite, the Sipalay diorite, etc. The form Pagatban diorite is preferred here, named for exposures along the course of the Pagatban River. Other good exposures are seen in the lower reaches of the Hinobaan Creek (Nauhan River) a few kilometres from Hinobaan town.

The Pagatban diorite constitutes a batholith whose outcrop extends from the Panay Gulf southeastwards for some 62 kilometres, almost to Talong Bay. Its width varies from $1\frac{1}{2}$ to 22 km. In detail, it embraces numerous elongate septa of Basak volcanic rocks in a pattern largely controlled by the NW-trending faults which dominate the structure. Whilst some displacement by NW and, to a greater extent, complimentary NE faults is seen, it appears that initiation of the faults predates intrusion. Apart from the late-stage differentiates, considerable variation in texture and composition occurs. The rock ranges from equigranular to porphyritic, from fine to coarse and from melanocratic hornblende diorite through hornblende quartz diorite to rather leucocratic quartz diorite or granodiorite. As indicated above, the presence of gabbro in the area may imply that the more mafic components of the batholith are a series of hybrids.

Porphyry copper type mineralization is found at a number of locations (Fig. 2), usually near to the margin and almost invariably associated with satellitic stocks of late stage differentiates—particularly andesite porphyry, diorite porphyry, dacite porphyry and quartz porphyry.

One variety of dacite porphyry is marked by large (up to 10 mm. or more) porphyritic crystals of oligoclase and smaller phenocrysts of quartz in which the prism faces are are largely suppressed. Five kilometres east of Campomanes Bay this rock forms an approximately vertical body resembling a composite volcanic pipe. East of Hinobaan the same rock type constitutes irregular dykes.

The Pagatban diorite has previously been inferred to be Eocene in age because of K/Ar dates on the diorites from Guimaras Island and from the Atlas mine, Toledo, Cebu (Wolfe, 1973). Recent radiometric work by Walther and his colleagues (1981) have now proven the latter to be 108 Ma (Middle Cretaceous). At the same time biotite in porphyritic tonalite from the Sipalay map was studied. From the description given it seems more likely that this sample is from the main Pagatban diorite than a differentiate. It was noted that cleaning of biotite from this sample was insufficient because of scarcity of material. A dating of 30.2 ± 4 Ma (Middle Oligocene) was obtained hereon.

Recently two additional age determinations of intrusive rocks from SW Negros have been made at the University of Amsterdam, The Netherlands. The author is indebted to the Philippine Bureau of Mines and Geosciences, Region VII, for permission to reproduce the following results from Priem (written communication).

Sample	K (% wt)	radiogenic ^{40}Ar (ppb)	atmospheric ^{40}Ar (% total ^{40}Ar)	calculated age (10^6 yr.)
YCP4 (Aya-Aya)	6.512	17.53	21	38.4 ± 2.0
NB-09 (Basay)	6.578	15.85	24	34.4 ± 2.0

These samples are derived from neighbouring localities near the south end of the Pagatban batholith and in both cases the indicated age is near to the Eocene/Oligocene boundary.

It is concluded herefrom that the age of the Pagatban diorite is latest Eocene to Middle Oligocene. The K/Ar date of 59 ± 2 Ma assigned to the diorite of Guimaras seems to be in need of re-examination. The Sara diorite, also with copper and molybdenum mineralization, of eastern Panay may also be a correlative of the Pagatban diorite.

Tabu Formation

Castillo and Escalada (1979) applied the name Tabu formation to what they believe to be the most extensive rock unit in SW Negros. This term was taken from an earlier unpublished report referred to as *Miranda et al.*, of which no further details are given.

In the latest publication by the Philippine Bureau of Mines and Geosciences (1981) Tabu has been abandoned in favour of the earlier terms Escalante formation (below) and Macasilao formation (above), both taken from northern Negros. Whilst these latter may well be the equivalents of the Tabu, until this is established and in pursuance of the group status philosophy set out above, a local name from SW Negros is preferred.

Included in Tabu on our map (Fig. 2) are strata mapped by the Philippine Bureau of Mines staff as Canturay formation, believed to be intermediate in position between two Neogene limestone formations.

A type locality was designated by Castillo and Escalada in a *roadcut near Barangay Tabu* (1979, p. 8). This village is located on the road to Bayawan, some 10–1 2 km. due south of Dancalan on the west coastal highway.

Good outcrops are also been along the Tablas river where a basal conglomerate is reported to be exposed. The formation was clearly deposited on an erosional base of SW Negros basement rocks (Basak andesite and Pagatban diorite) and is the oldest rock unit to extend beyond SW Negros into other parts of the island. At the type locality the Tabu comprises-well-bedded sandstone, siltstone and shale. Some of the finer beds are poorly sorted and elsewhere manganese lenses and volcanic interbeds have been noted.

Sometimes the finer components are either carbonaceous and limestone and coal members are reported from evidently correlative rock sequences.

The probably equivalent Escalante and Macasilao formations are said to be 1730 metres and from 300 to 3200 metres thick, respectively (Philippine Bureau of Mines and Geosciences, 1981). This same publication in table II–27 places the Tabu in the Oligocene, although no fossils were found by Castillo and Escalada (1979). The Escalante was dated as Late Oligocene, possibly extending into the Early Miocene, whilst the Macasilao formation is said to be Early to Middle Miocene.

Calaogao tuff

Another rock unit adopted by Castillo and Escalada (1979) from the report cited as *Miranda et al.* is Calaogao pyroclastics. It is said that the earlier writers believed this unit to be unconformable on the Tabu formation. The Philippine Bureau of Mines and Geosciences (1981) now seems to regard the Calaogao as a facies of the Tabu.

The form Calaogao tuff is preferred by the author. This formation is of limited extent in the northern part of southwest Negros and comprises mainly andesitic and dacitic pyroclastic rocks, with minor lavas.

Talave limestone

The Tabu formation, and its equivalents, is overlain by a strong development of limestone which similarly extends beyond SW Negros to the north of the island (and, in part at least, to neighbouring islands). This rock unit is here termed Talave limestone following one of the first names specifically given to an expression of this calcareous development in Negros (Corby *et al.*, 1951). As noted above, this is certainly a *sack* unit incorporating a number of formations, including two major limestones. Castillo and Escalada (1979) named these respectively as the Dacongcogan and Sipalay limestone in one of their tables although the latter formation seems to have been incorporated with sandstone, siltstone and shale in the Kalumbuyan formation in their text and map.

The earlier limestone has also been referred to as Salong limestone (Santos-Ynigo and Oca, 1946), Caliling limestone (Domingo, in manuscript) and Dansalan limestone (Caguiat and de la Concha, in manuscript).

