Mineral Distribution and Geological Features of the Philippines

Gabriel *Santos*, Jr.*

Abstract

The Philippine deposits are divided into two main groups based on their locations in the arc-trench system, namely frontal arc and third arc. Deposits occurring in the frontal arc are characterized mainly by the predominance of nickel, laterite, chromite and cupriferous massive sulfide, under a geologic setting distinguished by ultrabasic and basic volcanics and subordinate intermediate intrusive-metamorphic (schist) rocks. These regional rocks are adjacent to deep troughs or trenches.

Deposits belonging to the third arc are primarily characterized by the gold-bearing copper sulfides with pyrite and minor magnetite and molybdenite. The mineralizations are closely related to intermediate intrusives and intermediate-basic volcanics with occassional ultrabasics.

Southeastern Luzon could probably exhibit the features of both the frontal and third arcs. It is suggested that the Sulu Sea Basin could probably have been formed as a result of the extensional rifting of a part of the frontal arc.

Zusammenfassung

„Mineralverteilung und geologische Merkmale der Philippinen"

Auf Grund ihrer Lage im Bogen-Graben-System lassen sich die Lagerstätten der Philippinen in zwei Hauptgruppen teilen, nämlich die des frontalen und des dritten Bogens. Die Lagerstätten des frontalen Bogens sind vor allem durch das Vorherrschen von Laterit, Chromit und massigen, kupferhältigen Sulfiden mit begleitender Zinkblende gekennzeichnet. Die geologischen Formationen, in denen

* G. *Santos*, Philippine Atomic Research Center, Diliman/Quezon City, Rep. of the Philippines.

sie sich befinden, zeichnen sich durch die Anwesenheit von ultrabasischen bis intermediären Vulkaniten sowie untergeordnet von intermediären intrusiv-metamorphen (verschieferten) Gesteinen aus. Diese Gesteine liegen tiefen Trögen oder Gräben benachbart und werden in den südöstlichen Philippinen von der Philippinen-Störung abgeschnitten.
Die Lagerstätten des dritten Bogens sind vor allem durch die goldführenden Kupfersulfide mit untergeordnetem Pyrit, Magnetit und Molybdänit gekennzeichnet und eng mit intermediären Intrusivgesteinen und Vulkaniten, fallweise auch kleineren ultrabasischen Körpern, verbunden. Im südöstlichen Luzon sind wahrscheinlich Merkmale sowohl des frontalen wie des dritten Bogens vorhanden. Es wird angenommen, daß das Becken der Sulusee wahrscheinlich durch ausgedehntes Rifting eines Teils des frontalen Bogens entstanden ist.

Introduction

The purpose of this paper is to relate the mineral deposit distribution of the Philippines and the geologic features in the light of its island arc structures. This work is a part of a research program of the Philippine Atomic Energy Commission investigating the application of trace element distribution in mineral sulfides to the study of metallogenic provinces. Based on available data on Philippine mineral deposits and personal fieldworks, this investigation classifies mineral deposits on the basis of their geologic setting. The setting, in this case, is visualized in terms of elements of an arc-trench system (Karig, 1970). In the course of this study, attempts were made to explain certain "enigmatic" geologic features of the Palawan-Sulu Sea area.

General Setting

The Philippine Islands have a roughly triangular areal form and are located in the western Pacific between latitudes 5° and 20° North and longitudes 115° and 127° East. These islands include Luzon, the largest island in the north; Mindoro, Masbate, Panay, Negros, Cebu, Bohol, Leyte, Samar and other smaller islands comprise the central Philippine group; Mindanao, the second largest island, and the Sulu group of islands constitute the southern portion of the Philippines and are separated from Palawan by the Sulu Sea. (see Fig. 1). The eastern part of the archipelago from Luzon through the central Philippines and Mindanao constitute the mobile belt while the Palawan and Sulu Sea areas are considered as the stable region *(Gervasio*, 1964).
The areal distribution of principal oceanic troughs, mountain system and foci of deep-seated tectonic earthquakes and particular major mineral deposits have fairly good correspondence in the Philippine island arc system. Apparently, there seems to be some fundamental regional control governing metallization.

