

Some notes on magmatic activities and metallic mineral occurrences in northeastern Indonesia

RAB SUKAMTO AND T. SUHANDA
Geological Survey of Indonesia — Ministry of Mines
Jl. Diponegoro 57, Bandung, Indonesia

Abstract: The arcuate structure of the northeastern Indonesian Archipelago linking the Philippines and Papua New Guinea-Solomon Islands, respectively, to the north and east, comprises volcanic and non-volcanic island arcs.

In the volcanic island arcs acid and intermediate plutonic rocks are structurally related to hypabyssal and volcanic rocks, and form a distinct volcano-plutonic assemblage. In the non-volcanic island arcs ultrabasic and basic plutonic rocks are closely associated with basic effusives, and making up an ophiolite assemblage.

The composition of these island arcs reflects different types of metallic mineral belts.

INTRODUCTION

The purpose of this paper is to present some geologic information related to magmatic activity and metallic mineral occurrences in northeastern Indonesia which have been selected from old as well as new data. This is a part of a project to study the geological environment of the Indonesian mineral deposits in the framework of exploration activities as was previously discussed by Katili (1974, 1975).

The area of northeastern Indonesia has not been mapped completely. The sporadic and scattered geologic and mineralogic data is insufficient for accurate interpretation of tectonic or metallogenic processes. Since the Indonesian First Five Years Development Plan began, in 1969, the governmental agencies, like Geological Survey of Indonesia, Badan Tenaga Atom Nasional, etc., and state, as well as private companies, have carried out geologic and mineralogic investigations in broad areas. More geologic mapping and mineral exploration have been done since 1969 than in the past.

Northeastern Indonesia is part of the Circum-Pacific region, forming arcuate structures, and linking the Philippines to the north and Papua New Guinea — Solomon Islands to the east (Fig. 1). This area is comprised of several island arcs, both volcanic and non-volcanic, which are approximately parallel or sub-parallel to one another. The volcanic island arcs are dominated by pyroclastic, hypabyssal and acid to intermediate plutonic rocks which are genetically classified as magmatic rocks and structurally classified as volcano-plutonic rocks. The non-volcanic island arcs are characterized by basic and ultrabasic plutonic rocks associated with basic effusives.

Concerning the igneous activity and metallogenic concept some hypotheses have been advanced. Radiometric dating of igneous and metamorphic rocks in Indonesia have been summarized by Hehuwat (1975), who considered the radiometric ages to be still too scarce and too widely dispersed in space and time to warrant far-reaching conclusions (Fig. 3). In his preliminary conclusion Hehuwat distinguished from a radiometric age point of view, four main igneous events : Early Triassic (starting in the Permian), Early Cretaceous (starting in Late Jurassic), Late Cretaceous and Late Tertiary.