The upper limestone has often been correlated with the Pliocene-Pleistocene Carcar limestone of Cebu. The most recent Philippine Bureau of Mines stratigraphic column (1981) restricts the term Caliling limestone to this formation in Negros and separates this from the earlier limestone by the Paton-an formation. The latter comprises 490 metres of shale and sandstone with thin coal and conglomerates of Late Miocene to Early Pliocene age (Philippine Bureau of Mines, 1978). In some localities this is represented by volcanic rocks, some of which also occur above the limestones.

Geologists of CDCP Mining Corporation have recently collected samples of limestone for age determination at three points in the southern half of the area under review. These probably all come from the lower part of the Talave succession and point to a late Middle Miocene age.

PHYSIOGRAPHY

In reporting his reconnaissance in Negros, Willis (1937) made mention of a peneplain, which he said was tilted to the west. This seems to be the feature referred to in the topographic maps of the central part of SW Negros as *Tablas Plateau*, evidently named for the nearby Tablas River, or *Cabadiangan Plateau*.

At many points in SW Negros the skyline is formed by an elevated horizontal surface which evidently extends into the SE part of the island where, (Willis, 1937, p. 31) suggested that this feature may be constituted by tops of lava or mudflows. Good views of this level can be obtained in the vicinity of Hinobaan where the land rises rapidly to over 500 metres within 5 kilometres of the shoreline (Fig. 3). Owing to its gradational upper limits and to the effects of erosion, it is difficult to determine the maximum altitude of this surface, but a rather extensive flat area is present between 400 and 500 metres in elevation. Figure 3 shows there are two extensive tracts of land in SW Negros over 400 metres high, one in the centre and one in the north.

The central and larger upland area consists of a curved or L-shaped zone running NE for some 25 km. and then turning sharply to the SE. This alignment suggests some control by the NE and NW fault pattern. This dissected plateau is mostly underlain by basement rocks (Basak volcanics and Pagatban intrusives) and near its northern end the feature is rather sharply delimited against lower land formed of Talave limestone, although limestone also forms a small part of the upland area and reaches a height of 482 m. In the centre residual peaks rise above the plateau surface to 589 m. and to the east a small area (of gabbro) attains a little over 700 m. in height. This central upland forms the watershed between the Tyabanan and Pagatban rivers flowing south and to the north, the Sipalay and Tablas catchments flowing to west and east respectively.

North of the Sipalay-Tablas depression is the northern zone of high land, rather more dissected but generally aligned, with the regional stratification, ENE. In contrast to the central area, a considerable part of the northern plateau is built of limestone which here reaches its maximum elevation of a little over 500 m.

Since the Talave limestone also contributes to the plateau surface at around 500 m., it is considered that this feature may in fact be a gradation plain, comprised of both

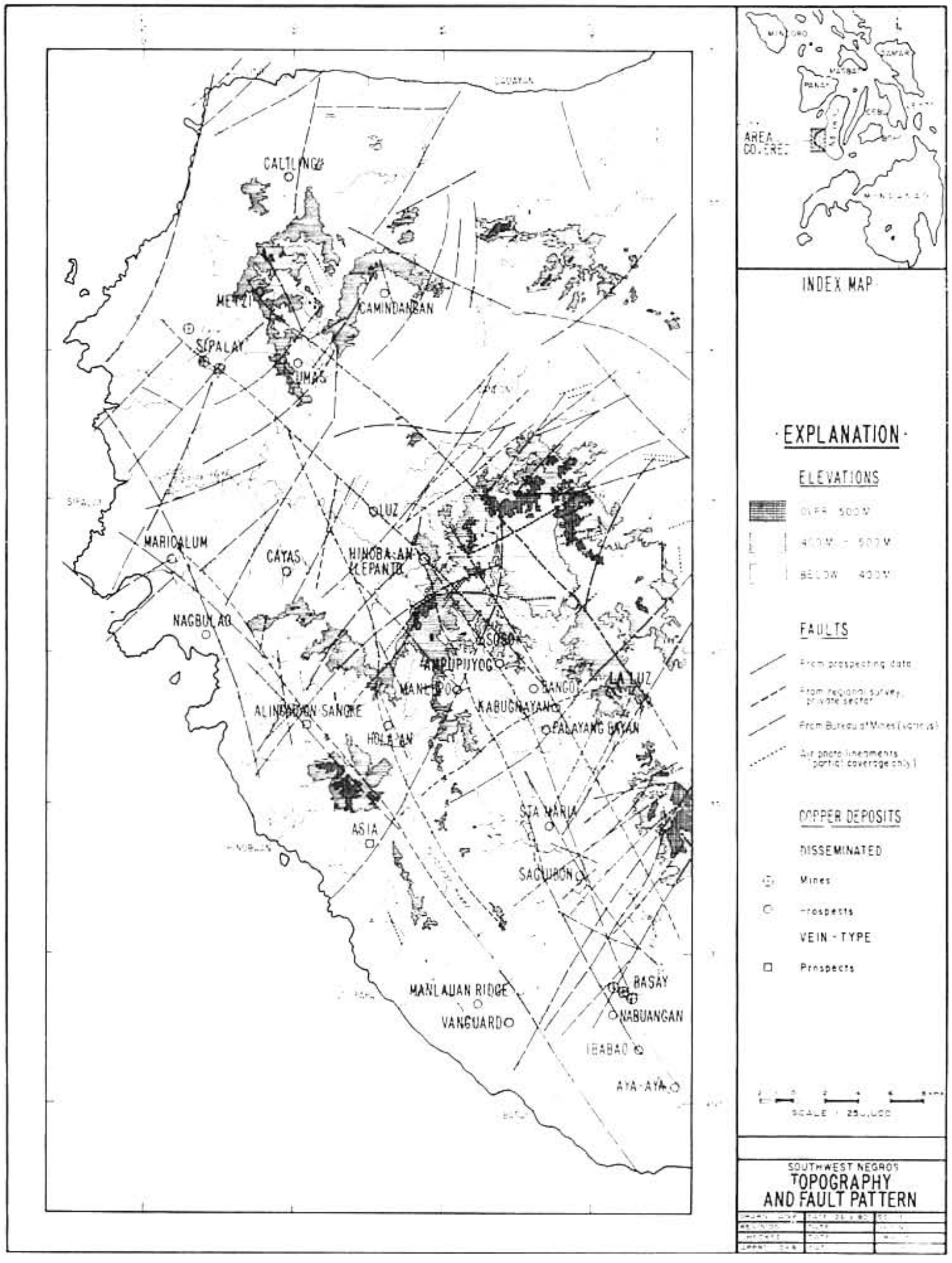


Fig. 3. Southwest Negros, topography and fault pattern.

erosional (basement) and constructional (limestone) elements. No evidence of the westward tilting reported by Willis (1937) has been seen although that worker may have been thinking in regional terms as there is an implication that he believes the peneplain in Negros to be homologous with that arched up to 900 m. in Central Cebu.