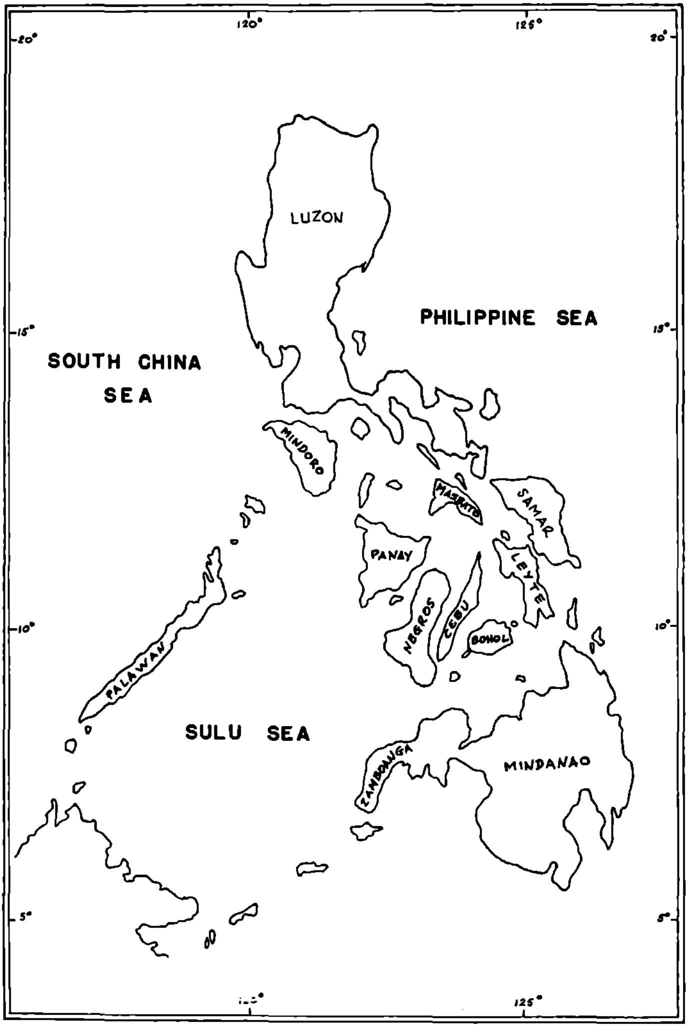


Fig. 1. Geographic Location of the Philippines.

The geology of the Philippines has been summarized in the "Geological Map of the Philippines" (1963), published by the Philippine Bureau of Mines. Other students of the Philippine geology include *Irving* (1949), *Corby* & al. (1951), *Ranneft* & al. (1960), *Gervasio* (1964) and *Melendres* (1971). The regional occurrences of mineral deposits particularly, copper-gold deposits were investigated by *Kinkel* & al. (1957), *Tupaz* (1960) and *Bryner* (1969).

Volcanic features dominate the regional geologic scene. Visualized in terms of the elements of an island arc system as defined by *Karig* (1970), the Philippine arc is roughly subdivided into parts of the frontal arc, inter-arc basin and third arc as shown in Figure 2. The location and dimensions of the basins were compiled by *Melendres* (1971). According to Karig, the third arc may be considered as a remnant of a former frontal arc and as a result of the extension between the frontal arc and the third arc, and inter-arc basin is formed.

In Fig. 2, the frontal arcs are situated in west Luzon-Palawan and southeastern portion of the archipelago. Parts of the third arc are found in northern Luzon

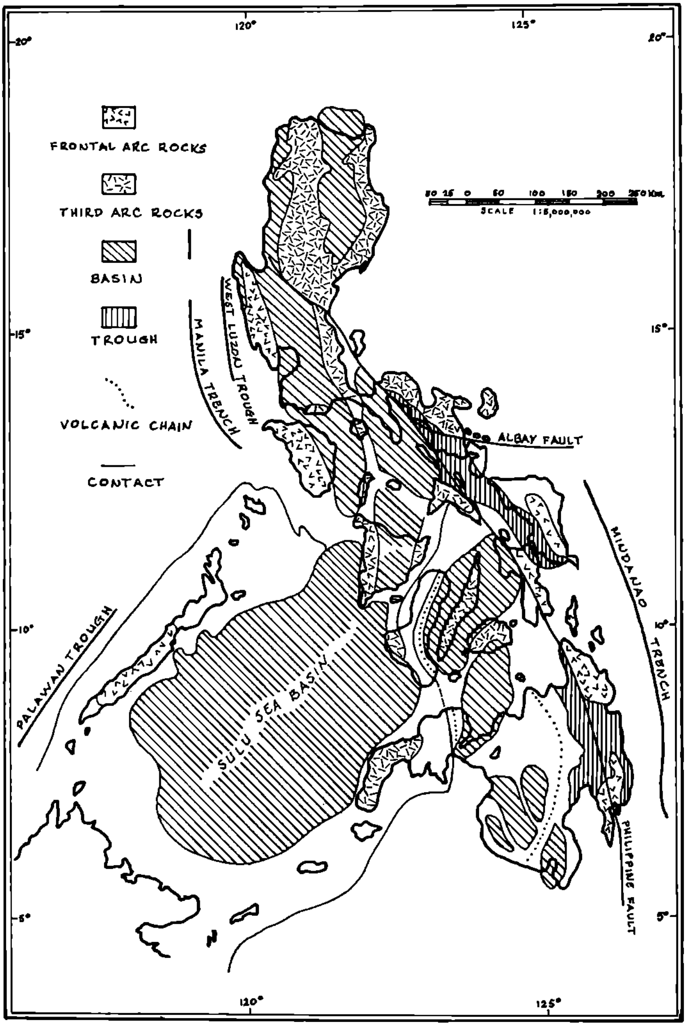


Fig. 2. Philippine Island arc System.

and in the islands of Central Philippines. The southeastern part of Luzon is classified as belonging more to the third arc than to the frontal arc. Elongate and narrow, locally discontinuous inter-arc basins separate the frontal arc from the third arc. The Sulu Sea basin, however, appears to approximate clearly the postulated origin by extensional rifting of inter-arc basin as observed by *Karig* (1970) in the Tonga-Kermadec, New Hebrides and Marianas island arc systems.