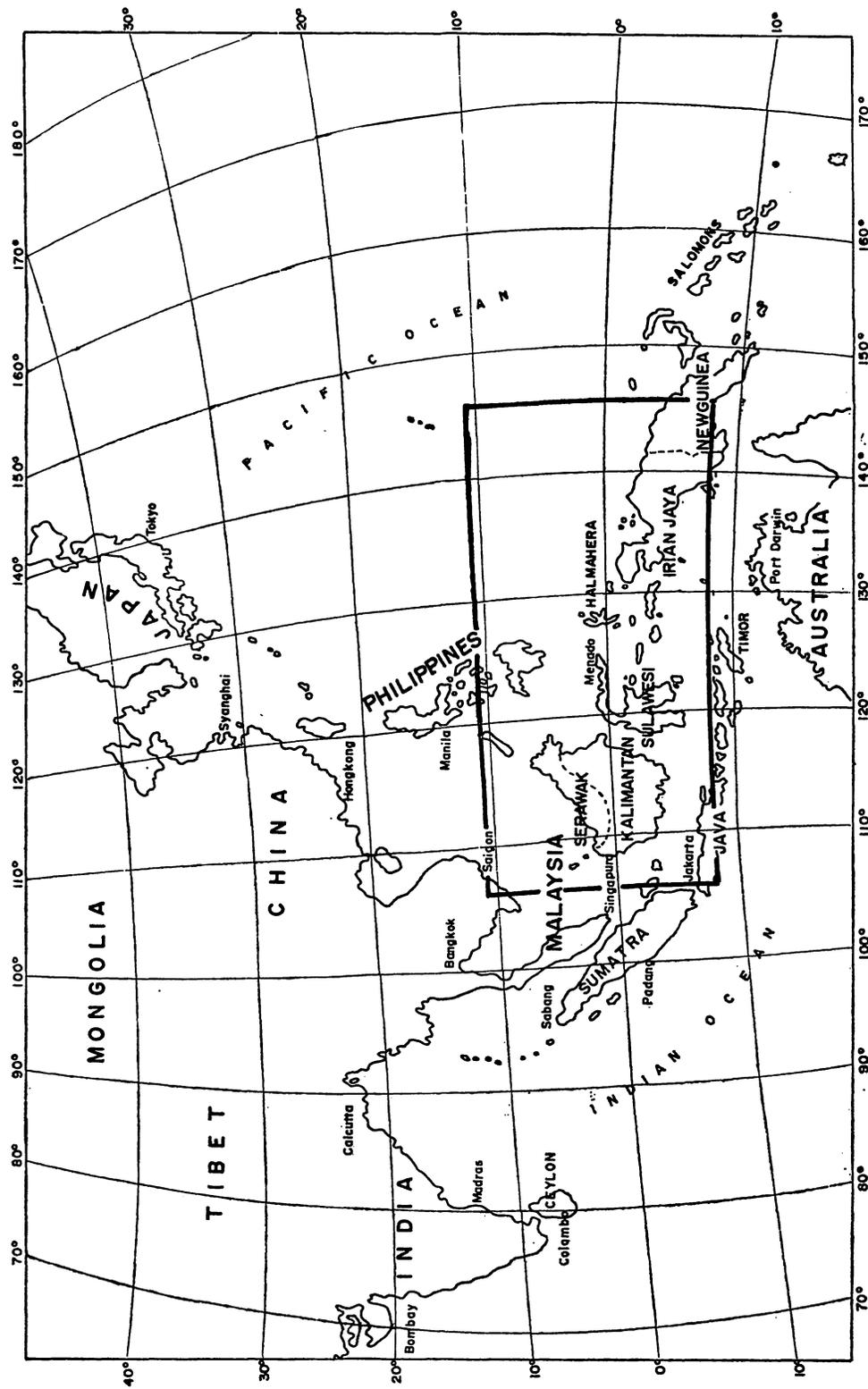


Fig. 1. Location of the area described in this paper.

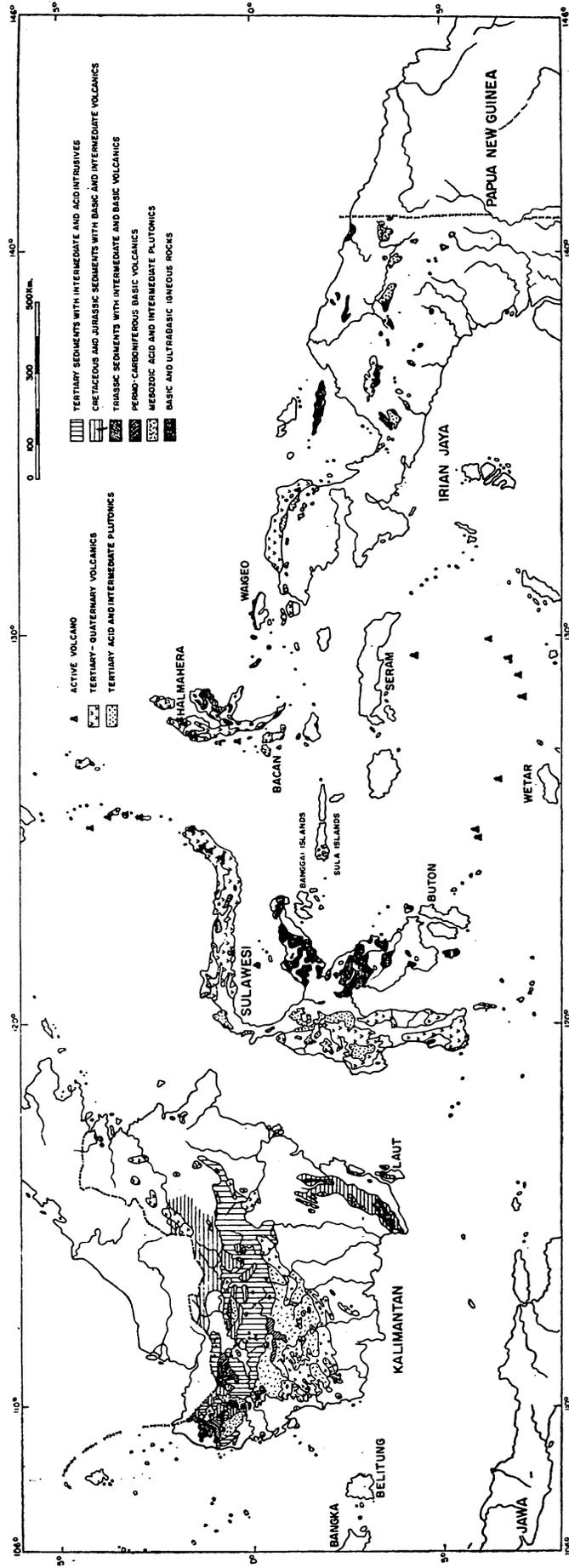


Fig. 2. Distribution of igneous rocks.

Another effort is in the refinements to the Westerveld's metallogenic concept which was advanced by Reksalegora and Djumhani (1973), and by Djumhani (1975). Based on the magmatic processes accompanying the various orogenic cycles Djumhani (1975) formulated a preliminary account of metallogenesis in Indonesia. Five episodes of orogenic events associated with mineralization were distinguished : Late Paleozoic to Early Jurassic, Middle Jurassic to Late Cretaceous, Middle Cretaceous to Early Tertiary, Middle Tertiary to Early Quaternary, and Late Tertiary to Recent.

SOME IDEAS ON MAGMATIC ORIGIN OF ISLAND ARCS

The arcuate structure of the Indonesian islands are parallel or subparallel with the curved belts of igneous rocks. Concepts of the origin of the igneous rocks in the island arcs in Indonesia were proposed as early as the beginning of this century. Past hypotheses have treated the layers of silicate beneath the crust as of igneous origin and of invariable bulk and composition which change only in distribution and structure. On the other hand van Bemmelen (1949) considered that the geochemical evolution of the earth is fundamentally related to its orogenic evolution, being the source of endogenic forces.

Recent publications attempt to elucidate the geological evolution on the bases of plate tectonics, such as, Coleman (1975), Dickinson (1970), Hamilton (1973), Hatherton and Dickinson (1969), Katili (1972, 1974, 1975), and others. In the concept of moving plates of lithosphere involving a large segment of the upper mantle as well as the crust, the island arcs are accounted for by the collision and subduction of two plates. The andesitic volcanism and granitic plutonism are the processes by which new continental crust emerges or reappears from the mantle (Dickinson, 1970).

