THE GEOLOGY AND GEOCHEMISTRY OF THE GUNUNG PANI GOLD PROSPECT, NORTH SULAWESI, INDONESIA

by

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I. INTRODUCTION

1.1 General

The Gunung Pani gold prospect in North Sulawesi, Indonesia is a volcanic-related low grade, large tonnage gold resource; a class of gold deposit currently actively being sought worldwide, due to high gold prices, advances in bulk mining and extractive metallurgy, and due to the virtual exhaustion of classical high-grade gold deposits.

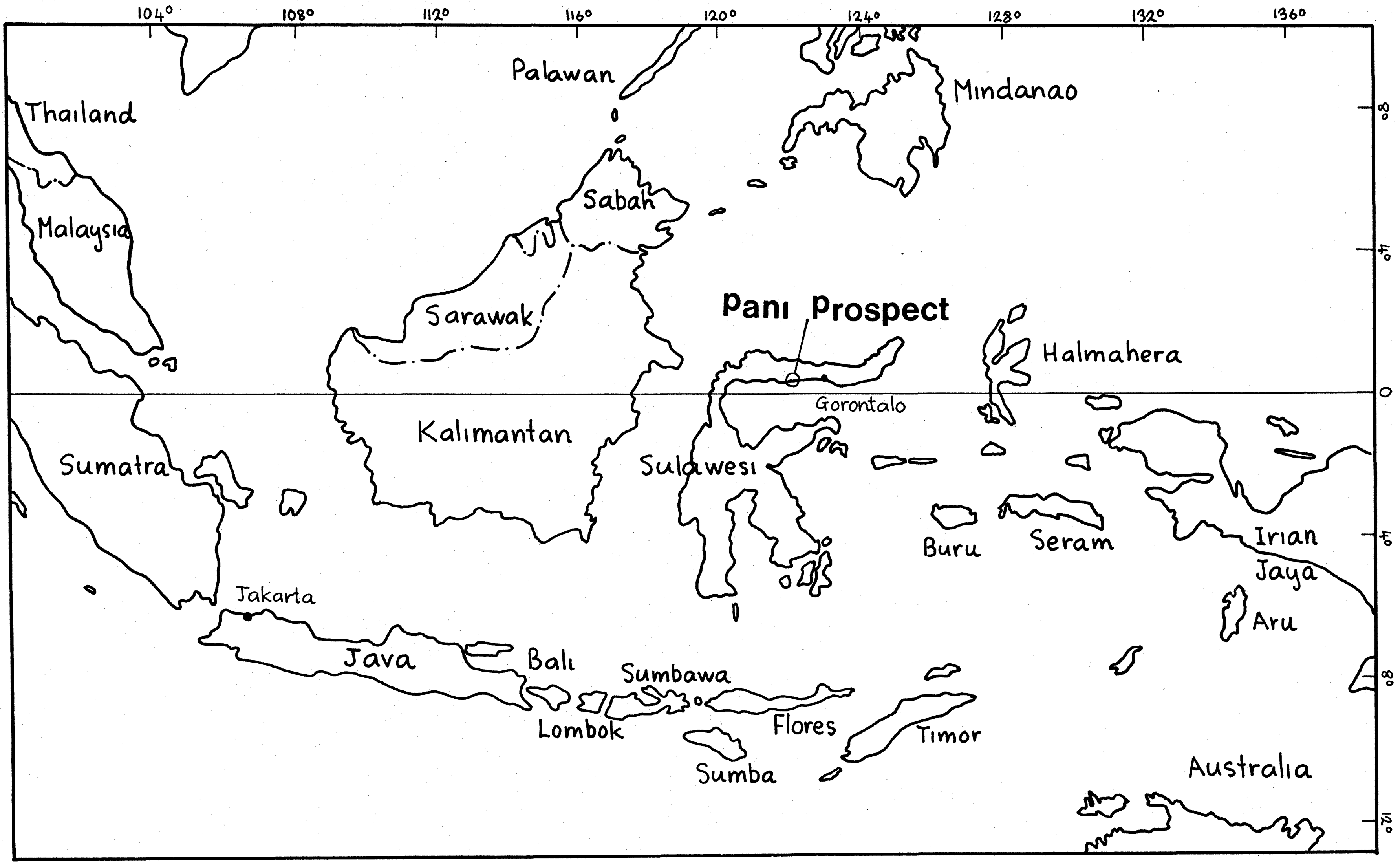
A study of exploration prospects, such as Gunung Pani, provides an opportunity to gain new insights into low grade gold mineralisation, to develop new conceptual models as new types of deposits are discovered, and to provide a better scientific basis for future exploration.

1.2 Location

The Gunung Pani gold prospect (Fig. 1) (Photo 1a,b) is located at longitude 122°E and latitude 0°33'N, 15km directly inland from the coastal village of Marisa in the north arm of the island of Sulawesi (formerly Celebes). The nearest large town is Gorontalo, 120km to the east with airport and harbour facilities. Indonesian internal air services have flights from Jakarta to Gorontalo daily. A 160km dry weather road connects Gorontalo to Marisa. Partly cleared land and villages extend from the coast in low country to within a few kilometres of the prospect which is in rugged rainforested topography at an elevation between 450m and 780m. From the Transit Staging Camp access is gained by an old track, winding 11km to the site of the exploration camp at Pani ridge.

Fig 1

LOCATION MAP



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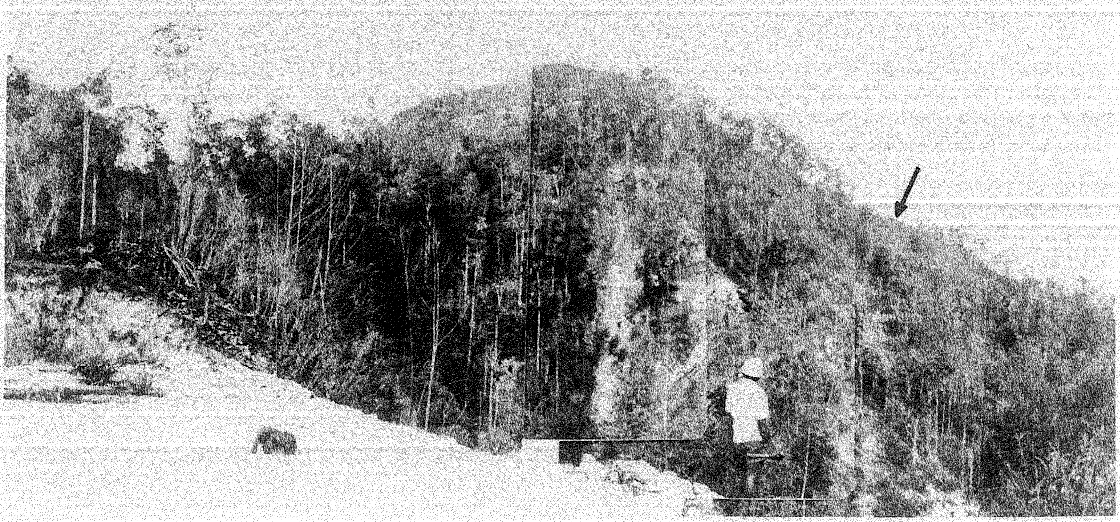


Photoplate 1 : Gunung Pani prospect.

