MINERALISATION ~~AT~~ IN THE GUNUNG LIMBUNG AREA, BOGOR ~~WEST JAVA~~, INDONESIA

by

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Thesis submitted for the Degree of
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in
ECONOMIC GEOLOGY

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Reported to :
1. The British Council
2. Directorate of Mineral Resources, Directorate General of Geology and Mineral Resources, Department of Mines and Energy, Indonesia.

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ABSTRACT

Quartz veins containing sulphides of Cu, Pb, and Zn and trace Au and Ag occur in a dioritic intrusion at Gunung Limbung in West Java (Indonesia).

Mineralogical, geochemical and fluid inclusion studies have been used to characterise the deposit and propose models of ore genesis.

The ore at Gunung Limbung is hosted in an (early) monzodiorite stock which was previously enriched in certain 'ore' elements. The mineralisation resulted from the filling of fissures and fractures by mineralised hydrothermal solutions forming a vein type deposit, and was formed in several stages. These are related closely to the subduction-related tectonic movements and magmatism (volcano-plutonism) of West Java which resulted in compressional and tensional forces. During and after mineralisation these tectonic movements caused brecciation of the ore.

The formation of ore resulted in alteration within the wall rock around the mineralisation zones, which zonally shows changes toward the ore zone from: propylitisation (at the outer margin) to sericitic-silicic-potassic alteration, and advanced argillic alteration at the ore zone.

The origins of the ore metals are still uncertain, but they could have been derived from either the country rock or from the (later) quartz diorite intrusion.

The temperature of the mineralisation by the fluids was 260° to 350°. Two fluids were involved, one with a low salinity (0.2%-5% wt NaCl eq.) with a high Ca/Na ratio and one with a higher salinity (10%-15% wt NaCl eq.) with a low Ca/Na ratio.

The hydrothermal solutions which were involved in the transportation and formation of ore were probably derived from meteoric/connate water mixed with magmatic fluids derived from the quartz dioritic intrusions.

The type of alteration, the characteristics of the hydrothermal solution (geochemically and geothermometrically determined) and the high concentration of certain elements (including Pb, Zn and Ba) within the host rock, are important criteria to be used as a tool in further exploration in the area.

The area is situated on the extension of the 'mineralisation belt' which run from north Sumatra into western Java and so has clear potential for the discovery of further deposits.

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CHAPTER I INTRODUCTION

This research was undertaken in fulfilment of the requirements for an M.Phil. degree in Economic Geology at Royal Holloway and Bedford New College, University of London.

A study area was chosen within the Gunung Limbung (Gunung means mountain) concession which is owned by P.T. Aneka Tambang, a government company which explores for and exploits most metallic mineral deposits in Indonesia. The area has a potential for base metal mineralisation, particularly lead and zinc, but the genesis and the origin of the mineralisation are still not known .

A period of one and half months from mid-December 1984 to the end of January 1985 was spent collecting data and making field observation of the area. This included surface and sub-surface (tunnel) investigations, and the study of drill cores.

I.1 The aim of the study

The study was carried out with the aim of discovering the genesis and the origin of the mineralisation in the area. This study is considered to be important since the area of interest is situated in the 'mineralisation belt' which runs along the entire length of Sumatra continuing to

Java. In addition to gold and silver, this belt also contains sulphide minerals of Cu, Pb and Zn.

A model for the ore genesis and the origin of mineralisation can then be used as a tool in the exploration for base metals. It may help to estimate the extension of the mineralisation in the Gunung Limbung area or in other areas around the mineralisation belt. The model may also be used for base metal exploration in other regions which have a similar geological setting.

I.2 Location, access and geographic setting

Gunung Limbung is situated in Jasinga district, about 60 km to the northwest of Bogor. Bogor itself is situated about 60 km from Jakarta or about 110 km from Bandung (see Fig. 1).

From Bandung the study area can be reached by car passing through a provincial road to Ngasuh and a village road from Ngasuh to Cisusuh. From Cisusuh the location can be reached in 15 minutes by foot.

Geographically, the area lies at the latitude between $6^{\circ}34'18"$ and $6^{\circ}35'45"$ south and longitude between $106^{\circ}23'44"$ to $106^{\circ}24'33"$ east.

The area mainly consists of hilly terrain (between 360 - 775 m above sea level) and has an area of 3.5 sq.km.

The main stream in the area is Cimangeunteung river, flowing down to the west, with many tributaries from Gunung Limbung and Gunung Karang forming a 'sub-radial' drainage pattern.

The closest villages to the study area are Cisusuh in the northwestern part, Gunungkembang in the southeastern part and Rancanangka in the southwestern part, from which the workers for the exploration activity of the project were mostly hired.

I.3 Previous work and history of exploration

The intensive exploration for base metals in Indonesia was started in 1969, following the beginning of the 'Five Year Development' programme.

In West Java, the exploration for base metals was carried out by the Exploration Division of the Geological Survey of Indonesia (GSI).

The first stage of the investigation was a general prospection by a geochemical reconnaissance survey (stream sediment sampling) covering South Banten, Jampang, South Bandung and South Tasikmalaya regions.

The reconnaissance survey of these regions was completed in 1971, and resulted in the discovery of some geochemical anomalies in Malingping, Gunung Gede, Gunung Sopal, and Cibareno areas.

The initial survey in these areas was then followed by a semi-detailed geochemical survey. Within the areas, only Gunung Gede area showed a good indication of base metal mineralisation, particularly for lead and copper.

A detailed exploration was then conducted in the Gunung Gede area, which included geochemical and geological surveys. The survey was finished in 1973 and resulted in the discovery of base metal geochemical anomalies in the Cikiam, Cibeureum, Cikawedukan, Gunung Limbung and Gunung Karang blocks. The result of the investigation is summarised in Fig. 2.

The final stage of the exploration was carried out by a GSI team and an Aneka Tambang team, and concentrated in Cikawedukan, Cikiam, and Cirempag blocks. The detailed survey on the Gunung Limbung and Gunung Karang block was carried out later.

The final investigation in Cikiam, Cikawedukan, and Cirempag blocks, which included bedrock geochemistry ('opening' and 'trenching'), geophysical survey (using IP method), and drilling, concluded that the deposits in these blocks were not of economic value.

In the Gunung Limbung and Gunung Karang block the final exploration method included bedrock geochemistry ('opening' and 'trenching'), geophysical survey (using IP method), drilling and tunnelling.

The bedrock geochemistry and geophysical survey were carried out by the GSI team and resulted in the discovery of many veins containing lead and zinc concentrations near

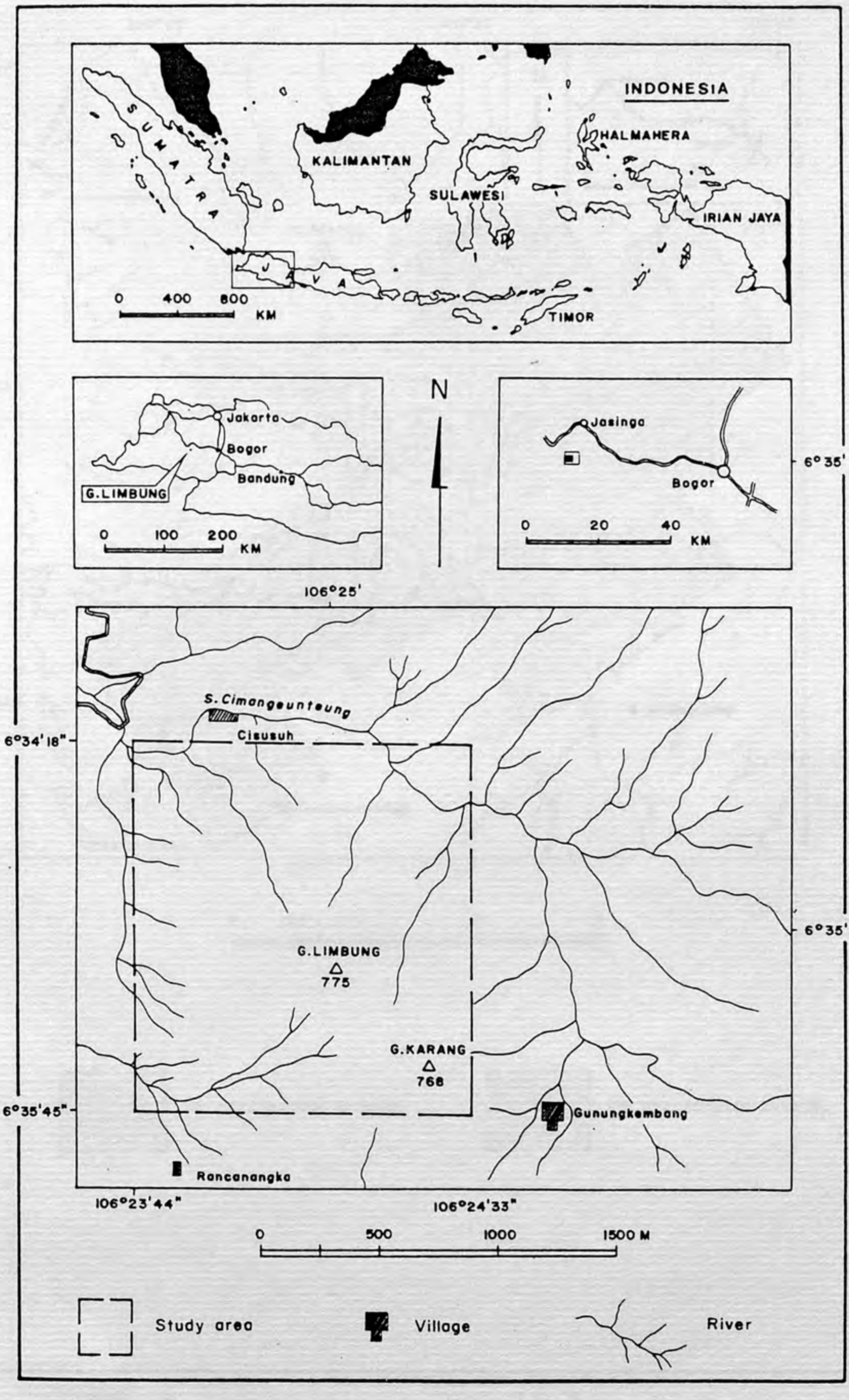


Fig. 1 Index map

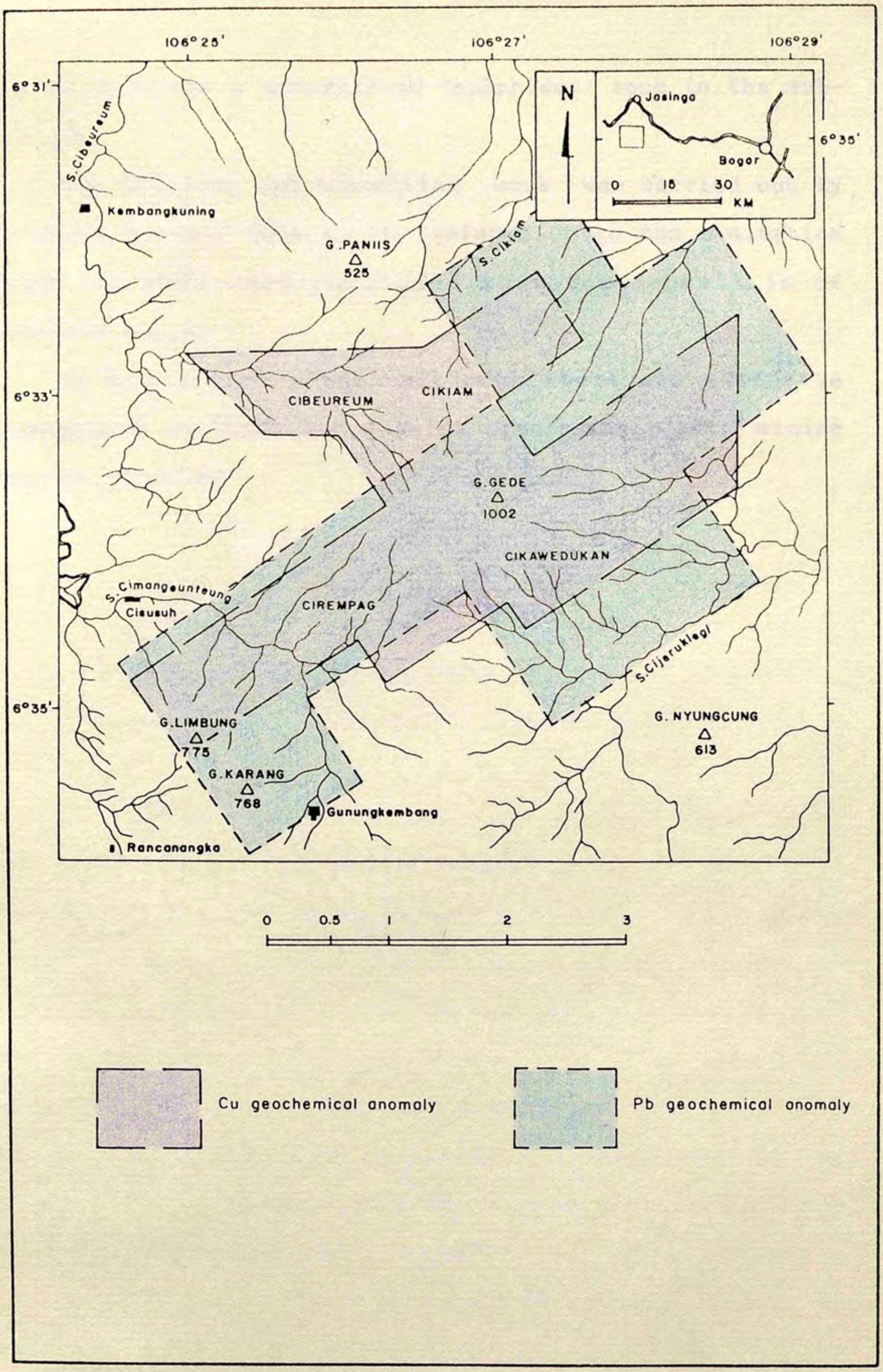


Fig. 2 Summary map of mineralisation in the Gunung Gede area (Data from GSI)

the surface and a mineralised (sulphides) zone in the subsurface.

The drilling and tunnelling work was carried out by an Aneka Tambang team which finished up to the evaluation stage in 1983, and concluded that the deposit is of economic value.

So far (March 1986), although there are extensive underground workings and a pilot processing plant, mining has not started.

CHAPTER II REGIONAL GEOLOGY

This chapter briefly describes the regional geology of West Java and includes the physiography, lithology and stratigraphy, tectonic setting, and the mineralisation of the region. This can then be used as a basis for the discussion of the geology of the study area.

II.1 Physiography

Regionally, West Java can be divided into two regions: a lowland plain in the north, and a mountainous belt in the southern part, comprising respectively 1/4 and 3/4 of the area.

The lowland plain, which is also called the Coastal Plain of Jakarta by van Bemmelen (1949), has a flat geomorphology and consists mainly of alluvial deposits and lahars (mud flows) from the volcanoes in the hinterland, with occasional exposures of slightly folded marine sediment.

The mountainous belt, in the southern part, is a part of the magmatic arc which trends from the north to the south of Sumatra, running to the eastern part of Indonesia passing through the island of Java.

Van Bemmelen (1949) divided the southern region of West Java into three zones : Bogor Zone, Bandung Zone and the Southern Mountains of West Java (Fig. 3).

The study area is situated in the western part of the Bogor Zone - a complicated anticlinorium slightly convex to the north with intensive folding and northward upthrust. This zone extends from Rangkasbitung in the west by way of Bogor to Bumiayu in the east (Central Java). According to van Bemmelen (1949), the core of this anticlinorium consists of Miocene strata and its flanks are formed by Pliocene and lower-Pleistocene deposits.

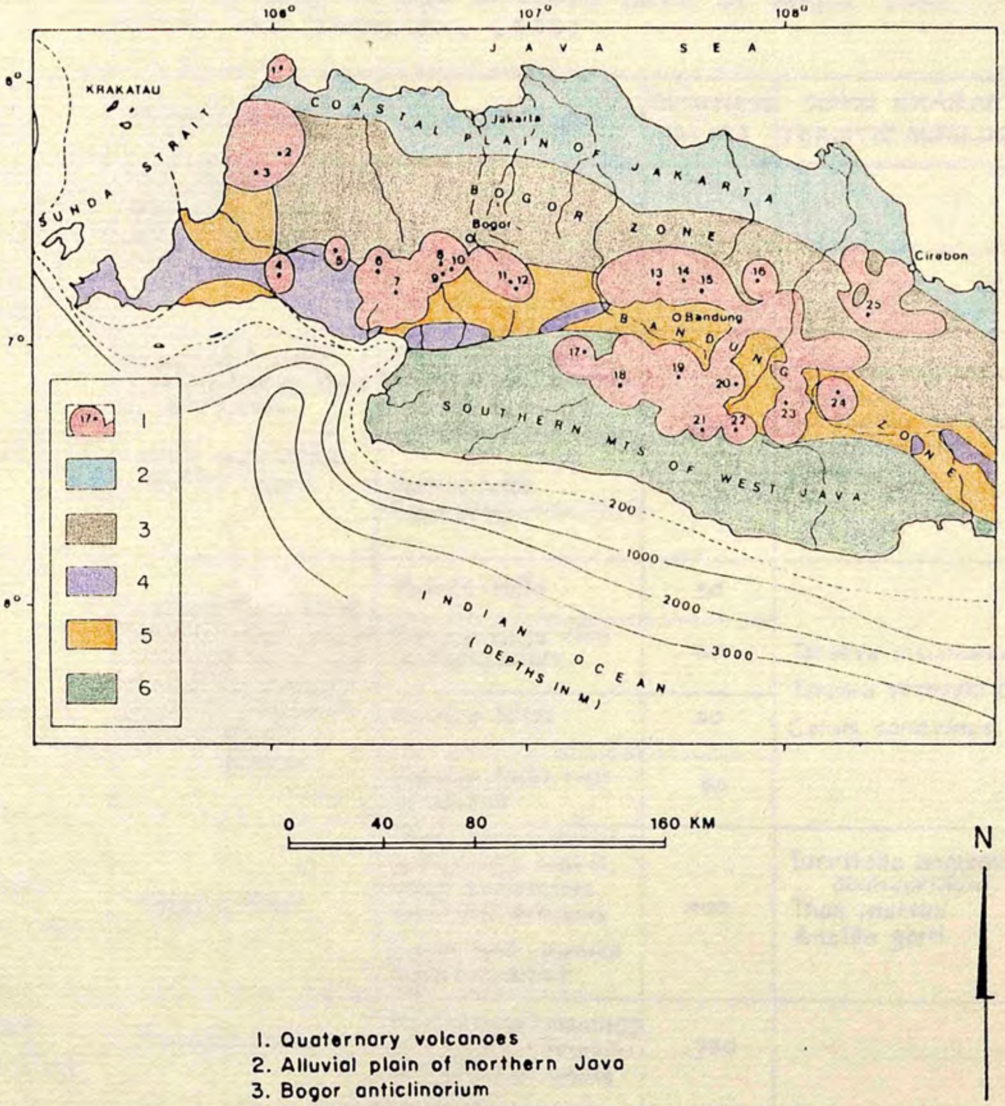
In the area near Jasinga, where the N-S trending anticline curves into an E-W directed anticlinorium of the Bogor Zone, the older Miocene strata have been intruded by necks and bosses of hornblende andesite, quartz diorite and porphyritic quartz diorite of upper-Miocene age (Gunung Gede and Gunung Limbung area).

II.2 Lithology and stratigraphy

The stratigraphy of the western part of the Bogor Zone had been arranged by van Bemmelen (1949), as can be seen in Table 1.

The oldest rocks are called the 'Badui Beds' (Lower 'Bojongmanik Beds') of lower to mid-Miocene age which are composed mainly of basal andesitic conglomerate and sandstone, limestone, marl and clay.

The Badui Beds are unconformably overlain by the



1. Quaternary volcanoes
2. Alluvial plain of northern Java
3. Bogor anticlinorium
4. Dome and ridges in the central depression zone
5. Central depression of West Java
6. Southern mountains

Volcanoes

1. Gn. Gede, 2. Gn. Karang, 3. Gn. Pulasari, 4. Gn. Malang, 5. Gn. Endut, 6. Gn. Halimun, 7. Gn. Halimun, 8. Gn. Gagak, 9. Gn. Endut, 10. Gn. Salak, 11. Gn. Pangrango, 12. Gn. Gede, 13. Gn. Burangrang, 14. Gn. Tangkuban Perahu, 15. Gn. Bukittunggul, 16. Gn. Tampomas, 17. Gn. Kendeng, 18. Gn. Patuha, 19. Gn. Malabar, 20. Gn. Guntur, 21. Gn. Papandayan, 22. Gn. Cikurai, 23. Gn. Galunggung, 24. Gn. Sawal, 25. Gn. Ciremai.

Fig. 3 Physiographic map of West Java
(After van Bemmelen, 1949)

Table 1. Stratigraphy of the western part of Bogor Zone (After van Bemmelen, 1949)

AGE	STRATIGRAPHY	COMPOSITION	THICKNESS (in m)	SOME CHARACTERISTIC MOLLUSCS
Holocene and Upper-Pleistocene	Volcanoes formed after block faulting and collapsed of the Danau Complex			
Middle-Pleistocene				
Lower-Pleistocene	Bojong Beds (and part of Cikeusik Beds in SW Banten. (Upper part of the Banten tuffs)	Glauconitic marls (tuffaceous) more or less sandy marls, with limestone lenses Pumice tuffs Basal conglomerate.	200	Turritela angulata. Tritonalia. Cantharus eulianus Trigonostoma. Clavus.
Upper-Pliocene	Cilegong Beds (pumice tuffs with marine intercallations) and part of the Cikeusik Beds ~ Cimanceuri Beds in South-Banten	Pumice tuffs	50	Terebra insulindae. Terebra Verbeeki (?) Conus sondeinus.
		Pumice tuffs rich in hornblende	60	
		Pumice tuffs	40	
		Pumice tuffs rich in biotite	50	
Middle-Pliocene	Cipacar Beds.	Upper part: tuffaceous glauconitic marls, clays, sandstones, andesitic breccias. Lower part : pumice tuffs (pisolitic)	400	Turritella angulata acuticarinata. Thais martini. Ancilla gerti.
Lower-Pliocene	Genteng Beds	Pumice tuffs (pisolitic) rich in plant remains and silicified woods.	730	
Upper-Miocene		Intrusions of hornblende andesite, diorite, diorite porphyry.		
Upper part of the Middle-Miocene	Bojongmanik Beds	Marls and clays with brown coal, tuffs, sandstones, andesitic gravels. In the upper part also pumice tuffs.	550	Vicarya vernaeulli calosa. Syphocyprae caput viparae. Paphia neglecta. Apolymetes grimesi elongata. Cultellus dilatatus
Lower to Middle-Miocene	Badui Beds. (+Lower Bojongmanik Beds).	Limestones, marls, clay-shales. Basal andesitic conglomerate and sandstones.		Turritella subulata. Amusium hulshofi

Bojongmanik Beds. These beds are composed of marl and brown coal, tuff, sandstone, andesitic gravels and (in the upper part) pumice tuff. In the upper-Miocene these beds were intruded by hornblende andesite and quartz diorite/porphyry quartz diorite. These beds are followed by the 'Genteng Beds', which are composed of pumice tuff. The Genteng Beds unconformably overlie the Bojongmanik Beds.

The Genteng Beds are unconformably overlain by the 'Cipacar Beds' of middle-Pliocene age, composed of tuffaceous glauconitic marl, clay, sandstone, andesitic breccia (in the upper parts) and tuff (in the lower parts).

In the upper Pliocene period, the 'Cilegong Beds' were deposited, conformably overlying the Cipacar Beds. The Cilegong Beds are composed of 40 m of pumice tuff, overlain by 50 m of pumice tuff rich in hornblende which is overlain by a further 50 m pumice tuff.

The Cilegong Beds are unconformably overlaid by the 'Bojong Beds' of lower-Pleistocene age, which are composed of basal conglomerates, pumice tuff, sandy marl, tuff and glauconitic marl.

In the mid-Pleistocene to upper-Pleistocene-Holocene periods, some volcanic products were deposited, uncoformably overlying the older sediments.

The dating of these rocks is based on the palaeontological evidence, as can be seen in Table 1.

Marks (1969) has also arranged a stratigraphic sequence of the Banten area (the most western part of the

Bogor Zone). He suggested that the Badui Beds were formed in the lower-Miocene period. The Badui Beds are unconformably overlaid by the Bojongmanik Beds of mid-Miocene age and Genteng Beds of upper Miocene to lower Pleistocene age and the Cimanceuri Beds of mid-Pliocene age. These are then unconformably overlaid by Quaternary sediments of Bojong and Cikeusik formation of lower-Pleistocene age; volcanic rocks of mid-Pleistocene age; sediments of upper-Pleistocene age and sediments of Holocene age.

The stratigraphic succession in the western part of the Bogor Zone refers to the geological events and the environment of the zone in the period between mid-Miocene and Pleistocene.

In the mid-Miocene period, clay-shale units were deposited, overlain by limestone in a neritic (shallow water shelf) zone. This is interpreted as a transgressive period. According to Gazali (1972) the limestone unit (containing coral) occurs mainly in the southern part of the Bogor Zone, which indicates that the neritic zone becomes shallower to the south. The transgressive event continued until the upper-Miocene period.

During the period mid-Miocene to upper-Miocene, small regressive events occurred in the area, which caused the formation of sandstone and andesitic gravels. When the regressive events occurred, the Bogor Zone lay within the littoral zone, and some lignite was formed.

The regression and transgression were caused by uplifting and downwarping due to the development of a structural system involving folding and faulting. This was followed by the first period of volcano-plutonism (andesitic-dioritic) in the southern part of the area. The development of the structural system and the volcano-plutonism is related closely to the tectonic movements in West Java. The uplifting in the Bogor Zone resulted in the erosion of clay and sandstone.

In the Pliocene period the marine transgression was still in progress. In the mid-Pliocene time fine sandstone, limestone and marl were deposited. Large tuff deposits were formed in the upper-Pliocene indicating that volcanism was very active in that period.

In the Plio-Pleistocene period the transgression ceased and the Bogor Zone was gently uplifted due to the second phase of igneous intrusion in the southern part of the area (this includes the diorite intrusion in the Gunung Gede area). This uplift resulted in the change of deposition and environment in the Bogor Zone from marine conditions to the land conditions which are found at the present time. The uplift was associated with erosion, and in the middle and the southern part of the Bogor Zone, the tuff of Pliocene age was totally eroded, and the older units of mid-Pliocene age (clay, sandstone) were exposed.

The second phase of igneous intrusion in the southern part of the Bogor Zone, resulted in the mineralisations seen in the Gunung Gede and the Gunung Limbung areas. The fissures which were formed by stuctural events in the lower to middle-Pliocene period were filled by hydrothermal solutions associated with the second intrusion, forming mineralised veins. The volcanic event in the Plio-Pleistocene period produced abundant volcanic materials which covered most of the Bogor Zone. At the same time erosion was occurring. Some of the volcanic products (e.g. andesitic breccia) still remain in the area around Gunungkembang village.

The erosion and the deposition are still occurring today, depositing the alluvial deposits, which can be found in some stream systems.

A part of the geological map of West Java which includes the western part of the Bogor Zone is shown in Fig. 4.

II.3 Tectonic setting

The regional tectonic setting of island of Java is strongly influenced by plate tectonics.

The Indonesian Archipelago has been fitted to plate tectonic models by Hamilton (1970) and Katili (1971), which were later improved by Hamilton and Katili (1973), Pupilli (1973) and Nishimura (1980).

Based on the plate tectonic theory, the Indonesian arc

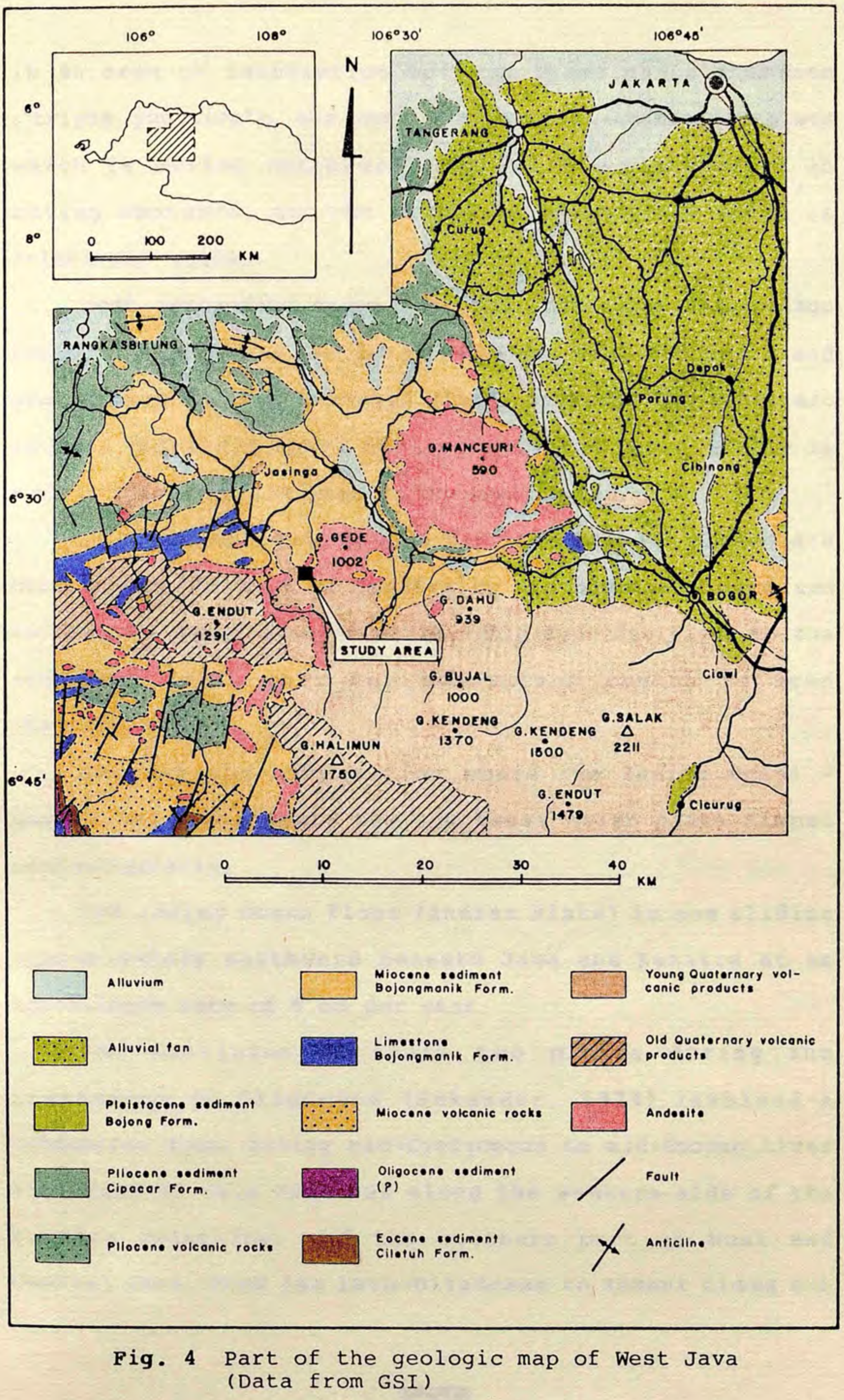


Fig. 4 Part of the geologic map of West Java (Data from GSI)

is an area of interaction between three major elements ('triple junction'): the East Indian Ocean-Australian plate which is moving northward, the Pacific plate which is moving westward, and the Southeast Asian plate which is relatively stable.