The frontal arcs are bounded by the Manila Trench and Palawan Trough in west Luzon-Mindanao and the Palawan island respectively; and the Mindanao Trench in eastern Samar, Leyte and Mindanao islands. The first marine geophysical surveys of west Luzon-Mindanao were conducted by *Ludwig* & al. (1967) and *Hayes* & *Ludwig* (1967) which led to the delineation of the Manila Trench and West Luzon Trough.

The localized small "basins" and "troughs" found in the archipelago are considered as parts of the inter-arc basin though they may not appear as much in the more ideal sense of the word as defined by Karig. This condition is brought about by the complexity of the Philippine arc to an arc system, wherein two oppsitley adjacent facing zones of convergence are in evidence. Arc to arc relationships are possible according to *Isacks* & al. (1968). The subduction zones are delineated by the Manila Trench in western Luzon and Mindanao Trench in eastern Mindanao as shown in Figure 2. The Mindanao Trench system has the typical features of the classical arc-trench system as regards seismicity, gravity anomalies and volcanism. Associated seismicity of the Mindanao region is fairly high in comparison to the west Luzon region. The focal depths of earthquakes in Mindanao area exceeds 300 kilometers. In west Luzon, seismic activity is restricted to depths well below 300 km *(Hayes & Ludwig,* 1967; *Morante,* 1970).

On the basis of dimension, the Mindanao Trench is much longer than the Manila Trench, which could account in part, for the latter's shallower seismic activity. *Datuin,* (1972) thinks that east of Luzon is probably the site of a developing trench on the basis of occurrences of earthquakes with shallow focal depths. He recognizes the presence of two blocks which represent the Philippine mobile belt, the Luzon and the Visayan-Mindanao blocks. The Philippine fault which passes through these blocks changes from dextral in Luzon to sinistral in the Visayan-Mindanao region. According to *Kintanar* (1966), "the Philippine fault is the only tectonic feature of regional consequences", though it is reasonable to expect that this fault has other branches. *(Irving,* 1951; *Melendres,* 1971). An inferred transform fault is probably developing. The trace of the inferred fault could pass through the Mindoro Reentrant and the Albay Reentrant. The Albay fault is probably a part of this transform fault. The presence of this rift or fault was suggested recently by *Santos* & *Wainerdi* (1969). Thrust faults appear to be a common feature of the frontal arc.

According to *Kintanar* (1966) based on 400 stratigraphic sections in various areas, radiodating, depositional environment, petrology and regional data... "the Philippines has been an archipelago since Upper Paleogene (Eocone-Oligocene). The position and shape of the islands have fluctuated with time, but the overall pattern has remained." The composite thickness of the (sedimentary) section is about 70,000 feet which are sub-divided into "five groups, each separated by an unconformity in areas of positive movement". The section "varies from mudstone to conglomerate and from limestone to chert." In general the sedimentary rocks are characterized as quartz-poor except in Palawan and southwestern Mindoro areas. Deposition environments ranges from abyssal to continental with common occurrences of turbidite deposits. Kintanar noted that since Eocene time the islands have been separated by deep troughs inter-connected by volcanic ridges on the sea floor. At times these ridges rise high enough to form islands and reefs. The Tertiary basins and troughs locations and boundaries compiled by *Melendres* (1971) are shown in Fig. 2.

Frontal Arc Rock Suite

Rocks found in the frontal arc are characterized by extensive ultrabasic- basic intrusive, of the Alpine type *(Thayer,* 1960) to basic volcanics with associated thick sedimentary rocks deposited in basins of miogeosynclinal type. The ultrabasic rocks consist mainly of serpentinized peridotite and dunite with minor gabbro and lesser pyroxenite. The rocks are typical of, though not confined to frontal arc environments. The volcanics are represented by the spilites-keratophyres and pillow lavas, most are interbedded with or intruded in marine sedimentary rocks. In the Mindoro-Palawan area, the sedimentaries consist of "arkosic sandstone, wacke and shale associated with quartzite" *(Gervasio,* 1966).

A basement complex of pseudostratigraphic sequences called "ophiolite assemblages" as defined by *Gervasio* (1966) and *Dickinson* (1971) are overlain by Triassic (?) to Jurassic graywacke-shale-chert limestone in the Palawan-Mindoro and western Zamboanga areas. *Gervasio* (1966). The ophiolites consist partly of greenchist and basic amphibolite schist and gneiss with meta-graywacke, phyllite and slate.