Below the summit surface other flat levels occur at different heights in different places. From a cursory study it is not possible to assign these to surfaces of regional extent, although such features may exist. Presumably these stepped surfaces represent still-stands of base level between the approximately 500 metre maximum and the present.

The surface of the Tablas plateau is typically covered by a thick cover of lateritic soil, particularly on basement rocks. Sevillano and Fernando (1981) report that around Basay the soil averages 5 m. in thickness. Most of the unweathered rock seen here occurs in the beds or banks of deeply incised watercourses. Often the latter show strong meandering, evidently developed during the stage of peneplanation and preserved after uplift. This phenomenon is especially well displayed by the Pagatban River and its tributaries.

Both the Pagatban and Tyabanan rivers show a general parallelism with the main NW-trending faults although in detail their meanders now diverge considerably therefrom. It is hypothesized that the courses of these rivers may have initially been controlled by the faults but that they subsequently wandered away from these features when the rivers were near to contemporary base level in the peneplanation stage.

Generation of this gradation plane has a bearing on exploration insofar as between the watercourses considerable weathering and leaching has taken place, diminishing the surface expression of mineralization. At the same time limited secondary enrichment of copper has occurred. There is also a possibility that there has been a build-up of electrolytes in the weathering profile here, affecting induced polarisation (I.P.) response.

As detailed above, the Talave limestone is thought to range in age from late Middle Miocene to Pliocene. It seems likely that it is the older part of the Talave which constitutes part of the gradation plane which may therefore be of Late Miocene to Early Pliocene age. Since considerable dissection has occurred it is further surmised that uplift took place some time ago and a Middle Pliocene data is suggested. It is not certain that peneplanation in Negros is contemporary with similar processes in Cebu. In the latter island, the surface arched up to 900 m. cuts across Miocene folds and is also believed to be of Pliocene development (Willis, 1937).

STRUCTURE

The geological structure of SW Negros is dominated by a series of long and generally rectilinear, NW to NNW-striking fractures. Associated therewith are numerous, usually shorter, NE-trending features and together the two appear to conform to a classical Anderson-type wrench fault pattern (Anderson 1951), which would suggest that they owe their origin to approximately N-S compressive stress. Only faults whose identity is more or less certain are shown in the geological map (Fig. 2) but on the topographic map (Figure. 3) the author has depicted all the faults postulated from all sources known to him.

The fault pattern is strongly expressed by the outcrop of the Pagatban diorite. Whilst some, at least, of its margins are formed by faults, others with a similar trend appear to be unfaulted—from which it is inferred that the fault system exerted a strong control on the emplacement of the batholith. The form and disposition of many of the dioritic differentiates also implies that these have been emplaced on or adjacent to fault planes.

Since the porphyry copper mineralization is principally associated with these late stage differentiates, it follows that the mineralization has a close relationship with the faulting, either because the faults constitute loci for the satellitic hypabyssal intrusives or because they afford conduits for the mineralization itself. Frequently, the mineralization is cut and displaced by NE-(more often) or NW-striking faults, which may result from renewed movement on earlier fault planes. Often, the sense of movement on these faults is equivocal. Castillo and Escalada (1979) suggested that movement along at least one of the major (NW) faults is right-lateral, whilst the maps of Sevillano and Fernando (1981) show that the NE faults displace the Basay orebodies in a sinistral sense.

Although these faults are believed to have originated early in the recorded history of SW Negros, some have been projected into the more recent sedimentary strata and, particularly in the limestone, have exerted control on the surface expression.

In view of the strong fault pattern it is not unexpected that jointing should be also well-developed. It is remarkable that in some cases a well-developed fracture pattern can be identified in aerial photographs. Closely-spaced parallel lineations, a few tens of metres to one or two hundred metres apart have been seen over areas of a few square kilometres. This phenomenon is best developed between the upper Pagatban and upper Sipalay rivers (E and S of the Hinobaan prospect). These close fractures are typically aligned E-W, sometimes diverging fan-wise. In some places two directions of close fracturing are present. Close fracturing has doubtless afforded a means of ingress for the agents of hydrothermal alteration and mineralization.

Because the structure is so strongly dominated by NW-SE directed faults and because bedding is sometimes dragged into parallelism with the faults, it is somewhat surprising to discover that the overall strike of the layered rocks in SW Negros is ENE. Due to the uneven distribution of structural information, it is only in the north that the attitude of the Basak formation can be discerned. Here dip angles range from 20° to 55°, mainly towards the NNW.

The more numerous strike readings in the Tabu formation show a wider range—from SE through E to NNE—but the mean direction is again ENE. The amount of dip is mostly between 10° and 25° and almost entirely between 5° and 55°. In the north dips are towards the north, in the centre undulating folding occurs whilst the restricted area of Tabu outcrop in the south shows a southerly dip.

The Talave limestone has a generally more restricted range of strike direction about an ENE mean and somewhat gentler dips than the Tabu (usually 10°–20°). Despite moderate undulation the overall inclination is to the south throughout the subject area.

Since the sedimentary rocks have the same strike but gentler dips than the Basak, it is considered that the structure of the former may have been "superimposed" upon the overlying sediments during the course of their consolidation and uplift. The overall disposition of the strata of the Tabu formation could be interpreted as some kind of regional doming, possibly also inherited from the basement. The rather consistent southward inclination of the superincumbent limestone, however, implies that the structure of the Tabu was originally assymmetric with a stronger northerly-dipping component.

The ENE strike of the Basak may have been syngenetic with the faulting as both may have been caused by N-S to NNW-SSE-directed compressive forces.

MINERALIZATION

The Sipalay mine of Marinduque Mining and Industrial Corporation constitutes a large-scale porphyry copper deposit with reserves of the order of one billion (10^9) tons of ore. 45 kilometres to the southeast is the Basay (Muhong) mining operation of CDCP Mining Corp. which perhaps contains a quarter of a billion tons of ore. In between the two are a series of porphyry-type prospects, the largest of which appears to be that at Hinobaan (NDC/Lepanto) where reserves are around 100 million tons. These all lie in the SW part of Negros. In other parts of the island a number of occurrences of copper have been found but, to date, no commercial potential has been indicated.

Review of the geologic map of SW Negros on which the mineralized location have been superimposed (Fig. 2) shows that the copper mineralization is related to—

(i) the margin of the Pagatban diorite
(ii) late-stage differentiates of the batholith
(iii) NW-SE faults.