According to plate tectonic models magmatism, plutonism and volcanism are intimately related to one another. Some models suppose the alkaline and calc-alkaline magma to be derived from the partial melting of the crust above the Benioff Zone. This magma is responsible for the formation of plutonic rocks at considerable depth, the formation of hypabyssal rocks as shallow intrusives, and the formation of effusive and eruptive rocks at the surface. The magmatic activity in this part of the globe are thought also to be responsible for the metallic mineral deposits.

Basic and ultrabasic igneous rock assemblages are conveniently and traditionally described as ophiolite, and normally are associated with pelagic red shale and radiolarian chert without high-temperature contact aureoles between them. Large tracts of peridotite along modern or ancient continental margins without high-temperature contact aureoles have led certain investigators to propose tectonic emplacement rather than igneous intrusion (Coleman, 1971). The ophiolites in northeastern Indonesia, which are largely in the non-volcanic area, form several curved belts parallel or subparallel to the volcano-plutonic belt.

Ophiolites are interpreted in plate tectonic models as oceanic crust originating at mid-oceanic ridges. The movements of the oceanic plate sometimes united the ophiolites with the continental edge. The ultramafic rocks in eastern Sulawesi province were apparently tectonically emplaced as a result of the westerly obduction of the oceanic plate onto the continental crust, and subsequently formed the basement upon which Mesozoic sediments, such as, red shale and radiolarian chert were deposited (Sukamto, 1975a, b).

MAGMATIC ACTIVITIES

Kalimantan

Volcanic rocks. Magmatic activity in Kalimantan extends from the Permo-Carboniferous until the Quaternary. Several magmatic episodes overlapped making the geology extremely complex. Magmatic activity started when basic volcanic rocks were deposited in the deep sea environment. Such basic volcanic rocks in central Kalimantan were included by Molengraff (1900) in the Danau Formation which was supposed to be pre-Cretaceous in age, probably Jurassic. But van Bemmelen (1949) suggested a Permo-Carboniferous age for this volcanic series and they were correlated with the basic volcanic rocks of a known Permo-Carboniferous formation by Zeylmans van Emmichoven (1939). Leichti, et. al. (1960) then divided the volcanics and correlated part of them to the Cretaceous Lupar Formation in the Sabah area, and the other part remains Permo-Carboniferous. Permo-Carboniferous volcanics occur locally in northwestern and central Kalimantan.

Late Triassic marine sedimentation was accompanied by contemporaneous major eruptions of andesitic and acidic lavas and tuffs, mostly of sub-alkaline composition over wide areas in northwestern Kalimantan (Haile, 1974). These volcanics were previously included in the Danau Formation by Zeylmans van Emmichoven (1939).

Breccias, tuffs and lavas of basic and intermediate composition which occur in association with quartzite, chert, jasper, hornstone, slate, and sandstone in central Kalimantan were correlated by Leichti, et al. (1960) to the Cretaceous Lupar Formation in the Sabah area. These volcanics were previously included in the Danau Formation (Zeylmans van Emmichoven, 1939). Minor acid and intermediate breccias, lavas and tuffs are interbedded with Cretaceous sediments in northwestern Kalimantan (Zeylmans van Emmichoven, 1939). In southeastern Kalimantan intermediate and basic lavas and tuffs are associated with Late Mesozoic sandstone, conglomerate, siliceous slate, clay-shale and limestone. Also, some basaltic and andesitic volcanics are interbedded with Jurassic sediments in northwestern Kalimantan.

Andesitic and basaltic lavas, breccias, agglomerate and tuffs, are sporadically scattered over the whole of Kalimantan. Most of these volcanics are considered to be Tertiary, and partly Quaternary in age (Wing Easton, 1904; Zeylmans van Emmichoven, 1939; van Bemmelen, 1939, Roe, 1957). Late Pliocene or Quaternary basalt, andesite, dacite and rhyolite lavas were extruded in Mount Niut and in the Muller Mountains, central and northeastern Kalimantan (Haile, 1974).

The volcanic rock complex in southwest Kalimantan is considered by Gueniot (1975a, b) to consist of a volcanic-sedimentary rock series which was intruded by Upper Triassic granites and subsequently overlapped by the Tertiary volcanic-sedimentary rocks. This undivided volcanic rock complex is comprised of basalts, andesites, dacites, rhyolites, keratophyres, quartz keratophyres, trachytes, and trachyandesites (Zeylmans van Emmichoven, 1939; van Bemmelen, 1939). Tertiary volcanic rocks also occur on Meratus Mountain, southeastern Kalimantan (van Bemmelen, 1949; Roe, 1957).

Intrusive rocks. The age of the intrusive rocks in Kalimantan is still uncertain. As no radiometric age determinations are available from this area, the ages are based only on stratigraphic relations and aureoles in the hostrocks.