The age of the basement complex which are found mostly in Palawan and Mindoro is probably Carboniferous to at least Permian based on discordant fossil-bearing sedimentary rocks. *Gervasio* (1966).

It is significant to note that the structural trend of the Triassic-Jurassic miogeosynclinal sedimentaries is north-south while the older folded belt of Palawan is northeast. *Gervasio* (1966; 1968). *Motegi* (1971) recognized this structural northeast "Palawan Trend" and suggests that this "ancient lineament" is closely related to the distribution of ore deposits. Both *Motegi* and *Ranneft* & al (1960) noted the strong northeast-trending tectonic lines in Zamboanga Peninsula.

On the basis of the juxtaposition of the north-south trending Tertiary quartz-rich sedimentary formations and the northeast trends of the pre-Tertiary igneous-sedimentary rocks of Palawan-Mindoro areas and in the light of new plate tectonics *(Dickinson,* 1971; *Dewey* & *Bird,* 1970; *Isacks* & al., 1968) it is suggested that rifting of the mio-geosynclinal rocks of Palawan and Mindoro occured probably from Carboniferous through Permian and that collision probably took place at the close of Jurassic to Early Cretaceous.

It may further be inferred that the Sulu Sea Basin was formed as a result of extensional rifting of the Palawan frontal arc on the basis of the following: (a) equivalent rock types found in Palawan and Zamboanga peninsula, (b) submarine morphology of Sulu Sea, *Irving* (1961), (c) the existence of the northeast "Palawan Trend" reflected by the Sulu island group through Zamboanga, (d) evidence of rapid subsidence of Sulu Sea, *Daleon* (1971).

Sediment thickness and distribution in the Sulu Sea may further substantiate this inference.

Third Arc Rock Suite

Intermediate intrusive-volcanics (diorite-andesite complexes) appear to be the distinctive rock of the third arc. Indeed, the core of structural highs in central Luzon consits of elongate synorogenic batholitic diorite masses which were intruded "near the end of middle Miocene time". These plutons generally trend northsouth *(Fernandez & Pulanco,* 1966). However, in Cebu and Negros islands, the Paleogene diorite masses associated with mineral deposits have northeast trends. (Atlas Mines, 1967; *Kinkel* et al, 1956).

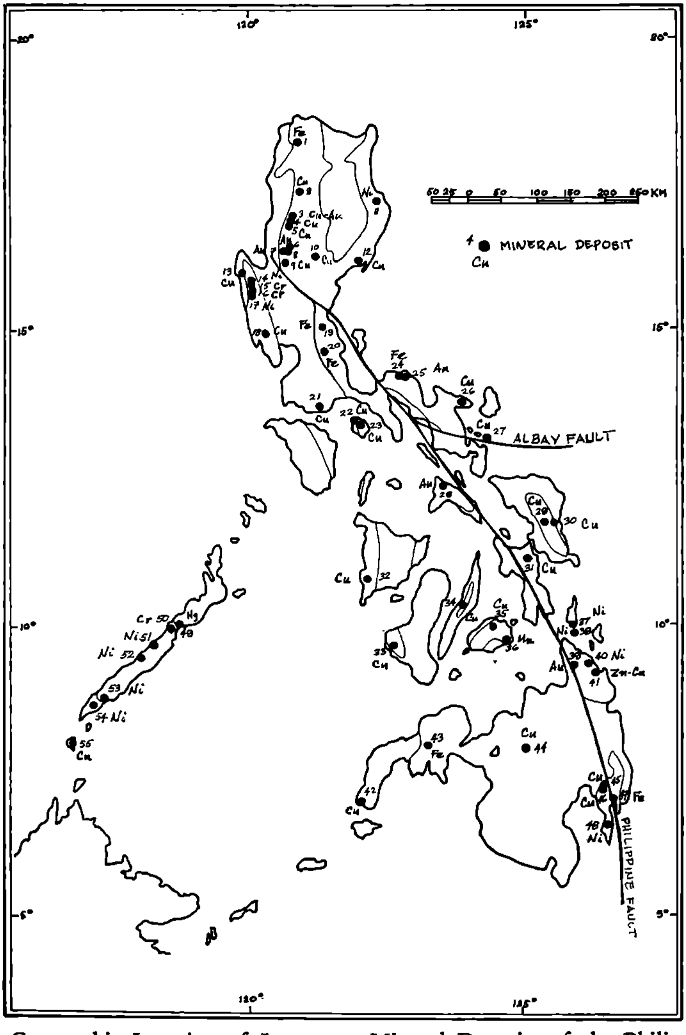
The basement rocks in Luzon are "crystalline schists and quartzites of pre-Jurassic age, Cretaceous-Paleogene volcanic flows, intercalated cherts, marble and extensive meta-sedimentary rocks", according to *Fernandez & Pulanco* (1966). They added that minor serpentinized peridotites appear to occur in places along faults of late Miocene sedimentary rocks. The undifferentiated schists represent metamorphism of basic flows and sandstone.