Most geologists agree that the Indonesian Archipelago can be divided into two large regions, West Indonesia and East Indonesia. Van Bemmelen (1949) included the Sunda arc in West Indonesia which geologically and tectonically is more simple then the East Indonesian region.

In West Indonesia (Sunda arc) the present plates are bordered to the west of Sumatra by a subduction trench and to the east by an area of strike-slip type faulting. To the south of Java, only the subduction trench is seen (Katili, 1972).

Java is the only region where the Indian Ocean - Australian plate meets the Southeast Asian plate almost perpendicularly.

The Indian Ocean floor (Indian Plate) is now sliding approximately northward beneath Java and Sumatra at an approximate rate of 6 cm per year.

The collision of these two plates during the Cretaceous to Oligocene (Sukendar, 1974) involved a subduction zone. During mid-Cretaceous to mid-Eocene times the trend of this zone was along the western side of the Sumatra coastline, and the southern part of West and Central Java. From the late-Oligocene to Recent times the zone shifted southward, and presently has a position some 250 km off the Java coastline. The plate interactions have influenced basement configuration and basinal sedimentation.

The features of the subduction system - trench, outer-arc ridge, outer-arc basin, volcano-plutonic arc, and foreland basin, are well illustrated from geophysical information from this area.

The Sumatra-Java trench forms a long linear depression between 70-100 km wide, extending for a distance appoximately 2500 km from northern Sumatra to Sumba in eastern Indonesia. The trench is only about 4500 m deep off northern Sumatra, but 6000-7000 m deep off South Java (Hamilton, 1979). According to Beck and Lehner (1974), from the seismic records, the trace of the Benioff Zone marking the upper surface of the Indian Ocean dips northward 5^{o}-8^{o} beneath the inner slope of the trench and steepens towards the south coast of Java to 60^{o}-75^{o} at a depth of 600 km beneath the Java Sea.

The continental slope rising from the Sumatra-Java trench is formed by subduction accretion resulting in the outer-arc ridge. This outer-arc ridge is a wholly submarine (within 1 km of sea level) feature off Java and the southernmost part of Sumatra. At the northern end of the Sumatra-Java trench (opposite Sumatra) the corresponding ridge rises above the sea level forming a linear group of islands. These differences in height of the ridge are attributed to the thickness of the sedimentary cover on the ocean floor which is available to be scraped off as the oceanic plate passes down the subduction zone.

The outer-arc basin is a topographic depression which lies between the outer-arc ridge and the Sumatra-Java islands. It is a broad basin with water depths typically 3000-4000 m off Java, but only 200-2000 m along most of Sumatra. This basin is composed of thick sediments which are little deformed beneath the centre of the landward side of the basin, but become increasingly deformed oceanward of the centre. Based on the seismic data, in some sectors the flat lying sediments beneath the axis of the outer-arc basin are at least 6 km thick.

The first phase of volcano-plutonic activity was located in the northern part of West Java and ran west-east parallel to the subduction trend. By the Oligocene this volcanic belt shifted to the southern part of Java. During late-Tertiary to Recent time it has moved towards the north, and at the present time the belt is located on the axial part of Java. This position is situated above the point where the underlying Benioff Zone reaches a depth of 200 km. The volcanic belt extending along the length of Java represents the magmatic arc of the Sunda arc system. The volcanoes are composite cones constructed predominantly of andesite lava and tuff rising above the arc massif of Neogene and older rocks which form the foundation of Java. The lavas which built the volcanoes are considered to have been produced by partial melting of the subducted oceanic plate and the overlying mantle, which possibly was contaminated by crustal material through which the magma passed on its way to the surface. Toward the end of the Paleogene the magma reached the surface and a period of strong volcanic activity began, producing 'old-andesite', the first cycle of Pacific volcanism (van Bemmelen, 1949). In the middle-Miocene the volcanic belt of Southern Java was pushed up by gabbro-dioritic to granitic batholiths which ascended into the very base of the old-andesitic volcanoes. These intra-Miocene holocrystalline igneous rocks are nowadays exposed in some places in the Western part of the Bogor Zone, South Banten and Jampang. In the young-Neogene, a second cycle of volcano-plutonism developed, which was terminated by a second impulse of uplift of the volcanic belt. In the Quaternary, a third cycle of volcanism began lasting until the present time. A typical feature of the second and third periods of volcanism is that the intrusion and extrusion along the northern margin of the geanticline of South Java show a tendency to differentiate into alkaline rocks. The young-Neogene intrusive necks of the Bogor Zone and the North Serayu Range (Central Java) often have an essexitic (alkali gabbro variety) character (van Bemmelen, 1949). Using geochemical analyses of basaltic rocks, Kuno (1966) demonstrated that there was a systematic relationship between the composition of the basaltic rocks and the depth of the underlying Benioff Zone. The main volcanic chain of Java includes high alumina basalts 150 km above the Benioff Zone, whilst on the north coast of Java, where the Benioff Zone lies at the depth of 400 km, highly alkaline leucite-bearing basalts have been extruded from volcano of Muria (northern part of Central Java).

The foreland basin of northern Java and the nearby off-shore areas are the site of active deformation and sedimentation. The sedimentary rocks record marine conditions during the earlier part of the Miocene, and a regression during the Neogene through decreasingly marine conditions to the present largely continental setting. Folding began in the Miocene in the south, while sedimentation continued in the north, where northward directed folds and thrusts were produced (Ringkasan, 1963). The Tertiary tectonic setting of West Java is shown in Fig. 5, and it can be seen that in Tertiary time the study area was situated in the foreland basin. From the stratigraphy of the Bogor Zone it can be seen that the basin is mostly composed of siliciclastic, bioclastic, and volcaniclastic sedimentary rocks. The sedimentary rocks are of 'fluvio-deltaic' non-marine (littoral) to marine (neritic) facies, composed of conglomerate, sandstone, claystone with bituminous clay and lignite intercalations, limestone and resin fragments. The occurrence of sandstone, clay, marl and limestone indicates that in Tertiary time the study area was influenced by regressive and

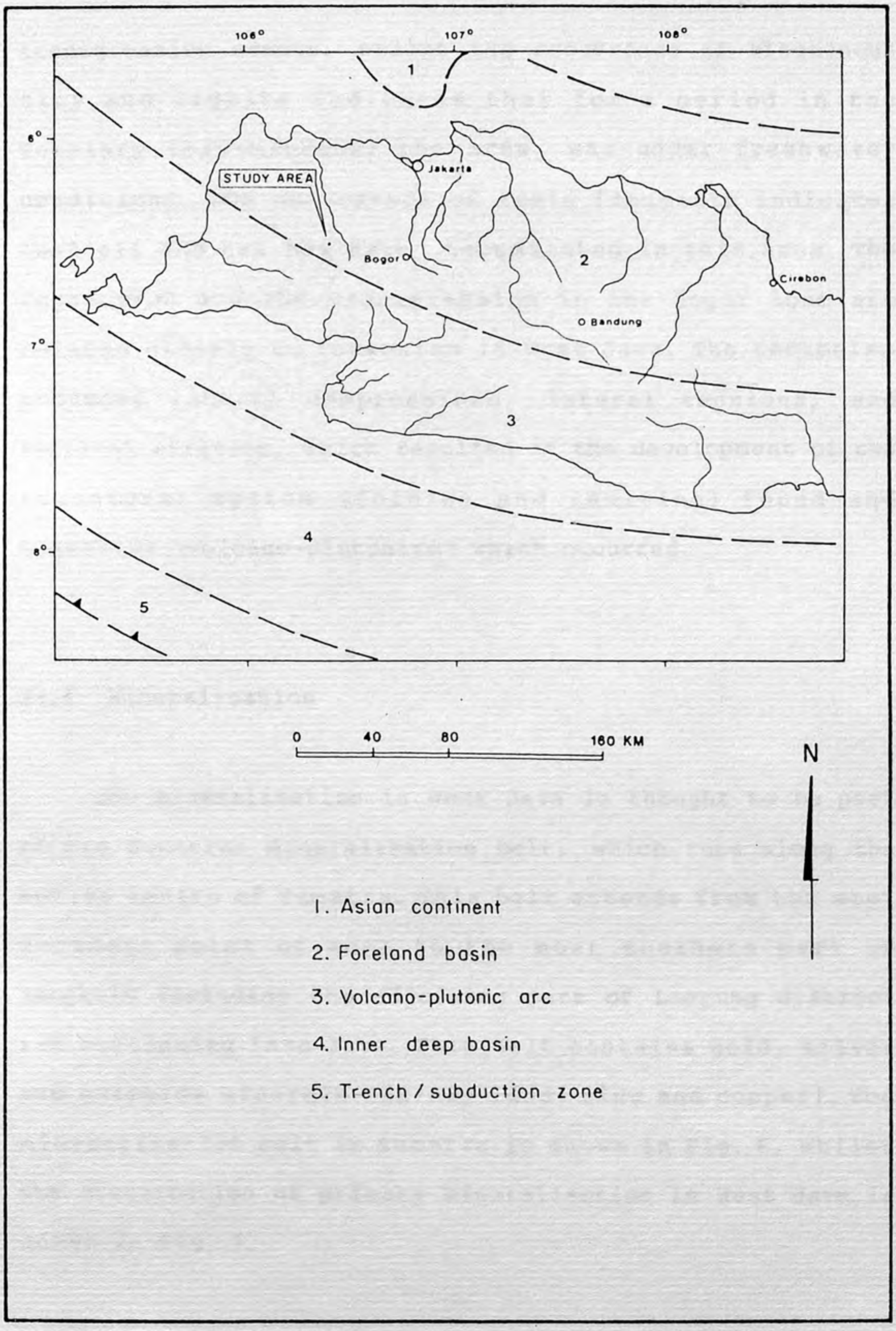


Fig. 5 Tertiary tectonic map of West Java (After Pupilli, 1973)

transgressive events, whilst the occurrence of bituminous clay and lignite indicates that for a period in the Tertiary (mid-Miocene) the area was under freshwater conditions. The occurrence of resin fragments indicates that oil and gas may have accumulated in this area. The regression and the transgression in the Bogor Zone are related closely to tectonism in West Java. The tectonism produced lateral compressions, lateral tensions, and vertical stresses, which resulted in the development of the structural system (folding and faulting) found and magmatism (volcano-plutonism) which occurred.

II.4 Mineralisation

The mineralisation in West Java is thought to be part of the Sumatran mineralisation belt, which runs along the entire length of Sumatra. This belt extends from the most northern point of Aceh to the most southern part of Bengkulu including the adjoining part of Lampung district and continuing into Java. This belt contains gold, silver and sulphide minerals (mainly lead, zinc and copper). The mineralisation belt in Sumatra is shown in Fig. 6, whilst the distribution of primary mineralisation in West Java is shown in Fig. 7.

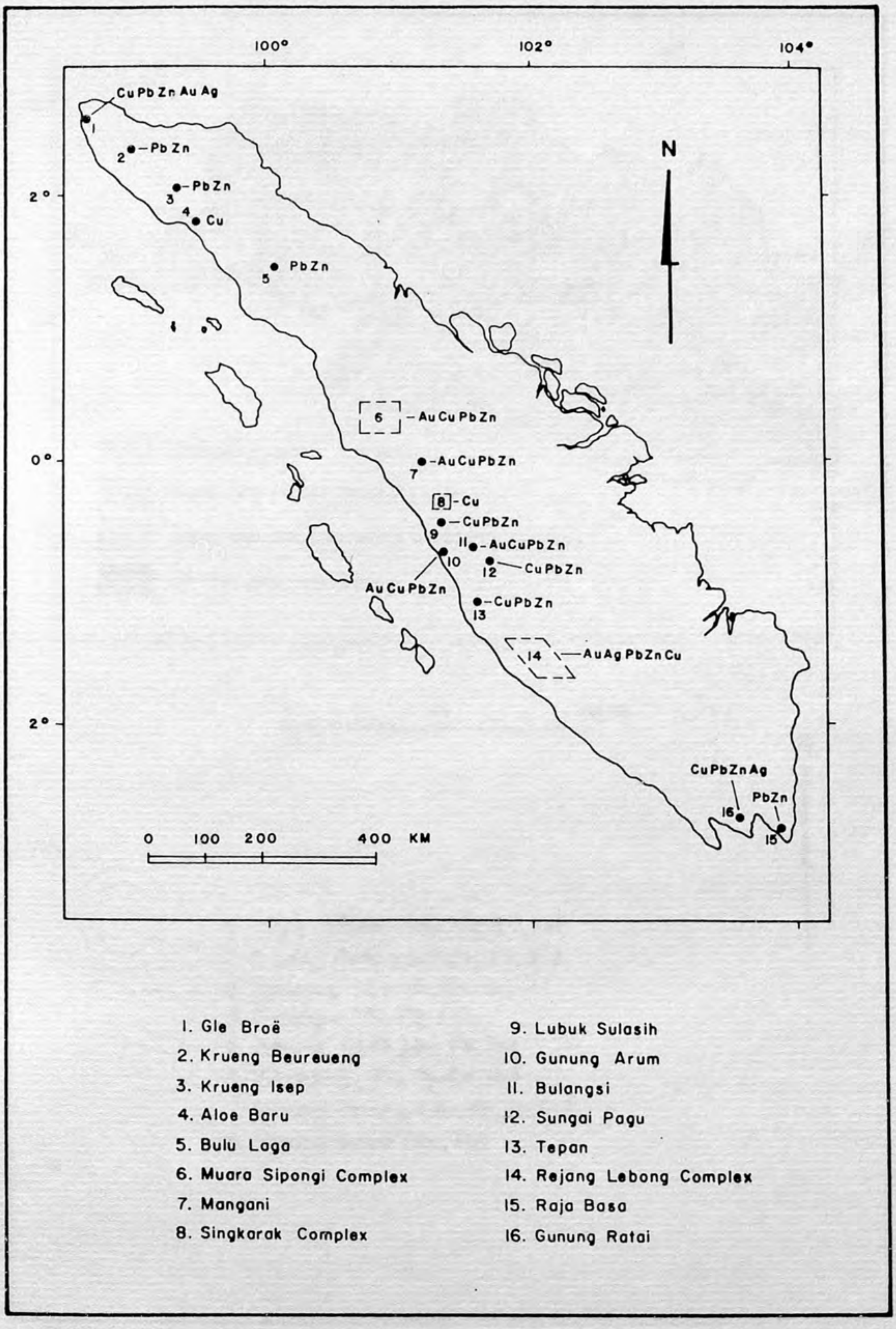


Fig. 6 Important primary metallic mineral concentration in Sumatra

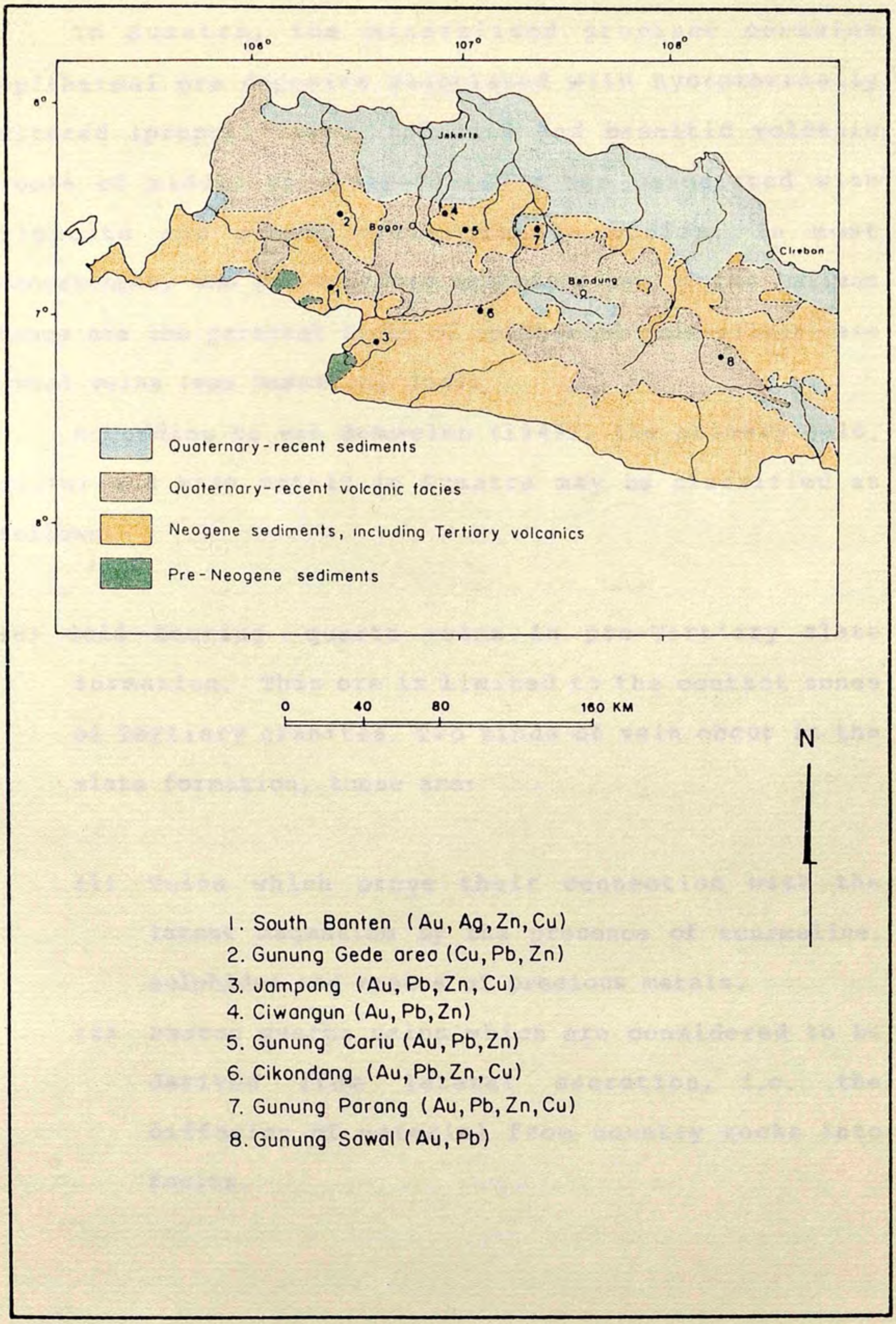


Fig. 7 Important primary metallic mineral concentration in West Java

In Sumatra, the mineralised province contains epithermal ore deposits associated with hydrothermally altered (propyllitised) andesite and basaltic volcanic rocks of middle to upper-Tertiary age associated with liparite and granodiorite/granite bodies. In most occurrences, the mid-Tertiary granodiorites of the Barisan Range are the parental rocks of epithermal gold-silver-base metal veins (van Bemmelen, 1949).

According to van Bemmelen (1949), the primary gold, silver and base metals in Sumatra may be classified as follows:

(a) Gold-bearing quartz veins in pre-Tertiary slate formation. This ore is limited to the contact zones of Tertiary granites. Two kinds of vein occur in the slate formation, these are:

    (1) Veins which prove their connection with the latest magmatism by the presence of tourmaline, sulphides and traces of precious metals.
    (2) Barren quartz veins which are considered to be derived from lateral secretion, i.e. the diffusion of material from country rocks into faults.

(b) The Tertiary so-called 'young gold-silver veins' associated with sulphides, closely connected with young-Tertiary volcano-plutonics (andesite, trachyte, rhyolite and dacite).

(c) Contact metamorphic deposits. Precious metals associated with sulphides (pyrite, chalcopyrite, galena and sphalerite) which occur in veins in the contact zones.

Among the mineralised zones in Sumatra, are the West Sumatra district (which includes the Muara Sipongi and Singkarak complexes, Mangani, Salida, Panindam, Balimbing, Gunung Arum and Bulangsi), and Rejang Lebong complex in Bengkulu district (which includes Lebong Tandai, Lebong Donok and Lebong Simpang). They notably contain workable gold deposits.

In the Rejang Lebong complex (known as the 'gold district') mining activities started in 1899 with the Rejang Lebong Mining Company in Lebong Donok. In 1912 the the Dutch East India Company started operating.

In the West Sumatra district, as early as the second half of the seventeenth century, a mine was operated by Dutch East India Company (van Bemmelen, 1949).

Organised gold mining in West Sumatra started in 1912 when Mangani gold mine came into operation. It was followed by Salida and Panindam mines, and later in 1930, the mines of Balimbing, Gunung Arum, Muara Sipongi and Bulangsi.

There is no exact information about the size and the grade of the deposits, but according to van Bemmelen (1949) the total mined tonnage in the West Sumatra district is about 1,771,000 tonnes of ore with a gold to silver ratio of 1:10 to 1:52; whilst in the Rejang Lebong complex the total mined tonnage is about 6,718,000 tonnes with a gold to silver ratio between 1:1 and 1:90.

Copper generally occurs in the neighbourhood of igneous rocks in adjacent contact zones. Among the mineralised localities, those of Singkarak and Muara Sipongi complexes are the most important ones (van Bemmelen, 1949). In the Singkarak complex (11 localities) the mineralisation was formed as a result of a late-Mesozoic granite batholith intruded into Permo-Triassic sediments, and emplacement of the batholith accompanied or followed by the formation of disseminated copper ore of pyrometasomatic type. The minerals found are chalcopyrite, bornite, covellite, cuprite, azurite, malachite and native copper. There is no information about the size of the deposits in this complex, but the copper content was reported to vary from 0.4 to 5 %.

In the Muara Sipongi complex (8 localities) the mineralisation occurs in veins associated with quartz and disseminated around the contact zone betweeen Tertiary granite and slate, and as lenses in limestone. The minerals found are chalcopyrite, bornite, chalcocite, azurite and malachite. The total reserveds are is about 110,000 tonnes containing 0.5 to 14.58 % copper.

Lead and zinc sulphide frequently occur in young-Tertiary 'gold-silver veins', but in relatively small amounts. Among the localities in Sumatra, the most important ones are Lubuk Sulasih and Sungai Pagu in West Sumatra district.

In Lubuk Sulasih the mineralisation occurs as veins and lenses associated with quartz, which are found in the propyllitic breccia-like andesite. Minerals found are galena (which has a high silver content) and sphalerite.

In Sungai Pagu, the mineralisation is of vein type, found in the contact zone between granodiorite and schist. The ore contains galena, silver, pyrite, Mn-oxide and a little gold. According to van Bemmelen (1949) the total ore reserves in those two areas is at least 2,240,000 tonnes containing 2.4 to 5.5 % Pb and 1.6 to 8.10 % Zn.

Exploration and mining activities for precious and base metals by Dutch companies in Sumatra were halted in 1940, but some of the gold deposits in the Rejang Lebong complex are still worked today, by a non-Indonesian company (in Lebong Tandai), and by local people (in Lebong Donok and Lebong Simpang).

In West Java, the mineralisation was formed in the mid-Miocene to Pleistocene periods. This mineralisation is abundant and contains a variety of minerals, but the most important are gold, silver, lead, zinc and copper. This mineralisation was formed in the Miocene rocks of the mountain belt. There is an intimate relationship between the mineralisation and the volcano-plutonic activities within the tectonic zones, and it is suggested that the mineralisation in West Java is related to the Mio-Pleistocene volcanism (Djumhani, 1981).

Among the localities of primary mineralisation in West Java, four localities have proved to be workable deposits. These four localities are:

(1) South Banten

A vein type deposit associated with quartz which is hosted in propyllitised andesite and trachyte of lower-Miocene age. The ore minerals which occur are electrum and argentite (as main ore minerals), sphalerite, galena, chalcopyrite and pyrite. The veins are found in the Cimandur basin, with mostly N-S directions. This deposit has been worked between 1940 and 1943 by Zuid Banten Mining Company (a Dutch mining company). The proved ore reserve was estimated at over 500,000 tonnes, containing at least 10 gm Au and 557 gm Ag / tonne. At the present time the concession is owned by P.T. Aneka Tambang.

(2) Gunung Cariu

A vein type deposit including sulphides of Cu, Pb, Zn, Fe (chalcopyrite, galena, sphalerite, and pyrite) with precious metals (gold and silver) associated with quartz. The veins trend approximately WSW-ESE. The host rock is propyllitised volcanics. At the present time the concession of this area is owned by a private company. No information about the size and grade of the deposit is available.

3) Cikondang

A vein type deposit consisting of quartz veins containing gold, silver, and sulphide minerals (galena, chalcopyrite, pyrite and arsenopyrite). The veins trend approximately N-S and are hosted in old andesite. The Rejang Lebong Mining Company had started mining in this area just before the Japanese invasion in 1943 (van Bemmelen, 1949). No information about the size of the deposit was available, but the grade of ore was reported to be about 15 gm Au per tonne, and 0.2 to 0.8 % Cu.

(4) Gunung Limbung

The mineralisation in the Gunung Limbung area is the subject of this thesis. As earlier mentioned, the concession is owned by P.T. Aneka Tambang. Since the negotiation for the mining rights between P.T. Aneka

Tambang and some non-Indonesian companies is still in progress, the size of the deposit and its grade cannot be given in this thesis.

Although the mineralisation in West Java is thought to be an extension of the Sumatran mineralisation belt, there are some characteristic differences between them. Gold and silver associated with copper, lead and zinc in the Western Coastal Range of Sumatra are predominantly of epithermal vein type, containing minor manganese with trace amounts of tellurium, bismuth and selenium. On the other hand, in the Southern Mountains of Java, the mineralisation is characterised by minor amounts of arsenic sulphide of vein type (Djumhani, 1981).

CHAPTER III FIELD OBSERVATIONS

Field observations were concentrated in the area where the mineralised veins mostly occurred. A period of three weeks was spent studying the area in the field using surface and sub-surface (tunnel) investigations, and drill cores. During this period many samples were collected for analysis later in the laboratory.

Some problems arose in collecting samples, since:

(1) The study area is mostly covered by forest and a thick top soil. This resulted in difficulty in finding outcrops of fresh rocks on the surface (a high rate of weathering is typical of tropical countries).

(2) During the exploration, a lot of trenches were made to expose the mineralised quartz veins. After a couple of years almost all of the trenches had collapsed and the vein could no longer be observed.

(3) The best way to observe the lithology and the mineralisation laterally and vertically is through the exploration tunnels. Unfortunately, some of the tunnels had collapsed. Although the broken material in the collapsed tunnels can be cleaned up, the tunnels are often dangerous to enter. The tunnels which still can be safely entered are tunnels T.400, T.460, T.490 and T.580 (Plate 12). The numbering of the tunnel is based on the elevation (in metres) above sea level (e.g tunnel T.400 is 400 m above sea level).

(4) All of the cores were stored in the sheds on the site. Unfortunately, some of the sheds plus the cores were destroyed in a fire. The cores stored in the surviving sheds were often unidentifiable as their labels had been lost.

III.1 Geomorphology

As part of the Bogor mountain range, the study area has a hilly geomorphology (medium to high). The elevation is between 360-775 m above sea level, with steep slopes.

The highest peaks are Gunung Limbung (775 m) and Gunung Karang (768 m). These two peaks are joined by a NW-SE ridge.

The high ground covers approximately two-thirds of the area, and is mostly coverd by a light forest, whilst the medium height ground is mostly cultivated (rice field and farms).

The drainage system of the area has a sub-radial pattern with 'V' shaped valleys which reflect the 'youth stage' erosion.

It is suggested that there is a relationship between the geomorphology which reflects the rate of erosion and the possible mineralised zone. Steep topography, controlled by the lithology may be used to suggest the mineralised zone, since the mineralisation in Sumatra and Java (within the mineralisation belt) is mostly associated with quartz veins which make the rock more resistant to erosion. This condition can be used to suggest either the extension of the mineralisation in the Gunung Limbung area or mineralisation in other areas which have similar geological environments.

The Gunung Limbung area is shown in Plate 1, whilst its topography can be seen in Fig. 8.

III.2 Lithology

Lithologically, the study area is composed of sedimentary, volcanic and intrusive rocks.

The oldest rock is an argillite (shale) which is found in the northern part of the area, and mostly outcrops along the Cimangeunteung river. The rock is part of the Bojongmanik Beds, which are widespread in the western part of the Bogor Zone. These beds are mainly composed of sandstone, pumice tuff, marl with molluscs, limestone, claystone with bituminous clay and lignite intercalations, and resin fragments. The thickness may be as much as 550 m (Effendi, 1974). The fossils found indicate a mid-Miocene age.