TABLE 1
STRATIGRAPHY OF THE IGNEOUS ROCKS

| A G E | KALIMANTAN | SULAWESI | BANGGAI-SULA | HALMAHERA | IRIAN JAYA | |
|------------------|--|--|---|---|---|------------------|
| QUATERNARY | <p>Andesitic and basaltic lava, breccia, and tuff, locally dacitic, rhyolitic, and trachytic.</p> <p>Granite, diorite, tonalite, granodiorite, andesite, basalt.</p> <p>Basaltic and andesitic breccia, tuff, and gabbro lava</p> <p>Granite, diorite, tonalite.</p> <p>Quartzdiorite, tonalite, diorite, granodiorite, Monzonite, granite.</p> <p>Andesitic lava and tuff. Granite, tonalite.</p> <p>Basaltic volcanic rocks. Gabbro.</p> | <p>Andesitic and basaltic breccia, lava, and tuff.</p> <p>Andesitic and basaltic breccia, lava, and tuff, partly dacitic, trachytic and alkaline.</p> <p>Granite, granodiorite, diorite, syenite, andesite, basalt, gabbro, trachyte.</p> <p>Basaltic and andesitic lava, breccia, and tuff, partly alkaline.</p> <p>Granodiorite, diorite, gabbro monzonite, phonolite, dolerite, kentalanite.</p> <p>? Dunite, harzburgite, pyroxenite, serpentinite, gabbro, basalt, diorite.</p> | <p>Rhyolite, dacite, andesite. Granite, granodiorite, diorite, syenite, diabase.</p> <p>? Andesite, dacite.</p> | <p>Andesitic and basaltic breccia, and tuff, partly trachytic.</p> <p>Andesitic and basaltic breccia, lava, and tuff. Diorite, granodiorite, gabbro.</p> <p>? Serpentine, peridotite, gabbro.</p> | <p>Andesitic and basaltic breccia, tuff, and lava. Granite, diorite, quartzdiorite, dolerite, lamprophyre, gabbro.</p> <p>? Basic and ultra basic rocks, partly harzburgite</p> | |
| | | | | | | <p>Pliocene</p> |
| | | | | | | <p>Miocene</p> |
| | | | | | | <p>Oligocene</p> |
| | | | | | | <p>Eocene</p> |
| <p>Paleocene</p> | | | | | | |
| CRETACEOUS | | | | | | |
| JURASSIC | | | | | | |
| TRIASSIC | | | | | | |
| PERMIAN | | | | | | |
| CARBONIFEROUS | | | | | | |

The oldest plutonic rocks in Kalimantan are probably the Permo-Carboniferous gabbroic plutonic masses in the Schwaner Mountain area, central Kalimantan (van Bemmelen, 1949). Large exposures of granitic to tonalitic batholiths in western Kalimantan were formerly considered to be emplaced in the Late Permian or Early Triassic (van Bemmelen, 1949; Haile, 1974). Recently these acid and intermediate batholiths were divided into two groups which probably are different in age. The groups form two elongated belts trending westerly. The western part of the Northern Belt consists mainly of quartz diorite and tonalite which varies locally to diorite, granodiorite, monzonite and granite. These rocks, which were previously considered to be post-Permo-Carboniferous and pre-Upper Triassic (Zeylmans van Emmichoven, 1939; van Bemmelen, 1939, 1949) are now thought to be mainly Triassic (Gueniot, 1975a). The western part of the Southern Belt consists of granite which varies locally to diorite and tonalite, and is thought to be mainly Cretaceous (Gueniot, 1975b). These rocks were previously considered to be post-Triassic, possibly intra-Jurassic and pre-Cretaceous (Zeylmans van Emmichoven, 1939; van Bemmelen, 1939, 1949).

Other supposed Cretaceous granitic intrusions, in southeastern Kalimantan, consist of small bodies of diorite and granite, which are exposed in the Meratus Mountains and in the upper reaches of Kapuas River (Zeylmans van Emmichoven, 1939; van Bemmelen, 1939, 1949). Late Cretaceous granite stocks (75–79 m.y. by K/Ar) were intruded in the western Sabah area, adjacent to northwestern Kalimantan (Haile, 1974). Late Cretaceous gabbro and dolerite stocks also occur in the Cretaceous volcanic complex in central Kalimantan (Roe, 1957).

Small bodies of Tertiary intrusives are scattered in the Lower Tertiary sediments along the middle and upper reaches of the Kapuas River, northwestern and central Kalimantan. The composition of the intrusives ranges from acid to basic. In the Ketungau basin, northwestern Kalimantan, the intrusives are granite, diorite and tonalite. In central Kalimantan the intrusives consist of microgranite, microgranodiorite and granodiorite (Roe, 1957). Haile (1974) mentioned sills and stocks of acid to basic composition in Tertiary sediments in northwestern and central Kalimantan. The supposed Late Triassic intrusion in northwestern Kalimantan was recently dated by the fission track method and yielded an Oligocene age (Wikarno, Geological Survey of Indonesia, written communication, 1975).

Small intrusives of Tertiary age also occur in the Meratus Mountain (van Bemmelen, 1949). Basaltic and andesitic dikes are reported in the eastern part of southwestern Kalimantan (Sudradjat, Geological Survey of Indonesia, oral communication, 1976) and are possibly of Tertiary age.

Ultrabasic and basic rocks. Ultrabasic and basic rocks in Kalimantan are well developed in the southern end of the Meratus Mountain, southeastern part of the island, and in the Laut and Sebuku islands. The rocks consist mainly of gabbro and peridotite, and some pyroxenite. Their age is supposed to be Cretaceous (van Bemmelen, 1949). In western Kalimantan the basic intrusions form isolated small bodies, trending northwest from Kotawaringin to the Sambas area. These rocks, which are thought to be Permian to Tertiary, are probably genetically different from the ultrabasic-basic assemblage in southeastern Kalimantan.

Sulawesi

Volcanic rocks. Volcanic rocks of Sulawesi Island cover extensive areas in western Sulawesi province (Sukamto, 1975a,b,c). The rocks are mainly coarse- and

fine-grained pyroclastics and lava flows of intermediate and basic composition. Dacitic and trachytic rocks also occur locally. Some volcanics contain highly alkaline minerals such as leucite and nepheline.

Volcanism in this area started during Paleocene time as indicated by a radiometric age of 58.5 m.y. on a pillow basalt flow from the south arm of Sulawesi. The main phase of the volcanism was during the Middle Miocene and produced an enormous volume of andesitic rocks. Most of the volcanics alternate with marine clastics and carbonates and some of the lavas show pillow structures. Marine conditions continued from the beginning of volcanism until Pliocene time. Since Late Miocene time some of the volcanic rocks were deposited on land, as are most of Quaternary volcanics. Volcanoes are still active in North Sulawesi.