The southeastern Luzon area bounded by the Philippine fault and Albay Fault could probably exhibit the characteristics of both the frontal and third arc. This is due to the nearness of the area to the boundary effects of the arc to arc nature of the setting. The Albay Fault in this regard, is taken as the trace of the inferred transform fault dividing the west Luzon and eastern Mindanao subduction zones. In the Paracale-Mambulao district (24,24), according to *Frost* (1959) a granodiorite stock has intruded a sequence of basic and ultrabasic rocks. Unconformably overlying the ultrabasics are a series of Miocene sedimentary rocks. These sedimentaries were in turn overlain unconformably by a sequence of volcanic flows of andesitic composition (Larap Volcanics). The writer has seen the presence of pillow lava with volcanic breccia in the Larap Volcanics indicating submarine deposition.

It is interesting to note that the Larap Volcanics include diorite-andesite-dacite assemblage (dioritic complexes) and basaltic-andesitic submarine flows. It will be recalled that in terms of igneous activity, the Paracale-Mambulao district have both the predominant rock types of the frontal arc (ultrabasic volcanic) and the third arc (intermediate intrusive-intermediate volcanics).

Mineral deposits

The mineral deposits are classified on the basis of their island arc setting, either under the frontal arc or third arc. This classification is summarized in Table 1. The geographic distribution of the mineral deposits is shown in Figure 3. The localities of these mineral deposits do not necessarily indicate their magnitude or economic importance, though some considerations were taken in weighing their economic potential. It must be added that there are numerous small copper-gold deposits that were not included in Fig. 3.



Fg. 3. Geographic Location of Important Mineral Deposits of the Philippines.

Table 1

Classification of mineral deposits of the Philippines

A. Frontal Arc

Map No.	Name & Location of Deposit	Type of Deposit	Geologic Setting	Ore Minerals	Ore Metals	Age
13	Barlo, Pangasinan	Massive sulfide	Inter-basic volcs	Py, cp, sl, bn, te, tn	Cu, Zn, Ag	Paleogene
14	Global Mining, Zambales	Laterite	Ultrabasic	Laterite	Ni, Co	
15	Acoje, Zambales	Massive-diss	Ultrabasic-basic	Cr, pn	Cr, Ni, Pt, Pd	U. Cretaceous (?)
16	Coto, Zambales	Massive-diss	Ultrabasic-basic	Cr	Cr	U. Cretaceous (?)
17	Midesco, Zambales	Laterite-diss	Ultrabasic-basic	Lat, pn	Ni	U. Cretaceous (?)
18	Dizon, Zambales	Diss — stock	Inter-basic	Cp, py	Cu, Au, Ag	
49	Tagburos, Palawan	Diss	Ultrabasic	Cinnabar	Hg	
50	Marsman, Palawan	Massive-diss	Ultrabasic	Cr	Cr	U. Cretaceous (?)
51	Long Pt., Palawan	Laterite	Ultrabasic	Lat-sap	Ni	
52	Berong, Palawan	Laterite	Ultrabasic	Lat-sap	Ni	
53	Brookes Pt., Palawan	Laterite	Ultrabasic	Gar	Ni	
54	Rio Tuba, Palawan	Laterite	Basic volcs	Lat-gar	Ni	
55	Lorraine, Balabac Is	Massive sulfide	ultrabasic	Py, cp, sl, bn	Cu	U. Cretaceous Early Eocene
32	Bongbongan, Panay	Massive sulfide	Basic volcs ultrabasic	Py, cp	Cu	
26	Sancho, Camarines S.	Massive sulfide	Ultrabasic metamorphics	Py, cp	Cu	U. Eocene
27	Hixbar, Rapu-Rapu Is	Massive sulfide	Metamorphics ultrabasic	Py, cp, sl, chal, cov	Cu, Zn, Au, Ag	U. Eocene
29	Bagacay, Samar	Massive sulfide	Inter intrus Inter volcs	Py, cp, sl, chal, cov	Cu, Zn	
30	Sulat, Samar	Massive sulfide	Inter volcs	Py, cp, bn, sl, gn	Cu, Zn, Pb	M. Miocene
31	Tigbao, Leyte	Massive sulfide	Inter volcs ultrabasic (?)	Py, cp, bn, sl, gn	Cu, Zn	
37	Dinagat Is, Surigao	Laterite-diss	Ultrabasic	Lateritic	Ni, Co, Fe	Miocene (?)
38	Nonoc Is, Surigao	Laterite-diss	Ultrabasic	Lateritic	Ni, Co, Fe	Miocene (?)