1a View of Pani ridge (elevation 600m) from the northern side of Gunung Baganite (arrow 2b). Drill site 3 (GPD3) in centre of photo, drill site 1 (GPD1) on left hand side. The camp (elevation 425m) is in the deep valley (Sungai Masina) beyond the ridge.
Valley in immediate foreground is Sungai Pani.

1b View of Gunung Baganite (elevation 780m) from drillsite 1 on Pani ridge. Contour trenches at 600, 650 and 700m elevation are faintly seen.
Valley in foreground is Sungai Pani.

In this part of North Sulawesi yearly rainfall is not particularly high, averaging about 1200mm (Trail et al., 1974), the wet season being between October and March.

The central part of the north arm of Sulawesi is known as Exploration Block 2 by the Indonesian Mines Department. The Gunung Pani prospect is within sub-block E.

1.3 Scope and aims of this study

From October 1981 to December 1982 the author was employed by P.T. Tropic Endeavour, Indonesia [wholly owned by Utah International Inc.] as senior geologist to geologically investigate and evaluate the Gunung Pani gold prospect. During the exploration period the prospect was geologically mapped, extensively channel sampled and drilled by seven wide spaced exploration drillholes, totalling 1739m. The deepest hole was 424.20m. In addition, reconnaissance mapping and stream geochemistry was undertaken for the entire Block E.

The present study, undertaken at the Australian National University, is a logical extension of the field programme, and aims to develop an understanding of genesis of the Gunung Pani mineralisation through integration of geological, petrographical and geochemical data.

An underlying theme or broader philosophical approach pursued during the field investigation and recurrent to this work is to consider mineralisation in terms of the broader geological environment.

Therefore attention is given to description, petrography and geochemistry of volcanic rocks, elucidation of the volcanic environment on local and regional scale, and interpretation of acid volcanic processes. Hydrothermal alteration and mineralisation is presented within this framework, followed by ideas towards a genetic hypothesis of gold mineralisation.

With respect to mineralisation one major objective was to study the primary occurrence and nature of the gold.

The research primarily utilised samples from the diamond core, as well as a selection of rock chips collected by the author during field mapping.

1.4 Previous work

Gold has been exploited from alluvial deposits in North Sulawesi at least since the 14th century, at which time Portuguese built fortifications at coastal villages and traded in gold (de Neve, 1984). Dutch mining engineers began to investigate economic mineral occurrences towards the end of the 19th century. Fennema commenced work in 1896 but died the following year (de Neve, 1984). The work was continued by Koperberg between 1900-1904. Koperberg's work was published in 1929 in a condensed form after his death

(Koperberg, 1929). Koperberg's original manuscript, referred to in old Dutch records, included detailed geological traverses and up to 3000 mineral occurrences from North Sulawesi but can no longer be located (de Neve, 1984). Van Bemmelen (1949) summarises much of the geology and mineral occurrences from the earlier work.

An attempt to exploit the Gunung Pani gold prospect was made by the Dutch at about the turn of the century.

The Dutch miners drove a number of adits (up to 30m) into Pani ridge and extensively pitted the area. Remains of machinery suggest a limited amount of crushing and smelting was done, but production is not known. At around 1910 a dredge operated in the broad river alluvials at Taluduyunu, and remains of machinery occur in the river near Transit Camp. Details of this operation are available in old Dutch records in Bandung, but have not been referred to by the author.

Tyrwhitt (1969) reported on mineral occurrences in the north arm of Sulawesi, including the Gunung Pani Prospect, for Newmont Pty Ltd.

Between 1971-1980, P.T. Tropic Endeavour, Indonesia, owned and operated by Endeavour Minerals, explored the Pani prospect area and associated alluvials by an extensive programme, including geological mapping, topographical survey and soil and rock chip geochemistry on ridge crests and along drainage courses. Gold mineralisation on Pani ridge and Gunung Baganite was defined by contour trenching, channel sampling and re-examination of the old Dutch adits. The alluvial deposits were tested by several Bangka drilling programmes and finally by sinking of 1m diameter costeans to bedrock. Despite a lengthy period of investigation, little progress was made in understanding the geology and gold mineralisation. The Pani Volcanics (informal name) were regarded as widely distributed in the Marisa hinterland, mainly as ridge top cappings. In Sungai Batudulanga it was recognised that Pani-type igneous rocks intruded an older basement (Bumbulan Complex of Trail et al., 1974). Circular structures noted from side looking radar (SLAR) imagery suggested a volcano-tectonic control, but this was undefined in terms of known distribution of the volcanics. At the prospect itself the imposing summit of Gunung Baganite was recognised as a possible volcanic neck. The gold mineralisation was linked strongly to silicification and argillic alteration, and to quartz veining, the latter especially at cliff lines around Gunung Baganite.

1.5 Terminology, including use of Indonesian words and names

Usage of geological terminology follows the AGI Glossary of Geology, and where possible usage is self explanatory. Certain Indonesian words are used referring to place names, including the name of the prospect, since these names are already entrenched in previous literature on the area and prospect including the Indonesian Mines Department records.

Indonesian words in text:

1. gunung - mountain

   e.g. Gunung Baganite - Mt. Baganite

2. sungai - stream

   e.g. Sungai Pani - Pani stream

The stratigraphic nomenclature for Exploration Block 2 is based on work by Trail et al. (1974). Drillholes at the Gunung Pani prospect are named GPD1 to GPD7 (GP : Gunung Pani; D : drillhole).