Ten samples of effusive rocks have been dated radiometrically. Nine samples resulted in various ages from 4.25 to 17.8 m.y. (Miocene). The remaining samples yielded an age of 58.5 m.y. (Paleocene, Table 2).

TABLE 2
RADIOMETRIC AGE DETERMINATIONS

| Location No. on Fig 3 | Rock type | Age in m.y. | | Type of analysis | Source |
|--------------------------|--------------------------|----------------|-------|---------------------|--------|
| 1. | Metabasalt (pillow lava) | 181 ± 5 | K-Ar | Whole rock | 5 |
| 2. | Diorite | 120 ± 4 | K-Ar | Whole rock | 5 |
| 3. | Granodiorite | 217 ± 5 | Rb-Sr | Whole rock | 5 |
| | Granodiorite | 212 - 224 | K-Ar | Biotite, hornblende | 5 |
| 4. | Diorite | 57.8 ± 3.5 | K-Ar | Whole rock | 6 |
| 5. | Monzonite | 94.2 ± 4.7 | K-Ar | Whole rock | 6 |
| 6. | Tuff | 58 | K-Ar | — | 7 |
| 7. | Microdiorite | 65.1 ± 3.9 | K-Ar | Whole rock | 6 |
| 8. | Hornblende hornfels | 81 | K-Ar | — | 7 |
| 9. | Diorite | 80 | K-Ar | — | 7 |
| 10. | Altered tuff | 115 | K-Ar | — | 7 |
| 11. | Gabbro | 99.7 ± 7 | K-Ar | — | 8 |
| 12. | Diorite/Gabbro | 58 | K-Ar | — | 7 |
| 13. | Gabbro | 7.36 | K-Ar | Whole rock | 1 |
| 14. | Basalt | 6.99 | K-Ar | Whole rock | 1 |
| 15. | Basalt | 7.5 | K-Ar | Whole rock | 2 |
| 16. | Aplite | 9.21 | K-Ar | Biotite | 1 |
| 17. | Diorite | 7.74 | K-Ar | Biotite | 1 |
| 18. | Basalt | 17.7 | K-Ar | Whole rock | 2 |
| 19. | Granodiorite | 9.03 | K-Ar | Biotite | 1 |
| 20. | Basalt | 58.5 | K-Ar | Plagioclase | 1 |
| 21. | Trachyte | 8.3 | K-Ar | Feldspar | 2 |
| 22. | Trachyte | 10.9 | K-Ar | Biotite | 2 |
| 23. | Dacite | 8.93 | K-Ar | Biotite | 1 |
| 24. | Andesite | 9.29 | K-Ar | Hornblende | 1 |
| 25. | Trachyte | 4.25 | K-Ar | Biotite | 1 |
| 26. | Tuff | 4.95 | K-Ar | Biotite | 1 |
| 27. | Granite | 6.25 | K-Ar | Biotite | 1 |
| 28. | Diorite | 10.6 | K-Ar | Biotite | 1 |
| 29. | Diorite | 13.8 | K-Ar | Hornblende | 1 |
| 30. | Basalt | 17.8 | K-Ar | Hornblende | 1 |

| Location No. on Fig 3 | Rock type | Age in m.y. | Type of analysis | Source |
|--------------------------|---|----------------|--|--------|
| 31. | Tonalite | 5.0 | K-Ar Biotite | 2 |
| 32. | Granodiorite | 5.47 | K-Ar Biotite | 1 |
| 33. | Granite dike | 8.10 | K-Ar Biotite | 1 |
| 34. | Granite | 3.35 | K-Ar Biotite | 4 |
| 35. | Granite | 1.62 | K-Ar Biotite | 4 |
| 36. | Granite | 1.68 | K-Ar Biotite | 4 |
| 37. | Hornfels | 4.80 | K-Ar Biotite | 4 |
| 38. | Granodiorite | 31.0 | K-Ar Feldspar | 2 |
| 39. | Granodiorite | 8.6 | K-Ar Biotite | 2 |
| 40. | Granite | 245 ± 25 | Rb-Sr Feldspar | 3 |
| 41. | Rhyolite | 330 ± 90 | Rb-Sr Whole rock | 3 |
| 42. | Granite | 235 ± 10 | Rb-Sr Feldspar | 3 |
| 43. | Rhyolite | 210 ± 25 | Rb-Sr Whole rock | 3 |
| 44. | Diorite, monzonite, andesite (11 samples) | 1.11—4.88 | K-Ar Biotite, hornblende, whole rock | 9 |
| 45. | Andesite (6 samples) | 13.5—16.6 | K-Ar Hornblende, plagioclase | 9 |
| 46. | Porphyry, granodiorite (20 samples) | 6.5—13.7 | K-Ar Biotite, hornblende, plagioclase | 9 |
| 47. | Microdiorite, dacitic rock, agglomerate, tuff (20 samples) | 2.4—6.6 | K-Ar Biotite, plagioclase, hornblende | 9 |

Source of data:

1. J.D. Obradovich (in Sukamto, 1975a, b, c)
2. Indonesia Gulf Oil Co. (in Sukamto, 1975a, b, c)
3. Mobil Oil Corp. (in Sukamto, 1975a, b, c)
4. Overseas Technical Cooperation Agency (in Sukamto, 1975a, b, c)
5. Priem, et al (in Hehuwat, 1975)
6. Patmosoekismo and Yahya (in Hehuwat, 1975)
7. Ben Avraham and Emery (in Hehuwat, 1975)
8. K a t i l i (in Hehuwat, 1975)
9. Page and Mc Dougall, 1972.