39	Cabadbaran, Agusan	Vein form	Inter volcs (?)		Au, Ag	
40	Cantillan, Surigao	Laterite	Ultrabasic		Ni	Miocene (?)
41	Lanuza, Surigao	Massive sulfide	Inter volcs Inter intrus	Py, cp, sl	Zn, Cu	
45	Sabena, Davao	Diss — stock	Inter volcs Intrus		Cu	
46	Masara, Davao	Vein form	Inter volcs & Inter intrus	Mag, sl, cp, py	Cu, Au, Ag	U. Miocene (?)
47	Mati, Davao	Replacement (?)	Sed-Inter volcs (?)	Mag	Fe	Pliocene
48	Pujada, Davao	Laterite	Ultrabasic	Lat-sap	Ni	

B. Third Arc

1	Lammin, Ilocos Norte	Replacement	Inter volcs Inter intrus	Mag, hem	Fe	Eocene
2	Lubuagan, Kalinga	Diss — stock	Inter intrus	Cp	Cu	U. Miocene
3	Lepanto, Bontoc	Vein form	Inter volcs Inter intrus	En, lu, tn, cp	Au, Cu, Ag	U. Miocene
4	Boneng, Benguet	Diss — stock	Inter intrus	Mag, cp, bn	Cu	
5	Sto. Niño, Benguet	Diss	Inter volcs basic intrus	Cp, mo, mag	Cu	U. Miocene (?)
6	Atok, Benguet	Vein form	Inter volcs	Au, cp, py	Au, Ag, Cu	U. Miocene
7	Thanskgiving, Baguio	Replacement	Inter intrus	Sl, cp, mag	Zn, Au, Ag, Cd	M. Miocene
8	Acupan, Antamok, Baguio	Vein form	Inter volcs & intrus	Au, ag, cp	Au, Ag, Cu	U. Miocene
9	Sto. Tomas II, Benguet	Diss — stock	Inter volcs & intrus	Cp, bn, py, mag, mo	Cu, Au, Ag, Fe	U. Miocene
10	Dupax, Nueva Vizcaya	Massive sulfide	Inter volcs & intrus	Sl, py, cov	Zn, Cu	
11	Palanan, Isabela	Laterite	Ultrabasic	Lat-gar	Ni	
12	Sierre Madre, Quezon	Diss	Inter volcs Inter intrus	Cp, bn, Mn oxide	Cu, Mn	
19	Kamatsihan, Bulacan	Replacement	Inter-basic volcs	Mag	Fe	
20	Sta. Ines, Bulacan	Replacement	Sed-inter volcs	Mag	Fe	M. Miocene
21	Lobo, Batangas	Vein form	Inter volcs	Cp, en, lu, chal, bn	Cu, Au, Ag	U. Miocene
22	CMI, Marinduque	Diss-massive sulfide	Basic volcs Inter intrus	Cp, bn	Cu, Au, Ag	

23	Marcopper, Marinduque	Diss — stock	Basic volcs Inter intrus	Cp, bn	Cu, Au, Ag	
24	Larap, Camarines Norte	Replacement	Metamorphics inter volcs basic-ultra	Mag, cp, mo, gn, py, Uraninite	Fe, Cu, Mo, Sl, Gn, Py, U	M. Eocene
25	Gumaus, Camarines Norte	Vein form	Inter intrus	Au, cp, gn	Au, Ag, Cu, Pb	
28	Aroroy, Masbate	Vein form	Inter intrus Metamorphics	Au	Au	
33	Sipalay, Negros	Diss — stock	Inter volcs Inter intrus	Cp, bn, mo	Cu, Mo, Au, Ag	Neogene
34	Lutopan, Cebu	Diss — stock	Inter volcs Inter intrus	Cp, bn, mag, by, mo	Cu, Py, Fe	Paleocene Early Eocene
35	Talibon, Bohol	Diss	Inter volcs & intrus	Cp, mo	Cu	
36	Anda, Bohol	Replacement	Basic volcs-sed	Mn oxide, Pyrolusite	Mn, Zn, Pb	Paleocene (?)
42	Ayala, Zamboanga City	Vein form	Inter intrus	Py, cp	Cu, Au, Ag	M. Miocene
43	Sibuguey, Zamboanga	Replacement	Sed-inter volcs	Mag	Fe	
44	Malaybalay, Bukidnon	Vein form Replacement (?)	Inter intrus Inter volcs	Cp, mag	Cu	

Symbols used

Diss	=	disseminated	cp	=	chalcopyrite	sap	=	saprolite
Stock	=	stockwork	sl	=	sphalerite	gar	=	garnierite
Inter	=	intermediate	bn	=	bornite	chal	=	chalcocite
Volcs	=	volcanics	te	=	tetrahedrite	mag	=	magnetite
Intrus	=	intrusive	tn	=	tennantite	hem	=	hematite
Sed	=	sedimentary	pn	=	pentlandite	gn	=	galena
Ultra	=	ultrabasic	cr	=	chromite	lu	=	luzonite
py	=	pyrite	Lat	=	nickel laterite	en	=	enargite

Substantial beach and off-shore titaniferous magnetite sands occurrences were not included in the classification of mineral deposits. These deposits are essentially found in western part of Luzon, eastern Leyte and northern Mindanao among others. These magnetite sands were probably derived mainly from the weathering of volcanic rocks *(Santos & Walters,* 1971). It is believed that these magnetites are erosional products of third arc volcanic rocks. Considering that the magnetite reserve of the western beaches of west Luzon alone is about a few tens of million *(Harrington & Andrews,* 1971), the total titaniferous magnetite reserve could easily reach more than 200 million metric tons for the entire Philippines.