The argillite is very fine grained and has a dark grey colour, and shows a good lamination. Sometimes this rock

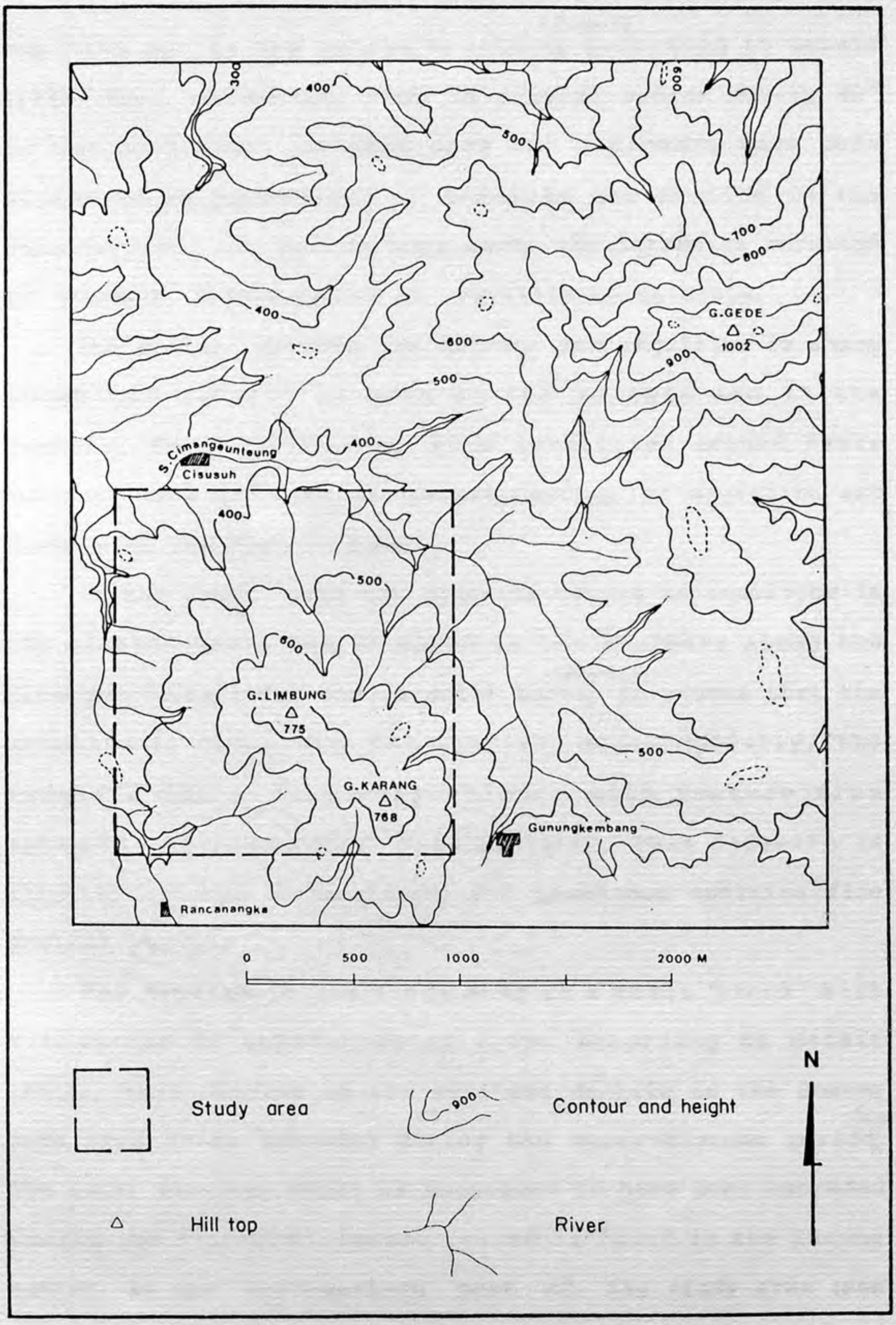


Fig. 8 Topographic map of Gunung Gede and Gunung Limbung area

contains pyrite and quartz veinlets (Plate 5). According to Gazali (1972) this sedimentary rock is dipping approximately 40° to the northwest. In this area the sediments have been disturbed by intrusions of andesite and diorite in the upper-Miocene period. In some parts the intrusion resulted in contact metamorphism of argillite to hornfels.

The contact between the diorite and argillite is sharp which can clearly be seen at the surface and in the tunnels. Some drill cores from localities around Pasir Patapaan show evidence of 'interfingering' of argillite and diorite at the contact zone.

In the study area the andesite occurs as xenoliths in the diorite whith can be found in the boulders along the Cimangeunteung river and in drill cores (Plate 6). It proves that the andesite is older than the diorite. Megascopically, the andesite has a dark grey colour, with texture from aphanitic to phaneritic (fine grained). This andesite is slightly altered (chloritised) and sometimes contains fine grained pyrite.

The diorite in the study area is a small 'stock' with a diameter of approximately 2 km. According to Gazali (1972), this diorite is the earliest diorite in the Gunung Gede area which intruded during the upper-Miocene period (Plate 2). The later diorite, which is suggested to have been intruded during the Plio-Pleistocene period is found in the Gunung Paniis in the northwestern part of the study area (see Fig. 2 for locality). This diorite is suggested to be the cause of the hydrothermal activity which resulted in the mineralisation in the Gunung Gede area (Gazali, 1972). In the Gunung Limbung area the earliest diorite acts as a host rock to the mineralisation. This diorite was studied in detail to determine what control it could have had in the mineralisation.

Megascopically, the diorite in the study area has a porphyritic texture with the size of the phenocrysts being up to 5 mm, in a fine to medium grained groundmass. The rock has a greenish-grey colour and is mainly composed of feldspar as groundmass and phenocrysts, with small amounts of quartz and amphibole. The rock is mostly altered (chloritised, epidotised), and often contains disseminated pyrite.

The geology of the study area is shown in Fig. 9.

III.3 Structures

As can be seen in Fig. 9, the structure of the area is dominated by faults which are marked by the occurrence of fault-breccia, 'slickensides', and the displacement of some rocks.

Based on occurrence, the fault system in the study area can be divided into two main stages:

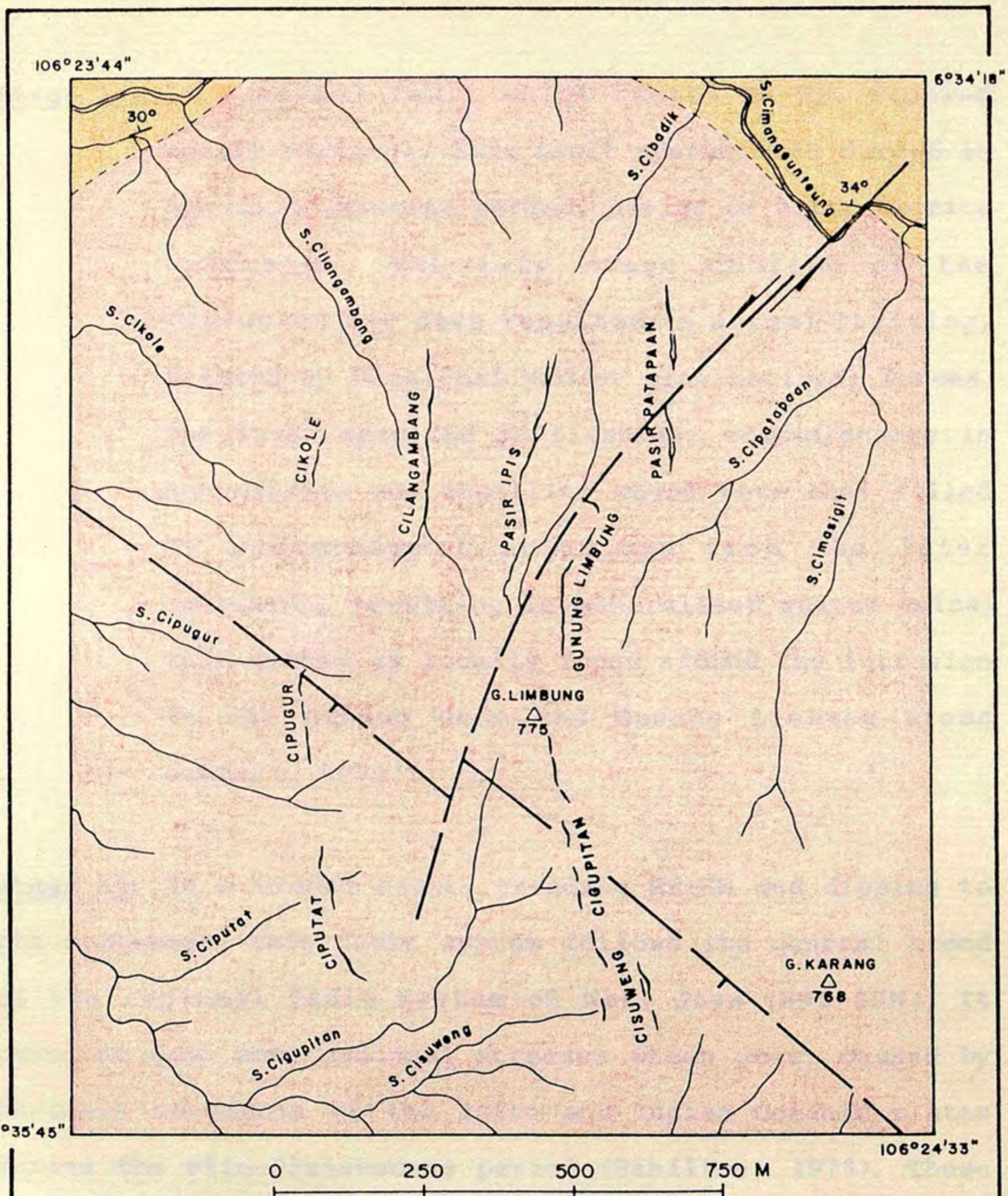


Fig. 9 Geologic map of the Gunung Limbung

Stage I : is a normal fault which trends NW-SE, dipping nearly vertical. This fault system was formed in the upper Miocene period, during or after diorite intrusion. The late stage cooling of the intrusion may have resulted in normal faulting, related to tensional and/or gravitational forces. The fault resulted in fissures, cracks/shears in the diorite and argillite which were then filled by hydrothermal solutions from the later intrusion, resulting in mineralised quartz veins. This system is locally found around the intrusion in the Gunung Gede and Gunung Limbung areas (Gazali, 1972).

Stage II: is a wrench fault, trending NE-SW and dipping to the southeast. This fault system follows the general trend of the regional fault system of West Java (NNE-SSW). It resulted from compressional stresses which were caused by tectonic movements of the Asian and Indian Oceanic plates during the Plio-Pleistocene period (Hamilton, 1979). These faults were suggested to have been formed in the Pleistocene period, after mineralisation. This suggestion is based on the fact that some of the earliest mineralised veins are brecciated. The breccia resulting from the faults of this stage were filled by un-mineralised hydrothermal solutions associated with another intrusion, forming 'barren' quartz veins.

III.4 Mineralisation

The mineralisation in the Gunung Limbung area occurs in quartz veins (breccia filling, fissure/cavity filling andfracture filling) in diorite and argillite; and disseminated in the immediate wall rocks. Some dissemination of sulphide material also occurs in the andesite xenoliths.

As mentioned earlier, two types of diorite intrusion occur in the Gunung Gede area. The earliest diorite intrusion occurs in the study area, which intruded during the upper-Miocene period. The later diorite intrusion is a quartz-diorite, which intruded during the Plio-Pleistocene period (Gazali, 1972). This quartz-diorite outcrops in Gunung Paniis and in some parts of the Gunung Gede area.

The effects of the earliest intrusion are found in the sedimentary rocks of mid-Miocene and upper-Miocene age including argillite, sandstone and limestone. The intrusion resulted in contact metamorphism of these rock units to hornfels, quartzite and marble. At the contact zones some typical contact minerals including actinolite, magnetite and hematite occur, but no mineralised veins are found either around the contact zones or within the sedimentary units. This indicates that the earliest diorite intrusion did not result in mineralisation in the area (Gazali, 1972).

However, the contact metamorphic effects of the Plio-Pleistocene intrusion (and associated mineralised veins) are found in the tuffaceous sandstone of Pliocene age as well as in the mid-Miocene and upper-Miocene rocks (Gazali, 1972).

Therefore, Gazali (1972) suggested that the mineralisation in the Gunung Gede and Gunung Limbung area was formed during the Plio-Pleistocene period, as a result of the hydrothermal solutions which were associated with the Plio-Pleistocene quartz-diorite intrusion.

In the study area, the hydrothermal solutions also resulted in a hydrothermal alteration within the host rock including chloritisation, epidotisation, sericitisation and sometimes kaolinisation (Plate 13)

From the surface (trenching) and sub-surface (tunnel) observation carried out by GSI and Aneka Tambang, at least 9 groups of veins were found in the Gunung Limbung area, with thickness varying from 0.7 to 3m ; and mostly containing pyrite, galena, sphalerite, bornite and some argentite (Suprayitno, 1972). The general trends of these veins are nearly N-S, dipping approximately 60°-70° to the east.

The position of the veins is shown in Fig. 8.

Only the Pasir Patapaan and Gunung Limbung veins have been intensively explored up to the evaluation stage, by deep drilling (up to a depth of -350 m from surface) and tunnelling. However, some 'information' drilling was also carried out on the other veins to obtain the vertical distribution of the mineralised veins.

From the observations in some tunnels, it can be concluded that the veins in the area (Pasir Patapaan and Gunung Limbung veins) can be divided into 4 types:

(1) Veins containing brecciated ore.

Originally the ore was probably a 'massive' which was formed during the earliest stage of the mineralisation as a result of fissure/cavity filling. The veins were then faulted and brecciated by the NE-SW fault. The ore is composed of galena (predominant), sphalerite, chalcopyrite and pyrite. The veins can be found in tunnel T.460.

(2) Veins containing breccia-filling ore

Brecciated host rock and ore filled by mineralised hydrothermal solutions formed a breccia-filling ore, containing sphalerite, chalcopyrite, galena and pyrite. The vein can be found in tunnel T.490. The ore may have been formed in the earliest stage of mineralisation, after the earliest NW-SE faulting.

(3) Veins containing brecciated ore and host rock

These differ from the veins of type (1) as the brecciated ore within the vein is filled by unmineralised quartz. The ore fragments are mostly of sphalerite which has a colloform texture, whilst the quartz shows a 'comb' structure. This vein probably formed as a result of the second stage of the hydrothermal activity (post NE-SW fault). The vein can be found in tunnel T.400.

(4) Quartz veins

  (a) Quartz veins containing stratified chalcopyrite, sphalerite, galena and pyrite. This vein can be found in tunnel T.400.
  (b) Quartz veins containing pyrite which are found anywhere within the ore zone and host rock.
  (c) 'Barren' milky quartz veins, which are also found anywhere in the ore zone and in the host rock.
  (d) Quartz veins containing chlorite, mostly occur as veinlets within highly chloritised host rock.

From the type of vein, it can be seen that at least three stages of mineralisation occurred in the area.

The first stage of mineralisation resulted from the earliest mineralised hydrothermal solution (related to the second diorite intrusion) which filled the cavities or fissures, and shears resulting from the NW-SE fault. This hydrothermal solution formed a massive ore which is mainly composed of galena (predominant), chalcopyrite, sphalerite and pyrite. This ore was then brecciated by NE-SW faults.

The second stage of the mineralisation resulted from the later mineralised hydrothermal solutions (from the same origin) which filled the brecciated wall rock and some first stage ore, forming a breccia-filling ore, which is composed of pyrite (predominant), chalcopyrite, galena and sphalerite.

The third stage of mineralisation resulted from mineralised hydrothermal solutions (also from the same origin) which filled the shears/cracks in the wall rock and 2nd stage ore, forming stratified chalcopyrite, pyrite, sphalerite, associated with quartz.

Sometimes, the sphalerite also occurs as a single (individual) vein, cutting the second stage ore. This vein was probably formed contemporaneously with the third stage ore, or later as the fourth stage of mineralisation.

During the field work, samples of host rock, quartz, clay, and ore were collected from the tunnels, outcrop and drill cores. The locality of the samples is shown in Fig. 10 and Fig. 11 whilst the types of sample and the method of analysis applied can be seen in Table 2.

For the purpose of analysis, some of the samples were prepared in the Directorate of Mineral Resources, Bandung, and some were prepared in London.

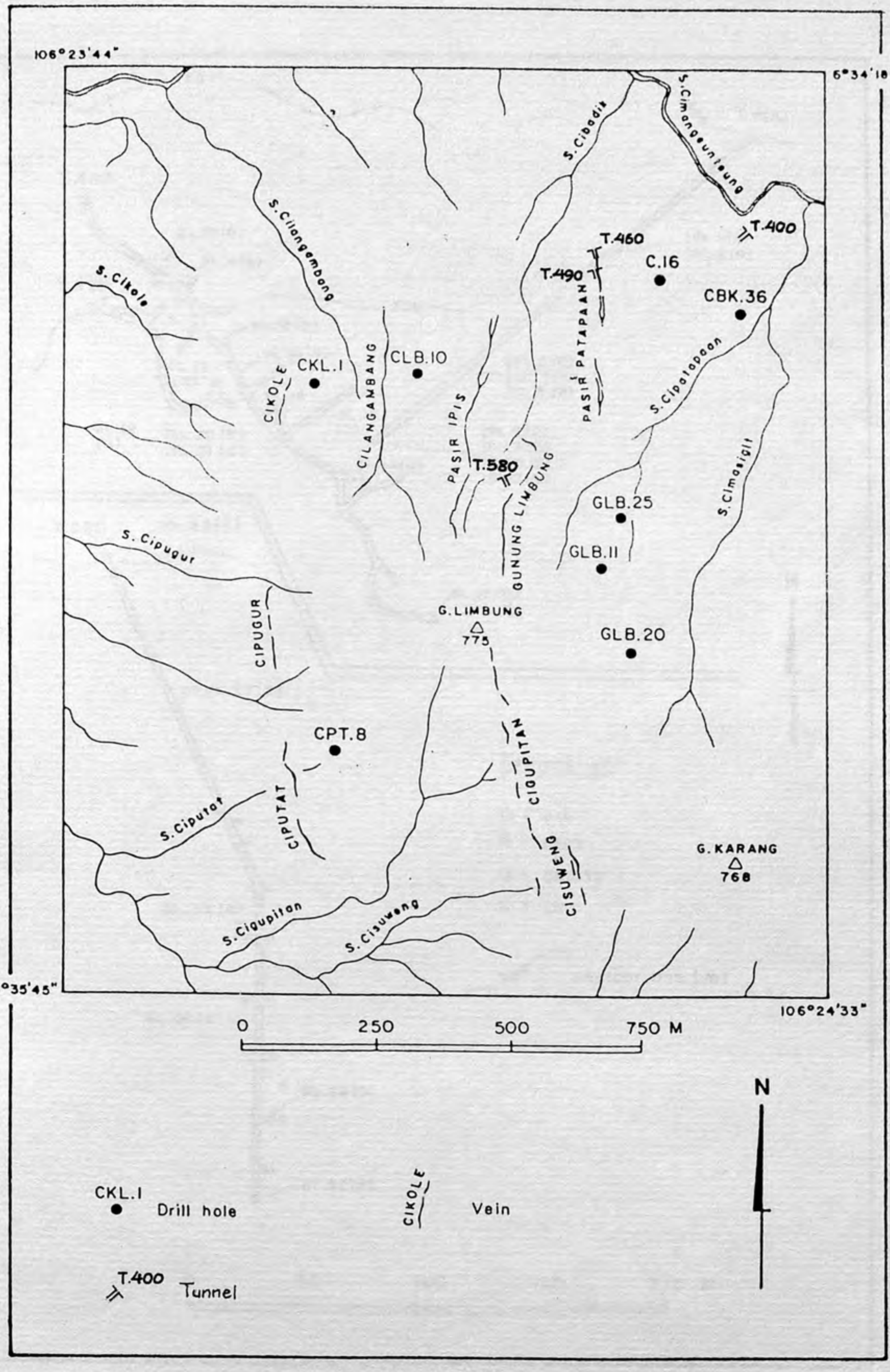


Fig. 10 Locality map for drill core samples

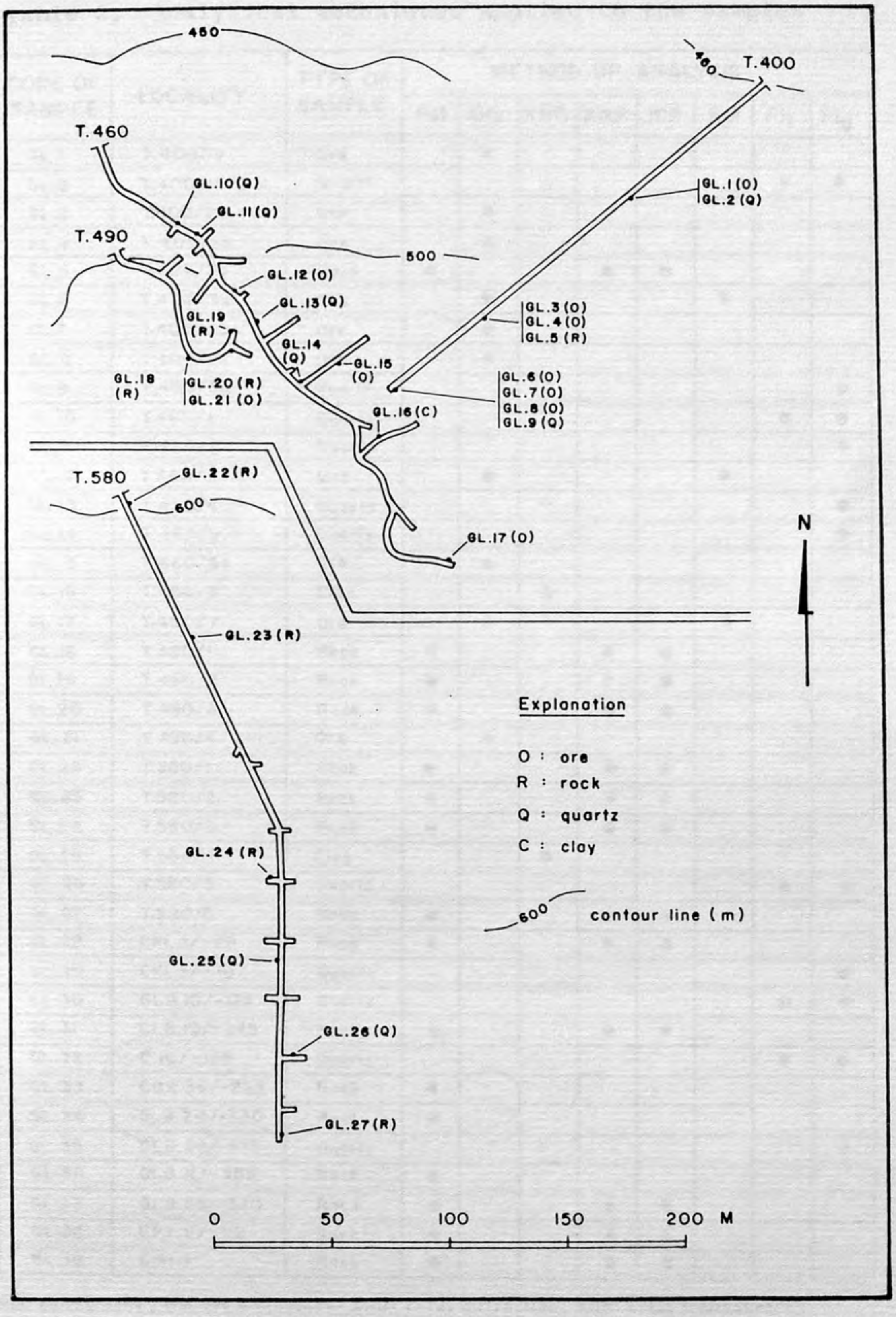


Fig. 11 Locality map for tunnel samples

Table 2. Analytical techniques applied to the samples

CODE OF SAMPLE	LOCALITY	TYPE OF SAMPLE	METHOD OF ANALYSIS							
			Pet	OM	XRD	XRF	ICP	EM	FI_t	FI_g
GL.1	T.400/1a	Ore		●						
GL.2	T.400/1b	Quartz							●	●
GL.3	T.400/2a	Ore		●						
GL.4	T.400/2b	Ore		●						
GL.5	T.400/2c	Rock	●			●	●			
GL.6	T.400/3a	Ore		●				●		
GL.7	T.400/3b	Ore		●						
GL.8	T.400/3c	Ore		●						
GL.9	T.400/3d	Quartz								●
GL.10	T.460/1	Quartz							●	●
GL.11	T.460/2	Quartz								●
GL.12	T.460/3	Ore		●				●		
GL.13	T.460/4	Quartz								●
GL.14	T.460/5	Quartz								●
GL.15	T.460/5a	Ore		●						
GL.16	T.460/6	Clay			●					
GL.17	T.460/7	Ore		●				●		
GL.18	T.490/1	Rock	●			●	●			
GL.19	T.490/2	Rock	●			●	●			
GL.20	T.490/3	Rock	●			●	●			
GL.21	T.490/4	Ore		●						
GL.22	T.580/1	Rock	●			●	●			
GL.23	T.580/2	Rock	●			●	●			
GL.24	T.580/3	Rock	●			●	●			
GL.25	T.580/4	Clay			●					
GL.26	T.580/5	Quartz							●	●
GL.27	T.580/6	Rock	●			●	●			
GL.28	CKL.1/-76	Rock	●			●	●			
GL.29	CKL.1/-107	Quartz								●
GL.30	CLB.10/-123	Quartz							●	●
GL.31	CLB.10/-245	Rock	●			●	●			
GL.32	C.16/-128	Quartz							●	●
GL.33	CBK.36/-225	Rock	●							
GL.34	GLB.20/-330	Rock	●							
GL.35	GLB.20/-375	Quartz								●
GL.36	GLB.11/-385	Rock	●							
GL.37	GLB.25/-370	Rock	●			●	●			
GL.38	CPT.8/-112	Rock	●			●	●			
GL.39	Cmt.1	Rock	●			●	●			

Pet: petrography ; OM: ore microscopy ; XRD: x-ray diffraction ; XRF: x-ray fluorescence ; ICP: inductively coupled plasma ; EM: electron probe micro analysis ; FI_t: fluid inclusion study (thermometry); FI_g: fluid inclusion study (geochemistry)

CHAPTER IV MINERALOGY

The methods used for the mineralogical studies included thin section petrography, X-Ray diffraction, ore microscopy and electron probe microanalysis.

The petrography was carried out using a transmitted light microscope and point counter, on thin sections of rock samples which were taken from tunnels, drill cores and outcrop. The thin section study revealed the minerals present, the texture, and the relative proportion of the minerals in the rock. Petrographic study was carried out mainly on the host rock in order to specify its nature more definitely and to estimate the type and the degree of the alteration.

X-Ray diffraction is particularly helpful in the study of fine-grained minerals. The X-Ray diffraction study was carried out on clay samples taken from the tunnels to define characteristics and to see how they fitted into the overall alteration pattern.

The ore microscopy was carried out on ore samples taken from tunnels, using a reflected light microscope. A study of the stucture and texture of the minerals present is very important since these features are a record of a condition under which the ore was formed, the process by which the ore was deposited, and the order in which minerals developed.

The electron probe microanalysis is essential for studying fine grained specimens where separation and subsequent analysis of very small grains of desired material, or identification under reflected light microscope is, either very difficult or impossible.

IV. I Host rock

The study of the host rock was carried out on the 12 hand specimens of the rocks megascopically, and their thin section microscopically. The study included noting their colour, texture, composition and relative proportion of the minerals within the rocks. This description includes the andesite xenolith to show the characteristic differences between the andesite and the dioritic rock.

From the the hand specimen examination, it was found that the host rock varied in colour from light-whitish grey to greenish grey. It has a porphyritic texture (with phenocrysts up to 5 mm long), and grain size from fine to medium. The minerals present are plagioclase (predominant) which occurs as phenocrysts and groundmass, quartz (some occurs as veinlets), amphiboles, and ore minerals (sulphides).

Microscopically, the host rock show seriatic to porphyritic textures, with shapes of crystal from anhedral to euhedral (hypidiomorphic) and grain size from fine to medium (Plate 3). The rocks are mostly composed of:

Plagioclase: occurs in the groundmass and phenocrysts, mosty ranging from oligoclase to andesine, with some albite which is mostly altered to chlorite.

Orthoclase: occurs as phenocrysts and in the groundmass. However, the occurrence of orthoclase in the groundmass was very difficult to identify. The presence of orthoclase was partly determined from the occurrence of sericite as an alteration product.

Quartz: mostly occurs as a secondary mineral (alteration product) in individual crystals which occur interstitial with other minerals in the groundmass, and as veinlets.

Hornblende: occurs as phenocrysts up to 1.5 mm long, mostly altered to epidote. (Plate 9)

Pyroxene: occurs as phenocrysts.

The relative proportion of the minerals within the rocks is shown in Table. 3.

Table 3. Composition and relative proportion of the host rock (point counter data)

CODE OF SAMPLE	MINERAL IDENTIFIED (%)							
	Plag+Orth	Q	Hbl	Prx	Chl	Epi	Ser	Opq
GL. 5	72	5	2	2	3	5	3	5
GL.19	73	4	3	1	4	5	4	4
GL.20	78	6	-	-	3	5	3	4
(*)GL.22	79	5	6	1	5	1	-	2
GL.23	75	6	3	-	3	5	2	5
GL.24	74	8	1	-	2	3	4	10
GL.27	76	7	2	-	2	3	4	7
GL.28	75	6	3	1	2	3	3	4
GL.34	76	5	2	2	3	3	4	4
GL.36	80	2	2	1	2	4	2	5
(*)GL.37	78	4	4	2	6	2	-	2
(*)GL.38	80	5	5	1	5	1	-	3
Mean proportion of the host rock (*)	70.0	4.7	5.0	1.3	5.3	1.3	-	2.3

Plag: plagioclase, Orth: orthoclase, Q: quartz,
Hbl: hornblende; Prx: pyroxene, Chl: chlorite, Epi: epidote,
Ser: sericite; Opq: opaque.