Intrusive rocks. Intrusive bodies, ranging from batholiths to thin dikes, occur in western Sulawesi province. Most of the relatively large intrusions are composed of granodiorite and granite. The smaller intrusive bodies are diorite, diorite porphyry, syenite, trachyte, gabbro, monzonite, phonolite, dolerite, and kentallenite (Sukamto, 1975c). Most of the dikes and sills consist of trachyte, andesite, microdiorite, basalt, gabbro or pyroxenite.

Radiometric dating on intrusive rocks from this area yielded the following : five samples are Pliocene (1.62 to 5 million years), ten Miocene (5.47 to 13.8 million years), and one Oligocene (31 million years) (Table 2).

Ultrabasic and basic rocks. Basic and ultrabasic rocks complexes form large exposures in the eastern Sulawesi province. The exposures have been considered to be the most extensive in the world (Rutten, 1927; Kundig, 1956; Sukamto, 1975b). The rocks consist of dunite, harzburgite, pyroxenite, serpentinite, gabbro, basalt, and some diorite in northeast arm of Sulawesi (Sukamto, 1975c).

Various ages have been assigned to the ophiolites i.e. Mesozoic, Mesozoic and Tertiary, pre-Late Cretaceous, post-Jurassic to pre-Miocene, Middle Miocene, and

younger than Miocene. All these ages are based on the presence of ophiolitic detritus in younger sediments. Sukamto (1975b, c) suggests that the ophiolites of this area are older than Triassic, and form the basement upon which Mesozoic sediments, such as, pelagic red shale and radiolarian chert were deposited.

Banggai-Sula Islands.

Volcanic rocks. The oldest volcanism in this area is represented by andesite and dacite in the basement complex of pre-Permo-Triassic age. Effusive rocks of Permo-Triassic age are locally overlying the basement complex. The rocks comprise mainly rhyolitic ignimbrites and vitrophyres (Sukamto, 1975c, d). Andesite and dacite are also found.

Whole rock rubidium/strontium analysis of a rhyolite from Mangole Island yielded an age of 210 ± 25 m.y., and a rhyolite from Peleng Island 330 ± 90 m.y. (Table 2).

Intrusive rocks. Bodies ranging from batholiths to thin dikes, unconformably underlie Jurassic conglomerate and sandstone, and intrude the basement complex. The largest intrusives consist of muscovite granite, granite porphyry, granodiorite, diorite and syenite. Most of the granites are characterized by their pink colour (Sukamto, 1975c, d). The small intrusives range widely in composition, e.g., pegmatite, aplite, microdiorite, and diabase.

Some of the intrusives have been subjected to either hydrothermal or dynamothermal alteration (Koolhoven, 1930). A granite near the west coast of Sulabesi Island has been sheared, and has a foliated structure. Rubidium/strontium dating on feldspar from granites on Banggai and Taliabu Islands yielded 235 ± 10 m.y. and 245 ± 25 m.y. (Table 2).

Halmahera

Volcanic rocks. Extensive areas of volcanic rocks dominate the western part of Halmahera and the islands from Bacan to Ternate. The rocks are mainly breccias, tuffs and lavas of andesitic to basaltic composition (Apani, Supriatna and Yasin, Geological Survey of Indonesia, oral communication, 1975). Some trachytic rocks occur locally in the Quaternary volcanics. The Tertiary volcanics are partly hydrothermally altered and are propylitized and mineralized.

Volcanism in this area probably started during the Early Tertiary, and has become stronger in the younger stages. Most of the Tertiary volcanics are intercalated with marine sediments and carbonates. Some lavas show pillow structure. The Quaternary volcanics are deposited mainly on land and most were produced by still active volcanic centres.

Intrusive rocks. Compared with Kalimantan, Sulawesi, and Irian Jaya, Halmahera and the adjacent islands have only small exposures of intrusive rocks. Stocks and thin dikes on Bacan and Halmahera islands consist of diorite, granodiorite, quartz diorite, and gabbro. The dioritic and gabbroic intrusives in the eastern part of Halmahera are probably associated with an ophiolite complex.

Although the age of the intrusions of the island is not known, they certainly produced the alteration and mineralization in the Tertiary country rocks.

Ultrabasic and basic rocks. In the eastern part of Halmahera they form an ophiolite complex. Recent mapping by the Geological Survey of Indonesia proved that no large exposures of ophiolite rocks exist in the western part of Halmahera as had been previously reported, although two small exposures were confirmed. Ophiolite rocks also occur on the islands east and south of Halmahera, such as Gebe, Gag, Kawe, Waigeo, Bisa, and Obi Islands.

The ophiolites in this area consist of serpentinite, peridotite of varying types, and metagabbro. These rocks, which were designated by van Bemmelen (1949) as young Mesozoic ophiolites, are actually not proven to be of that age. Bessho (1944) proposed a Late Cretaceous age for the ultrabasic and basic rocks in this area.

Irian Jaya

Volcanic rocks. In Irian Jaya, they are associated partly with Tertiary limestone of the Auwewa Formation, and cover vast areas in the northern part of the island which was designated as the North New Guinea province by Visser and Hermes (1962). The rocks are mainly volcanic breccias, lavas and tuffs of andesitic composition. Basaltic and rhyodacitic rocks are subordinate. Most of the rocks are considerably propylitized and partly silicified.

The main phase of the volcanism in the northern part of the Kepala Burung (Vogelkop) area is considered by d'Audretsch et al. (1966) as slightly older than the Miocene limestone of the Auwewa Formation. Limited volcanism continued during Plio-Pleistocene time. In the latter stages, the volcanic rocks appear more acid in composition.

Various ages have been assigned to the volcanic rocks in this area : Late Tertiary or Quaternary (Zwierzycki, 1932), Middle Oligocene to Upper Miocene (Visser and Hermes, 1962), and Paleogene (Molengraaff, in d'Audretsch et al., 1966).