Frontal Arc Mineral Deposits

The principal type of mineral deposits in the frontal arc in the order of predominance are: (a) lateritic soil (b) massive sulfide (c) massive-disseminated and stockwork (d) minor replacement and vein deposits.

Alpine-type ultrabasic complexes and their associated basic volcanics distinguish the frontal arc rocks. The ultrabasic rocks consist mainly of serpentinized peridotite, gabbro, dunite and minor pyroxenite and dolerite. Tropical weatherring in the western parts of Zambales-Palawan and eastern Samar and Mindanao areas has produced thick lateritic blanketing of the ultrabasics. Tropical chemical weathering of the ultramafic rocks has resulted in the economic concentration of nickel-cobalt-iron metals in lateritic soils. The lateritic nickel deposit at Nonoc island (58) alone which is currently being developed have the following mineable reserves (O'Kane, 1971) shown in Table 2.

Table 2

Nickel Reserve of Nonoc island, Philippines

Cut-off Grade % Ni	Area of Orebody (hectares)	Reserve DMT	Grade % Ni	Grade % Co	Grade % Fe	Stripping Ratio
0.9	1 436	75 104 000	1.22	0.10	38.4	0.61

According to O'Kane the combined nickel mineralization present in the smaller group of islands near Nonoc are greater than the Nonoc reserves. The probable nickel ore reserves of Hinatuan, Awasan, Hanigad and Southern Dinagat (37) island are shown in Table 3.

Table 3

Nickel Reserves of Hinatuan, Awasan, Hanigad and Southern Dinagat Islands (O'*Kane*, 1971)

Location	Area (Hectares)	Selected cut-off Grade % Ni	Probable Reserves DMT	Grade - % Ni	Co	Fe
Hinatuan Island	529	0.9	27 467 000	1.27	0.14	39.7
Awasan Island	105	1.0	3 922 000	1.23	0.13	40.8
Hanigad Island	50	1.0	3 810 000	1.23	0.09	32.7
Southern Dinagat	1 152	0.9 & 1.0	49 518 000	1.21	0.13	40.2
TOTAL	1 836	—	84 717 000	1.23	0.13	39.8

Table 4

Reserves and Assays of Philippine Nickel Deposits (Board of Investment Data, 1972)

Type of Ore	Positive Reserves (metric ton)	Grade %	Geologic Reserves (metric ton)	Grade %
Laterite	155	1.24—2.0	418	0.8 —2.0
Garnierite	32	2.06—2.24	25	1.75—2.24
Nickel sulfide	1	0.7	0.6	0.7
Saprolite	—	—	197	1.37—1.53
TOTAL	188		640.6	

Important deposits found in the serpentinized ultramafic rocks are mainly chromite with minor associated nickel-platinum sulfide metals. The chromites are favorably localized in serpentinized dunite or troctolite (*Thayer*, 1960).

The chromite deposits occur in massive-disseminated form with distinctive layering or banding in serpentinized dunite. In Acoje (15), the chromite is associated with nickel-platinum-bearing sulfides (*Irving*, 1950). The Acoje deposit is high in chromium and low in aluminium while the Coto (16) chromite is high in aluminium and magnesium, and low in chromium, (*Fernandez*, 1960). There are a number of chromite bodies distributed in west Luzon and Palawan, however, it appears, that Acoje, Coto and the much smaller, Marsman chromite (50) are the only ones that formed economic mineral deposits.

The massive sulfides are equivalent to the massive and range mineralogically from nearly pure pyrite to intimately mixed pyrite, (chalcopyrite), sphalerite, galena and barite".

Massive sulfide deposits of the cupriferous or "Kuroko" types are often associated with the basic volcanics. The volcanics are mainly spilitic-keratophyric rocks with pillow lavas and associated chert (*John*, 1963; *Bryner*, 1969).

To a lesser degree disseminated-stockwork occur in basic intrusives (?). An example of this is the Dizon copper deposits (18). The author strongly suspects that similar types of deposits may be located along the periphery of major ultramafic complexes, on the side away from oceanic deeps.

Third Arc Mineral Deposits

The third arc type of deposits, in their order of importance, are: (a) disseminated-stockwork (b) vein (c) replacement (d) minor massive sulfide and lateritic soil.