Since the proportion of orthoclase in the groundmass was difficult to estimate (because of the grainsize), the relative proportion of plagioclase and orthoclase was combined as a single figure (Plagioclase plus Orthoclase). However, a rough estimate of the unaltered roks is at least plagioclase : orthoclase = 65 : 35. The mean proportion of minerals within the host rock was calculated from the mineral proportions of the three freshest rocks (GL. 22, GL. 37 and GL. 38).

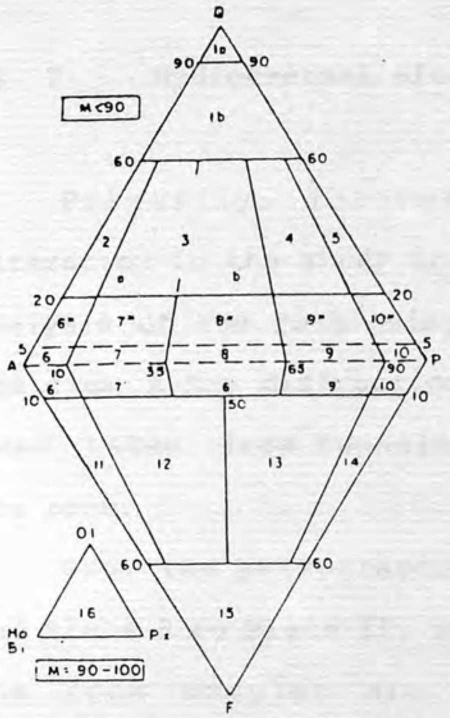


Fig. 12
General classification and nomenclature of plutonic rocks according to mineral content
(After Streckeisen, 1976)

Q + A + P = 100, or A + P + F = 100.
1a, quartzolite (silexite); 1b, quartz-rich granitoids, 2, alkali-feldspar granite; 3, granite; 4, granodiorite; 5, tonalite, 6*, quartz alkali-feldspar syenite; 7*, quartz syenite; 8*, quartz monzonite; 9*, quartz monzodiorite/quartz monzogabbro; 10*, quartz diorite/quartz gabbro/quartz anorthosite; 6, alkali-feldspar syenite; 7, syenite; 8, monzonite; 9, monzodiorite/monzogabbro; 10, diorite/gabbro/anorthosite; 6', foid-bearing alkali-feldspar syenite; 7', foid-bearing syenite; 8', foid-bearing monzonite; 9', foid-bearing monzodiorite/monzogabbro; 10', foid-bearing diorite/gabbro; 11, foid syenite; 12, foid monzosyenite (syn. foid plagisyenite); 13, foid monzodiorite/foid monzogabbro (essexite = nepheline monzodiorite/monzogabbro); 14, foid diorite/foid gabbro (theralite = nepheline gabbro, teschenite = analcime gabbro). 15, foidolites; 16, ultramafic plutonic rocks (ultramafitolites).

Based on the nature of the rocks, the minerals occurring and their proportion; and following the Steckeisen (1976) classification of plutonic rocks (see Fig. 12), the host rock can be classified as between hornblende diorite and hornblende monzo-diorite.

Geochemical analysis of the host rock substantiates this classification (see CHAPTER V).

IV. 2 Hydrothermal alteration

Primarily, information about the hydrothermal alteration in the study area was obtained from petrographic analysis of the rock using a transmitted light microscope and from X-Ray diffraction analysis on clay samples which were taken from tunnels T. 580 and T.480 adjacent to the ore zone.

From the petrographic analysis, as shown in Table 3 and Plate 8 to Plate 11, it can be seen that almost all of the rock samples are hydrothermally altered. The alterations found within the host rock include propylitisation (chloritisation and epidotisation), sericite-silicic-potassic alteration, and advanced argillic alteration (kaolinisation). The strongest alteration (silicic-potassic) occurred in the host rock closest to the ore zone.

As mentioned earlier, tunnel T. 580 displays the best conditions for investigating the host rock, since the tunnel is relatively straight and long (see Fig.11 and Plate 12). The tunnel is about 290 m long, oriented approximately 160°. At about 160 m from the entrance, the tunnel cuts the Gunung Limbung vein. From that point, the tunnel turns to the south. Although the tunnel does not cut the vein perpendicularly, visually the host rock from the beginning (sample GL. 22) to the ore zone (samples GL. 24 and GL. 27) shows a zonal gradation in alteration. Around the beginning of the tunnel the host rock is weakly altered,and toward the ore zone the alteration become stronger. As can be seen in Table 3, the alteration products of the host rock around the entrance are dominated by chlorite and some epidote. Further into the tunnel (at sample locality GL. 23) the proportion of the epidote as well as quartz increases, whilst the proportion of chlorite decreases. Towards the ore zone the proportion of quartz, sericite and K-feldspar increases at the expence of the plagioclase phenocrysts. In addition, the proportion of chlorite at the ore zone is at its lowest level. In other words, the alteration of the host rock from the entrance of the tunnel to the ore zone shows a change from mainly propylitic (chloritisation and epidotisation) to a sericitic-silicic-potassic assemblage. The proportion of pyrite also increases from the entrance of the tunnel toward the ore zone. The changes of the alteration of the host rock can clearly be seen in Plates 8, 9 and 10.

Clay minerals are also found as an alteration product in the ore zone in tunnels T.580 and T.480. Using X-Ray diffraction, the clay minerals from these two tunnels were analysed to obtain the mineralogical composition of the clays. The principle of the X-Ray diffraction method and the details of the sample preparation can be seen in Appendix A.

The X-Ray diffraction traces of these two clay samples (GL. 16 and GL. 25) are shown in Fig. 13 and Fig. 14, whilst the peak identifications and minerals responsible can be seen in Table 4. The angle (2θ) and intensity were calculated from X-Ray diffraction traces, whilst the spacing (d) and the peak identification were obtained from tables in Borg and Smith (1969), and Fang and Bloss (1966).

Table 4. Results of the clay sample analysis (based on the X-Ray diffraction pattern)

A - Code of sample: GL.16

2θ	d	I	Possible Mineral
12.29	7.20	3	Kaolinite
20.80	4.27	2	Quartz
24.85	3.58	5	Kaolinite
26.60	3.35	1	Quartz
29.10	3.07	9	Kaolinite
36.55	2.46	6	Quartz
39.58	2.29	7	Quartz
40.40	2.23	11	Quartz
42.29	2.13	4	Quartz
45.80	1.98	12	Quartz
50.20	1.82	8	Quartz
55.00	1.67	10	Quartz

Explanation:

2θ : angle

d : spacing

I : peak identification

B - Code of sample: GL.25

2θ	d	I	Possible Mineral
6.30	14.03	9	Kaolinite
12.66	7.00	4	Kaolinite
20.25	4.39	8	Nacrite
21.12	4.21	3	Kaolinite
22.80	3.90	12	Kaolinite
23.80	3.74	5	Quartz
25.28	3.52	6	Kaolinite
26.90	3.31	1	Quartz
27.85	3.20	2	Quartz
30.08	2.97	7	Kaolinite
31.10	2.88	10	Quartz
32.69	2.74	18	Kaolinite
33.30	2.69	13	Dickite
35.03	2.56	11	Kaolinite
36.85	2.44	15	Quartz
38.80	2.32	20	Kaolinite
39.78	2.27	19	Quartz
40.60	2.22	21	Quartz
42.09	2.15	17	Quartz
42.78	2.11	14	Quartz
46.10	1.96	16	Quartz

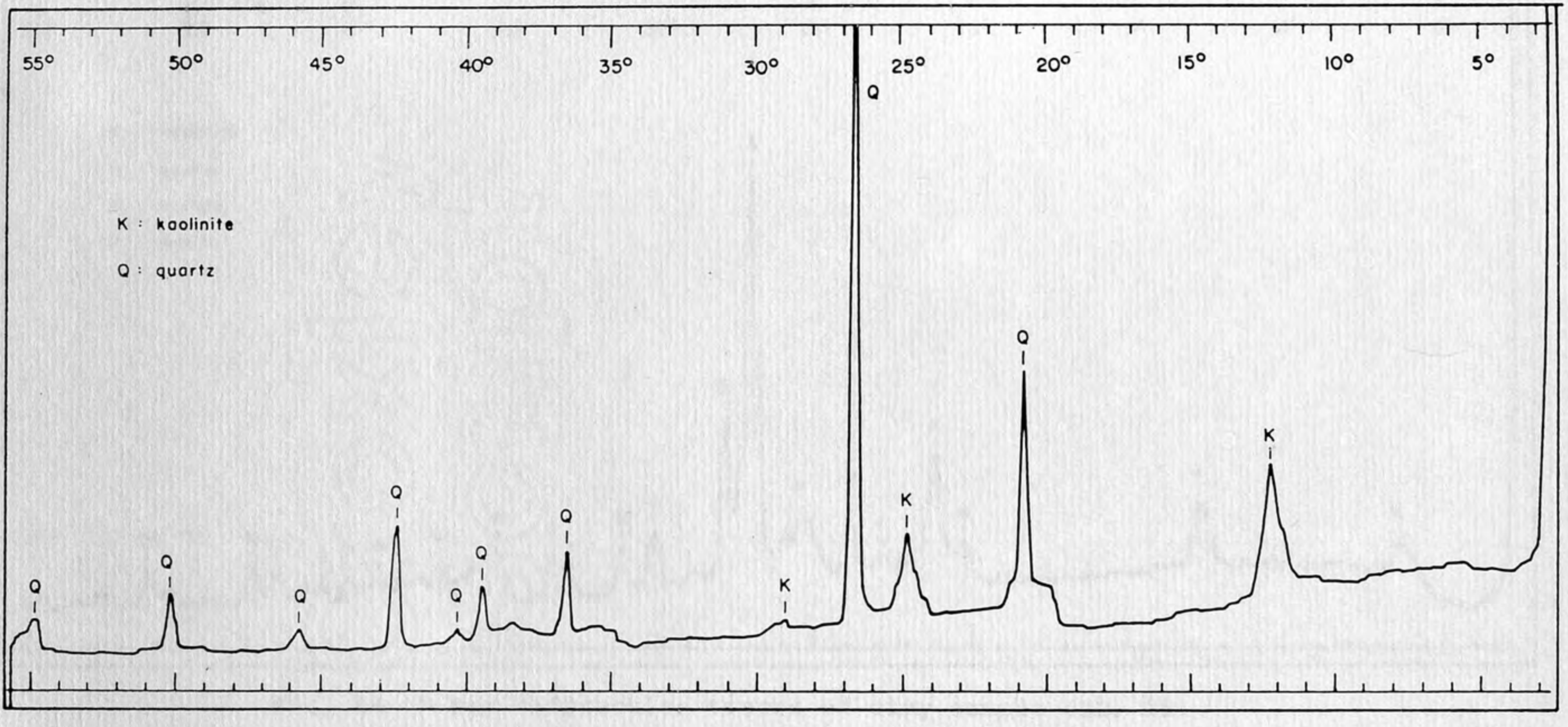


Fig. 13 X-Ray diffraction traces of clay sample (GL. 16)

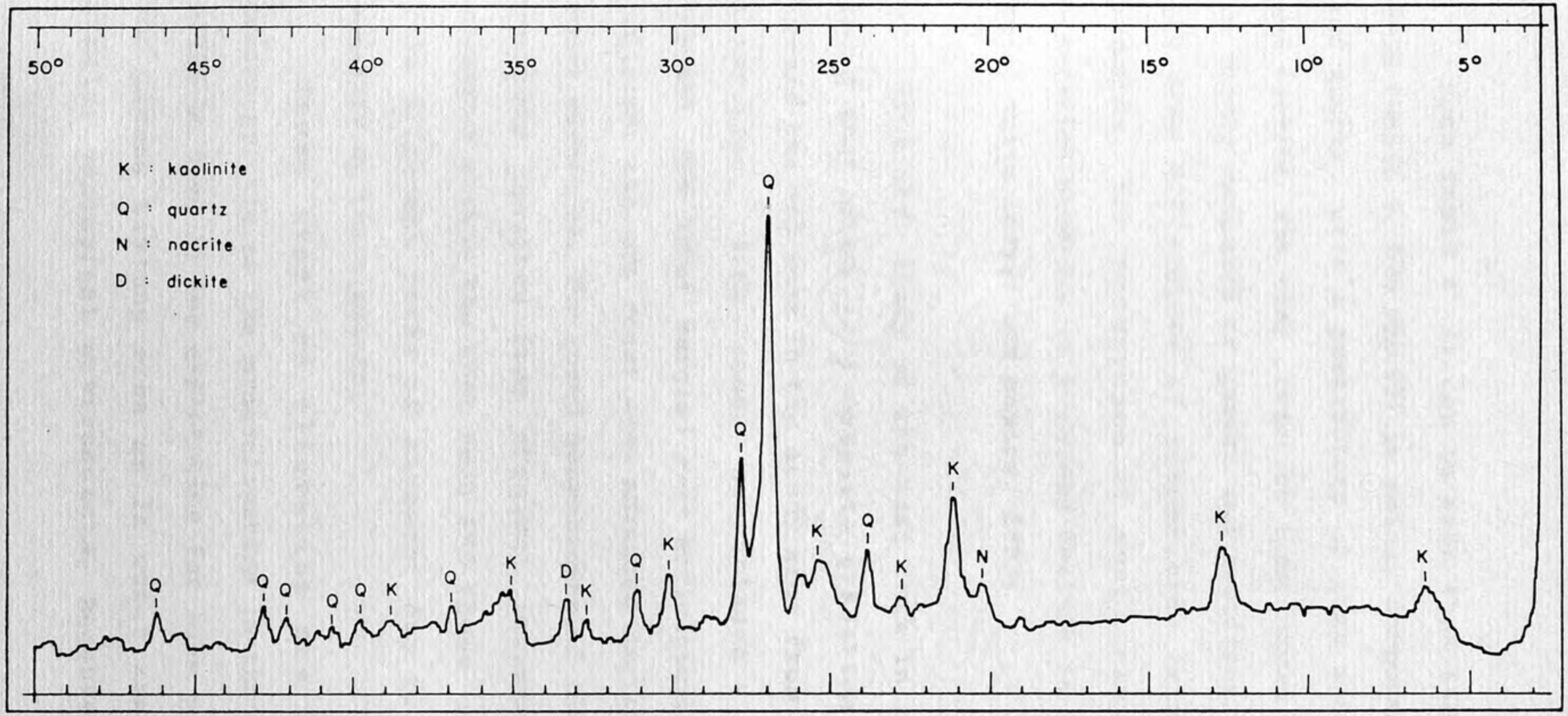


Fig. 14 X-Ray diffraction traces of clay sample (GL. 25)

From Table 4 it can be seen that the clay fraction from tunnel T. 580 (GL.25) is mainly composed of kaolinite and quartz, with a possibility of some additional dickite and nacrite. The clay fraction from tunnel T. 460 (GL. 16) is mainly composed of quartz and kaolinite. Although there are some differences of composition between these two samples, the occurrence of such clay minerals as alteration products is a common feature in and around base metal veins (Meyer and Hemley, 1967).

From the study of the host rock in tunnel T.580 it found that there is a complete gradation in alteration toward the ore zone in the study area from weak to strong alteration, with zoned assemblages - e.g propylitic (around the outer margin) ---- sericitic-silicic-potassic (adjacent the ore zone) ---- advanced argillic (at the ore zone) envelopes. The zoned assemblages of altered host rock probably resulted from chemical interactions between elements within the host rock and those in the solution, with different rates of movement due to the different mobility of the elements.

These types of alteration are an important characteristic of the mineralisation in the study area, and could be used in the exploration for base metals either in the Gunung Limbung area or in other areas which have similar geological environments. Because the width of visible alteration in tunnel T. 580 is 100 m, the wall rock alteration assemblages provide a distinctive, large target that could be useful during drilling and mapping (both surface and underground).

IV. 3 Mineralisation

To obtain the information about the mineralisation in the study area in more detail, 10 samples were studied megascopically and microscopically. The locality of the samples can be found in Table 2 and Fig. 11.

The megascopic study on the ore provided the information about the stages of formation and, to some extent the conditions under which the ore was formed.

An additional study on some ore samples by electron probe microanalysis was also carried out to obtain data on the occurrence, composition and relative proportion of some fine-grained minerals which were very difficult to determine under the optical microscope. This included the possible occurrence of silver within galena and relative concentrations of iron in sphalerite. This data is important considering that Au and Ag will be a bi-product of the proposed mine. The basic principle of electron probe microanalyses is shown in Appendix B.

From the study of the samples megascopically and microscopically, and from the appearance in the field, the ore in the study area can be classified into three general groups: (a) 'brecciated ores' (Plate 14), (b) 'breccia filling ores' (Plate 20), and (c) 'stratified/banded ores' (Plates 15 and 22). These groups of ores were formed in different stages and under different conditions.

(a) Brecciated ore

These ores were formed as a result of fissure-fillings which were then deformed and brecciated due to compressional and tensional stresses related closely to the tectonic movements of West Java. Later hydrothermal solutions filled the deformed ore with gangue and resulted in two types of brecciated ore in the area, which structuraly and compositionally show different characteristics.

The first type of brecciated ore has a coarse grain size (up to 1 cm in diameter), is more massive and contains less gangue (quartz). It is assumed that this ore was formed by compressional stresses, and the ore is marked by a lack of spaces, making the passage of later hydrothermal solution difficult and resulting in a lower proportion of quartz within the ore (Plate 16). The ore is dominated by galena, some chalcopyrite, and small amount of sphalerite. This type of ore was particularly abundant in tunnel T. 460 (GL. 15).

The second type of brecciated ore (samples GL.4, GL.7, GL.12 and GL.17) shows similar textural and compositional characteristics to each other. The ore minerals occur as aggregates and as fragments associated with quartz (Plate 24). Some cavities within the breccia were filled by later hydrothermal solutions often producing quartz with a 'comb' structure. The ore minerals of this type were mostly dominated by sphalerite, chalcopyrite and galena (Plate 18). They differ from the first ore in that the proportion of pyrite in this ore is more abundant.

Polished section study showed that both types of the brecciated ores have a similar mineral texture :

Galena occurs as aggregates of sub-anhedral grains, containing pyrite and chalcopyrite. The galena is mostly intergrown with sphalerite, but sometimes is also found as individual grains. A deformed structure were found in the galena, which can clearly be seen in Plate 17.

Sphalerite occurs mostly as intergrowths within galena, often containing fine oriented lamellae and small blebs of chalcopyrite (Plates 19 and 21).

Chalcopyrite occurs as fine inclusions in sphalerite and as coarser grains enclosed in galena. Sometimes chalcopyrite is also found as individual grains scattered in quartz. Some of the chalcopyrite grains were replaced by chalcocite and covellite, forming a rim structure (Plate 25).

forming a colloform texture (Plate 20). The space between the mineralised fragments is occupied by quartz which often forms a 'comb' structure.

Ore of this group is found in tunnels T.400 (GL. 8) and T.490 (GL.21). However, these two ores exhibit a different mineral composition, which probably resulted from two different stages of formation. Ore of GL.8 is dominated by sphalerite, whilst ore of GL. 21 is dominated by pyrite.

From the microscopic study it was found that these two samples also have similar characteristics, and have relatively simple mineral paragenesis compared with the brecciated ore.

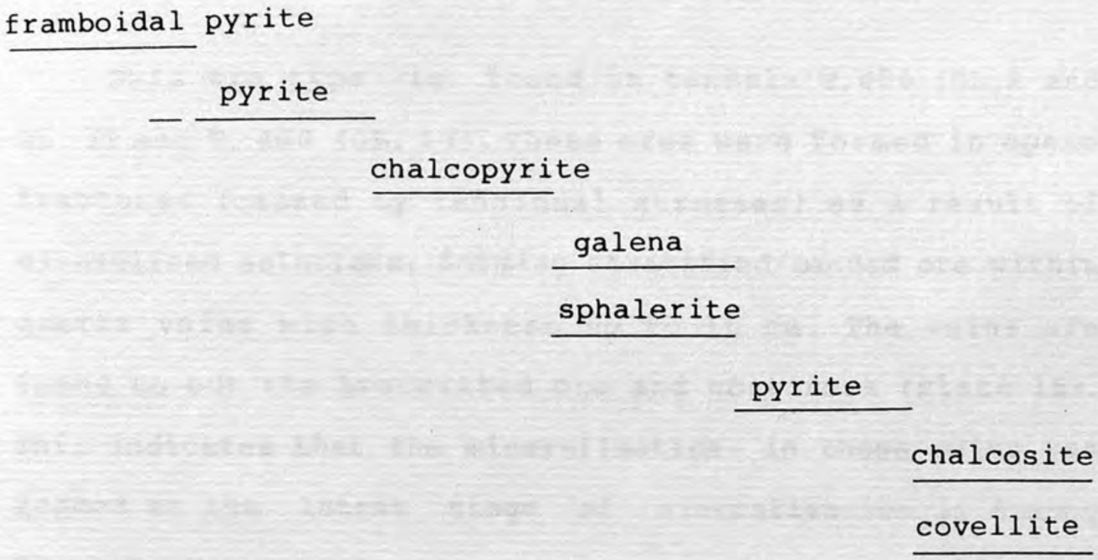
Sphalerite contains tiny lamellae and small blebs of chalcopyrite, and small grains of galena as inclusions.

Chalcopyrite and galena are found as minor constituents in this ore. Chalcopyrite mostly occurs as inclusions in sphalerite; whilst galena occurs enclosed within sphalerite, but is sometimes found intercalated with pyrite.

Pyrite occurs mostly as an aggregate, and as individual grains scattered in the quartz or as inclusions in sphalerite.

Pyrite occurs as individual cubic crystals, and as small framboidal aggregates surrounded by chalcopyrite. Sometimes, the framboidal pyrite is also found surrounded by cubic pyrite (Plate 26). However, some of the cubic pyrite is also found surrounding chalcopyrite (Plate 27). The occurrence of two types of pyrite in the brecciated ore indicates more than one generation of pyrite. Framboidal pyrite in generally formed earlier than cubic pyrite in mineralised veins (Craig and Vaughan, 1981).

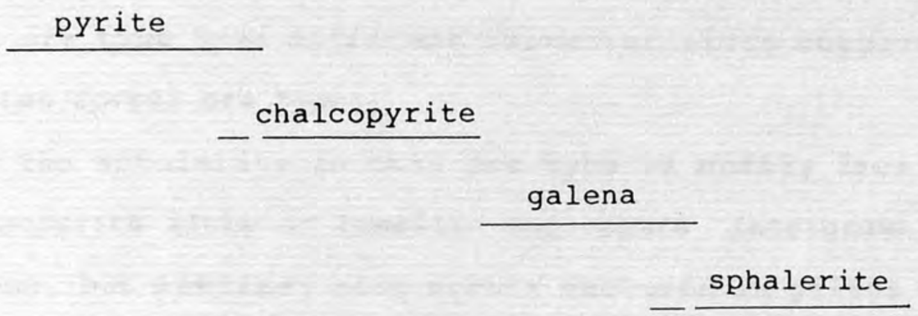
Possible mineral paragenesis:


framboidal pyrite
pyrite
chalcopyrite
galena
sphalerite
pyrite
chalcosite
covellite

(b) Breccia-filling ore

In earlier faulted and brecciated wall rocks (sometimes mineralised) the fractures were later filled by mineralising solutions. The ore minerals are mostly concentrated on the surfaces of the brecciated fragments

Possible mineral paragenesis:



(c) Stratified / banded ore

This ore type is found in tunnels T.400 (GL.1 and GL. 3) and T. 460 (GL. 17). These ores were formed in opened fractures (caused by tensional stresses) as a result of mineralised solutions, forming stratified/banded ore within quartz veins with thickness up to 10 cm. The veins are found to cut the brecciated ore and host rock (Plate 15). This indicates that the mineralisation in these veins was formed at the latest stage of mineralisation in Gunung Limbung.

Two types of ore were found in the study area. The first type is a stratified ore associated with quartz and mainly composed of sphalerite, chalcopyrite and pyrite (GL. 1 and GL. 17). The second type is a single banded sphalerite associated with some quartz, with thickness approximately 1.5 cm.

Polished section study showed that the minerals within this ore type have different characteristics compared to the two former ore types.

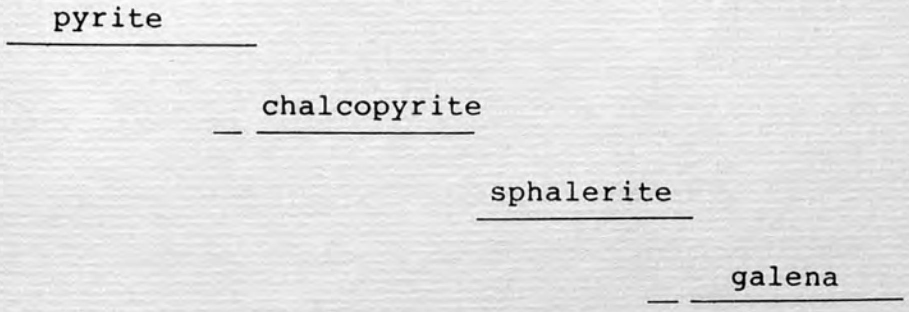
The sphalerite in this ore type is mostly free from chalcopyrite blebs or lamellae and occurs intergrown with galena, but somtimes also occurs enclosed in galena or as individual grains scattered in quartz.

Chalcopyrite occurs as lamellae (Plate 23), sometimes intergrown with pyrite. Some fine-grained chalcopyrite is also found on sphalerite grains.

Galena occurs intergrown with sphalerite, sometimes containing pyrite inclusions.

Pyrite occurs as aggregates up to 2 mm in size, enclosed in chalcopyrite and as individual grains scattered in quartz. Some fine-grained pyrite is also found enclosed in sphalerite and galena.

Possible mineral paregenesis:



Electron probe micro analysis was carried out on three ore samples and in particular on the sulphides to obtain data on concentrations of minor elements.

Due to technical problems, only a qualitative study could be carried out in this work. The study was carried using an energy dispersive X-Ray detector.

From this study it was found that there is a marked iron concentration in the sphalerite. This is not surprising but no other trace constituents were detected.

It was also found that the galena in the ore contains silver, at a concentration around several hundred ppm. This knowledge will be important when it comes to extracting the precious metals from the ores.

Rather surprisingly, iridium was also detected in the galena. At present there is no explanation for the presence of this rare element.

No other trace constituents were detected in any of the sulphides, so the location of the trace gold content remains a mystery.

IV. 4 Conclusions

From the petrographic analysis it was found that the hostrock at Gunung Limbung can be classified between hornblende diorite and hornblende monzodiorite. This naming is based on the composition and relative proportion of the essential minerals (plagioclase, orthoclase and quartz) and accesory mineral (amphibole) within the host rock (further study using geochemical methods, confirms the name of the host rock more precisely).

The hydrothermal activity which formed the veins (mineralised and unmineralised) resulted in alteration of the host rock around the veins. From the study of the host rock from tunnel T. 580, it was found that the alteration visually shows a zonal gradation toward the ore zone. From the microscopic analysis of the host rock and X-Ray diffraction analysis of clay samples, it was found that the alteration within the host rock shows changes toward the ore zone with a sequence : chloritisation, epidotisation, sericitisation, silification, potassic alteration and kaolinisation. This type of alteration can be simplified as (toward the ore zone) propylitic ---- sericitic-silicic-potassic ---- advanced argillic envelopes.

From the study of ore samples megascopically, it was found that three types of vein occur in the study area : brecciated ore, breccia-filling ore and stratified/banded ore, and these are generated at different stages. The brecciated ore represents the earliest ore, the breccia-filling ore is a later generation, and the stratified/banded ore is the latest generation.

From the position of the altered rock and the appearance in the field it can be concluded that the alteration of the host rock is related to the earlier 'brecciated ore' and 'breccia-filling ore' formation.

Ore microscopy shows that the sphalerite contains tiny lamellae and small blebs of chalcopyrite inclusions. This is one of the indications of a high iron content and high temperature sphalerite (Oelsner, 1966). The iron content of the sphalerite is also seen from the electron probe microanalysis. This study also showed that the galena contains silver and iridium.

The fact that the minerals within the ore mostly have a similar paragenesis indicates that the same mineralising event occurred over a large area.

From these features it can be concluded that several episodes of hydrothermal activity resulted in the different ore types. These stages of ore formation were related closely to the tectonic movements and pluto-volcanism in the area. The history can be summarised as follows :

Intrusion I : ------------- Gunung Limbung
Host rock
--- Faulting
Fissuring

Intrusion II: Gunung Paniis Hydrothermal activities
Fissure filling
--- Mineralisation I
(massive ore)

Faulting (compr. stresses)
Brecciation
--- Mineralisation II
(brecciated ore)

Faulting (tens. stresses)
Fracturing, cracking
--- Mineralisation III
(breccia-filling ore)

Faulting (tens. stresses)
Cracking
--- Mineralisation IV
(strat./banded ore)

CHAPTER V GEOCHEMISTRY

Geochemical analyses were performed to obtain data on the concentration of elements in the host rock and its altered equivalent. This work was carried out mainly to assess the nature of the alteration assemblages and the mobility of the elements during hydrothermal activity. In addition it provided data on the geochemical characteristics of the unaltered igneous host rock.

The geochemical study was carried out on 13 samples of igneous rock ranging from fresh to highly altered. Some samples were obtained from underground traverses (tunnel T. 580) from fresh to progressively more altered rock.

To obtain concentrations of major and minor elements, samples were analysed by X-Ray fluorescence. For the trace elements, Inductively Coupled Plasma emission spectrometry (ICP) was applied. The principles of the X-Ray fluorescence and ICP methods, and the sample preparation methods can be found in Appendices D and E.

V.I Host rock

X-Ray fluorescence analysis provides concentrations of oxides of some major elements, including SiO_2, Al_2O_3, total Fe as Fe_2O_3, MgO, CaO, Na_2O and K_2O, and the minor elements TiO_2, MnO and P_2O_5. These elements can often be used as an aid to rock classification.

The results of chemical analysis of major and minor elements of the fresh host rock and alteration assemblages are shown in Table 5.