II. REGIONAL GEOLOGY

2.1 Introduction

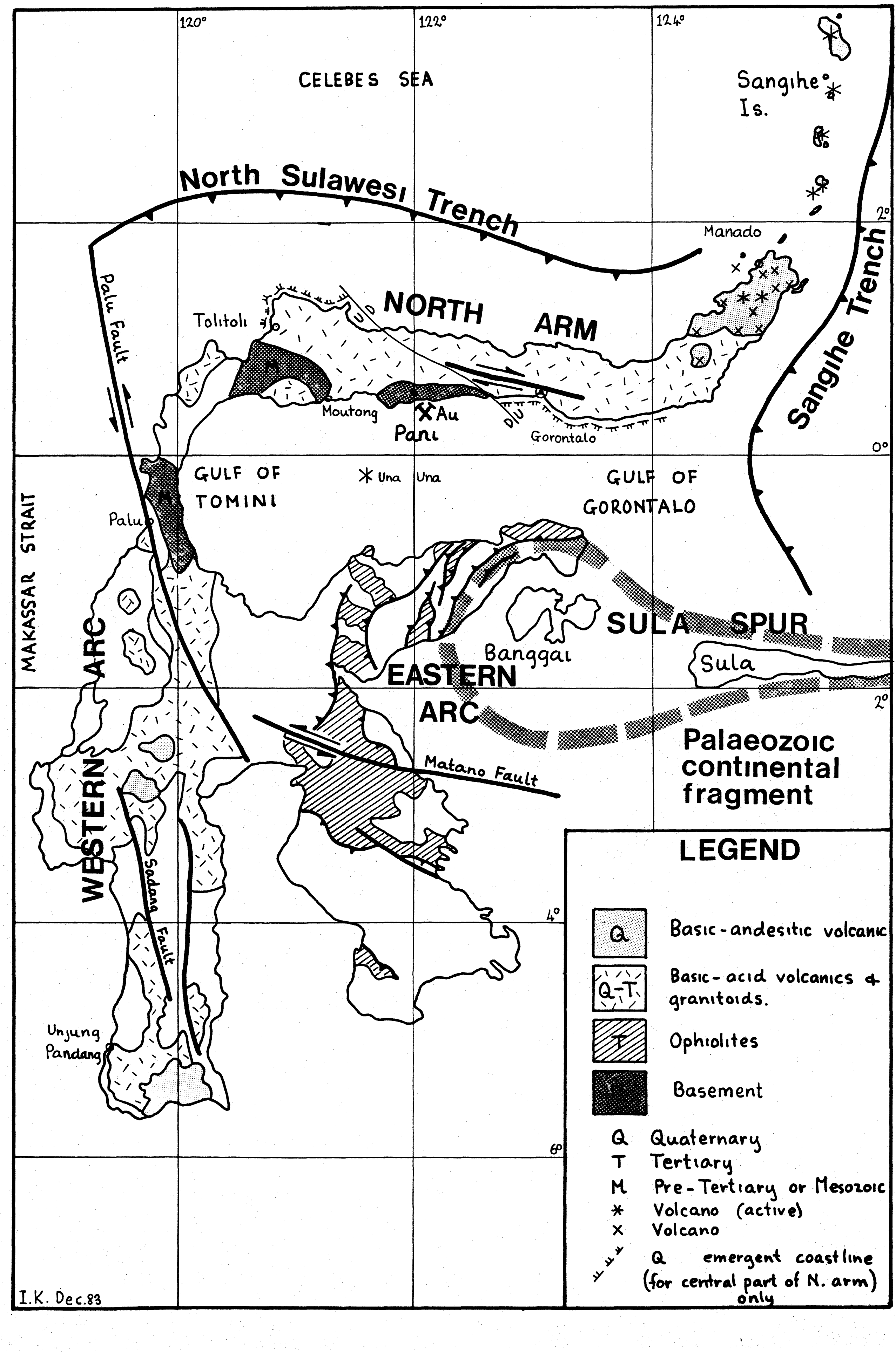
The north arm of Sulawesi is characterised by typical island arc volcanic, plutonic and sedimentary rock assemblages. In a broad sense successive components become younger to the east along the north arm of Sulawesi; from pre-Tertiary metamorphic basement near Palu to Quaternary volcanics and active volcanicity near Manado, and to the north in the Sangihe Island Arc chain. It is likely the north arm represents a Tertiary island arc system analogous to the present Sangihe Arc (Hamilton, 1979); and in terms of metallogenesis it can be compared to the Philippine porphyry copper and gold provinces.

2.2 General

The Tertiary arc system can be described by three main components (Fig. 2 and Plate 1): (1) an early arc submarine basaltic volcanic assemblage; (2) sub-aerial island arc andesitic volcanics and granitoids; and (3) the syn-volcanic volcaniclastic assemblage.

There is evidence of a pre-Tertiary basement near Palu and at Moutong, composed of amphibolite, micaschist, gneiss, metamorphosed limestone and granitoids (Sukamto, 1973; Ratman, 1976).

Fig. 2 : Main tectonic elements and igneous rock assemblages of Sulawesi



The Tinombo Fm (Sukamto, 1973; Ratman, 1976; Trail et al., 1974) represents an early arc volcanic assemblage of probable Eocene age and is composed of phyllite, slate, red chert overlying basic lavas and agglomerates, including pillow lavas. The Tinombo Fm is overlain by the Bilungala Volcanics (the sub-aerial andesitic arc) and a wide apron of volcaniclastics derived from the growing Bilungala Arc (Plate 1).

The Miocene Bilungala Volcanics (Trail et al., 1974) are composed mainly of andesitic volcanics, minor basalt and rhyolite and are interbedded or grade laterally into sequences of greywacke with minor limestone. The volcaniclastics belong to the Dolokapa Fm (Trail et al., 1974) which were deposited synchronously with the emergent volcanic arc. The Bilungala Volcanics are intruded by granodiorites and quartz diorites with associated gold-rich porphyry copper mineralisation east of Gorontalo, in the Tombulilato district.

The Miocene Bilungala Arc is considerably eroded, as is evident from the large area of exposed granitoids. A great deal of the detritus has been deposited in the Gulf of Gorontalo, which is 2000 metres deep, but contains in addition 5000 metres of Quaternary sediment, and in the Sulawesi Sea, into the North Sulawesi Trench, where 2000 metres of sediment occurs in water depth up to 5000 metres (Hamilton, 1979, Plate 1). Coarse fanglomerates of Bilungala Volcanic detritus (Quaternary and possibly Recent) with interbedded coral reef lenses fringe parts of the coastline.

At least in the central part of the north arm, renewed volcanic activity occurred during Plio-Pleistocene time, producing widespread acid and intermediate pyroclastics (Wobudo Breccia) along the northern part, and basic to acid pyroclastics along parallel rifts (Pinogu Volcanics). Descriptions by Trail et al. (1974) and Tropic Endeavour geologists (pers. comm.) suggest the Pinogu Volcanics may be a bimodal acid-basic volcanic suite.

In North Sulawesi the Miocene Bilungala Volcanics or their equivalents are overlain by Quaternary and active andesitic stratovolcanoes that form the southern extension of the Sangihe Arc (Morrice et al., 1983).

2.3 Marisa area

2.3.1 General

The Marisa hinterland is dominated regionally by basaltic rocks belonging to the Tinombo Fm (Plate 1).