The disseminated-stockwork deposits are mainly of the porphyry copper types which occur in diorite complexes (intermediate intrusive-volcanics) (4, 5, 9, 23, 33, 34). The principal copper mineral is chalcopyrite with associated lesser bornite, pyrite, magnetite, molybdenite, gold and silver.

Quartz veins with gold and silver deposits are found in Northern Luzon (3, 6, 7, 8), southeastern Luzon (28) and Masbate island (28). These gold deposits include the polymetallic type exemplified by Lepanto (3) and Thanksgiving (7). The important copper minerals in Lepanto are enargite, luzonite and tellurides of gold and silver. At Thanksgiving, the minerals present are chalcopyrite, sphalerite and galena with associated gold tellurides. *(Bryner,* 1969).

The gold vein ore deposits at Acupan (8) and Atok (6) are characterized by quartz-calcite-gold mineralization. Generally, gold particles, "0,5 mm to micron sizes, occur in lusters", though gold are also present as tellurides. (BCI, 1967). Base metal sulfides with associated gold occur in minor amounts.

Paracale-Mambulao (southeastern Luzon) and Masbate areas are pre-war gold producing districts. The quartz-gold-bearing sulfides are associated with intermediate intrusive (granodiorite-diorite stock).

Replacement deposits are nearly restricted to iron-base metal sulfide mineralizations (1, 17, 20, 24, 43). *Bryner* (1969) prefers to call this type of deposits as pyrometasomatic deposits while Harrington and *Andrews* (1971) are inclined to call it contact-metasomatic deposits. Host rocks are limestone or calcareous sedimentary rocks adjacent to intermediate volcanics- intermediate instrusives. The chief iron mineral is magnetite and subordinate hematite. In Larap, the massive magnetite orebody is adjacent to a chalcopyrite-molybdenite-magnetite deposit containing uraninite. In Sta. Ines (20), there are also two massive deposits, magnetite and pyrite-pyrrhotite-chalcopyrite. *(Harrington & Andrews,* 1971).

The lateritic soil deposits are primarily aluminous. They are confined mostly in the northern coast of Mindanao. The deposit contains alumina and iron oxides together with other oxides. The average chemical analyses of this aluminous lateritic deposit is: 34.40 % Al_2O_3 9.59 % Fe and 35.23 % SiO_2 (Philippine Bu. of Mines, 1962). Since the aluminous laterite is still non-economic as a source of aluminium raw material, due to high silica content, only the nickel laterite (11) was plotted in Fig. 3.

Period of Mineralization

The age of chromite and massive sulfide deposits could probably span from Upper Cretaceous to Early Eocene. It must be noted that dating of the host rocks of the mineral deposits are inferred from associated fossil-bearing sedimentary series. The age of the nickelferous lateritic soil deposits is still problematical, though Harrington and *Andrews* (1971) suggest that laterization probably commenced during Miocene time in the Nonoc area.

The period of mineralization in the third arc ranged from Upper Paleocene to Upper Miocene time. According to *Wolfe* (1971) the potassium-argon datings of andesites and diorites (dioritic complexes) ranged from Eocene, Oligocene through Miocene. Most of the datings, however, are concentrated during Upper Miocene-Lower Pliocene time. It appears then that this period indicated extensive intermediate intrusive, intermediate volcanic activities and metallization.

It is evident then that there were, at least two major periods of mineralizations involved in the Philippine Island arc system, namely, during Upper Cretaceous to Lower Eocene in the frontal arc and Upper Miocene-Lower Pliocene time in the third arc. There are reasons *(Wolfe,* 1971) to believe, however, that Eocene time is probably another major period of metallization.

Conclusion

In summary, the Philippine mineral deposits are subdivided on the basis of their association with the structural elements of the island arc system. The Philippine archipelago is an "arc to arc" island system with two transform faults. Nickel-cobalt-iron, massive sulfide and chromite deposits occur in ultrabasic instrusive and basic volcanics of the frontal arc.

Copper-gold-silver-magnetite concentrations in disseminated-stockwork, vein and replacement type deposits are typically formed in the third arc. The regional rocks are mainly intermediate intrusive-volcanics (diorite-andesite complexes) intruding Tertiary volcanic-sedimentary sequences.

On the basis of the juxtaposition of the north-south trending Tertiary sediment formations and the northeast trends of the pre-Tertiary igneous-sedimentary rocks of Palawan-Mindoro areas, it is suggested that the date of collision probably occurred at the close of Permian to early Cretaceous. The quartz-rich sediments of Palawan-Mindoro deposited under miogeosynclinal environments indicate acidic source rocks. It may be deduced on the basis of marine fossil evidence that the date of rifting of these quartz-rich formations was probably late Carboniferous time.

Structural and geological evidences support the thesis that the Sulu Sea basin was formed as a result of extensional rifting of the Palawan frontal arc. This implies that a part of the Zamboanga Peninsula was formerly adjacent to Palawan.

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