Table 5. Concentration of major and minor element oxides of the rocks

CODE OF SAMPLE	O X I D E S (%)									
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Total
GL. 5	67.36	16.36	9.13	4.17	1.08	0.59	5.20	0.95	0.56	0.23	99.46
GL.18	63.35	16.81	5.57	1.70	1.58	0.72	8.67	0.52	0.37	0.19	99.47
GL.19	68.22	18.14	2.13	0.30	1.05	0.22	8.57	0.53	0.12	0.18	99.46
GL.20	66.86	12.47	11.44	1.62	0.22	0.33	5.73	0.37	0.61	0.13	99.74
(*)GL.22	64.04	16.46	5.18	1.78	4.10	3.53	3.38	0.53	0.31	0.19	99.98
GL.23	64.20	16.52	5.39	1.77	2.29	1.30	6.15	0.51	0.59	0.18	99.06
GL.24	64.42	16.21	6.57	1.44	0.32	0.39	9.37	0.45	0.32	0.12	99.94
GL.27	65.31	14.88	6.48	1.63	0.53	0.97	7.03	0.44	0.43	0.13	98.82
GL.28	65.18	16.51	5.13	1.80	2.26	4.44	4.51	0.51	0.30	0.19	100.39
GL.31	71.75	13.25	8.05	1.91	0.18	0.16	3.60	0.55	0.31	0.07	99.68
GL.34	62.10	16.65	6.20	2.35	3.75	3.43	4.71	0.64	0.37	0.18	100.39
(*)GL.37	62.70	16.77	5.29	2.07	4.25	3.17	4.44	0.55	0.31	0.18	99.68
(*)GL.38	64.15	16.70	5.11	1.97	4.53	3.48	3.39	0.54	0.25	0.18	100.08
Mean value of unaltered host rock (*)	63.63	16.64	5.19	1.94	4.29	3.39	3.37	0.54	0.32	0.18	99.91

The rock samples GL. 22, GL. 37 and GL. 38 are the freshest and exhibit only weak amounts of alteration (see Plates 3 and 8). From Table 5 it can be seen that the concentration of these three samples is relatively similar. Therefore, the concentrations of major elements within these samples may be used as an aid in classification of the Gunung Limbung host rock.

The chemistry of the Gunung Limbung host rock was compared with that for some intermediate rocks (including andesite and diorite) to see if the analyses could confirm the petrographic study.

The mean concentration of major oxides within the intermediate rocks was obtained from the literature and was based on the study of rocks collected from various parts of the world, and from a locality of vein type mineralisation (i.e. Butte, Montana). This data is compared with the Gunung Limbung host rock in Table 6.

Table 6. Concentration of major and minor elements oxides in some intermediate rocks

ORIGIN OXIDES	(1)	(2)	(3)	(4)	(5)
SiO_2	58.60	54.20	65.49	51.86	63.63
Al_2O_3	15.38	17.20	14.49	16.40	16.64
Fe_2O_3	8.93	8.40	5.01	9.70	5.19
MgO	3.22	4.40	2.45	6.12	1.94
CaO	7.03	7.90	4.29	8.40	4.29
Na_2O	3.84	3.70	2.80	3.36	3.39
K_2O	1.46	1.10	2.66	1.33	3.74
TiO_2	0.89	1.30	0.65	1.50	0.54
MnO	0.18	0.20	0.10	0.18	0.32
P_2O_5	0.25	0.30	0.21	0.35	0.18

(1) Island arc andesite (Talasea, New Britain)
- Lowder and Garmichael, 1970

(2) Average andesite
- Wedepohl, 1969

(3) Butte quartz monzonite
- Knopf, 1967

(4) Average of 50 analyses of diorite around the world
- Muller and Saxena, 1977

(5) Gunung Limbung host rock from average of 3 analyses

From Table 6, it can be seen that the concentrations of major oxides within the Gunung Limbung host rock are near the concentration of major oxides within quartz-monzonite and diorite. This data support the results of the petrographic analysis (see CHAPTER IV), on the naming of the host rock. So, the geochemical analysis proves that the naming of the host rock as a monzodiorite is reasonable.

One interesting point concerns the mean concentration of K_2O in the rock from the study area, which is relatively high. The high concentration of K_2O within the host rock seems to be in accordance with van Bemmelen's (1949) suggestion that intrusions and extrusions of magma along the margin of the geanticline of South Java show a tendency toward differentiation into alkaline rock. According to van Bemmelen (1949) the young Neogene intrusive necks and bosses of the Bogor Zone are one example, which often have an 'essexitic' character. Furthermore, Kuno (1966) demonstrated (using geochemical analysis of basaltic rocks) that the differentiation of the high alumina basalt on the main volcanic chain of Java and the high alkaline leucite-bearing basalt on the north coast of Java is related closely to the depth of the underlying Benioff Zone.

V.2 Hydrothermal alteration assemblages

Hydrothermal alteration is primarily a metasomatic process involving significant changes in rock and mineral composition at approximately constant volume, through chemical reactions. The metasomatic changes may involve either addition of an ion to the rock or its removal in the aqueous phase.

The most important process of metasomatism in most kinds of wall rock alteration is that of mineral hydrolysis, or hydrogen metasomatism. In this process hydrogen ions are added into the host rock, a mole equivalent of metal cations is released and the hydroxyl-to-hydrogen ratio in this solution is increased (Meyer and Hemley, 1967). Example of hydrolysis include epidotisation of hornblende (hornblende is the first mineral attacked at the outer edge of wall rock alteration with precipitation of epidote and pyrite), sericitisation of orthoclase, or sericitisation of chlorite. An example of one chemical reaction is the hydrolysis of K-feldspar :

$$\underset{\text{(orthoclase)}}{3KAl_3Si_3O_8} + 2H^+ \text{ -- } \underset{\text{(sericite)}}{KAl_2AlSi_3O_{10}(OH)_2} + 2K^+ + \underset{\text{(quartz)}}{6SiO_2}$$

This reaction would explain the occurrence of secondary quartz.

Conversely, the relative hydrogen ion concentration in the solution may be increased by reactions such as the conversion of albite to chlorite, or the conversion of andesine to clinozoisite, with an example of a typical chemical reaction :

$$2NaCaAl_3Si_5O_{16} + Na^+ + H_2O \text{ -- } Ca_2Al_3Si_3O_{12}(OH) + 3NaAlSi_3O_8 + H^+$$

(andesine) (clinozoisite)

The principal additional cations involved in alteration reactions are sodium, calcium, potassium, magnesium, iron and aluminium. The cations may be added in varying amounts depending upon the alteration process.

According to Meyer and Hemley (1967), rarely the alteration zones show a net loss of base equivalents. This loss can range from very small, in the instance of propylitic alteration, to substantial in the sericitic and advanced argillic assemblages, and silicification. Most sericitic and argillic envelopes lose between 3 and 8 gram equivalents of aluminium, sodium and potassium per 1000 cm^3 of rock. Aluminium is the least mobile of all cations. Alteration reactions can often be closely approximated assuming constancy of alumina at constant volume of rock. However, locally small losses may be evident during argillisation or sericitisation, and complete extraction may result from total silicification or vein replacement. Calcium and sodium are usually heavily depleted in alteration. In granodiorite systems, magnesium is also extensively removed. Iron is quite variable, depending upon the alteration phase (carbonate, chlorite or sulphides). In most example of sericitisation and K-silicate alteration, potassium is commonly added. Almost invariably, the ratio of potassium to sodium increases toward the sulphide ore.

As can be seen in Table 5, the concentration of major and minor elements within the altered rocks shows a variation. The variation is probably due to the grade of alteration which relates to the position of the rock to the ore zone.

As in the petrographic analysis, GL.22, GL. 23, GL.24 and GL.27 will be used as the basis for the discussion of the hydrothermal alteration of the host rock, since these rocks visually show a gradation in alteration toward the ore zone. From the microscopic analysis it was proved that the alteration of the host rock changes toward the ore zone from propylitic to sericitic-silicic-K-silicate and advanced argillic envelopes.

From the chemical data as shown in Table 5, it can be seen that there is some change in the concentration of major elements from the entrance (GL. 22) toward the ore zone (GL.23, GL. 24 and GL. 27). These are shown in Fig. 15.

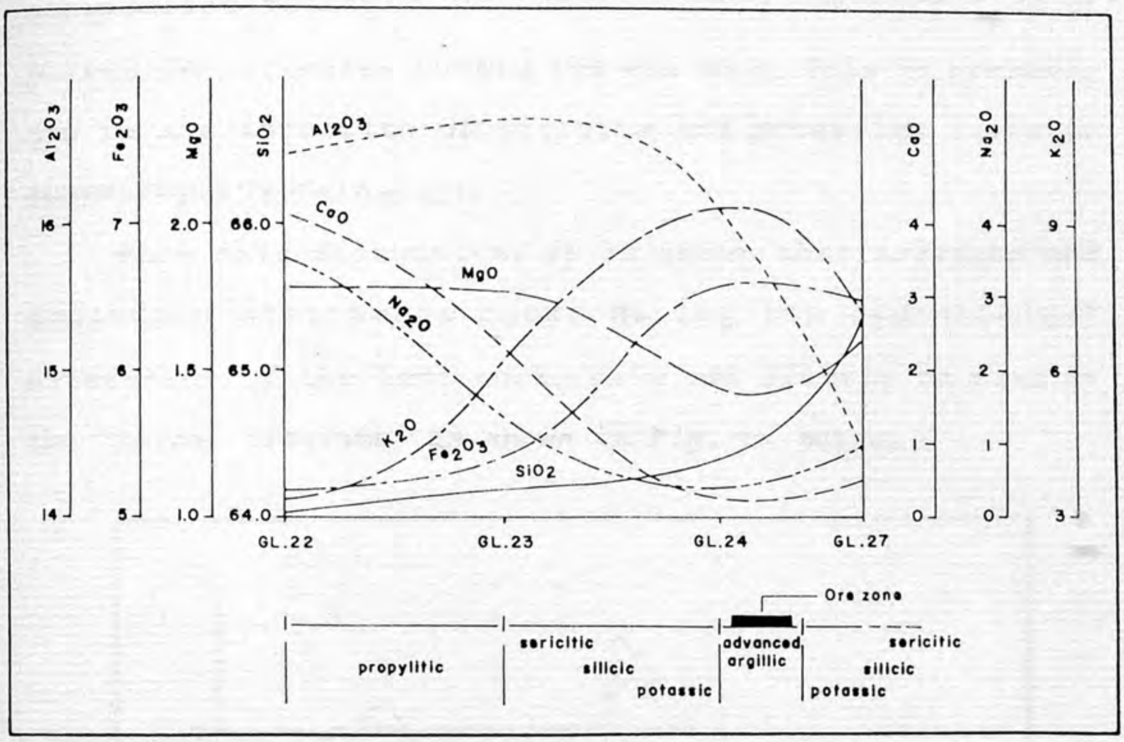


Fig. 15 Graph of concentrations of some major elements illustrating the type of alteration

From Fig. 15, it can be seen that the concentration of silica increases only slightly; whilst the concentration of aluminium decreases toward the ore zone. Thus the secondary quartz formed from silica released during alteration, and not from the introduction of Si in the solution. The concentration of iron increases toward the ore zone. This is in accordance with the increase of the proportion of pyrite as seen in thin sections (see Table 3). Magnesium, calcium and sodium show a depletion; calcium and sodium in particular, are heavily depleted. This is probably due to the breakdown of hornblende and plagioclase feldspar. In contrast, the concentration of potassium increases toward the ore zone. This is probably due to the formation of sericite and potassium silicate assemblages (K-feldspar).

From this discussion, it is shown that addition and depletion ofelements occur during the hydrothermal alteration of the host rock. This can clearly be seen in the 'spider diagrams' as shown in Fig. 16 below.

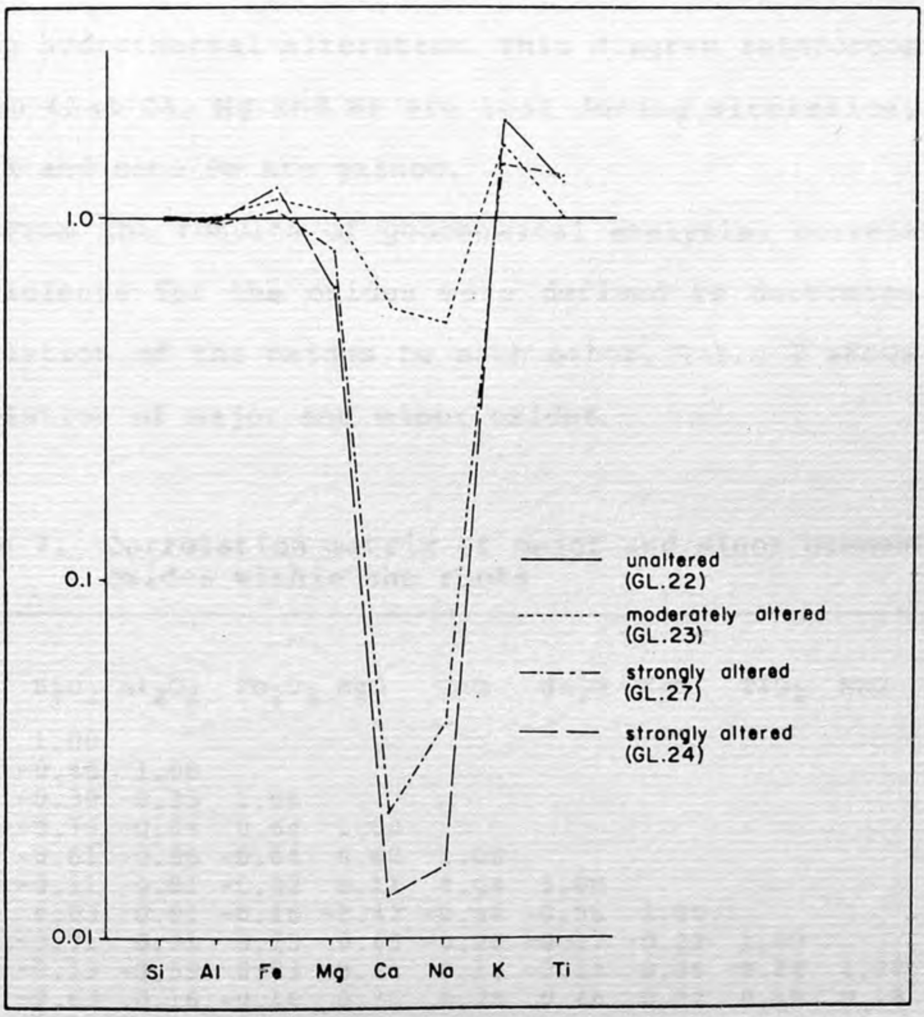


Fig. 16 The 'spider diagram' of some major and minor elements illustrating the addition and depletion of the elements during hydrothermal alteration (Adapted from Pearce, 1983)

The diagram was constructed using the concentration of major and minor elements in the 4 samples GL. 22, GL. 23, GL.24 and GL.27. Concentrations of elements in GL.22 were used as standard, since this sample is the freshest one among the samples from tunnel T. 560. The points which are joined by lines are logarithmic concentration ratios of one rock compared to the standard rock. The values above the 1.0 value indicate the addition of the elements, whilst the values below 1.0 indicate the depletion of the elements during hydrothermal alteration. This diagram reinforces the notion that Ca, Mg and Na are lost during alteration, and that K and some Fe are gained.

From the results of geochemical analysis, correlation coefficients for the oxides were derived to determine the correlation of the oxides to each other. Table 7 shows the correlation of major and minor oxides.

Table 7. Correlation matrix of major and minor element oxides within the rocks

	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
SiO_2	1.00									
Al_2O_3	-0.46	1.00								
Fe_2O_3	-0.30	-0.33	1.00							
MgO	-0.76	-0.04	0.64	1.00						
CaO	-0.61	-0.06	-0.04	0.60	1.00					
Na_2O	-0.11	-0.01	-0.37	0.11	0.64	1.00				
K_2O	0.03	0.01	-0.16	-0.42	-0.46	-0.56	1.00			
TiO_2	-0.71	0.71	0.23	0.65	-0.28	-0.17	-0.22	1.00		
MnO	-0.29	-0.59	0.73	0.46	0.14	-0.13	0.06	-0.14	1.00	
P_2O_5	-0.63	0.16	-0.16	0.35	0.78	0.46	0.02	0.19	0.18	1.00

As a warning it must be borne in mind that some correlation is bound to occur as the values are part of a fixed total.

From Table 7, it can be seen that some of the common mafic mineral-forming elements including Fe, Mg, Ca, Mn and Ti show a good correlation, although their concentration in the host rocks are relatively low, compared with the mean concentration for other intermediate rocks (based on the number of samples analysed [13] a value for the correlation coefficient 'V' of 0.6 exhibits a good correlation - Howarth, 1983). This positive correlation presumably relates to the proportion of hornblende in the rocks. However, these elements mostly have a negative correlation with the the felsic mineral-forming elements (Si,Al). This means that with an increase in the felsic minerals (e.g. quartz, alkali feldspar) the concentration of mafic minerals decreases. This is a normal condition within intermediate rocks. The positive correlation between Ca and P is probably due to occurrence of apatite, a common accessory mineral. The positive correlation of Ca and Na presumably relates to the proportion of plagioclase. The negative correlation between these two elements (Na and Ca) and K probably relates to the depletion of Na and Ca, and the addition of K concentration in the rock during hydrothermal alteration.

The positive and negative correlations of some major and minor elements mentioned, are illustrated in the diagrams in Fig.17. Fig.17 (a), (b), (e), (f), (g) show negative correlations; whilst Fig. 17 (c), (d) and (h) show positive correlations.

Some trace elements within the host rocks were also determined. The study was carried out by comparing the concentration of elements within the rocks from the study area, with the mean concentration of those elements within intermediate rocks. The mean concentration of elements used in this study is the mean value for concentration of trace elements in diorite by Turekian and Wedepohl (1961), Vinogradov (1962) and Jeffery (1975). This mean value is shown in Table 8.

Table 8. Concentration of some trace elements in an 'average' intermediate rocks

Ba	Ce	Co	Cr	La	Li	Nb	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
260	81	8	68	*)	30	28	40	20	300	110	30	56	200	30

*) No information.

The concentration of some trace elements within the host rock can be seen from the analytical results which are shown in Table 9.

From Table 9, it can be seen that some trace elements, including Ba, Pb, Zn Co, Sr and V, have concentrations above the mean value of those elements within intermediate rocks.

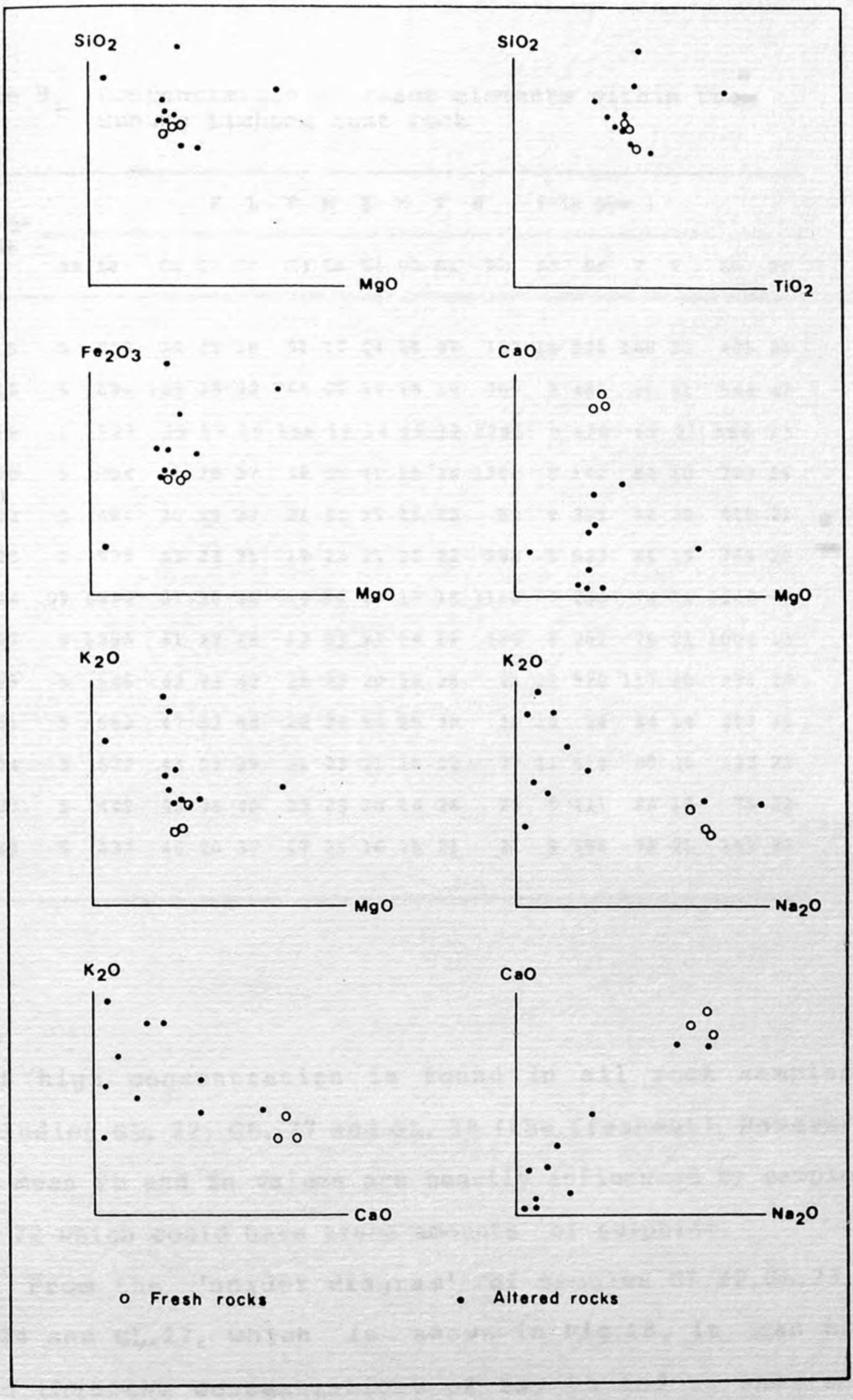


Fig. 17 Diagrams of correlation of some major and minor elements

Table 9. Concentration of trace elements within the Gunung Limbung host rock

CODE OF SAMPLE	ELEMENTS (in ppm)																
	As	Ba	Ce	Co	Cr	Cu	La	Li	Nb	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
GL. 5	5	812	38	25	58	51	17	24	16	37	103	19	521	168	20	405	26
GL.18	5	1694	125	23	32	768	62	17	18	19	708	9	486	80	61	544	47
GL.19	5	1527	29	17	19	156	19	14	16	12	2246	9	420	65	21	566	23
GL.20	5	1204	41	26	27	38	19	41	15	24	1368	6	142	64	10	707	16
GL.22	5	494	45	25	37	21	24	15	15	23	53	9	399	84	20	419	21
GL.23	5	978	43	23	35	19	23	21	16	22	288	9	527	81	19	769	20
GL.24	59	1648	31	20	22	19	16	25	16	18	1118	7	236	74	14	1346	9
GL.27	5	1253	41	22	28	17	23	23	14	19	586	8	282	76	21	1004	13
GL.28	5	646	42	23	42	21	22	20	16	26	21	12	522	117	20	235	29
GL.31	5	662	47	23	48	12	24	57	16	38	30	13	54	84	14	297	64
GL.34	5	672	43	23	39	21	23	21	15	22	77	11	515	99	20	122	22
GL.37	5	449	43	36	40	23	23	20	14	24	29	9	411	88	19	75	22
GL.38	5	632	46	20	37	17	25	16	15	21	21	9	396	72	21	152	37

This high concentration is found in all rock samples including GL. 22, GL. 37 and GL. 38 (the freshest). However, the mean Pb and Zn values are heavily influenced by sample GL. 22 which could have trace amounts of sulphide.

From the 'spider diagram' of samples GL.22,GL.23, GL.24 and GL.27, which is shown in Fig.18, it can be seen that the concentrations of Ba, Pb and Zn show an increase during hydrothermal alteration.

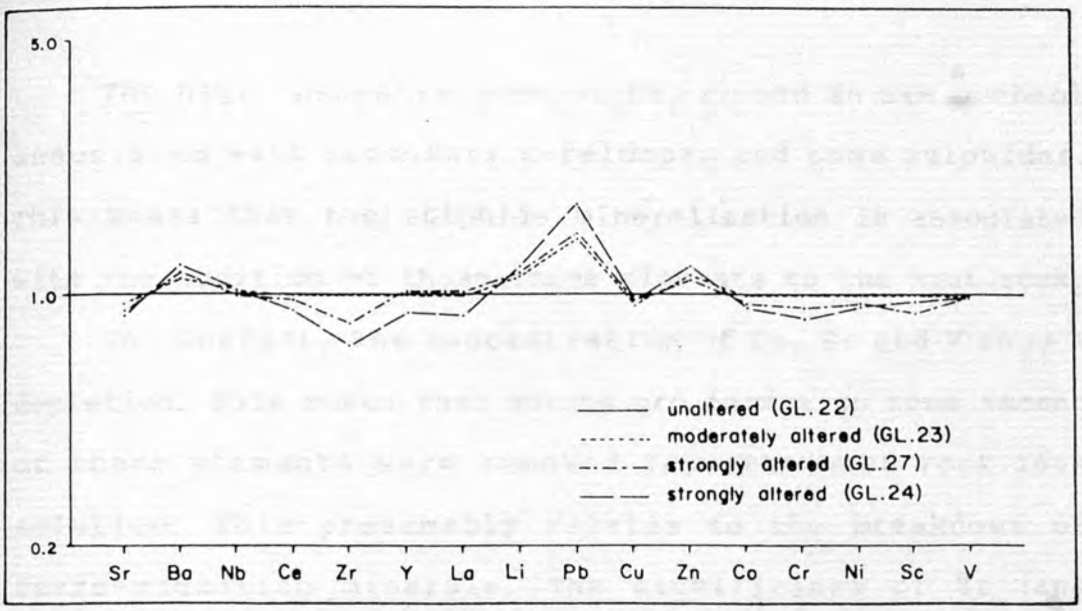


Fig. 18 The 'spider diagram' of some trace elements within the host rock illustrating the addition and depletion of the elements during hydrothermal alteration (Adapted from Pearce, 1983)

This addition to the system can also be seen from the increase of the concentration of those elements toward the ore zone, which is shown in Fig. 19.

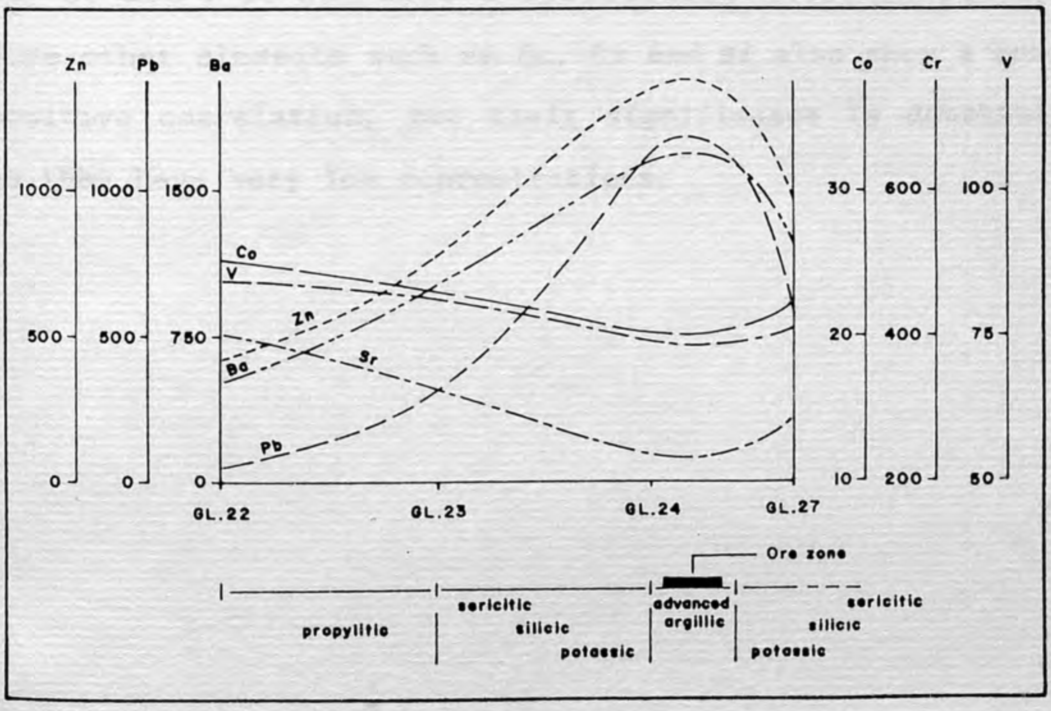


Fig. 19 Graph of concentration of some trace elements related to the type of alteration

The high concentrations of Ba, Pb and Zn are probably associated with secondary K-feldspar and some sulphides. This means that the sulphide mineralisation is associated with the addition of those three elements to the host rock.

In contrast, the concentration of Co, Sr and V show a depletion. This means that during ore formation some amounts of these elements were removed from the host rock into solution. This presumably relates to the breakdown of ferro-magnesian minerals. The significance of Zr (and possibly some other elements) is unclear.(It is probable that these elements were not dissolved completely during the HF dissolution for the ICP analysis.)

From the correlation matrix of trace elements within the host rock which is shown in Table 10, it can be seen that Ba, Pb and Zn show a good positive correlation, but Co, Sr and V do not show a correlation witheach other. Some other elements such as Sc, Cr and Ni also show a good positive correlation, but their significance is doubtful, as they have very low concentrations.