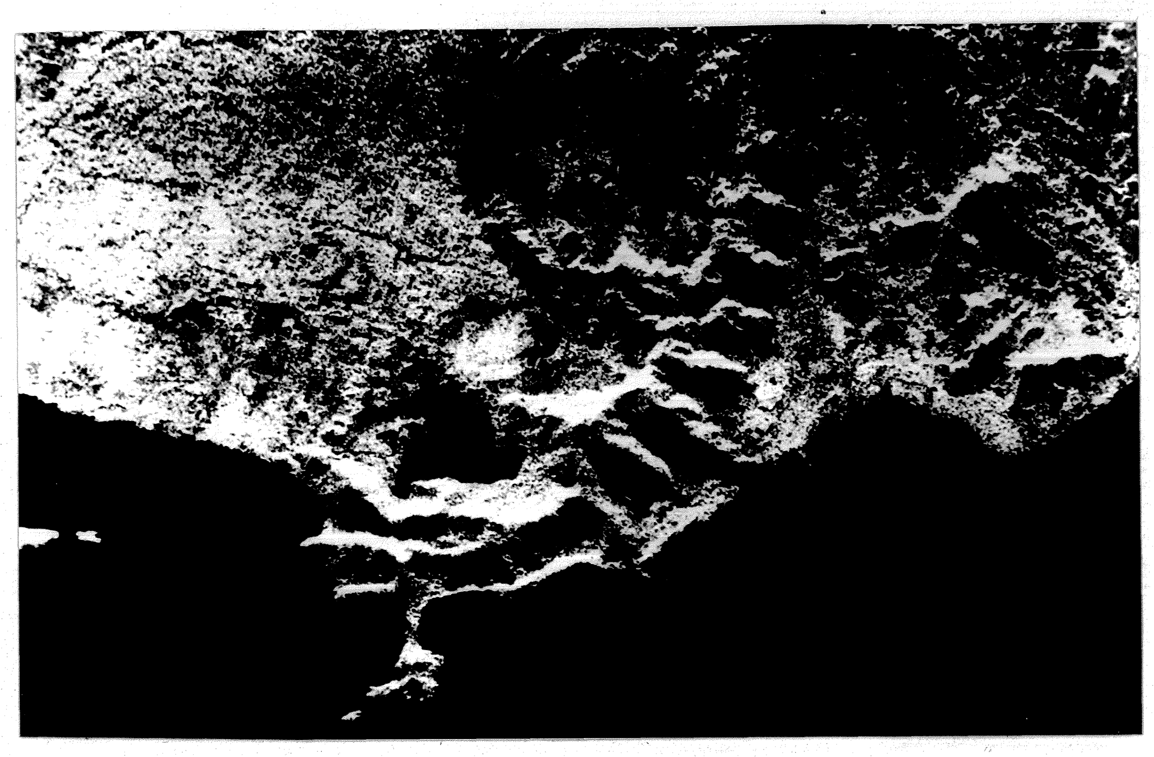
Along the coast and in the area of the Gunung Pani prospect metadolerites and amphibolites intruded by granitoids are found. It is not clear how these rocks are related to the Tinombo Fm, but it is possible that at least the amphibolites represent older basement. Based on Trail's et al. (1974) mapped distribution of amphibolite an area of older basement is tentatively shown on Plate 1.

The granitoid-amphibolite basement is extensively intruded by dolerite dykes that may belong to the Tinombo Fm basaltic volcanism.

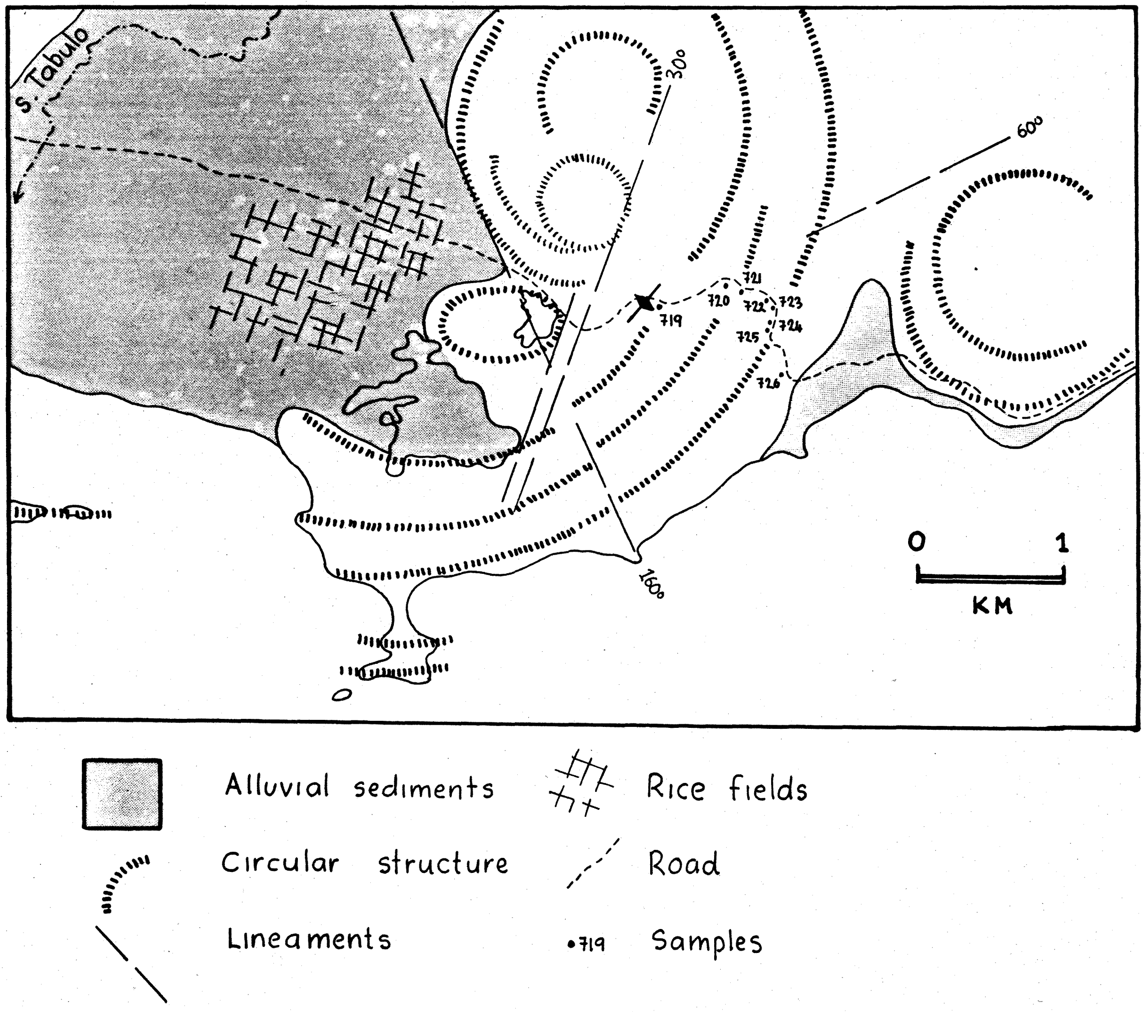
The Gunung Pani gold prospect occurs in younger acid volcanic rocks (Plio-Pleistocene?), referred to as the Pani Volcanic Complex. Distinctive lithology and large scale circular structure of the Pani Complex relates it to several other similar volcano-tectonic structures, which are unexplored or only cursorily examined. The Tabulo structure (Photo 2), 18km to the SE, is a ring-dyke complex, 3km in diameter, intruded into the metabasic and granitoid basement, where erosion has entirely removed the volcanic superstructure. Unlike the Pani Complex, no gold is associated with the Tabulo structure. The Molango structure (Plate 1) 35km NW of the Pani Complex, is poorly known, but is a circular feature shown by Trail et al. (1974) to be partly composed of Pani volcanic rocks, and of similar size. An old gold working is shown located near or in this structure.