In this mineral sub-province we are aware of 27 copper deposits of some significance. 17 of these fall in a central belt which is almost co-terminous with the outcrop of the Pagatban batholith, extending NNW for some 57 km., but with a width no greater than 5 km. Included here are the Sipalay and Basay mines (two deposits each), the Hinobaan deposit which is now (1982) being prepared for operation, another deposit (Saguibon) which will probably furnish additional feed for the Muhong (Basay) mine and a variety of others at various stages of knowledge and development (Fig. 2).

A western belt of mineralization, parallel to the main belt and separated therefrom by some 5 km., comprises 7 occurrences of much less economic appeal than those in the central tract. Test drilling has been conducted on two of the prospects, known as Nabulao and Maricalom, with generally low amounts of copper being encountered although some gold is also contained in the latter area.

The three remaining prospects known in SW Negros lie to the east of the main Pagatban outcrop, although they are associated with small bodies of dioritic rock. Prospecting results therein to date (including five diamond drill holes at La Luz) have revealed only low concentrations of copper.

The two discernible mineral belts are very narrow. In fact, the three principal deposits together with a number of smaller prospects may be related to two faults, with slightly different azimuths, which are confluent near the Hinobaan deposit (Fig. 3). The Negros porphyries generally have a steeply-dipping tabular form aligned, apart from Sipalay, with the NW-SE faults. Hinobaan may be an erosion remnant of a tabular body. They are normally cut by post-mineral faulting, often of the subsidiary NE-SW set. Strong pyrite *haloes* are the exception rather than the rule and seem to be well-developed only at Basay and Aya-Aya. That at Sipalay is moderately developed. The other deposits are mostly of a type designated as *structurally restricted* by Pelton and Smith (1976).

Deposits in the main belt appear to be all of porphyry type and the larger ones, at least, are associated with at least two distinct types of differentiate. These correspond approximately to (quartz) diorite (porphyry) and dacite porphyry respectively. A breccia pipe, with pebble dykes, constitutes the satellitic Baclao orebody of Sipalay. This is the sole example of this type of feature reported from SW Negros although others may occur in association with a possible volcanic plug east of Maricalom and with the Aya-Aya deposit at the south end of the belt. Although marginal facies of the batholith are recorded outside the main belt, discrete differentiates have not been recognised. In the western belt, two deposits are known to be of mixed sulphide vein type and at least one other comprises dominantly fracture-filling rather than disseminated mineralization. The three prospects east of the main batholith seem to be of low-grade, disseminated type.

As a general rule the porphyry copper deposits of the Philippines exhibit very limited secondary enrichment. This feature is perhaps better developed in SW Negros than elsewhere in the country and seems to be related directly to the peneplain surface at Sipalay (Kinkel *et al.*, 1956) and at Basay where commercially significant quantities of enriched copper ore has been exploited (Vasquez, 1982). Supergene enrichment to a depth of 60 m. and a grade of 1% copper was found at Hinobaan where a leached capping 5 to 15 metres thick occurs.

The economic significance of deep weathering of the SW Negros peneplain has been referred to above (Sevillano and Fernando, 1981). Uplift of this surface produced incision of the drainage and exposure in the river beds and banks. Possibly earlier positive tectonic tendencies of the SW Negros block explain the exposure and erosion of the copper deposits here. Smith and Pelton (1976) believe the Sipalay mineralization to represent a low level of a porphyry system. The limited amount of pyrite and the presence of bornite offer some support for this view, although mineralization has been reported from drill holes down to 850 m. It is also believed that a large volume of ore has been eroded from the Hinobaan deposit.

The latest Eocene to Middle Oligocene age indicated for the parent batholith in the SW Negros porphyry copper sub-province is, at the present level of knowledge, unique for the Philippines.

Another characteristic of the porphyry copper deposits of SW Negros is that, in distinction from similar mineralization elsewhere in the country, they bear economically significant, but variable, amounts of molybdenum and correspondingly smaller gold contents. The mean molybdenum value of the three main deposits is 0.015% and gold is 0.06 g/t.

Molybdenum mineralization seems to be somewhat independent of copper. In the Aya-Aya prospect a leucocratic quartz porphyry stock was found to be low in copper but to contain significant molybdenum. Further, studies at Basay on one level in the SE pit indicated that molybdenum has a linear zonation broadly coincident with the long axis of the orebody, but different from the copper distribution pattern (Westra, written communication).

A number of authors have said or implied that continental crust is the main source of molybdenum in large-scale deposits. Westra and Keith (1981) state, however, that strontium and sulphur isotope studies, the lack of relationship between molybdenum deposits and crustal thickness in the western U.S.A. and the high molybdenum content of some carbonatites all suggest that molybdenum has a mantle source. The same authors further declare that molybdenum deposits are independent of geological environment but are highly dependent on magma series geochemistry which is strongly influenced by the phlogopite field. In subduction, most hydrous minerals are dehydrated before reaching a depth of 150 km., but K, F and minor H_2O may be carried in phlogopite to depths over 250 km. Deep melt fractions enriched in these materials may then transport molybdenum up into the crust.

Although few of the Negros porphyry deposits have pyrite *haloes*, geochemical prospecting has revealed a large and clear zinc *halo* in some cases.

Despite their apparent similarities the SW Negros porphyry deposits show varied geophysical responses. In the case of magnetics this situation is understandable in view of the fluctuating and apparently random distribution of magnetite. Much, at least, of the magnetite here is derived from the heterogenous metavolcanic country rocks. A Japanese aerial magnetic survey commissioned by the private sector some years ago revealed a number of anomalies reportedly with a partial and inconsistent relationship to porphyry mineralization.

A subsequent (1977) airborne magnetometer survey by the Bureau of Mines was flown at the rather high altitute of 4000 to 5000 feet. The SW Negros porphyry province is distinguished herein from a magnetically *quiet* background as a belt of rapidly varying magnetic field with negative anomalies up to − 350 mT (Fig. 4). The latter appear to reflect overall deep crustal conditions, however, and no detailed correlation with mineralization is possible. (Palacky, personal communication).