Table 10. Correlation matrix of some trace elements within the Gunung Limbung monzodiorite

	As	Ba	Ce	Co	Cr	Cu	La	Li	Nb	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
As	1.00																
Ba	0.46	1.00															
Ce	-0.21	0.31	1.00														
Co	-0.24	-0.53	0.05	1.00													
Cr	-0.39	-0.70	0.03	0.40	1.00												
Cu	-0.12	0.55	0.93	-0.11	-0.17	1.00											
La	-0.23	0.32	0.99	0.01	-0.04	0.93	1.00										
Li	0.01	-0.10	-0.12	0.09	0.26	-0.24	-0.18	1.00									
Nb	0.11	0.49	0.63	-0.42	0.03	0.73	0.61	-0.01	1.00								
Ni	-0.24	-0.57	-0.08	0.34	0.90	-0.27	-0.17	0.64	0.02	1.00							
Pb	0.25	0.79	-0.08	-0.46	-0.79	0.24	-0.05	-0.08	0.19	-0.63	1.00						
Sc	-0.26	-0.35	-0.06	0.09	0.85	-0.07	-0.11	0.15	0.25	0.76	-0.42	1.00					
Sr	-0.27	-0.35	0.22	0.04	0.20	0.28	0.24	-0.31	0.26	-0.20	-0.19	0.30	1.00				
V	-0.15	-0.35	-0.07	0.22	0.81	-0.10	-0.15	-0.05	0.15	0.67	-0.47	0.92	0.46	1.00			
Y	-0.14	0.40	0.94	-0.07	-0.05	0.96	0.96	-0.39	0.65	-0.25	0.02	-0.01	0.44	-0.01	1.00		
Zn	0.70	0.74	-0.12	-0.42	-0.61	-0.01	-0.13	0.03	0.08	-0.41	0.50	0.39	0.27	-0.30	-0.09	1.00	
Zr	-0.38	-0.45	0.07	-0.01	0.76	-0.04	0.04	0.51	0.24	0.79	-0.44	0.72	-0.14	0.45	-0.02	-0.60	1.00

V.3 Conclusion

Geochemical analyses of the samples of host rock have confirmed that the host rock in the study area is a monzodiorite. The rock was altered as a result of metasomatism from hydrothermal solution during ore formation.

From the traverse in tunnel T. 580, it was found that there is a gradual increase in the degree of, and change in type of, alteration from the fresh rock toward the ore zone.

In general terms the change in type of alteration is: propylitisation - sericitisation - silicic/K-silicate alteration - advanced argillitisation. The alteration of the host rock involves both the addition and removal of some elements with respect to the host rock. The added major elements include iron and potassium, whilst those depleted include sodium, calcium, magnesium and small amounts of aluminium.

The hydrothermal alteration has also resulted in the addition of some trace elements including barium, lead and zinc. However, a depletion in concentration of some trace elements has also occurred, namely cobalt, cromium, nickel and scandium.

From the chemical analysis it is found that some trace elements possibly including those of economic interest (lead and zinc) have concentrations above the background value for those elements in 'typical' intermediate rocks. This fact indicates that the host monzodiorite in the study area was already enriched in these elements prior to mineralisation. These high concentrations were probably an original feature of the melt at this locality and were further concentrated at the top of the intrusion by normal differentiation processes (perhaps associated with late-magmatic activity).

The hydrothermal solutions (which are associated with the later intrusion of quartz diorite) probably caused a redistribution of these elements within the monzodiorite. In other words, the mineralisation in the study area resulted from the addition of those elements from the host rock.

Thus, the analysis of fresh igneous hosts for elements such as barium, lead and zinc, may be a useful parameter during exploration in this region, particularly at the initial stage for defining potentially mineralised and 'barren' intrusives.

CHAPTER VI FLUID INCLUSION STUDIES

The study of fluid inclusions in minerals has been developed recently into an important branch of geology. It has proved particularly useful in the field of ore genesis where the inclusions in the ore and gangue minerals can be used to 'finger print' certain types of ore-forming fluids, to characterise particular ore mineral assemblages and to define areas where these fluids are most likely concentrated. In particular, it has provided valuable data on the temperature of ore formation or subsequent metamorphism, and on the chemistry of the ore fluids, which subsequently can provide an important guide to pressure conditions during mineral formation.

With the development of techniques for fluid inclusion study, much emphasis has been given to its use in the study of the nature of hydrothermal fluids in the crust (Takenouchi, 1971).

Fluid inclusion studies usually involve thermometric analysis and chemical analysis, and are commonly carried out on quartz and other semi-transparent minerals (e.g sphalerite)

The thermometric analysis incorporates both heating and freezing studies. This type of analysis is the most popular and widely-used non-destructive analytical technique and is used to measure the temperature of the phase changes which take place in the inclusions during heating and cooling.

The heating study was carried out to obtain data on the homogenisation temperature. When the two-phase inclusions are heated, the size of the bubble decreases until it finally disappears. So, the ultimate aim of the heating study is to measure the final temperature of homogenisation (i.e the temperature at which the inclusion becomes a one-phase system). Normally, for the two-phase inclusions, this is the temperature of the total liquid-vapour homogenisation. However, for the inclusions containing daughter minerals an additional temperature (the temperature of salt dissolution) can also be measured.

The freezing study is a non-destructive method to obtain data on the salinity of the inclusions. The term freezing refers to the procedure whereby an inclusion is cooled below room temperature to observe the liquid-solid transformation (i.e solidification). Actually, because of metastability, the liquid in the inclusion may not freeze until temperatures much lower than the freezing point have been attained. For this reason it is more usual to observe the melting temperature of the frozen solid.

Data obtained during freezing can be extensive and refers primarily to fluid composition and density. This is important for the interpretation of the homogenisation data. Theoretically, liquid plus vapour inclusions containing pure water or pure non-aqueous fluid (e.g. CO_2) should freeze to give solid plus vapour at a well defined temperature, for example H_2O at +0.015° C and CO_2 at -56.6° C (Shepherd, Rankin and Alderton, 1985). In practice this is rarely observed because the fluid seldom consists of a single component. The presence of additional components greatly extends the temperature interval over which solidification and melting take place. The range of melting is therefore a direct function of chemical composition.

By careful observation and accurately measuring the temperature at which the phase changes take place, it may be possible to estimate the PVTX (pressure-volume-temperature-composition) state of the fluid at the time of trapping.

In thermometric analysis a knowledge of pressure at the time of trapping is an important factor. It provides a means for correcting the homogenisation temperature to obtain the true trapping temperature (i.e the so called 'pressure correction'). Homogenisation temperatures are usually a minimum estimate of trapping temperature - the difference a being function of the pressure at the time of mineral formation.

Theoretically, the pressure involved at the time of trapping may be between two extremes:

Minimum pressure, is a pressure which a liquid can sustain and is equal to its vapour pressure at any given temperature and composition. If the pressure falls below this value the liquid will boil (Shepherd at al, 1985). If the fluid inclusions show no evidence of trapping from a boiling fluid, it can be safely assumed that the pressure was greater than this minimum value.

Maximum pressure, is a pressure which results from the overlying rocks (i.e superincumbent load) and is known as the 'lithostatic pressure'. If the fluid has been open to the surface, the pressure is due to the overlying head of water and is referred as the 'hydrostatic prassure'. Many fluid systems lie or alternate between these two extremes (Shepherd at al, 1985). The maximum pressure can be obtain by converting the overlying rock weight to lithostatic pressure using a general formula:

$P = H \times \rho \times g$, where :

H is depth (thickness of overburden)

ρ is density for lithostatic overburden

g is the gravitational constant

Before making thermometric runs, it is important to make a description of the distribution and the type of the fluid inclusions within the host mineral. In other words, the sample description is the first stage of any fluid inclusion investigation. By observing the abundance, distribution, gross composition and the shape of inclusions, it is possible to assess whether the inclusions are primary or secondary in origin. The sample description is particularly important since the optics of the heating stage are much poorer than those of normal microscopy.

Thermometric analysis is a powerful technique for obtaining information on the composition and density. However, fluid inclusions are often chemically complex and the observed phase change may not be specific enough to derive more than a qualitative estimate of composition (Shepherd et al., 1985).

Recently, chemical analysis has become an important aspect of fluid inclusion studies, to resolve the more detailed chemistry and obtain the quantitative composition of the inclusions.

Although numerous methods have been developed for fluid inclusion analysis, most of the more established ones are specific to particular groups of elements. However, many reseachers have found these to be sufficient for their needs.

VI.1 Methods

As mentioned earlier, the fluid inclusion studies were carried out to obtain data on the temperature, salinity, and chemistry of the mineralising fluids. These parameters can then be used to clarify the type and the origin of the ore-forming fluid and to define the area where the fluid was concentrated.

In this study, fluid inclusions in 10 quartz samples were studied. The samples were taken from tunnels T.400, T.460, T.580 and from drill cores of CKL.1, CLB. 10, GLB. 20; whilst the methods used were thermometric analysis and chemical analysis. The type of quartz which was used in this study and the techniques applied are shown in Table 11.

For the sample description and thermometric analysis, 5 specimens were selected based on their size, crystallinity, and transparency. The samples were then prepared as 'wafers' (i.e doubly polished sections).

To make the wafers, the samples are taken through several stages of sawing, polishing and grinding. The flow-chart of the preparation of fluid inclusion wafers is shown in Fig. 20.

The final thickness of the wafer will depend on the size and the abundance of the inclusions and the transparency of the mineral, but a thickness between 0.2 and 0.5 mm are recommended for most samples.

Table 11. Type of quartz sample and method of analysis applied

CODE OF SAMPLE	LOCALITY	ANALYSIS METHOD	TYPE OF SAMPLE
GL. 2	T.400/1B	- Thermometric and chemical	- Quartz vein containing stratified ore minerals (chalcopyrite, pyrite, sphalerite), with thickness of approx. 5 cm. Crystal size: 2-4 mm
GL. 9	T.400/3D	- Chemical	- Breccia-filling quartz
GL.10	T.460/1	- Thermometric and chemical	- Crack-filling quartz, large crystal
GL.11	T.460/2	- Chemical	- Breccia-filling quartz
GL.13	T.460/4	- Chemical	- Breccia-filling quartz associated with mineralised (sphalerite, pyryte) fragments
GL.14	T.460/5	- Chemical	- Quartz vein (2 cm thick), containing sphalerite, chalcopyrite and pyrite
GL.26	T.580/5	- Thermometric and chemical	- Crack-filling quartz, large crystal
GL.29	CKL.1/-107	- Chemical	- Breccia-filling quartz
GL.30	CLB.10/-123	- Thermometric and chemical	- Breccia-filling quartz
GL.32	C.16/-128	- Thermometric and chemical	- Quartz vein containing chalcopyrite, pyrite and sphalerite
GL.35	GLB.20/-375	- Chemical	- Breccia-filling quartz

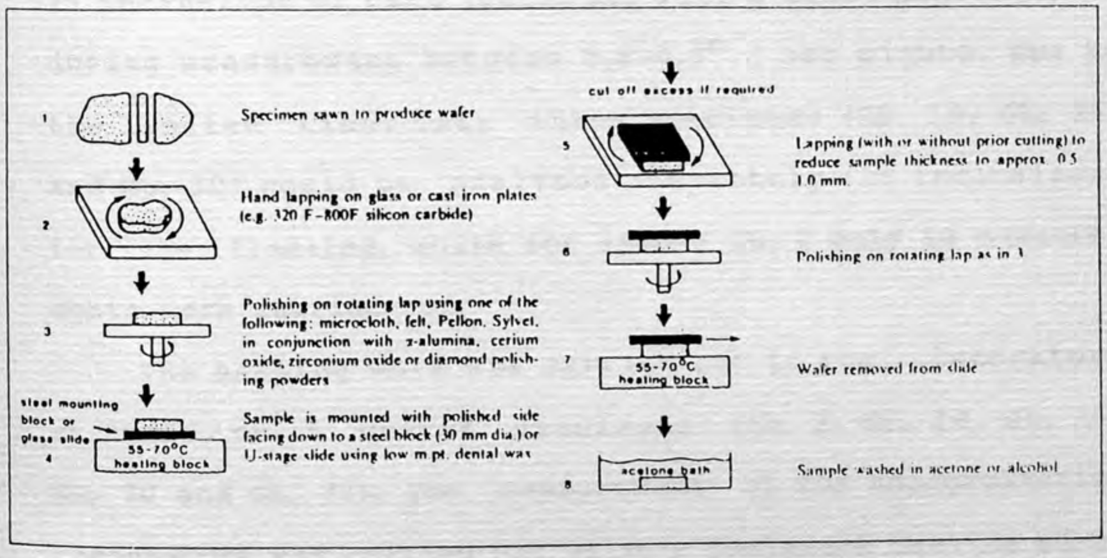


Fig. 20 Flow chart showing basic steps in the preparation of fluid inclusion wafers (After Shepherd at al., 1985)

During the sample description, several photomicrographs of typical fluid inclusions were made, which were then used to relocate the inclusions for the thermometric analysis.

Due to some technical problems, the freezing and heating studies were carried out in different laboratories.

The freezing work was carried out at the British Geological Survey (BGS), using a Linkam TH 600 stage which was mounted on a Leitz ortholux microscope. The coolant medium in this work was liquid nitrogen. The stage had previously been calibrated using inorganic and organic salts.

The salinity of the inclusion was estimated from the first and final melting of the ice during re-heating, after the inclusions were frozen by decreasing the temperature. Meuasurement of the melting temperature of ice was made on 25 inclusions of each specimen, with a final heating rate during measurement between 0.5-0.9^{o} C per minute. Due to the limited time, only three specimens (GL. 10, GL. 26, and GL. 30) could be analysed completely (25 inclusions) for the freezing, while for sample GL. 2 only 10 measurements were carried out.

The heating work was carried out in the laboratory at RHBNC, on 5 quartz specimens (GL. 2, GL. 10, GL. 26, GL. 30 and GL. 32). The measurement of the homogenisation temperature was carried out using a Chaixmeca heating stage which was mounted on a Zeiss optical microscope. The rate of heating was controlled manually to about 2-5° C. In this work, 50 inclusions were measured for each sample.

Chemical analysis of inclusions was carried out by ICP using the 'crush-leach' method, with the aim to obtain the data on the concentration of some common cations (including Na, K, Ca, Fe, and Mg).

To prepare the samples for analysis, several stages of disaggregation, purification and crushing were adopted.

The first stage is disaggregation - to make the sample into grains with a size of 0.5-2 mm. This was carried out by a mechanical 'jaw' or 'roller' crusher, or by using a large mortar and pestle. To obtain a uniform product, nylon or brass sieves were then used to screen the grains.

The second stage is that of mineral purification. The first step of this stage is to separate sufficient pure mineral for analysis. Impure grains were removed with tweezers whilst viewing the crushed sample under a binocular microscope. After separation, the sample was cleaned in a hot acid for several hours. Concentrated HCl is very efficient to remove iron oxide staining. Finally the sample was repeatedly washed in doubly-distilled and deionised water (DDW) to remove all traces of acid, and then dried at a gentle heat (about 100° C) in an oven. The mineral sample is now effectively ready for crushing.

To make a solution, a few grams of sample are crushed in DDW to release the fluid for analysis. This is traditionally done by hand using a mortar and pestle. In this work, clean plastic and rubber gloves were worn to reduce the effect of contamination. Before starting the crushing, the mortar and the pestle were cleaned by duplicating the grinding action, first with dilute HNO_3 and then several times by DDW. The purified sample is then added to the pestle and few mls of DDW added. When the crushing is complete, the mortar is washed with a little DDW and the liquid retained in the pestle. The pestle is then tilted, and the contents washed into a centrifuge tube (see Appendix D for the procedure).

Once the solution has been obtained in the required state it is ready for analysis. Standard aqueous solutions covering the expected range of concentration of elements were also analysed. A blank is also run in a similar fashion, but with no mineral sample present (i.e just DDW).

In addition, a scanning electron microscopic (SEM) study was carried out to analyse the solid phases (daughter minerals) in the inclusions. This method is carried out on the opened inclusions, which were obtained by fracturing the wafer around the region of interest.

To prepare the sample for SEM, the fractured wafers are mounted on a 'stub'. The 'stub' is usually made of aluminium and has a flat upper surface on which the wafers are mounted. To make the wafers easier to mount, a pair of grooves (a few mm deep and at 90° to each other) are cut in the top surface. The grooves give support to the fragile up-standing wafers. Using epoxy resin the wafers are then glued into the grooves with the newly-fractured surface facing upwards. Once mounted, the sample was stored in a dessicator to prevent long-term efflorescence of hygroscopic daughter minerals and to prevent the accumulation of dirt.

Immediately before viewing under the SEM, the sample was coated with a conducting layer of carbon to promote the bombardment by electrons.

VI.2 Results

From the microscopic observation of the samples, it was found that at room temperature, most of the inclusions observed are two phase (liquid plus vapour) varieties. A solid phase (daughter mineral) was also found in some of the inclusions (Plates 28 and 30), although most of these were very difficult to identify.

Fibrous daughter minerals were particularly abundant in inclusions from GL. 30. This daughter mineral is probably dawsonite - $NaAl(CO_3)(OH)_2$ (Shepherd et al., 1985).

Some of the solid phases, as found in sample GL.2, have a relatively large size compared with the host inclusions. These are probably captured minerals, i.e those which have been accidently trapped with a portion of fluid (Shepherd et al., 1985). This is also probably true of some of the opaque (sulphide) phase seen in inclusions in all samples.

Most of the inclusions within the samples have a degree of filling (i.e ratio of liquid volume to total volume) between 70-80 %. The size of the inclusions which can clearly seen vary from 10 to 100 milli-microns. Some of the inclusions are smaller than 10 milli-microns (too small to be observed).

The inclusions mostly occur along growth zones parallel to the crystal faces (Plate 28), whilst some of the inclusions are randomly distributed. They have various shapes, being irregular or elliptical. Some of the inclusions appear to be isolated and have the form of negative crystals of quartz.

The appearance (shape and distribution) of the inclusions suggests that they are mostly primary inclusions, i.e. formed contemporaneously with the enclosing crystals and therefore represent samples of the original fluid from which the host mineral was deposited.

From the observations, it was also found that many of the inclusions are 'necked' (Plate 29). Some also are definitely secondary inclusions - those that formed by any process (e.g deformation) after the crystallisation of the bulk of the host mineral is essentially complete (Roedder, 1984). If either of these catagories of inclusion were noted they were excluded from the study.

The results of the salinity measurement of fluid inclusions within quartz samples GL.10, GL. 26, GL. 30 and GL.2 are shown in Fig.21. This figure illustrates the frequency distribution of the salinity of fluid inclusions within the samples.

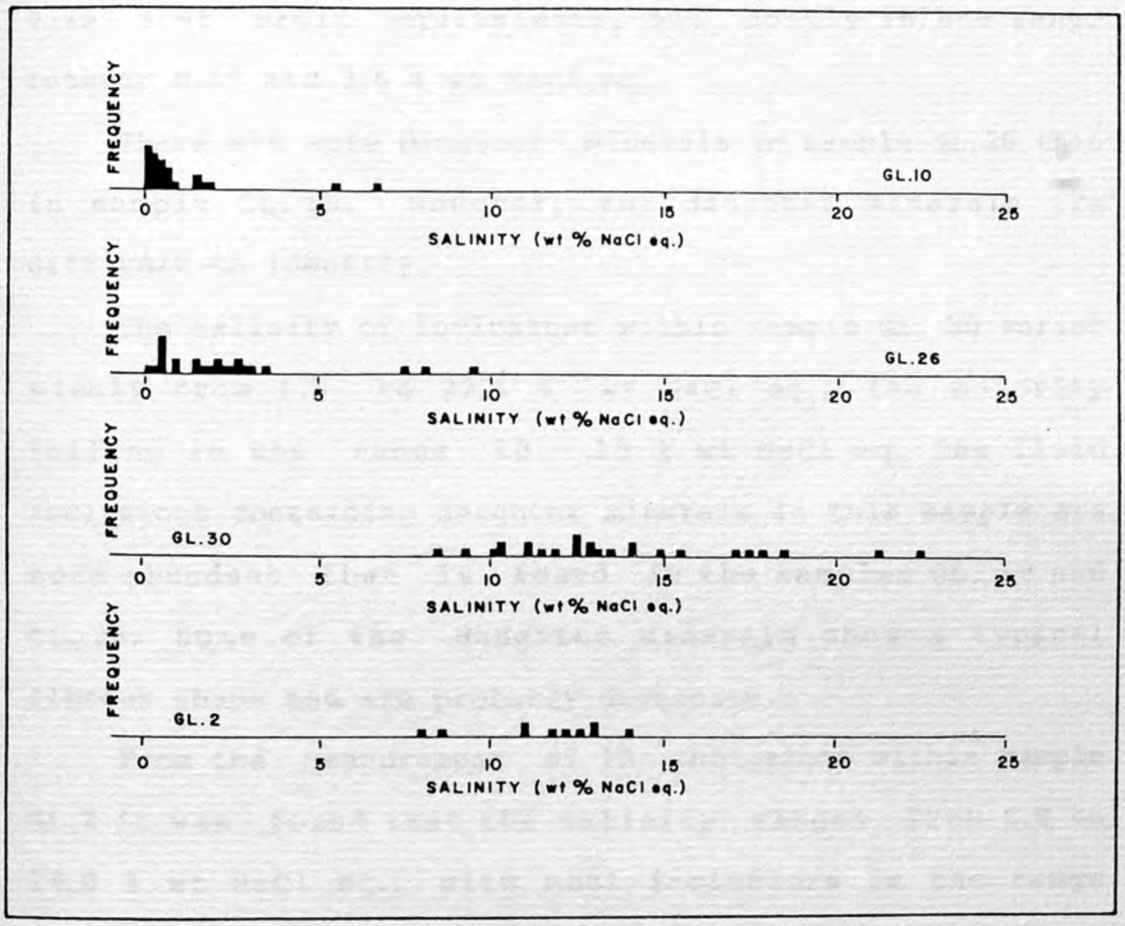


Fig. 21 Distribution of salinity of fluid inclusions within quartz sample

From Fig. 21 it can be seen that the salinity of the inclusions has a wide range.

Sample GL. 10 has a range of salinity between 0.2 and 6.7 % wt NaCl equivalents. Most of the salinity values are distributed between 0.2 and 2.0 % wt NaCl equivalents. Some of the inclusions contain small opaque dots which are probably sulphide minerals.

Sample GL. 26 has a salinity ranging from 0.15 to 9.45 % wt NaCl equivalents, but mostly in the range between 0.15 and 3.6 % wt NaCl eq.

There are more daughter minerals in sample GL. 26 than in sample GL. 10. However, the daughter minerals are difficult to identify.

The salinity of inclusions within sample GL. 30 varies widely from 8.5 to 22.6 % wt NaCl eq., the majority falling in the range 10 - 15 % wt NaCl eq. The fluid inclusions containing daughter minerals in this sample are more abundant than is found in the samples GL. 10 and GL. 26. Some of the daughter minerals show a typical fibrous shape and are probably dawsonite.

From the measurement of 10 inclusions within sample GL.2 it was found that the salinity ranges from 8.0 to 14.0 % wt NaCl eq., with most inclusions in the range between 11 and 14 % wt NaCl eq. Some of the inclusions also contain daughter minerals (small dots of an opaque mineral) but not as many as found in sample GL. 30.

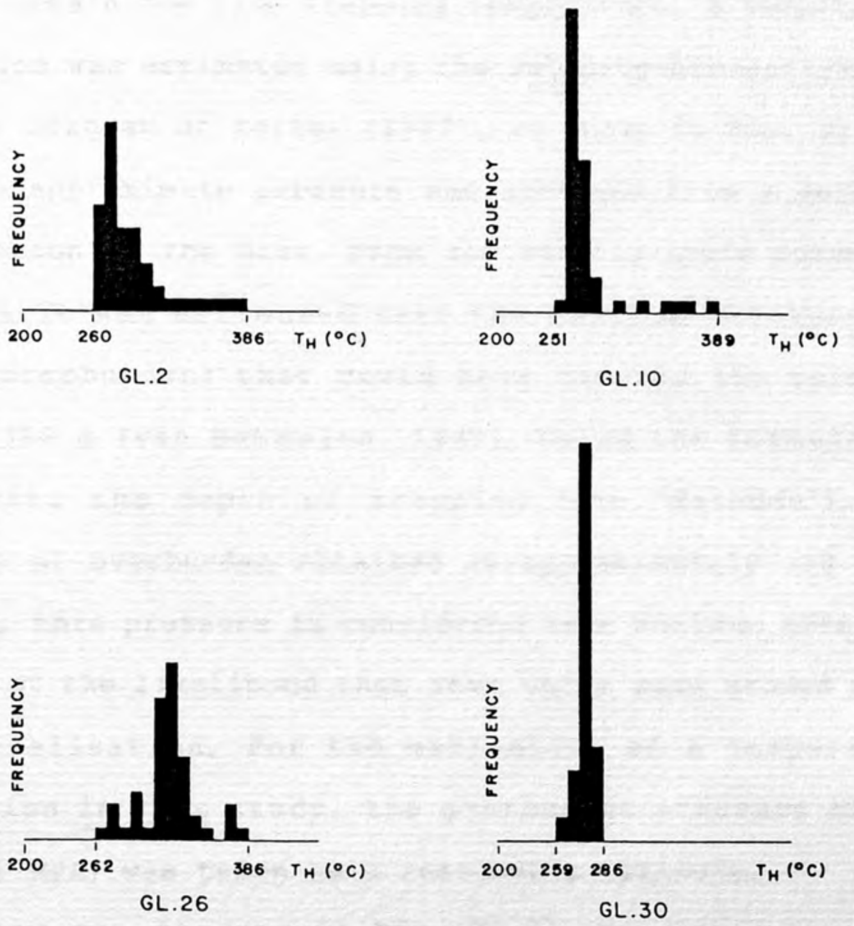
From the salinity measurements on those four samples it can be said, however, that the fluid inclusions within the samples can be divided into 2 groups.

The first fluid type has a salinity between 0.15 and 5 % wt NaCl eq. This group is most abundant in the inclusions within samples GL. 10 and GL. 26.

The second fluid type has a salinity between 10 and 20 % wt NaCl eq., and is represented by inclusions within samples GL. 30 and GL. 2. Although the measurement of salinity in sample GL. 2 was carried out on 10 inclusions, from the concentration and distribution obtained it may be assumed that other inclusions within this sample have a similar salinity.

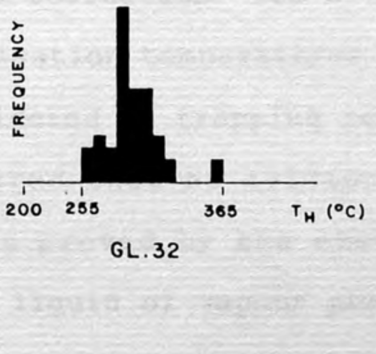
From the first melting measurements of the fluid inclusions within the samples, it was found that the first ice melting was often below -21° C, and often between -35 and -40° C. This indicates that there are many other salts within the inclusions beside NaCl (especially Ca or Mg).

The results of heating measurements of inclusions within the samples are shown in Fig. 22. The figure illustrates the homogenisation temperature (T_H) of the inclusions and the frequency distribution, and it can be seen that the homogenisation temperature of the inclusions ranges from 255° to 389° C. However, the highest frequency distribution occurs at temperatures between 260° and 270° C for sample GL. 10, between 270° and 280° C for samples GL. 2 and GL. 30, between 290° and 300° C for sample GL. 32, and between 330° and 340° C for sample GL. 26.



GL.2 GL.10

GL.26 GL.30



GL.32

Code of Sample	Hom. Temperature	
	Range (°C)	Highest Freq. (°C)
GL. 2	260-386	270-280
GL.10	251-389	260-270
GL.26	262-387	330-340
GL.30	259-286	270-280
GL.32	255-365	290-300

Fig. 22 Distribution of homogenisation temperature (T_H) of fluid inclusions

To obtain the true trapping temperature, a temperature correction was estimated using the salinity-homogenisation-pressure diagram of Potter (1977), as shown in Fig. 23.

The approximate pressure was obtained from a geologic construction of the area. From the stratigraphic column of the area it was estimated that the maximum thickness of rocks (overburden) that could have covered the veins is about 1300 m (van Bemmelen, 1949). Using the formula for estimating the depth of trapping (see 'Methods'), the pressure of overburden obtained is approximately 350 bars. However, this pressure is considered as a maximum pressure, because of the likelihood that some units were eroded prior to mineralisation. For the estimation of a temperature correction in this study, the overburden pressure of 250 bars (25 MPA) was taken as a reasonable estimate.

Using the diagram in Fig. 23 it was found that the temperature correction for all samples fell at and below 20° C. According to Yazima and Ohta (1979), a pressure correction of 20° C and lower, can be ignored. Therefore a pressure correction was not applied in this study. So, the homogenisation temperatures measured in the heating work can be considered as trapping temperatures. However, it must be remembered that no evidence of fluid boiling was found. This was proved by the absence of extremely high or low density liquid of vapour phases in the inclusion.