As well as major volcano-tectonic structures, there are many smaller circular structures, some superimposed and nested in larger features (Photo 2), widely distributed along the coast from Tilamuta to west of Marisa, but due to only poor SLAR imagery available to the author these features have not been interpreted in detail. They are the remnants of an extensive intermediate-acid volcanic field, generally eroded to

Photoplate 2 : SLAR imagery of the Tabulo ring-dyke Complex and interpretation



INTERPRETATION



subvolcanic levels. This volcanic field is referred to as the Pani Volcanics.

From the sparse data it is suggested that the volcano-tectonic structures occur in a linear ESE to E-W trend, comparable with major tectonic elements of this part of North Sulawesi.

In the Pani Volcanic Complex the youngest intrusives and pyroclastics are distinctive, due to lack of hydrothermal alteration and resemble lithologies mapped elsewhere as Pinogu Volcanics. They also bear remarkable similarity to a single specimen collected from Una-Una, which is an active volcanic island 60km SW of Marisa (Fig. 2). The Una-Una volcanics are mineralogically unusual, due to the conspicuous presence of biotite (Neumann van Padang, 1951; Katili et al., 1963).

2.3.2 Granitoids

2.3.2.1 Medium-grained hornblende-biotite granodiorite

Basement granodiorites occur from Marisa east to Tilamuta and in the vicinity of the Gunung Pani prospect, but their size, distribution and field relationships are poorly known. The granodiorites are medium-grained, equigranular or coarsely foliated and appear to have complex interfingering relationships with amphibolites. These textures are typical of a high-grade metamorphic, and in part migmatite terrain.

Outcrops of these granitoids near the Gunung Pani prospect consist of up to 50% quartz; 40% sodic plagioclase and 8% ferromagnesian minerals, mainly hornblende, and 2% opaques. The ferromagnesian minerals are highly altered, replaced by chlorite and epidote; epidote entirely pseudomorphing hornblende. K-feldspar content is very low and commonly not detected by sodium-cobaltinitrite staining. It is possible that in highly altered specimens quartz has replaced primary mineralogy. Relatively unaltered, texturally similar hornblende-biotite granodiorites occur in the left hand branch of Sungai Batudulanga (e.g. S397) and consist of approximately 30% quartz, 15% hornblende and biotite and 50% sodic plagioclase. K-feldspar content, as revealed by sodium-cobaltinitrite staining, is a few percent or less. A chemical analysis of sample IKS21, collected near the prospect, supports a very low K_2O content.

The petrography, chemistry (Table 1) and geological setting is consistent with an interpretation that these are low K-granitoids and may have formed in an oceanic crustal environment but better data is required to test this tentative hypothesis.

2.3.2.2 Foliated microgranodiorite

Associated with the low K-granitoid-amphibolite terrain is a large area of fine-grained foliated biotite-hornblende granodiorite. The Pani Volcanic

Table 1 : Geochemistry of the basement granitoids

	IKS 8	IKS 21
SiO_2	66.50	73.10
TiO_2	0.44	0.32
Al_2O_3	16.25	13.10
Fe_2O_3	2.12	1.19
FeO	0.98	0.90
MnO	0.04	0.04
MgO	1.40	0.85
CaO	3.98	2.27
Na_2O	3.77	4.72
K_2O	2.88	0.86
P_2O_5	0.08	0.01
S	-	0.09
H_2O^+	0.92	1.17
H_2O^-	0.20	0.27
CO_2	0.22	0.75
Total	99.97	99.72
Ba	750	130
Rb	82	31
Sr	462	216
Pb	29	20
Zr	111	116
Nb	6.5	1.0
Y	12	35
La	21	7
Ce	44	17
V	27	27
Cr	6	-
Ni	3	-
Cu	3	5
Zn	43	29
K/Rb	292	230
Rb/Sr	0.17	0.14
K/Ba	32	55
Sr/Ba	0.62	1.66

IKS 8	Foliated microgranodiorite	Location : Sungai Batudulanga
IKS 21	Low K-granitoid	Location: Transit Camp

Complex intrudes mainly the foliated microgranodiorite on its N side, while to the SW the adjacent basement is composed of low K-granitoid. The low K-granitoid basement is intensively intruded by dolerite dykes (Tinombo Fm age?), while in the foliated microgranodiorite dolerite dykes are rare or absent. Amphibolite xenoliths which are spatially and perhaps temporally related to the low K-granitoid are common in the foliated microgranodiorite. These relationships suggest the foliated microgranodiorite is younger than the low K-granitoid-amphibolite basement and possibly postdates the Tinombo Fm. Chemically the foliated microgranodiorite is typical of continental calc-alkaline igneous rocks (Table 1), and not unlike the Pani Volcanics (refer to section 4.5.1).

The foliated microgranodiorite is composed of 60% plagioclase, 25% quartz and 5-10% biotite and hornblende in varying proportion, and 2% opaques (magnetite). Plagioclase is strongly zoned, euhedral and occasional larger crystals give a porphyritic appearance. The enclosing fabic is strongly oriented and envelops the plagioclase crystals (Photo 3a). Quartz is strained, interlocking and forms a metamorphic foliation with oriented crystals and clots of ferromangesian minerals. K-feldspar is mainly anhedral and interstitial.

The foliated granodiorite is texturally incompatible with high level intrusion, but consistent with deep level granitoid emplacement and high pressures.

2.3.3 Amphibolites

Amphibolites are typically medium-grained, equigranular or coarsely foliated and composed of; 50% hornblende, 35% plagioclase, 10% interstitial quartz and 5% disseminated opaques. A few specimens are composed almost entirely of coarse intragranular aggregates of hornblende.

Apart from an association with low K-granitoids, structural and field relationships are poorly known.

2.3.4 Tinombo Fm basalts

From the work by Trail et al. (1974) much of the Marisa hinterland is composed of basalts, including pillow lavas, dykes and minor pelagic sediments. The Tinombo Fm is thought to be of Eocene age (Trail et al., 1974) and unmetamorphosed or metamorphosed to lower greenschist facies grade (Photo 3b).

The higher ranges inland from Marisa around Gunung Paal Dua are composed of a thick sequence (>500m) of shallow dipping (S to SE) basaltic lavas and minor basic pyroclastics, intruded by dolerite dykes. Dolerite and basalt dykes are common everywhere. Near the summit of Gunung Paal Dua (elevation 1500m) the basaltic sequence is overlain by thin beds of red pelagic siltstones containing planktonic foraminifera (K.A.W. Campbell, pers. comm.), followed by a sequence of acid volcanics.