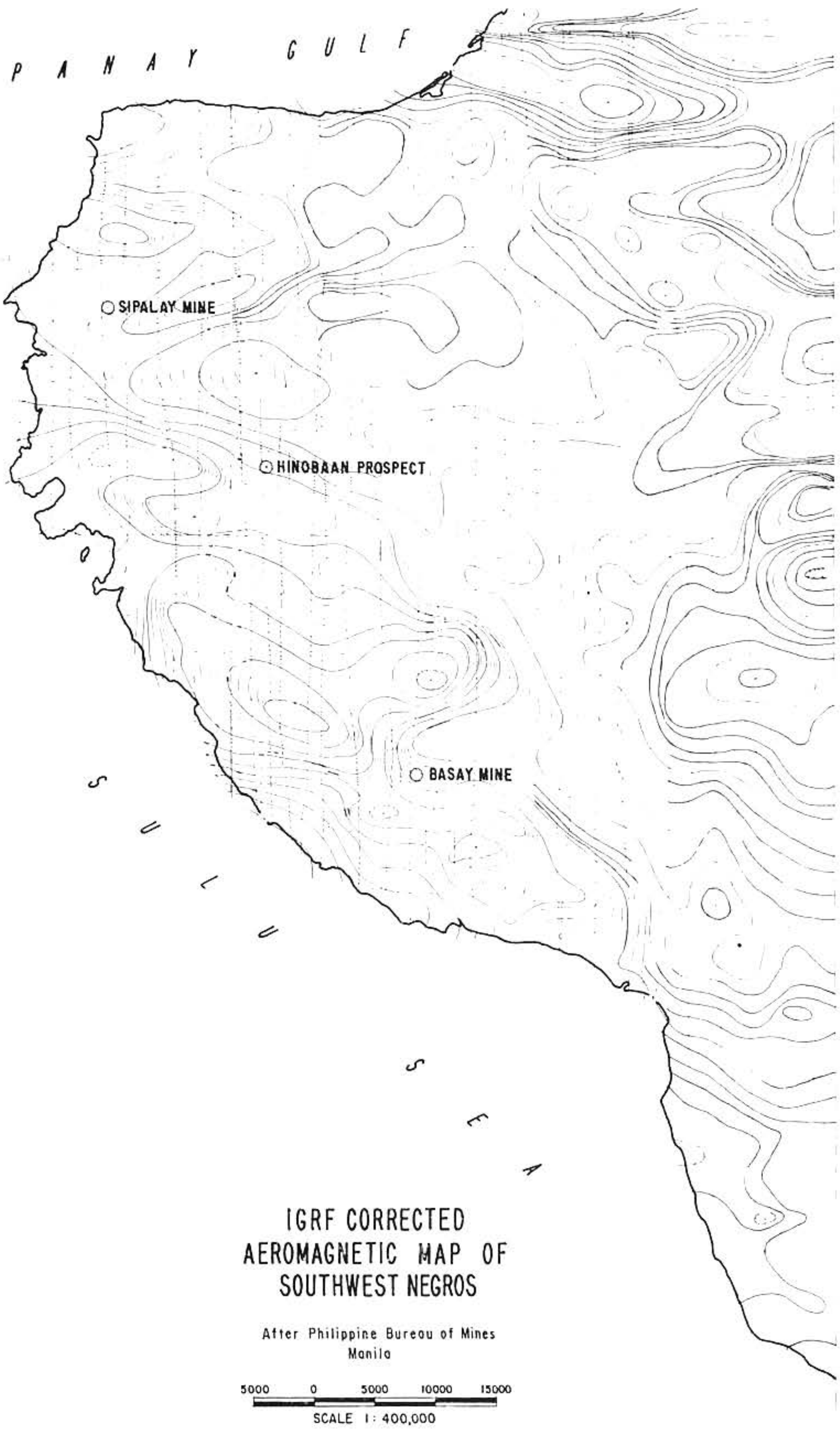


Fig. 4. IGRF corrected aeromagnetic map of southwest Negros.

The results of some resistivity and induced polarization surveys in SW Negros were presented by Pelton and Smith (1976). The Sipalay ore showed a low frequency effect and high resistivity. At the other end of the porphyry belt, the core of the Basay (Muhong) orebody also gave a high resistivity response but with a high PFE. Hinobaan, however, showed a low resistivity and a high FE. The Luz prospect, four km. NW of Hinobaan was said to have revealed both high PFE and high resistivity where drill holes showed oregrades. An additional hole in high PFE and high resistivity here yielded low values, however.

On several occasions drilling of high resistivity/high I. P. anomalies has yielded low concentrations of copper. This may be due either to concentration of electrolytes in the peneplain producing anomalously low resistivity readings or to sulphide systems composed largely of pyrite.

TECTONIC DEVELOPMENT

Most attempts to understand the tectonics of the Philippines start with Gervasio's (1966) division of the country into a N-S mobile (seismic) belt and a stable (aseismic) region to the SW, around the Sulu Sea. SW Negros lies adjacent to the boundary between these two tectonic provinces. A faulted contact (the *Apo Fracture Zone*) was postulated between them (De Boer *et al.*, 1980) but Hamilton (1979), Cardwell *et al.* (1980) and Acharya and Aggarwal (1980) believe rather in an east-dipping Benioff zone along this line, interrupted where it is impinged upon by the Palawan and Sulu-Zamboanga ridges. The northern, major, part of this Benioff system comprises the Manila Trench. Cardwell and his colleagues (1980) have designated the two southern, shorter and shallower sections as the Negros Trench (after Hamilton) and the Cotabato Trench.

In addition to the radical differences in seismicity, the geological histories of these major tectonic provinces have little in common, suggesting that these may have evolved at some distance apart.

Karig (1973) amongst others has suggested that a subduction system flipped over from the east to the west side of the Philippines in Miocene time. Holloway, (1980) believes, however, that a subduction zone was in place on the (present) west side of the Philippines by the Late Eocene and the enquiries of McCabe and his co-workers (1982) support easterly directed subduction here at least by the Oligocene.

Part of the eastward-dipping zone evidently passed along the western side of Panay island where Hamilton (1979) has demonstrated the former occurrence of a rather complete set of consuming plate margin elements (Fig. 5), including melange in the west (Antique Range), an outer-arc basin in the centre of Panay (Iloilo basin) and a magmatic arc in the east (Sara diorite and Guimaras diorite, intruded into andesitic volcanic rocks). The melange zone exhibits thrusting involving rocks as old as Late Jurassic—Early Cretaceous (McCabe *et al.*, 1982) and evidently as young as Early to Middle Miocene. In the Iloilo basin are strata of Oligocene to Holocene date, including Late Oligocene to Early Miocene volcanic components. The one (K/Ar) age determination made on diorite from the magmatic arc (Guimaras) have a