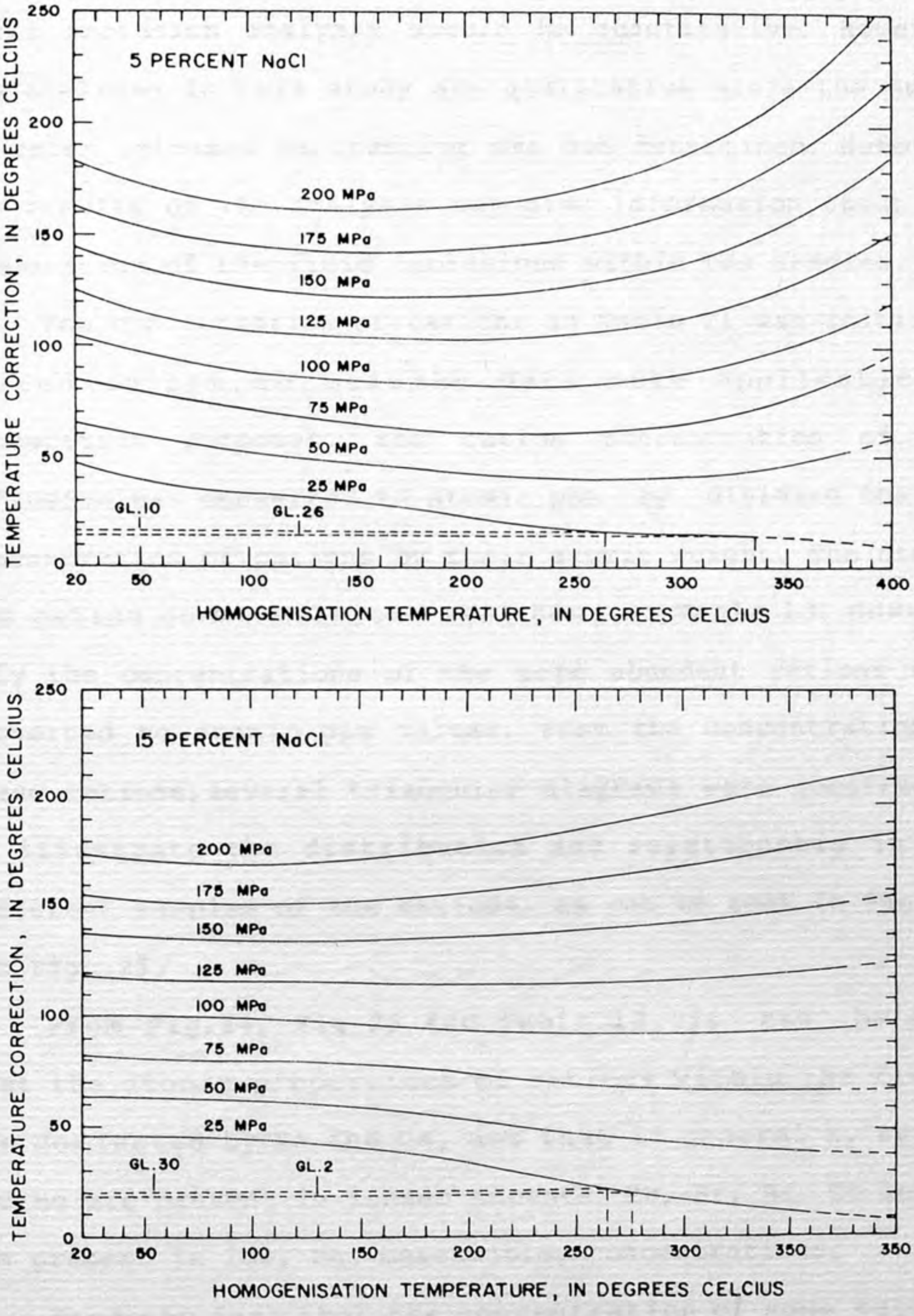


Fig. 23 Temperature correction for fluids as a function of homogenisation temperature (After Potter, 1977)

The results of chemical analysis of fluid inclusions from 11 quartz samples are shown in Table 12. Ideally a fluid inclusion analysis should be quantitative. However, the analyses in this study are qualitative since the amount of water released on crushing was not determined. However, the results of the analysis may give information about the composition of the fluid inclusions within the samples.

The concentration of cations in Table 11 was initially stated in ppm. To make the data more applicable for comparative purposes, the cation concentration of the inclusion was converted to atomic ppm by dividing the ppm concentration of cations by their atomic weight. The atomic ppm cation concentrations are shown in Table 13. However only the concentrations of the more abundant cations were converted to atomic ppm values. From the concentration of these cations, several triangular diagrams were constructed to illustrate the distribution and relationship in the different samples of the cations, as can be seen in Fig. 24 and Fig. 25.

From Fig.24, Fig.25 and Table 13, it can be seen that the atomic proportions of cations within the fluids are dominated by Na and Ca, and that in general K, Fe, Li and Mg are present in lesser amounts. Mn, Sr, Ba, Cu and Zn are present in low, but measurable, concentrations.

From the fact that the concentration of some cations within the host rock (including Na, Ca, Mg and Al) show a depletion during alteration (see Fig. 16), it is presumed

Table 12. Volumetric ppm concentration of cations in the fluid inclusions

CODE OF SAMPLE	CATIONS CONCENTRATION (ppm)										
	Na	K	Ca	Fe	Mg	Mn	Sr	Ba	Cu	Zn	Li
GL. 2	5.29	1.38	5.42	0.29	0.35	0.10	0.06	0.02	0.31	0.11	0.13
GL. 9	4.33	1.13	5.00	0.52	0.38	0.11	0.04	0.02	0.34	0.14	0.18
GL.10	0.18	0.20	2.19	0.23	0.30	0.06	0.02	0.01	0.11	0.02	0.08
GL.11	0.42	0.75	5.19	1.03	0.63	2.02	0.05	0.04	0.16	0.18	0.23
GL.13	4.04	0.67	3.52	0.33	0.32	0.11	0.04	0.02	0.10	0.08	0.15
GL.14	0.33	0.19	1.71	0.19	0.31	0.06	0.01	0.01	0.11	0.06	0.17
GL.26	0.17	0.40	1.81	0.18	0.30	0.05	0.01	0.01	0.10	0.12	0.11
GL.29	1.00	0.80	2.83	0.50	0.39	0.21	0.02	0.02	0.13	0.08	0.17
GL.30	5.33	1.21	5.15	0.22	0.33	0.16	0.02	0.02	0.11	0.10	0.11
GL.32	3.08	0.75	3.13	0.21	0.32	0.07	0.01	0.01	0.11	0.05	0.14
GL.35	1.25	0.63	2.89	0.31	0.34	0.09	0.01	0.01	0.10	0.10	0.11

Table 13. Atomic ppm concentration and ratio of some cations in the fluid inclusions

CODE OF SAMPLE	CATIONS					$\frac{K}{Na}$	$\frac{Ca}{Na}$	$\frac{Fe}{Na}$	$\frac{Mg}{Na}$
	Na	K	Ca	Fe	Mg				
GL. 2	0.23	0.04	0.14	0.01	0.01	0.17	0.60	0.04	0.04
GL. 9	0.19	0.03	0.12	0.01	0.02	0.16	0.63	0.05	0.11
GL.10	0.01	0.01	0.05	0.01	0.01	1.00	5.00	1.00	1.00
GL.11	0.02	0.02	0.13	0.02	0.03	1 00	6.50	1.00	1.00
GL.13	0.18	0.02	0.09	0.01	0.01	0.11	0.50	0.60	0.60
GL.14	0.01	0.01	0.04	0.01	0.01	1.00	4.00	1.00	1.00
GL.26	0.10	0.01	0.05	0.01	0.02	0.05	5.00	0.25	0.50
GL.29	0.40	0.02	0.07	0.01	0.02	0.05	1.75	0.25	0.50
GL.30	0.23	0.03	0.13	0.01	0.01	0.13	0.56	0.04	0.04
GL.32	0.13	0.02	0.08	0.01	0.01	0.15	0.62	0.08	0.08
GL.35	0.05	0.02	0.07	0.01	0.01	0.40	1.40	0.20	0.20

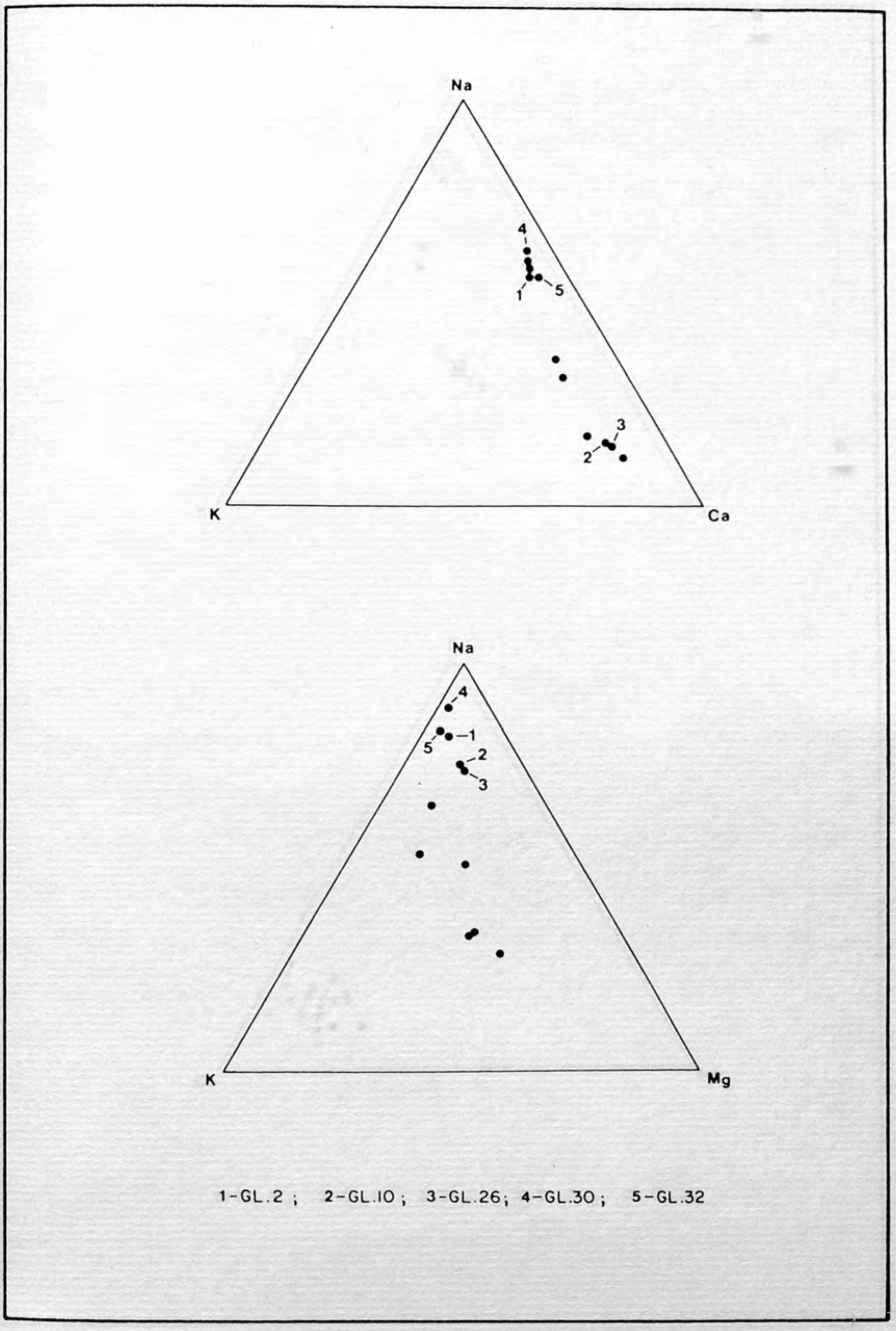


Fig. 24 Distribution of cations within inclusions (atomic proportions)

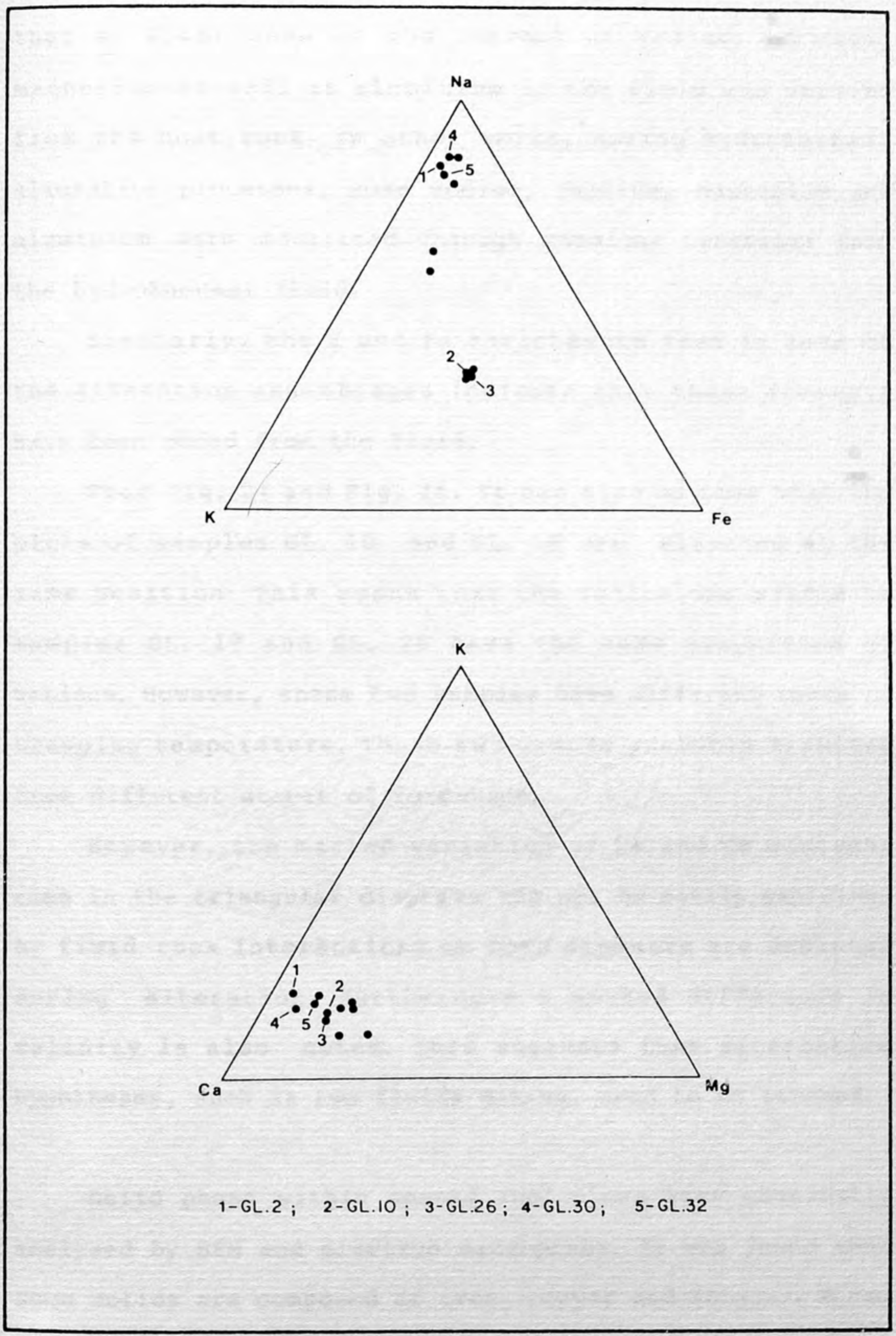


Fig. 25 Distribution of cations within inclusions (atomic proportions)

that at least some of the content of sodium, calcium, magnesium as well as aluminium in the fluid was derived from the host rock. In other words, during hydrothermal alteration processes, some sodium, calcium, magnesium and aluminium were mobilised through chemical reactions into the hydrothermal fluid.

Similarly, the K and Fe enrichments seen in some of the alteration assemblages indicate that these elements have been added from the fluid.

From Fig. 24 and Fig. 25, it can also be seen that the plots of samples GL. 10 and GL. 26 are situated at the same position. This means that the inclusions within the samples GL. 10 and GL. 26 have the same proportion of cations. However, these two samples have different range of trapping temperature. These two sample probably resulted from different stages of formation.

However, the marked variation of Na and Ca contents seen in the triangular diagrams can not be easily explained by fluid-rock interactions as both elements are depleted during alteration. Furthermore a marked difference in salinity is also noted. This suggests that alternative hypotheses, such as two fluids mixing, need to be invoked.

Solid phase within opened inclusions were chemically analysed by SEM and electron microprobe. It was found that some solids are composed of iron, copper and sulphur. These minerals may be chalcopyrite and are trapped phases rather than daughter minerals. These phases probably crystallised in the moving fluid and were later trapped in the growing inclusions. If so, the fluids in the inclusions would be saturated in Cu, Fe and S, and would be representative of the ore-bearing fluid. Alternatively, some faulting or shearing of the ore could have caused later hydrothermal solutions to carry the minerals, which were then 'captured' in the inclusion as can be seen in Plate 31. Other probable daughter minerals were also found from the analyses. The only elements identified from these minerals were aluminium and sodium. These minerals are probably dawsonite (as already suggested from microscopic observation). If this identification is correct, then a certain amounts of CO_2 must be present in the fluid.

As suggested from the salinity measurements, which are marked by low to moderate salinities, daughter minerals of sodium chloride or potassium chloride were rarely found in the inclusion.

VI.3 Conclusions

From the thermometric (freezing and heating), chemical and scanning electron microscopic analyses, information was obtained which could be used to help determine the origin of the hydrothermal solutions causing ore mineralisation.

The inclusions within the samples show a wide range of salinity. Samples GL. 10 and GL. 26 have arange in salinity between 0.2 and approximately 10 % wt NaCl eq., but the distribution is concentrated around 0.2 - 4 % wt NaCl eq. A wider range of salinity was found in inclusions in samples GL. 2 and GL. 30. The salinity of the inclusions of these samples ranges from about 8 to 23 % wt NaCl equivalent, with the highest distribution occurring around 10 - 15 % wt NaCl eq. From the salinity data of the 4 samples, it can be said that the salinity of inclusions within the samples can be classified into two ranges. The first range is a fluid salinity between 0.2 and 5 % wt NaCl eq., and the second range is a salinity between 10 and 15 % wt NaCl eq.

The results of homogenisation temperature measurements show that there are no major differences recognised in the homogenisation temperature of the inclusions among the samples. The homogenisation temperature of inclusions within samples GL.2, GL.10, GL. 26, GL. 30 ranges from

260° to 300° C. However, a slightly higher homogenisation temperature is seen for the inclusions within sample GL.30 (of the order of 330° - 340° C).

The temperature correction estimation from the salinity, pressure and homogenisation data falls at and lower than 20° C. This is considered to be small, and therefore can be ignored for trapping temperature estimation. So, in this study the homogenisation temperature was considered to be equivalent to the trapping temperature.

From chemical analysis of the fluid inclusions it was found that the concentration of cations in the inclusions is dominated by sodium and calcium, with lesser amounts of iron, lithium, potassium and magnesium.

From the fact that the concentration of some cations in the host rock in tunnel T.580 (including Ca, Na and Mg) toward the ore zone shows a depletion (see Fig. 15), it is possible that some of the sodium, calcium and magnesium in the inclusions was derived from the host rock. In other words, during the hydrothermal alteration some amounts of sodium, calcium and magnesium were released to the fluid whilst some potassium was added to host rock. The relatively low concentration of potassium in the inclusion fluids could be caused by the loss of K, to form sericite and K-feldspar in the altered rocks.

However, there is also a variation in the salinity of the inclusions within the samples, and this cannot be readily explained by rock alteration processes. Fluid mixing seems a more likely explanation.

According to Eastoe (1978) and Takenouchi (1980), low salinity fluid inclusions indicate that the fluid originated from circulating meteoric / ground waters. On the other hand, in the absence of boiling, a moderate salinity for fluid inclusions suggest the possibility of magmatic fluids. Thus, there is the possibility of mixing between pre-heated meteoric / ground waters and more saline water of magmatic origin (e.g Watanabe, 1978). The relatively low and uniform temperature indicates that this 'magmatic' fluid had already been cooled - possibly by the mixing with the cooler meteoric fluids.

Thus, it is suggested that the hydrothermal solutions involved in the mineralisation in the study area were originally derived from mixing of pre-heated meteoric waters and magmatic waters exsolved from the quartz-diorite intrusions.

The differences of trapping temperature of the inclusions in the different samples reflects several generations of mineral formation. It is likely that the lower temperatures indicate a later stage of mineral formation (Roedder, 1967).

CHAPTER VII GENESIS AND ORIGIN OF THE MINERALISATION

This chapter briefly describes the genesis and origin of the mineralisation at Gunung Limbung, based on the field observations and laboratory work.

The mineralisation at Gunung Limbung is closely related to plutonic igneous host rocks which were emplaced during the Plio-Pleistocene period.

From the estimation of overburden thickness from the stratigraphic column it is suggested that the earlier Gunung Limbung monzodiorite and the later Gunung Paniis quartz diorite intrusions were emplaced at shallow to moderate depth (i.e. up to approx. 1500 meters). These intrusions were emplaced into Pliocene sediments (predominantly volcanoclastic), and were associated with regional tectonic fractures. On stratigraphic evidence these two intrusions were emplaced within a small time span.

From work in adjacent areas it is suggested that the mineralisation was related to the later intrusion of quartz diorite, but it is emplaced in monzodiorite which was previously enriched in certain 'ore' elements (Pb, Zn, Ba). The ore was formed in fissures and fractures formed as a result of compressional and tensional forces within the monzodiorite, resulting in a classic vein-type deposit.

Whether the ore is directly related to the quartz diorite intrusion itself or secondary processes is unclear. However, the mineralisation is intimately associated with the movement of hot fluids (i.e. hydrothermal solutions), which acted as metal transporters.

There are four possible sources of hydrothermal solutions which need to be considered here:

(1) The process of crystallisation, including differentiation and crystal settling gradually increases the concentration of the more volatile and fugitive constituents in a magma. The lighter, volatile fraction, plus compounds that crystallise at lower temperatures than the bulk of the magma, accumulate near the top of the magma chamber. The volatiles and the materials of low freezing point are the 'mother liquor' of pegmatites and hydrothermal fluids. Water with this origin is 'magmatic water'. It contains various elements (including sulphur, chlorine, arsenic, etc) known as 'mineralisers' (i.e. metal transporters) which are present in small but essential amounts in all magmas (Park and MacDiarmid, 1970).

(2) Water derived from the atmosphere/surface (including rain, snow, and rivers) which penetrates the rock is termed 'meteoric water'. Such water sinks into the earth and assumes the temperature of the enclosing rocks. As a result the water temperature generally

increases with depth of circulation. The contents of dissolved mineral substances generally increase as water temperature inceases (Park and MacDiarmid, 1970).

(3) Water trapped in sediments at the time they were deposited is known as 'connate water'. This term was first used for brine flowing into the deeper levels of the Michigan copper mines. Many connate waters are rich in sodium and chlorine and may contain barium, strontium and nitrogen (White, 1957). Brown (1965) says that metals, particularly lead, are concentrated in connate waters which are activated by magmatic processes.

(4) Under favourable circumstances, connate and meteoric waters enclosed in rocks buried below the surface of the earth may be set in motion and made chemically reactive by heat and pressure accompanying magmatic intrusion or regional metamorphism. These are so called 'metamorphic waters', and many geologists believe that these waters are active ore carriers. According to Boyle (1979), metamorphic water is mainly derived by dehydration of hydrous silicate minerals such as mica during metamorphism. This style of mineralisation is called the metamorphic hydrothermal association and includes regional metamorphism and contact metamorphism. This type of water is not a favourable source of hydrothermal solutions in the

study area, since there is no extensive metamorphic terrain found in this region.

From the fluid inclusion studies it has been found that the hydrothermal solutions involved in the formation of ore at Gunung Limbung had a variable salinity (0.2-5 % wt NaCl eq. to 10-15 % wt NaCl eq.), and moderate temperature (ranging from 260° to 350° C). The low salinity tends to suggest that these solutions were generated from meteoric waters (Takenouchi, 1979). The moderate salinity fluid probably had a different origin and could have been caused by mixing of fluids for example meteoric water with connate water or magmatic water. The moderate temperatures suggests an input from magmatic water; this assumption is in accordance with what geologists conclude, that hydrothermal ore bearing fluids may be composed largely of meteoric or connate waters (or mixtures of these two waters) activated by means of igneous intrusion and possibly combined with fluids emitted from the magma (Park and MacDiarmid, 1970).

Recent research in intrusive igneous environments like that of Gunung Limbung, utilising $^{18}O : ^{16}O$ and other isotopic ratios (Marmount, 1983), strongly suggest that ore metal deposition took place essentially from 'meteoric water', set into convective circulation with rising igneous intrusions. This concept is illustrated in Fig. 26.

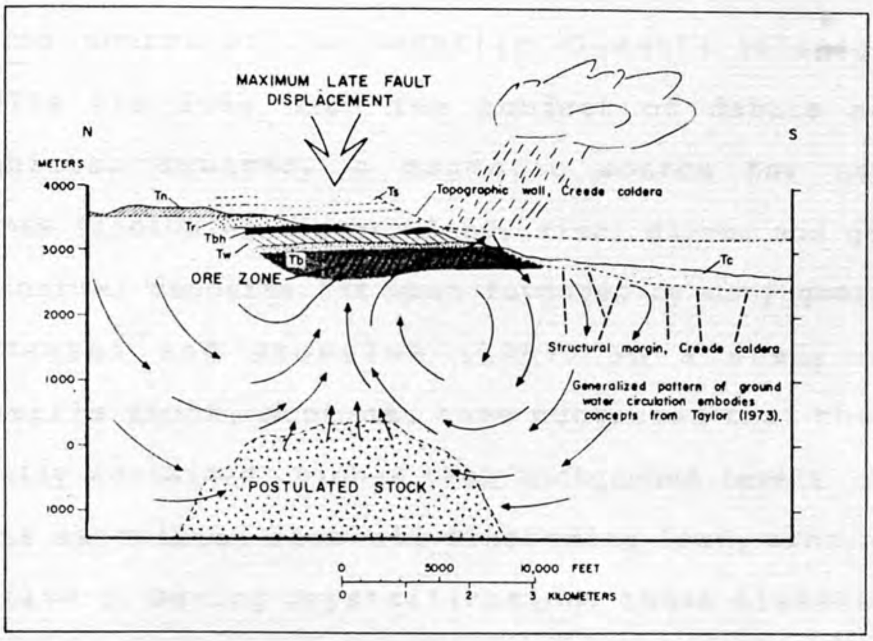


Fig. 26 Conceptual model of 'meteoric water' circulation, with an idealised example: the north-south section through the Creede mining district, Colorado
Tc, Creede Formation; Ts, Snowshoe Mountain Tuff; Tn, Nelson Mountain Tuff; Tr, Rat Creek Tuff; Tbh, andesite of Bristol Head; Tw, Wason Park-Tuff; Tb, Bachelor Mountain Member, Carpenter Ridge Tuff.
(From: Steven and Eaton, Econ. Geol., 70, 1975)

Although no isotopic work has yet been carried out at Gunung Limbung, the setting can be compared to other areas within the Circum Pacific Belt which have similar types of mineralisation and alteration, igneous intrusion, ore forming temperature, nature of ore zones and tectonic system (see Appendix E for the examples). Possible sources of the hydrothermal solution involved in the formation of ore at Gunung Limbung are much meteoric water, mixed with more saline water of magmatic origin.

The source of the metallic elements in epigenetic deposits has long been the subject of debate amongst geologists. However, a magmatic source for metallic elements (including copper, lead, zinc, silver and gold) in hydrothermal deposits has been favoured by many geologists.

Mantei and Brownlow (1967) in a study of the Marysville stock, Montana, have suggested that the magma initially contained higher than background levels of gold and its associated elements (including lead, zinc, copper and silver). During crystallisation, these elements were concentrated in the residual phases, migrating towards the margins of the intrusion.

However, Tilling et al. (1973) have demonstrated that the metallic element content of unaltered igneous rocks is restricted and is normally not higher than background levels. They emphasise that higher metallic element contents result from secondary processes, rather than from the initial magmatic abundance. This is demonstrated by surface geothermal systems in which both the hydrothermal fluid and the country rocks are low in metal element content. Yet, a long-lived hydrothermal system can increase the metal concentration to several hundred times background levels.

Kwong and Crocket (1978) in a study of various rock types in the Kakagi Lake area of northern Ontario, concluded that the primary gold and associated element contents of igneous rocks do not play a role in subsequent concentration. They note that quartz and feldspar are poor retainers of gold and associated elements compared to ferromagnesian minerals, and if the elements do not separate from the melt along with the early stage of mafic minerals, they will not be retained in the residual felsic magma, but will be lost to the volatile phase. So, a direct magmatic origin for primary gold and associated mineral deposits in this case is not likely.

However, both of these studies have proposed that the metals may be derived either from magma or from the surrounding country rock. At Gunung Limbung there is no definite evidence as to the origin of the metals or the hydrothermal fluid. The country rock could have supplied some of the metals. This assumption is based on the suggestion that activated meteoric and connate waters can be ore metal carriers, and from the fact that there has been an addition of barium and lead to the host rock. These are metals which are commonly concentrated in connate water and mineral deposits associated with connate brines (Evans, 1980).

The elements within the country rock (volcanics and shales) were then leached out and transported by meteoric water. The mixing of meteoric and connate waters with magmatic water may also have added some amounts of the 'ore' elements from the magma to the solution, resulting in an increase in concentration of certain elements in the hydrothermal solution. This would follow from the high level of some the ore elements in the unaltered igneous rock.

With regard to the classical scheme of classification, hydrothermal solutions give rise to hypothermal (high-temperature hydrothermal deposits nearest the intrusion), mesothermal (moderate-temperature hydrothermal deposits at some distance outward), and epithermal (low-temperature hydrothermal deposits farther outward or near the surface) types of deposits. The general temperature ranges as determined by methods of geothermometry are 300°-500° C for hypothermal deposits, 200°-300° C for mesothermal deposits and 50°-200° C for epithermal deposits (Park and MacDiarmid, 1970). However, these temperatures are now believed to be too low, especially for the hypothermal deposits that evidently reach 600° C (Jensen and Bateman, 1979).

The fluid inclusion work carried out in this study shows that the temperatures of formation of the metal deposit at Gunung Limbung are between 260° and 350° C. Therefore, it can be concluded that the deposit in Gunung Limbung is a mesothermal vein-type deposit. The veins were formed in several stages during the Plio-Pleistocene period from hydrothermal solutions closely associated with the dioritic igneous activity.

In conclusion, the ore metals could have been derived from either the country rock (leaching from volcanics and shales) or from the magma.

The hydrothermal solutions which acted as a transport medium were probably a mixed meteoric/connate water, which interacted with the fluid emitted from the magma. The position of the monzodiorite host rock and the quartz diorite intrusive (which caused the mineralisation) are relatively close, indicating that meteoric waters were circulated at a relatively shallow depth. This means that the emplacemant of the quartz diorite intrusion played a multitude of roles in the introduction, remobilisation and concentration of the metals.

CHAPTER VIII CONCLUSIONS AND RECOMMENDATIONS

From the descriptions and discussions in the previous chapters, some conclusions concerning the mineralisation at Gunung Limbung can be made.

The mineralisation at the Gunung Limbung deposit is made up of sulphides of Cu, Pb, and Zn in quartz veins within monzodiorite.