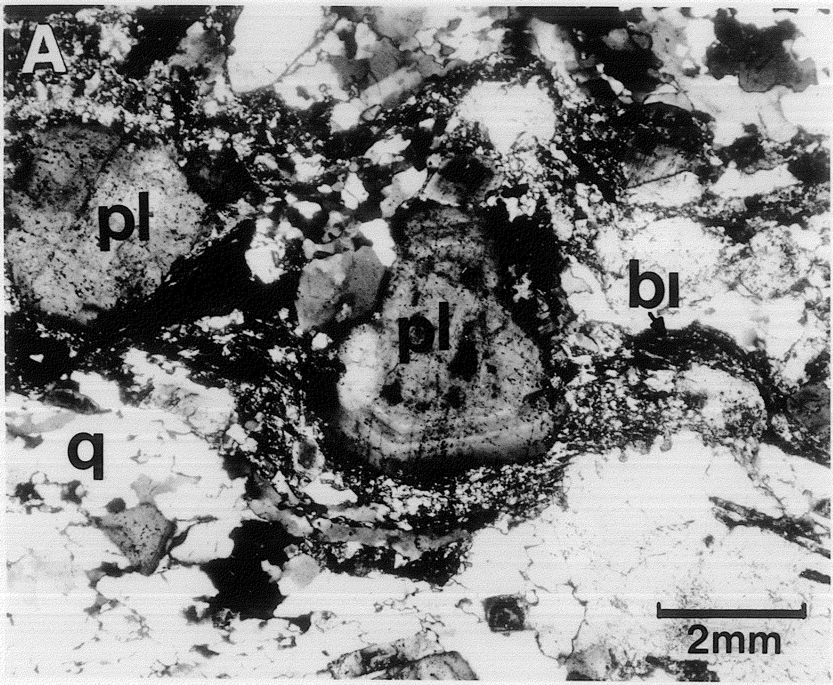
Photoplate 3 : Foliated microgranodiorite and metadolerite

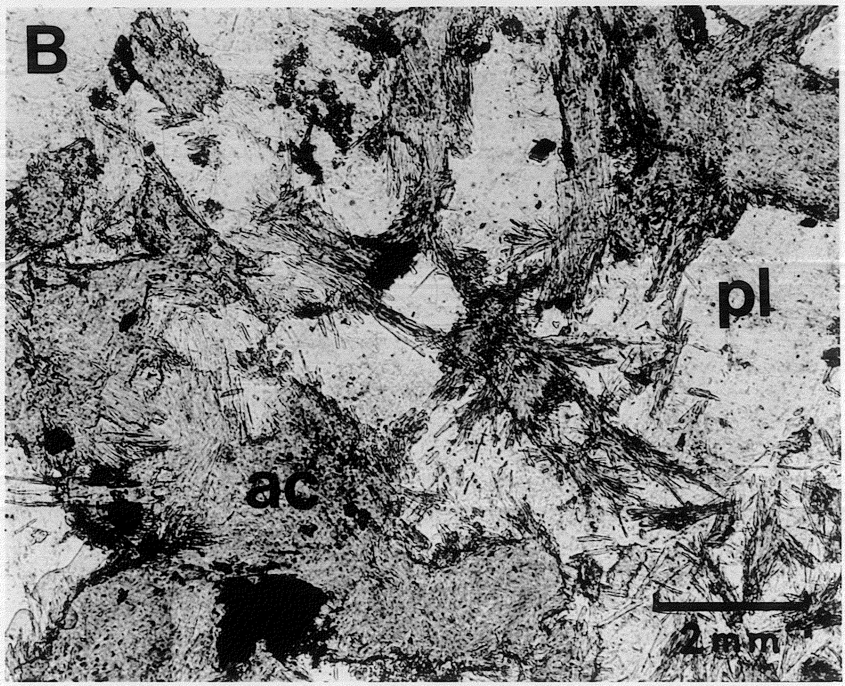
3a Foliated microgranodiorite.
Zoned plagioclase phenocrysts in a foliated matrix of interlocking quartz and biotite. Coarser aggregates of quartz with interlocking boundaries enclose the mafic-rich layers. Quartz crystals are mechanically strained (top right).
X-nicols.

3b Metadolerite.
Acicular actinolite replacing former ferromagnesian minerals, 50%; plagioclase and minor quartz (not shown).
X-nicols.

Symbols

q : quartz; pl : plagioclase; bi : biotite;
ac : actinolite.


A
pl
pl
bi
q
2mm


B
pl
ac
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2.3.5 Pinogu Volcanics

At Marisa and to the west outcrop fresh unaltered porphyritic basalts and basaltic breccias of unknown distribution. SLAR imagery suggests volcanic morphologies such as small volcanic cones and craters are preserved. These rocks are correlated to the Pinogu Volcanics which are best known in the Limboto Depression, and east of Gorontalo in the S. Bone valley.

2.3.6 Una-Una Volcano

A single specimen from an unknown locality from the Una-Una volcanic island consists of 40% plagioclase, 7% biotite and 5% hornblende phenocrysts (1-2mm), in a dark microcrystalline opaque-rich siliceous matrix. The plagioclase is strongly zoned, and commonly contains inclusions of biotite and apatite needles. Phenocrysts are moderately flow oriented and the specimen evidently represents an andesitic lava flow.

2.4 Plate tectonic interpretations

It is well recognised in the literature that the Island of Sulawesi (Fig. 2) comprises structurally two different igneous assemblages and perhaps tectonic terrains(1); the eastern arc of Tertiary mafic and ultra-mafic rocks, including amphibolite, greenschist

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(1) in the sense of 'suspect terrains', Coney et al. (1980).

and glaucophane-lawsonite metamorphics; and the western arc of (?)pre-Cretaceous metasedimentary basement and largely unmetamorphosed, Neogene basic to acid volcanics and granitoids (Brouwer, 1947; Sukamto, 1975; Katili, 1978; Hamilton, 1979). Katili (1978) has drawn an analogy to the paired metamorphic belt concept of Myashiro (1961).

The tectonic evolution of Sulawesi is subject to considerable debate.

Katili (1978) envisaged a north-south trending and east facing Tertiary arc-trench system originating well east of present day Kalimantan and the Asian continental margin, and colliding, first with the Australian-New Guinea continental margin in early Pliocene, producing severe deformation and obduction of ophiolite (the eastern arc), followed by movement westward and final collision with Kalimantan (Asian continental margin). The latter event resulted in emplacement of ophiolite in the Meratus Mountains of Kalimantan. Finally Sulawesi rifted from the Asian continent during a Quaternary opening of the Makassar Strait.

Other scenarios (Hamilton, 1979; Otofuji et al., 1981), and perhaps more realistic in the author's view, envisage that the western arc developed in the vicinity of the Asian continental margin and was perhaps similar to the present day Sangihe Arc, and by Early Tertiary time had become part of Kalimantan, but then was separated by rifting (Makassar Strait) during the Pliocene.