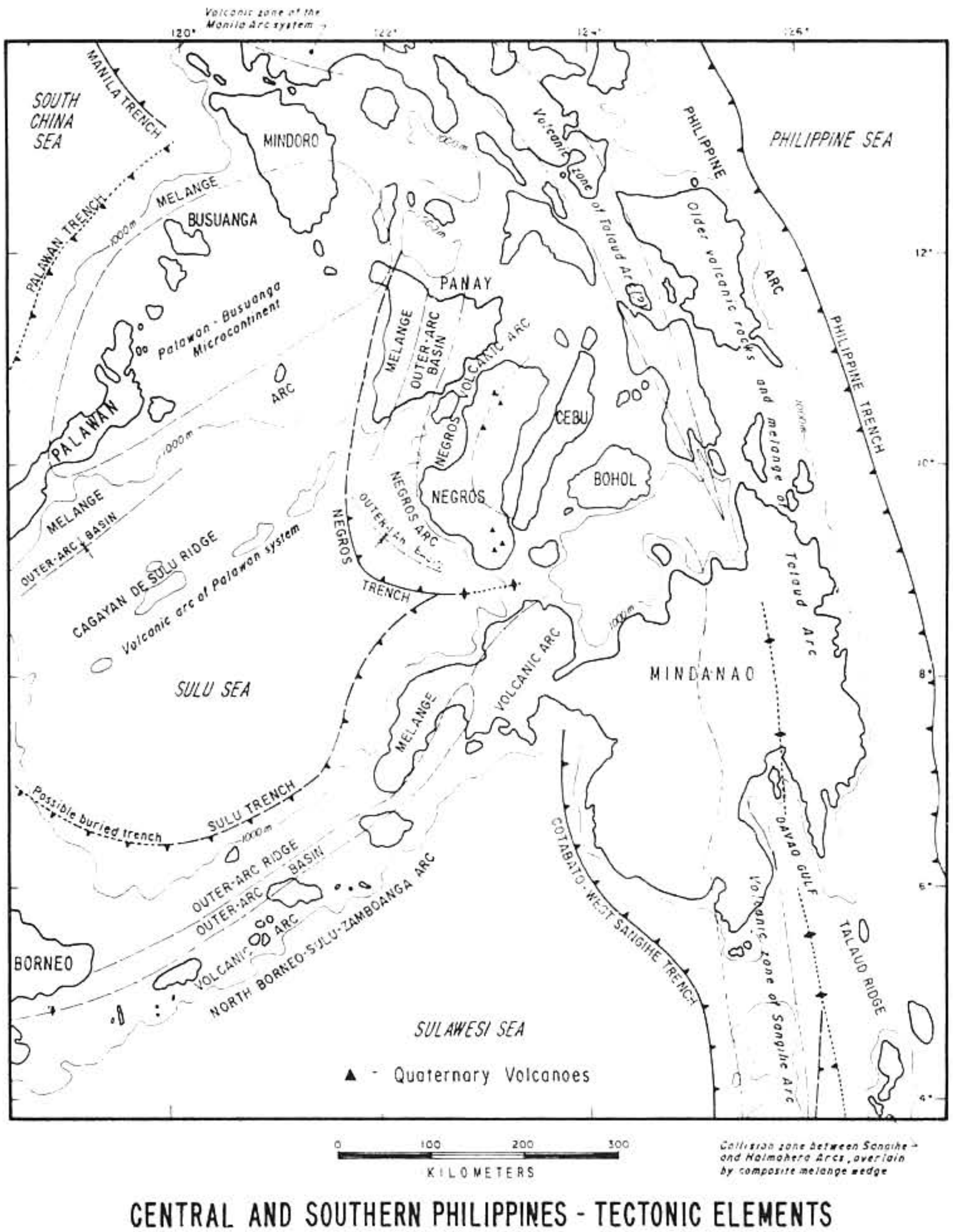


Fig. 5. Central and southern Philippines tectonic elements (after Hamilton, 1979).

Palaeocene/Eocene date (Wolfe, 1973). Lithologies of the eastern Panay rocks are very similar to those of the volcanic and plutonic basement of SW Negros and the Oligocene date of the Pagatban diorite seems appropriate for that of eastern Panay and finds support from observations relayed by McCabe *et al.* (1982, p. 326). Furthermore, SW Negros and E. Panay have similar positive (over 75 mgals) free-air gravity anomalies (Watts *et al.*, 1981) and may represent different sections of the same magmatic arc, as postulated in Hamilton's figure III (1979) wherein the Iloilo basin is also projected into the SW Negros offshore tract. These proposed correlations are further extended by Hamilton by joining the modern submarine trough to the west of the Antique melange with the present-day trench off SW Negros (Fig. 5).

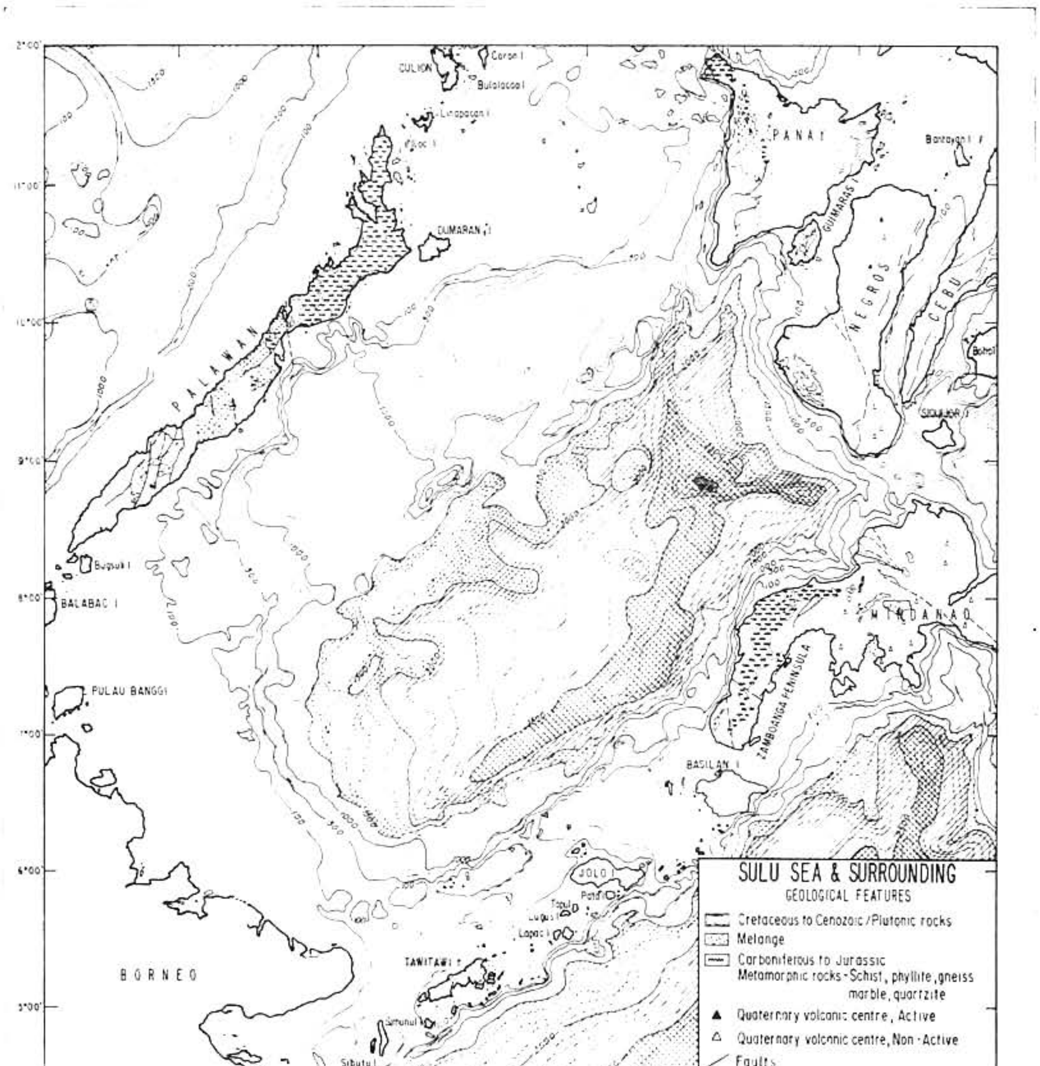
In fact the free-air negative gravity anomaly of the Antique trough is not prolonged south of Panay. A separate negative anomaly near the Negros Trench continues into the Iloilo basin and both are bordered to the east by the positive anomaly mentioned above (Watts *et al.*, 1978).