Intrusive rocks. Intrusions of batholithic dimensions as well as numerous smaller ones are found in this region. The batholithic intrusives are of granitic to granodioritic composition. The stocks and very thin dikes have a very wide range in composition, i.e., from granitic to basaltic.

The age of the granitic rocks has not been confirmed by radiometric dating. Based on their contact relations with formations of known age d'Audretsch, et al (1966) assigned them to post-Silurian, pre-Triassic, Upper Paleozoic, pre-Upper Oligocene, and pre-Middle Miocene. Other workers have assigned ages ranging from pre-Upper Carboniferous to Plio-Pleistocene. Visser and Hermes (1962) assigned them to pre-Upper Carboniferous, pre-Upper Cretaceous, and Plio-Pleistocene, Schippers (in d'Audretsch, et al, 1966) assigned them to post-Miocene, and Loth & Molengraaff (in d'Audretsch, et al, 1966) and Zwierzycki (1928, 1932) assigned them to post-Jurassic. Diorite to quartz monzonite intrusions of Tembagapura (Ertsberg) produced copper, gold, silver and iron mineralization, and contact metamorphism within bounding sediments. The Jurassic-Cretaceous Kembelengan sandstone and siltstone have been converted to dense quartzite and hornfels, whereas the Oligocene limestone have been metamorphosed to marble (Flint, 1972). This phenomenon indicates certainly that the age of some of the intrusives is post-Oligocene.

The present authors correlate the granitic rocks of Irian Jaya with those of the adjacent areas, Banggai-Sula Islands in the west and Papua New Guinea in the east.

Radiometric age determinations on granitic and rhyolitic rocks from Banggai-Sula Islands yielded a Permo-Triassic age (210–245 m.y.; Table 2). Visser and Hermes (1962) considered these islands to be part of the Central New Guinea province. More than 57 samples of intrusive and effusive rocks from Papua New Guinea have been analyzed, and all show an age of Pliocene to Miocene (1.11 – 16.6 m.y., Page and Mc Dougall, 1972). Irian Jaya is the extension of two geologic provinces, Papua New Guinea from the East and Banggai-Sula from the West, and has had the same history of magmatism.

Ultrabasic and basic rocks. In Irian Jaya ultrabasic rocks may be intrusive, or oceanic ultramafic slabs thrust over the Silurian Kemoen Formation. Some workers consider the ultrabasic rocks as dikes, sills or lenses (d'Audretsch et al. 1966; Visser and Hermes, 1962). D'Audretsch, et al (1966) suggested that the emplacement of ultramafics in Irian Jaya was pre-folding of the Silurian Kemoen rocks, in the geosynclinal stage, preceding the Devonian orogenesis.

The ultrabasic and basic rocks in this area were classified by van Bemmelen (1949) as Young Mesozoic ophiolites. These rocks, which generally consist of harzburgite in Cyclops area and Waigeo Island, are badly fractured and jointed, and form separate blocks and boulders (Reynolds, et al., 1972). According to van Bemmelen these ophiolites are overthrust masses. They may be correlative with those found in Papua New Guinea which Davies (1971) concluded were slices of oceanic mantle and crust thrust southwestward over the sialic basement.

Exposures of Permian and Triassic igneous rocks (possibly some Permo-Carboniferous) are scattered in a westerly trending zone through central and northwestern Kalimantan. The northern part of this zone overlaps with another containing Cretaceous and Jurassic volcanic and intrusive rocks. Jurassic igneous rocks occur only in northeastern Kalimantan. The Cretaceous volcanic and intrusive rocks form a curved belt trending from northwestern Kalimantan eastward through the central part of the island and then turn to the northeast. Another Cretaceous volcano-plutonic arc trends northeast in the Meratus Mountains region of southeastern Kalimantan.

Large masses of Mesozoic granites in western Kalimantan are difficult to correlate with those in adjacent areas. Tertiary and Quaternary volcanics and intrusives are scattered over the whole area. It is also difficult to draw a Tertiary-Quaternary igneous belt in Kalimantan, although the area of Tertiary-Quaternary igneous rocks clearly becomes narrower in the northeastern part of the island and continues northeastward into the Sulu Archipelago and onto the western part of Mindanao Island in the Philippines.

Exposures of basic and ultrabasic igneous rocks in the Meratus Mountains area and in Laut and Sebuku islands form a curved belt that trends north northeastward, and mostly overlaps with Cretaceous and Tertiary volcano-plutonic igneous belts.

Sulawesi comprises two parallel igneous belts, trending north in the south, turn right-handed in the middle and north again in the north. As mentioned previously, the western igneous belt is characterized by volcano-plutonic rock assemblage, whereas the Eastern Belt is characterized by basic and ultrabasic igneous rocks.

The western Sulawesi igneous belt can be traced from South Sulawesi, through the western part of Central Sulawesi and North Sulawesi, and continues northward