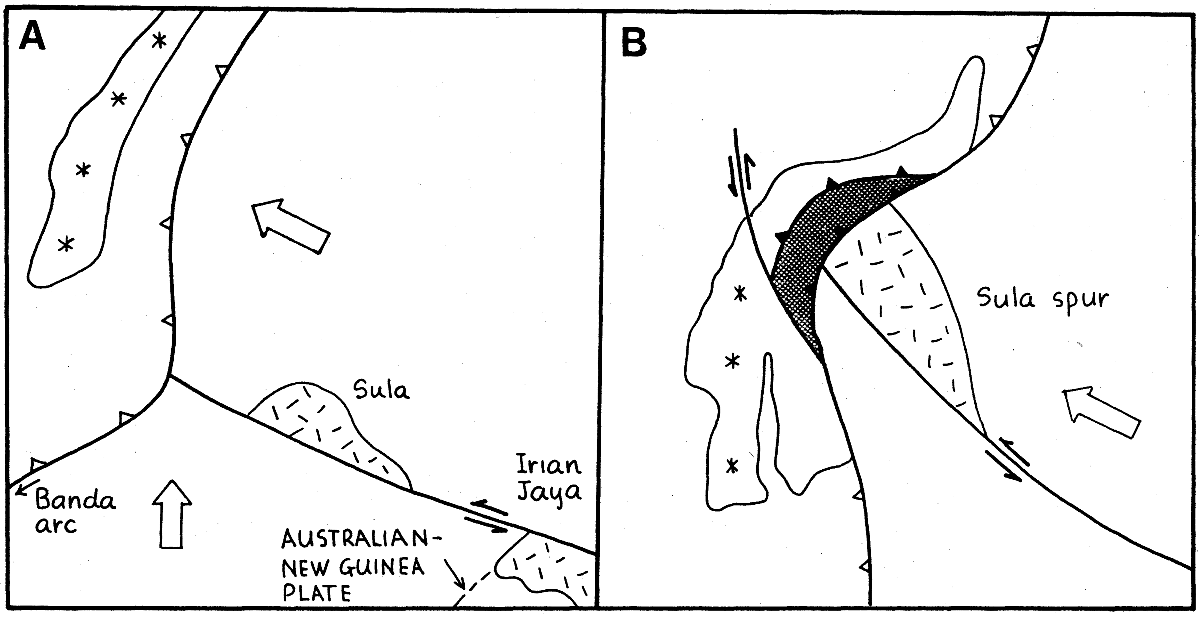
Hamilton (1979) interprets the geology of both the west and east arcs to record eastward migration of a west dipping subduction system during Cenozoic time and tectonic accretion of material, culminating with imbricated tectonic complexes and emplacement of the Sulawesi Ophiolite Belt in Eastern Sulawesi due to Miocene collision with westward drifting continental fragments (Buton and Sula). (See also Silver et al., 1983a). Otofuji et al. (1981) consider the eastern arc has affinities with Mesozoic sedimentary successions in the Banda Arc, Timor, Ceram and with parts of Australia, and with westward drift and collision it became part of western Sulawesi during Miocene time. They, as well as Silver et al. (1983b), postulate the Miocene collision and obduction may have resulted in the oroclinal folding of the northern arm of the western arc. Hamilton (1979) regards the oroclinal bending of the north arm to be mainly of Quaternary age related to sinistral movement on the Palu Fault coupled with active subduction in the North Sulawesi and Sangihe Trench systems.

A Miocene to Recent tectonic evolution of Sulawesi, based mainly on the work by Hamilton, is shown in Fig. 3.

Fig 3 : Miocene - Recent tectonic evolution of Sulawesi

Early Miocene 20my ago

Middle Miocene 10my ago



(A) Westward drifting Continental fragment detached from the Australian-New Guinea Plate - the Sula spur.

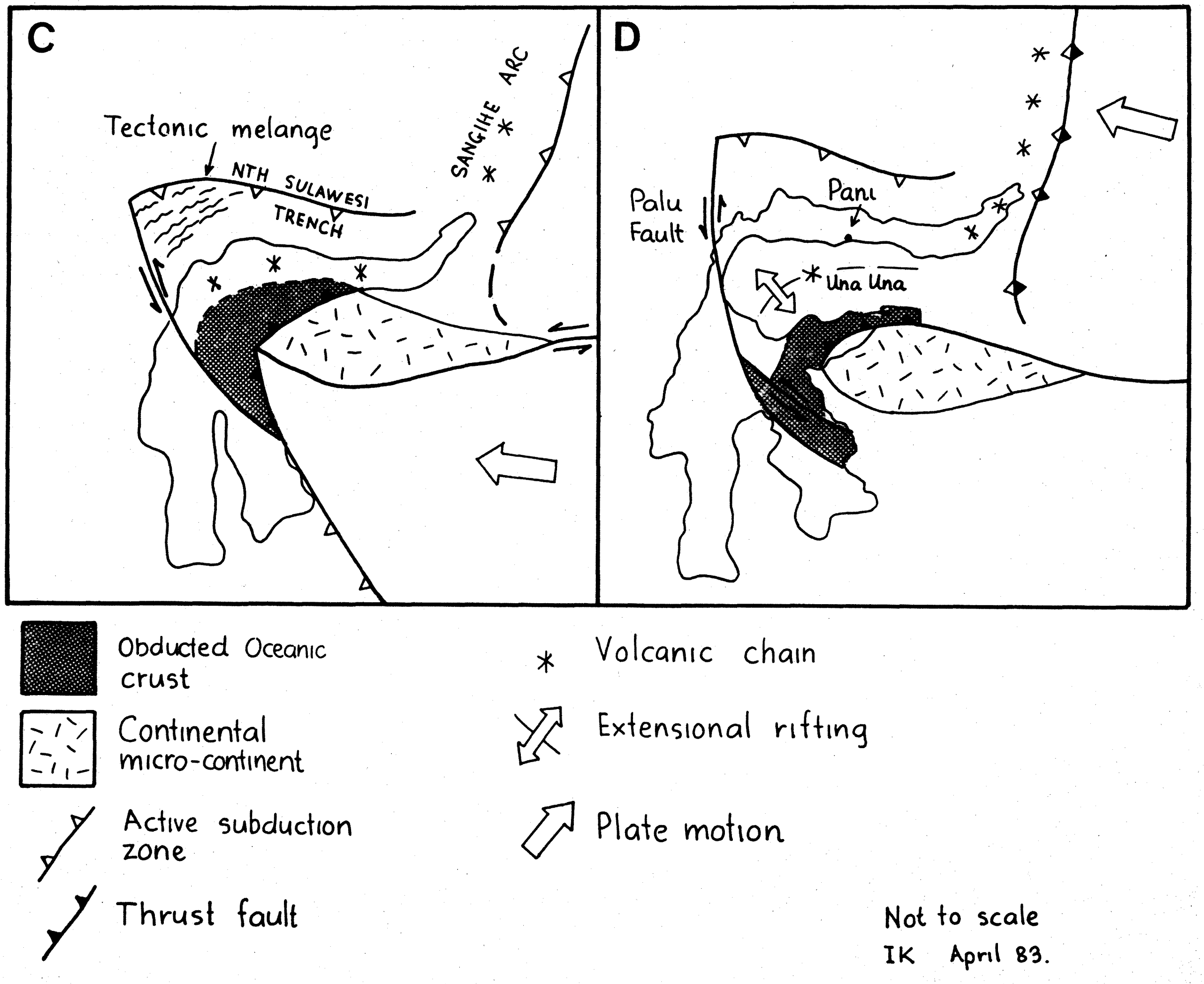
(B) The Sula spur collides with the west Sulawesi arc. Obduction of Oceanic crust; deformation of former N-S arc.