Fig. 6 demonstrates that the Negros Trench proper is very short and highly curved, with a maximum length of perhaps 350 km. and a maximum depth of 3049 fathoms (5574 m.). It has also been shown by Cardwell and others (1980) that whilst shallow earthquakes, with hypocentres less than 70 km. deep, are numerous in and around the Antique trough and also occur in the Iloilo basin, only four are well-established off SW Negros. Acharya and Aggarwal (1980) present a focal mechanism solution for one of these consistent with NE underthrusting along the Negros Trench and marine seismic profiles show sediments of the Sulu Basin being underthrust in the same direction (Mascle and Biscarrat, 1978).

One interpetation of the earthquake data shows the seismic zone from the Negros Trench as barely attaining the 80 km. minimum depth of initial magma generation, at an angle of 28° (Cardwell *et al.*, 1980, Fig. 3C). Another version (Acharya and Aggarwal, 1980, Fig. 6) represents a Benioff zone extending down to some 140 km. with a mean inclination of 53°. These divergent interpretations are reproduced here in fig. 7.

Deep earthquakes beneath the western Visayas and western Mindanao, also included on fig. 7, are related by both geophysical teams to an ancient subduction zone inclined westwards from the vicinity of the Philippine fault zone (Davao-Agusan-Leyte). This subduction system, evidently a northward continuation of the Sangihe arc, has been active at least since the early Middle Miocene according to Hamilton (1979, p. 194).

The Negros Trench as seen today thus appears to be a geologically young feature. It has been invoked to explain the Quaternary volcanoes of Negros (Cardwell *et al.*, 1980; Acharya and Aggarwal, 1980), although by the interpretaion of the former investigators it is barely deep enough, particularly for the earlier activity. It is noted, moreover, that the Negros volcanoes lie at varying distances (50 to perhaps 140 km.) from the axis of the trench and hence form an arc of different curvature from the trench and which extends beyond the southern limit of the trench into northern Zamboanga (Fig. 6).



Bathymetric data from Defence Mapping Agency, Washington D.C.
Geological data modified from Bureau of Mines, Manila
Geological Maps of the Philippines 1963 and 1981

Fig. 6. Sulu Sea and surrounding area — geological features.

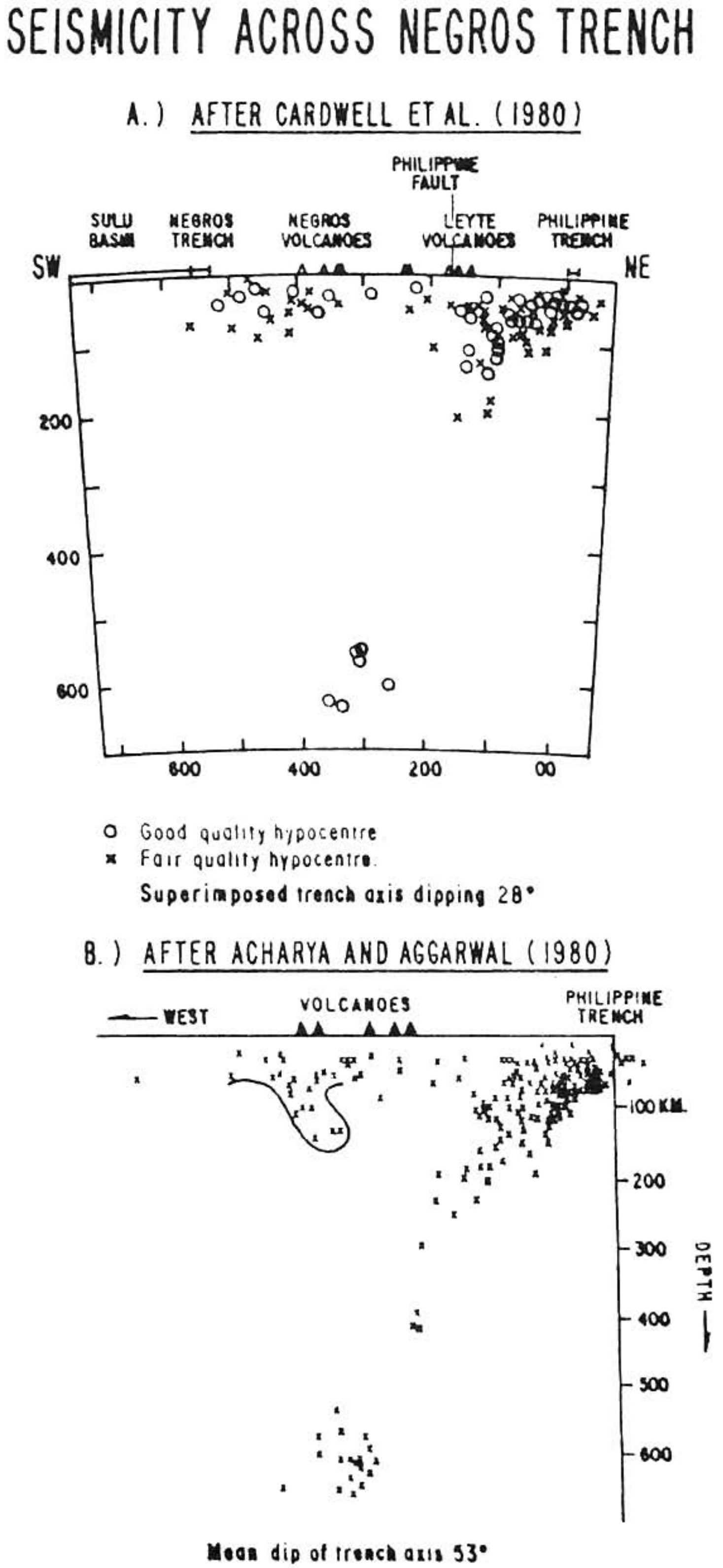


Fig. 7. Seismicity across Negros Trench: a) after Cardwell *et al.* (1980); b) after Acharya and Aggarwal (1980).