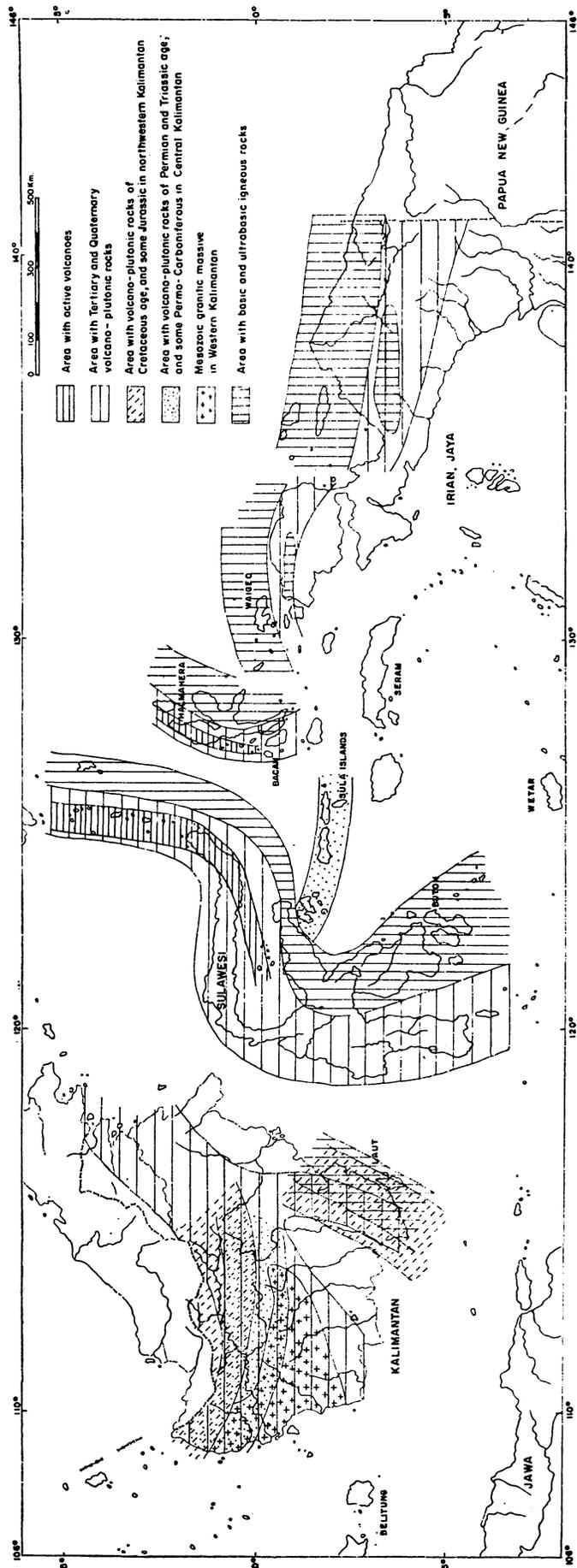


Fig. 4. Igneous belts.

through the middle part of Mindanao in the Philippines. This area has been active magmatically since Early Tertiary time.

The eastern Sulawesi belt is morphologically traceable in the submarine ridge, trending north northeastward between the north arm of Sulawesi and Halmahera, and continues through the Talaud Islands and northward into the eastern Mindanao. Exposures of basic and ultrabasic igneous rocks occur in the eastern Sulawesi belt as well as in the Talaud Islands. Small exposures of ultrabasic igneous rocks in South Sulawesi are found as part of the basement complex.

A similar configuration to that of Sulawesi can be observed in Halmahera Island and the surrounding area, where two parallel igneous belts trend northerly. The western igneous belt is characterized by a volcano-plutonic rock assemblage and the Eastern Belt by basic and ultrabasic rocks. Magmatism in the western belt has existed since the Early Tertiary. A thick volcanoclastic sequence covers most of the area. Two small exposures of ultrabasic igneous rocks in the south arm of Halmahera are probably part of the basement complex.

The extension of the eastern Halmahera igneous belt to the south is not clear but it may connect with another basic and ultrabasic igneous belt in Irian Jaya which trends westward. The ultrabasic rocks in Gebe, Gag, Bisa and Obi islands may belong either to the belt entering from the north or that from the east.

Most of the basic and ultrabasic igneous rocks in Irian Jaya are in the northern coastal areas in the east and on the islands north of Kepala Burung in the west. Locally the basic and ultrabasic igneous rocks lie within the area of volcano-plutonic belt.

A belt of volcano-plutonic rocks of Tertiary age trends westerly in the central part of Irian Jaya. This belt shifts to the northern coast in Kepala Burung on the western part of the island. The belt does not extend westward but continues eastward to the Tertiary volcano-plutonic belt in Papua New Guinea.

A single igneous belt trends in Banggai-Sula Islands, and contains both acid and intermediate effusives and intrusives of Permo-Triassic age. Magmatism there began before Permian time as indicated by intermediate effusives in the basement complex.

SUMMARY OF METALLIC MINERAL OCCURRENCES

Associated igneous rock assemblages of a certain episode and related metallic mineral deposits are more or less similar in every part along the curved belts of igneous rocks (Fig. 5). The metallogenic concept of mineral deposits of Indonesia as proposed by Westerveld (1952), based on the assumption that there is an intimate relationship between phases, of folding, tectonic styles and age of mineralization, was formerly acceptable because of its simplicity and applicability. Closer study by Reksalegona and Djumhani (1973) on available old as well as new data of mineral occurrence resulted in some features which fit and do not fit the concept. The sporadic geologic and mineralogic data available at present shows that certain groups of metallic minerals are associated with certain assemblages of igneous rocks.

Based on plate tectonic theory Katili (1974) assumed that the mineralization in parts of northeastern Indonesia, such as in the Sulawesi, Halmahera, and Irian Jaya areas are influenced by the presence of very rich polymetallic nodules of oceanic

materials which originated from the Pacific Ocean. He strongly recommends exploration of the promising areas of eastern Indonesia.

As shown on Figures 4 and 5 the curved belts of long-continuing magmatic activity overlap laterally and cross one and another. Two main igneous assemblages can be clearly distinguished and their associated metallic minerals differ. The volcano-plutonic igneous assemblages are related to the deposition of Au, Cu, Pb, Zn, Ag, Fe, Mo, etc., whereas the basic and ultrabasic igneous assemblages are associated with Cr and Co, and lateritic Ni mineral deposits. More specific consideration of metallogenic concepts must await new data.

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