(C) North Sulawesi subduction initiated. Deformation continues - clockwise rotation of the N.E. arm.

(D) Extensional rifting. Silicic + basic volcanic activity (Pani Volcanics).

Miocene-Pliocene boundary 5my ago

Present



Not to scale

IK April 83.

2.5 Discussion

The occurrence of red pelagic siltstones with planktonic foraminifera at Gunung Paal Dua is evidence for a deep water environment, and suggests that at least till the (?) Miocene emergence of the Bilungala Arc the area was submerged and comprised ocean floor with water depths in excess of 200m. The Tinombo Fm is interpreted to represent an early-arc assemblage, possibly with geochemical affinity to island arc tholeiites (Jakeš and White, 1972).

The basic volcanic and clastic assemblage of the Tinombo Fm would be analogous to the present day submarine facies of the Sangihe Arc. This interpretation of the Tinombo Fm differs slightly from that by Trail et al. (1974) who consider it to be an ocean basalt assemblage, rather than specifically the base of an island arc.

The acid volcanics on Gunung Paal Dua may be related to the Bilungala Volcanics, outcropping 100km to the east.

The relationship between the Tinombo Fm and the metadolerites and amphibolites is uncertain as apart from metamorphic grade they differ little. One possibility is that the amphibolites are simply metamorphosed Tinombo Fm basalts, due to granitoid intrusion in which case basement of a pre-Tinombo Fm age does not necessarily occur in the area. Alternatively the association of low K-granitoids and amphibolites may be interpreted as the root zone of a former Oceanic Island Arc.

Disposition of the major geological units, major faults and morphology define a structural grain parallel with the E-W trend of the north arm and discordant ESE. The Limboto Depression, near Gorontalo, one of a number of such features, is the expression of extensional rifting with associated basaltic volcanicity (Plio-Pleistocene Pinogu Volcanics).

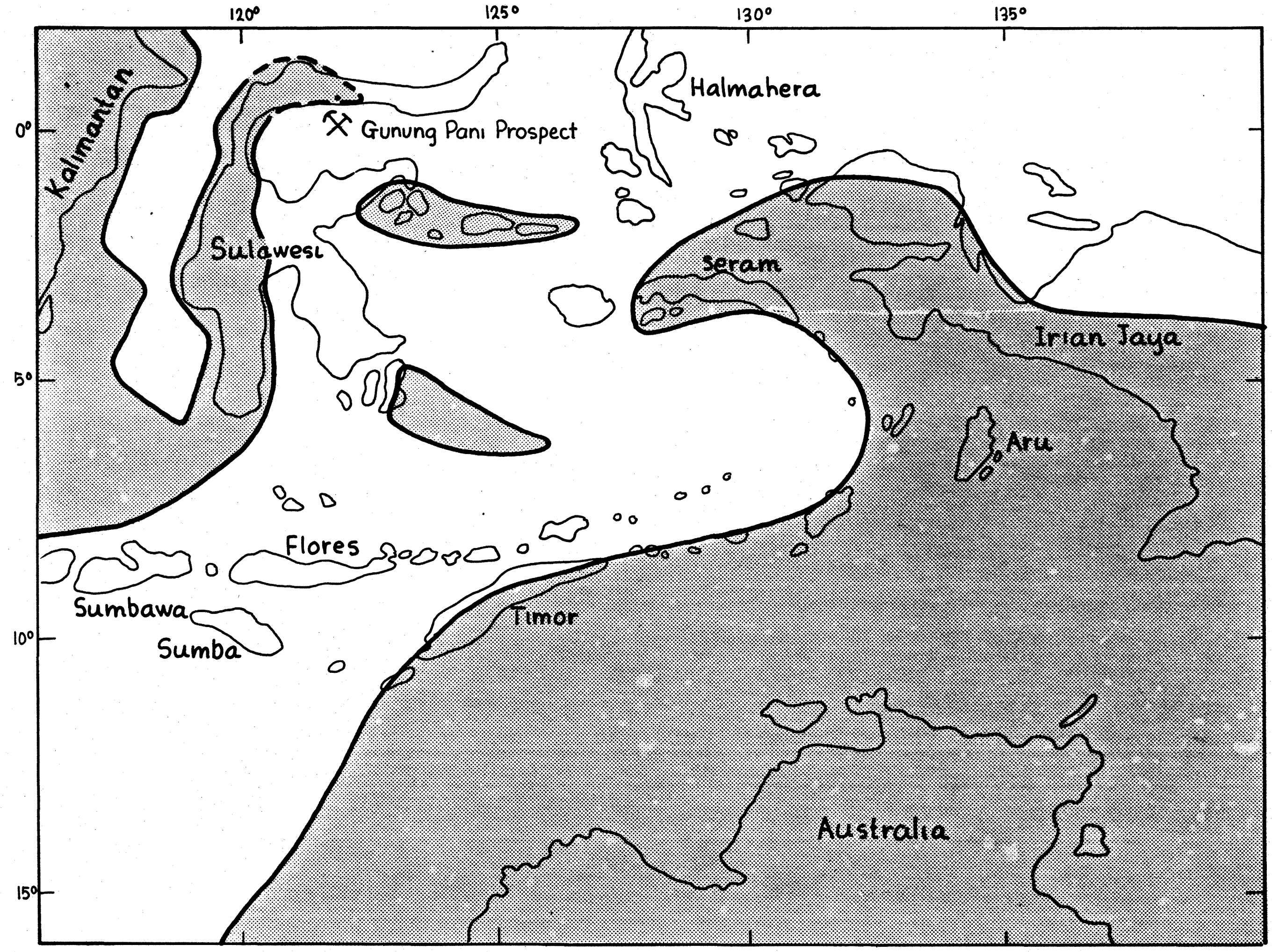
This volcanic activity may be due to back arc rifting related to the active North Sulawesi Trench system. This interpretation would be consistent with the suggestion that the Pinogu Volcanics are a bimodal acid-basic volcanic suite.

The Pani Volcanics can similarly be expected to be controlled by extensional tectonics, but the control is not obvious.

Recognition of the broad island arc character of the north arm with progressive younging to the NE raises the question how extensive the underlying older pre-Tertiary cratonised basement is, which probably occurs near Palu. A compilation of the distribution of pre-Tertiary continental crust in Indonesia by Hamilton (1979) is shown in Fig. 4, and suggests at least the western part of the north arm may be underlain by older basement, but probably not extending as far as the Bilungala Arc andesite volcanic pile.

Fig 4

DISTRIBUTION OF PRE TERTIARY CONTINENTAL CRUST IN SOUTH EAST INDONESIA



Adapted from Hamilton (1979)

▨ **Pre Tertiary Continental Crust**

The broad pattern of the north arm and relationships to the Western Sulawesi Arc, and north to the Sangihe Arc, suggests that crustal evolution along island arc chains, as well as parallel, may be a sequential and long lived process, currently poorly understood.