Whether or not Quaternary vulcanism owes its origin to the Negros Trench it is clear that there is no justification for correlating this modern feature (estimated at 1.6 to 2.8 Ma old at a subduction rate of 5 cm./yr.) with the Pagatban diorite of SW Negros, dated at 30 to 38 Ma. Possibly the present day Negros Trench is a resurgent feature on or near to the site of an early Tertiary trench.

Turning now to the so-called stable region, Taylor and Hayes (1980) have shown that the eastern half of the South China Sea was formed in mid-Oligocene to early Miocene times by N-S sea-floor spreading. The approximately meridional eastern and western margins of the Palawan-Busuanga block, possibly controlled by transform faults, are in accord with this spreading system but it is difficult to relate hereto the NE orientation of the North Borneo-Palawan subduction system. Anticlockwise rotation of this system has been proposed (Haile *et al.*, 1977; Hamilton, 1977) but the present writer has difficulty in explaining substantial rotation of a long-established trench presumably rooted in the mantle. At the end of their account, however, Hayes and Taylor (1980, p. 103) add that in the western third of the South China Sea basin there appears to be northeast-trending relict spreading centre. This feature parallels the salient structural components of the Sulu Sea basin, i.e., the Palawan ridge to the NW, the NW margin of the oceanic crust together with the Cagayan de Sulu ridge in the centre and the Zamboanga-Sulu subduction zone in the SE. A causal relationship may be inferred.

Hamilton (1977 & 1979) reports subduction in the Palawan Arc during Palaeogene and Miocene times. Possibly subduction here was terminated by the blocking effect of the Reed Bank (Holloway, 1980). In such cases the Benioff zone normally reverses direction (i.e., flips) or advances out to sea. In the case of an intra-oceanic arc, however, there seems to exist the possibility that a subduction zone may retreat (i.e., step back farther from the spreading centre). This seems especially likely in the case of the Sulu Sea where more continental crust was being imported on the NW side of the Palawan subduction zone. The most ready solution to choking of this system may have been a withdrawal of subduction to the position of the Sulu-Zamboanga arc. Since this arc seems to date from the Oligocene it might be that the Sulu Sea commenced life as a back arc basin in the Palawan subduction regime (as postulated by Holloway, 1980). There is no evidence of magnetic lineaments to support this hypothesis, however.

NW-SE (and later N-S) spreading of the China and adjacent seas or NE-ly subduction beneath the Negros magmatic arc although today the Sulu Trench is confluent with the Negros Trench. Hamilton (1979) is uncertain whether the two features are in collision or whether they represent *oroclinal bending of a previously continuous arc*. Various authors (e.g. Mascle and Biscarrat, 1978) believe in collision between the Palawan-block (or Palawan-Busuanga micro-continent) and Panay, an event dated by McCabe *et al.* (1982) as Late Oligocene to Miocene.

Since the principal phase of China Sea spreading was parallel or at a small angle to the western margin of the *mobile belt* and because the Palawan block was apparently translated southward, it seems that the latter did not actively approach the Visayas but rather the Visayan area moved west to impinge on Palawan.

The collision seems to have terminated subduction in the original Negros trench and subduction may then have *flipped* from the west to the east side of the southern Philippines. This hypothesis is supported by Hamilton's (1979) contention that westward subduction in the Sangihe arc commenced at least by early Middle Miocene and by the appearance of a line of volcanoes in the central Visayas region in the early Middle Miocene (Mueller *et al.*, 1980). The Sulu-Zamboanga arc may also be in collision with central block of Mindanao, but we have no data on the possible timing of this.

Neogene sedimentary facies in the Central Visayas generally strike NNE or perpendicular to the direction of spreading of Pacific Ocean and presumed underthrusting which, however, is considered to have been oblique to the NNW-trending plate margin (Wolfe, in manuscript).

At least since the early Middle Miocene also SW Negros acted as a tectonically positive element of the basement (other such area are central Cebu and north and east Bohol). It seems that part of the area was emergent around Middle Miocene times and subject to both subaerial and submarine erosion, reducing much of the basement surface to a peneplain which was gradually, although not entirely, buried under encroaching ramparts of Talave limestone to produce a more widespread *gradation plain*.

Subsequent uplift of the SW Negros gradation plain, probably in the Pliocene, is a further expression of the positive tectonic character of the basement here. This elevation was not uniform and there was evidently an element of southerly tilt. Moreover, this movement seems to have had the effect of imprinting basement structures on the sedimentary cover. Conceivably the uplift was related to the collision of the Talaud or eastern Mindanao arc with Sangihe/Central Mindanao.

Following the *docking* of the Talaud arc, two new subduction zones were instituted on either side of the southern Philippines — one at the Philippine trench and the other on the approximate location of the former Benioff zone on the west side of the mobile belt which had now become subdivided into the Manila, Negros and Cotabato Trenches. In the Negros sector therefore the latest (evidently Pliocene) subduction was restricted to the foreshortened Negros Trench between the Cagayan de Sulu ridge and the Sulu-Zamboanga arc. It may also be that renewed attempts to subduct Palawan and Zamboanga caused the uplift of SW Negros.

It appears that penetration of the renascent subduction zone to depths of 80-plus kilometres has resulted in the generation of andesitic magma whose access to the surface may have been controlled by pre-existing features. The north Negros volcanoes are close to the site of early Middle Miocene (18–14 Ma) volcano of south Negros and the coastal maars to the north are on the margin of the Tanon Strait graben, of Late Miocene origin according to Mueller *et al.* (1980). The latest volcanoes of north Zamboanga may also have been fed by ancient conduits as they do not seem to be underlain by a contemporary subduction zone.

Thus whilst Cardwell and his collaborators (1980) aver that the Negros Trench is a young feature and Hamilton (1979) indicates that it is old, the author's view is that this is a resurgent subduction zone probably destined to be aborted, as Acharya and Aggarwal (1980, p. 51) suggest, as the Philippine Trench becomes the dominant means of absorbing the consuming forces between the Eurasian and Philippine plates.

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