From field observations, and megascopic and microscopic analysis of the ores, it has been found that the mineralisation in Gunung Limbung was formed in several stages resulting in different types of ore. However, the ores have a relatively similar mineral paragenesis, indicating that the minerals have a similar origin.

The deposit has a hydrothermal origin. The mineral bearing hydrothermal solutions were concentrated in fissures, and faults which were related closely to the magmatism and tectonic movements of West Java.

From the fluid inclusion studies it was found that the homogenisation temperature mostly ranges from 260°-300° C. Some inclusions, however, show a higher temperature range (340°-350° C). It is suggested that the homogenisation temperature of the fluid inclusions within the quartz is close to the trapping temperature and furthermore is close to the temperature of the fluid at the time of ore formation, since the ores are closely associated with the quartz. The range of salinity of the fluids is large, mostly ranging from 0.2%-15% wt NaCl equivalents. Two distinct fluid groups can be noted, one with a salinity of 0.2%-2% wt NaCl eq. and one with a salinity of 10%-15% wt NaCl eq. The low salinity fluid group is characterised by relatively high Ca/Na ratios whilst the higher salinity fluid group is characterised by relatively low Ca/Na ratios. The plots of fluid inclusion chemistry on a triangular Na-K-Ca diagram are suggestive of a mixing of two fluids, one relatively Ca-rich, and one relatively Na-rich. An alternative possibility, that the fluid is one which is continually evolving chemically, is also possible but less likely.

From the microscopic analyses of the host rocks from the tunnels it has been found that there are zonal changes in alteration around the ore zone, from propylitic (farthest) to sericitic-silicic-potassic, and advanced-argillic envelopes (closest). An increase in potassium content in the host rock toward the ore zone is also shown from chemical analysis, and is due to the formation of secondary K-feldspar and to a lesser extent sericite during alteration. This zone of K-enrichment forms a zone up to 50 metres around the mineralisation.

The chemical analysis of trace elements within the rock samples shows that most of the altered host rocks have high concentrations of barium, lead and zinc. In tunnel T.580 the concentration of barium, lead and zinc within the host rock shows an increase toward the ore zone. It is clear that there have been additions of these elements to the host rock during hydrothermal alteration.

Therefore, it can be concluded that the ore in Gunung Limbung area is a typical mesothermal vein deposit associated with intermediate igneous (subvolcanic) rocks. It is not at present clear where the hydrothermal solutions which were involved in the formation of ore in the area were derived from. It is possible that they were made up of meteoric water (characterised by the low salinity fluids) which mixed with magmatic water from later intrusions (marked by the higher salinity and temperature fluids).

Likewise the ore metals could have been derived from the country rocks (volcanics and shales), which were leached out by the circulation of meteoric water accompanying the quartz diorite intrusion. This could have acted as a 'heat engine', resulting in a mineralised hydrothermal system. In its circulation the meteoric water could have mixed with fluid emitted from the intrusion, which may also have added some amounts of the 'ore' elements to the solutions.

Further studies are recommended on the rocks of the Gunung Gede-Gunung Limbung area and some of these are in progress.

The most important are:

(1) Geochemistry. There appears to be potential for discriminating the mineralised intrusives on the basis of their trace element content. Chemical analysis of fresh igneous rocks for barium, lead and zinc appears to be useful, especially at the initial stage of exploration for defining potential mineralised and 'barren' intrusive rocks. Further, more detailed studies are necessary to substantiate this. Additionally, such a study could throw light on the origin of the ore metals.

(2) Radiometric dating is necessary to define the ages of the igneous intrusions and the age of the mineralisation associated with the igneous activity. This work (K-Ar or Rb-Sr) could be carried out on fresh rocks or their altered equivalents and would help to define the association between mineralisation and magmatic activity.

(3) Wall rock alteration studies may be useful for determining the lateral extension of the mineralisation. The wide wall rock alteration assemblages (e.g. in tunnel T.580) might be useful in the exploration context

during drilling or during surface and underground mapping. This is especially true for the zone of K-enrichment which can be at least 50 metres wide and therefore constitutes a large target area.

(4) Stable isotope studies. Finally, and perhaps most important, analysis of oxygen and hydrogen isotope ratios in alteration minerals and inclusion fluids should be obtained. Such an approach would be extremely useful for obtaining information on the origin of the hydrothermal fluids responsible for alteration and mineralisation and therefore for understanding the genesis of the ore deposit.

There is great potential for further exploration in the area, both for Cu, Pb and Zn, and for Au and Ag in association with these metals. Similar intrusives should be studied in detail by mapping (including trenching), geochemistry, and geophysics. The deep weathering and thick vegetation in the region will probably hinder such activity. At present it is not entirely clear what the controls on the ore mineralisation at Gunung Limbung are, but the igneous intrusions clearly play an important role and should be the main targets in any exploration programme.

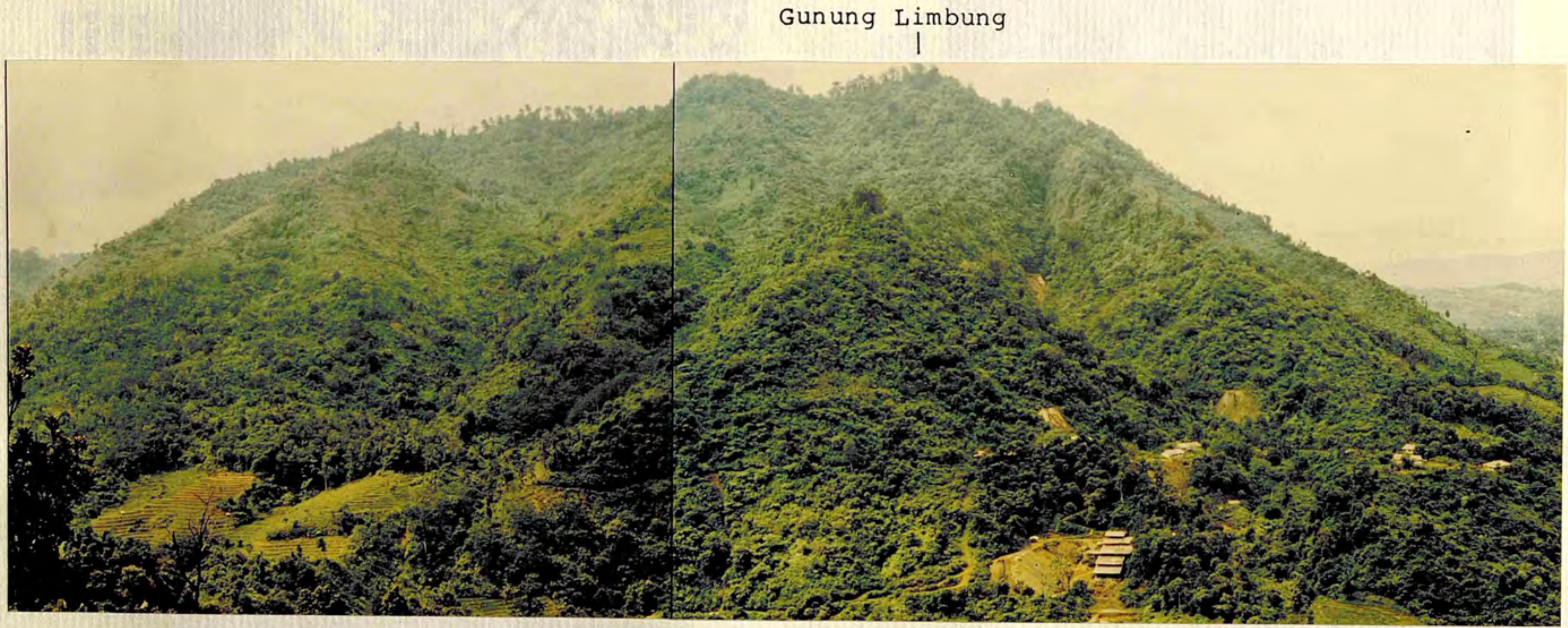


Plate 1. The features of Gunung Limbung (facing south).

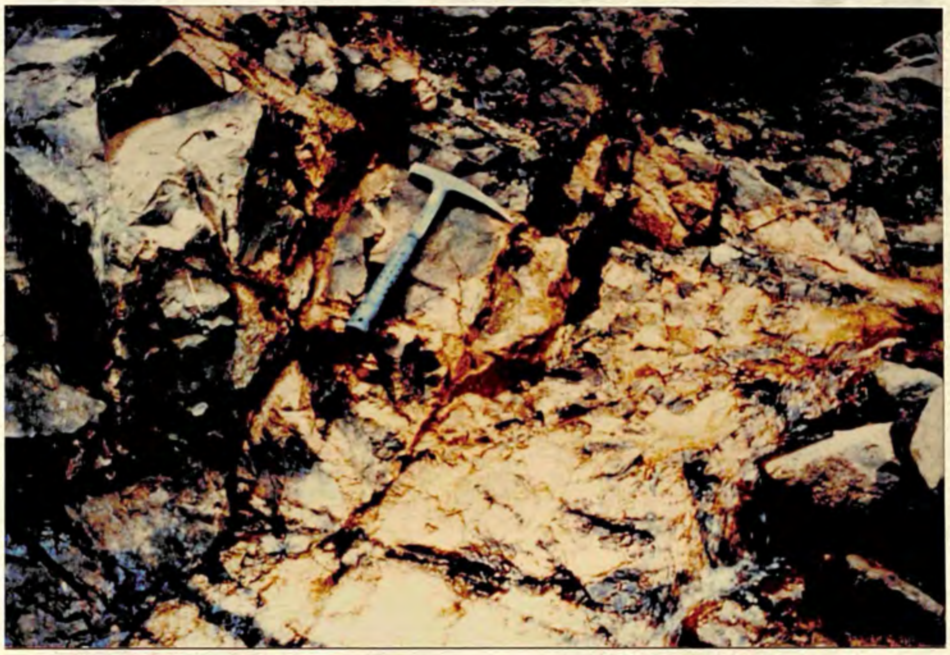


Plate 2. The feature of the monzodiorite outcrop.
Locality: around tunnel T. 400.

Plate 3. Thin section of the monzodiorite, showing hornblende and alkali- and plagioclase-feldspar phenocrysts in a plagioclase groundmass.
Horizontal edges of the photograph ~ 2.75 mm.

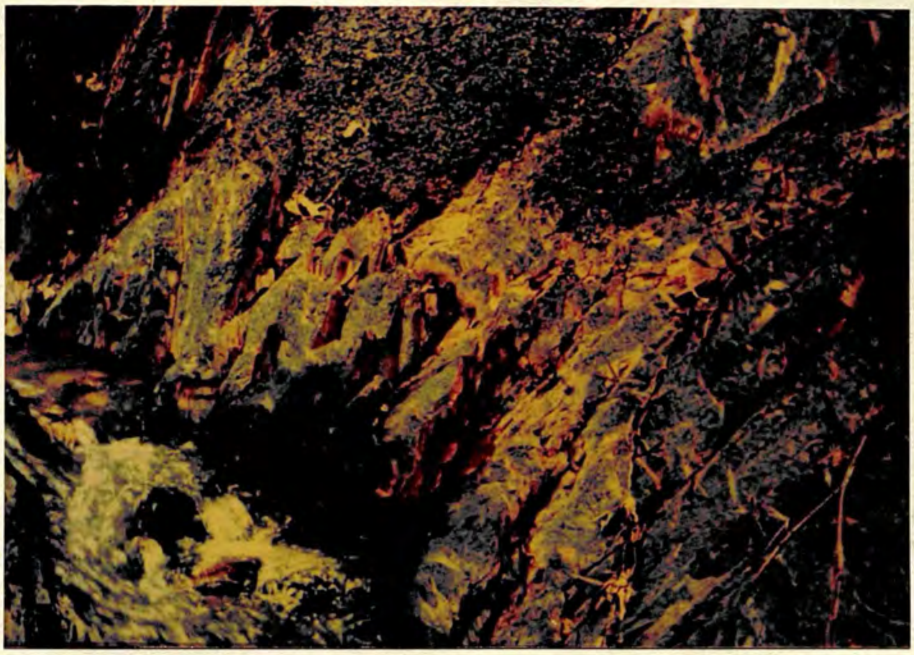


Plate 4. The feature of the argillite outcrop. Locality: western the monzodiorite stock.

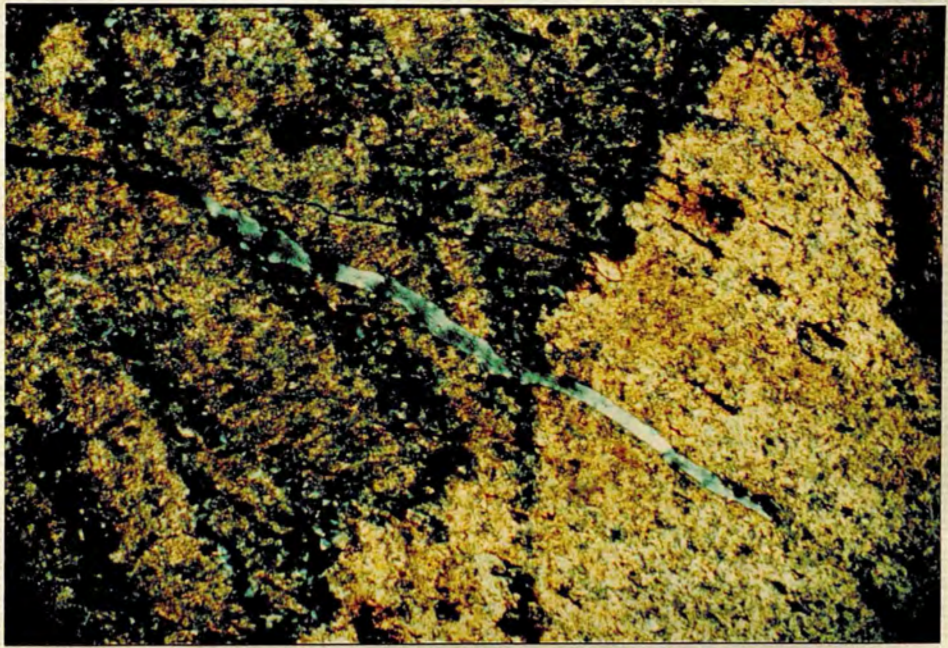


Plate 5. Thin section of the argillite, showing a parallel optical fabric, cut by veinlets. Horizontal edges of the photograph ~ 2.75 mm.

Plate 6. Features of the andesite xenoliths in the monzodiorite boulders along Cimangeunteung river.

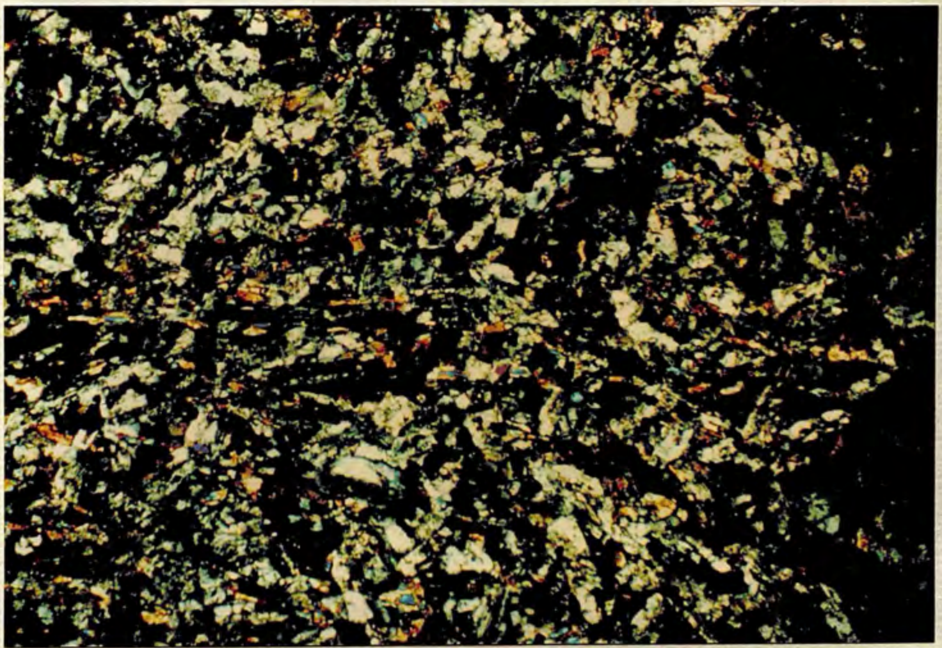


Plate 7. Thin section of the andesite xenolith, showing oriented plagioclase grains.
Horizontal edges of the photograph ~ 2.75 mm.

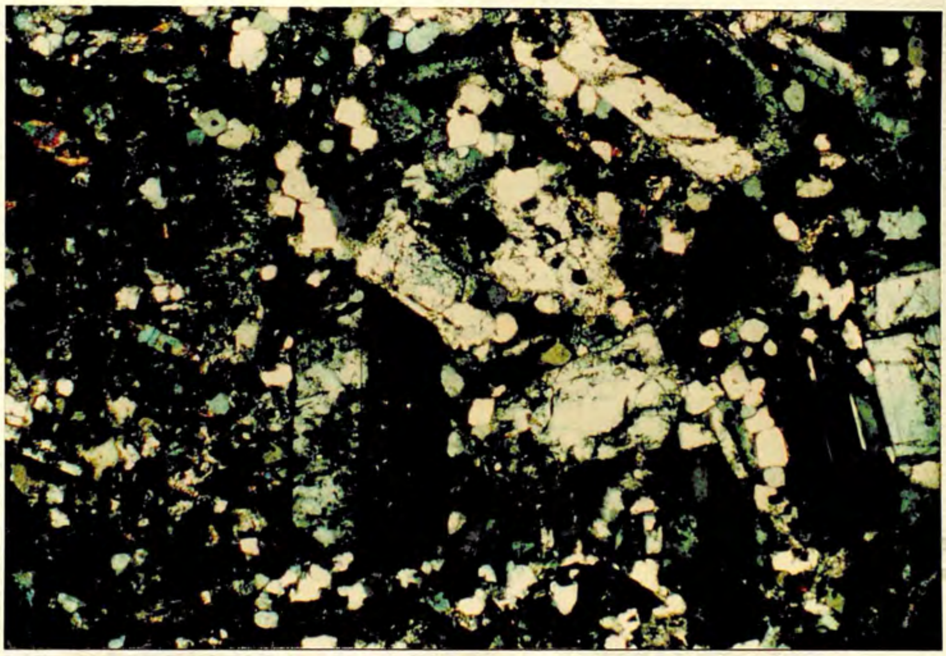


Plate 8. Thin section of least altered monzodiorite from tunnel T.580, about 100 m from the ore zone (GL.22), showing fresh andesine phenocrysts in a plagioclase groundmass.
Horizontal edges of the photograph ~ 2.75 mm.

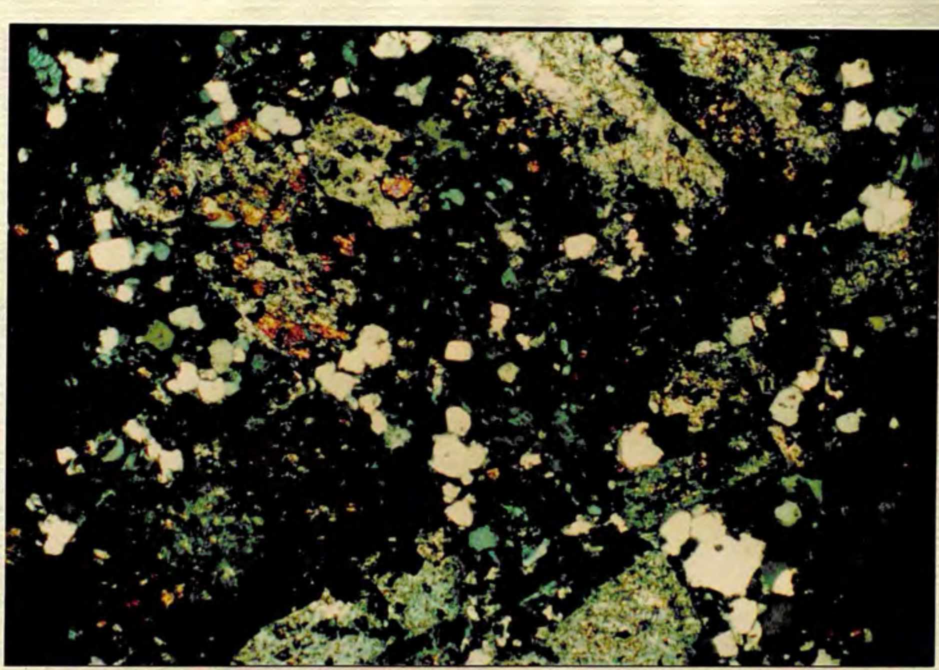


Plate 9. Thin section of moderately altered monzodiorite from tunnel T.580, about 50 m from the ore zone (GL.23), showing the epidotisation, and little sericitisation.
Horizontal edges of the photograph ~ 2.75 mm.

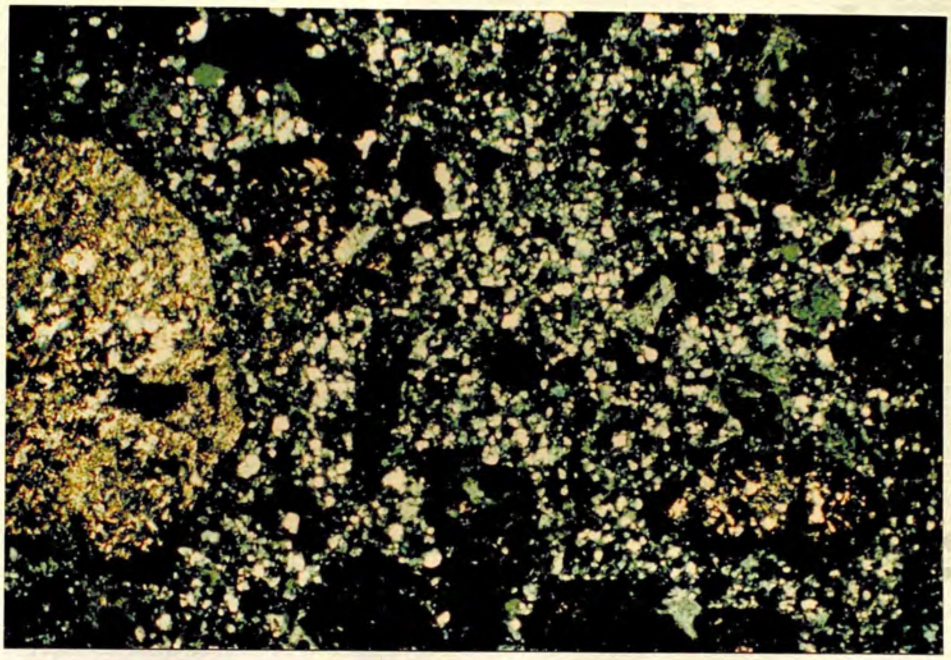


Plate 10. Thin section of strongly altered monzodiorite from tunnel T.580, adjacent to the ore zone (GL.24), showing highly silicification and sericitisation.
Horizontal edges of the photograph ~ 2.75 mm.

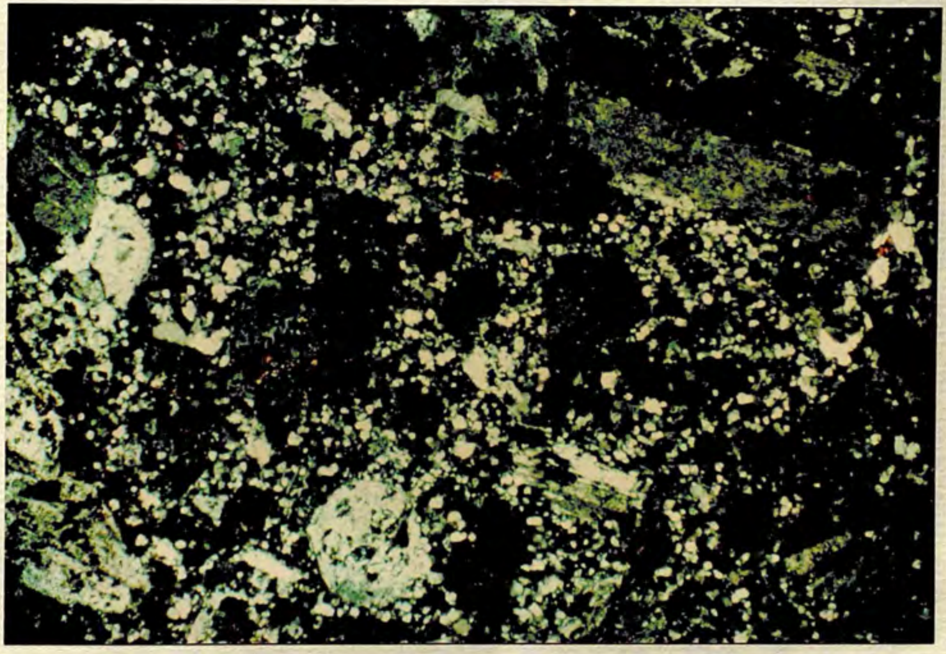


Plate 11. Thin section of strongly altered monzodiorite from tunnel T.580, adjacent to the ore zone (GL.27), showing much silicification and K-feldspathisation.
Horizontal edges of the photograph ~ 2.75 mm.

Plate 12. The entrance to tunnel T.580, which is completely in monzodiorite.

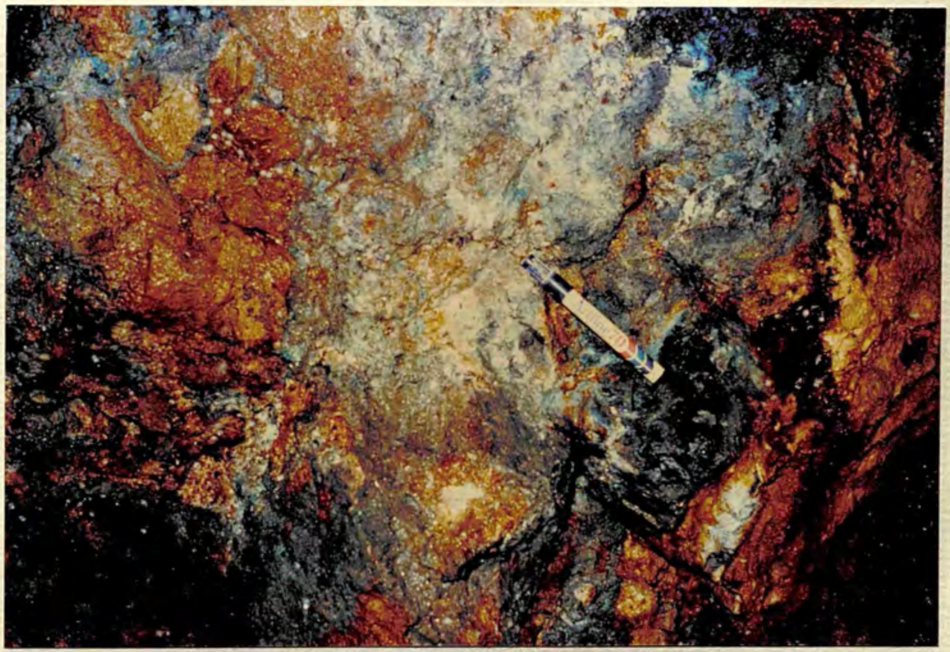


Plate 13. The features of parts of ore zone in tunnel T.580, mainly composed of chalcopyrite (which is partly altered to malachite and azurite) associated with quartz filling the breccia; showing an advanced argillic anteration of the host rock.

Plate 14. The feature of the brecciated ore, showing a massive ore composed of galena (dark grey) and chalcopyrite and pyrite (yellow).
Locality: tunnel T.400.

Plate 15. The features of the mineralised quartz-veins cutting monzodiorite, cut by another mineralised vein.
Locality: tunnel T.400.

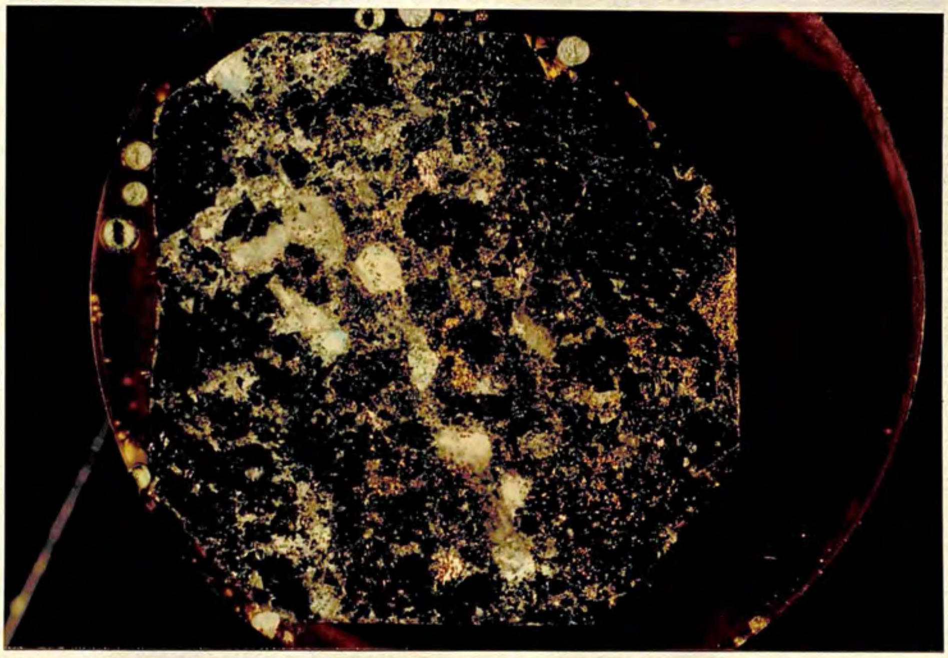


Plate 16. The feature of the brecciated ore (GL.15), mainly composed of galena (dark brown) and chalcopyrite (yellow) associated with little quartz (white).
Diameter of the mounting is 3 cm.

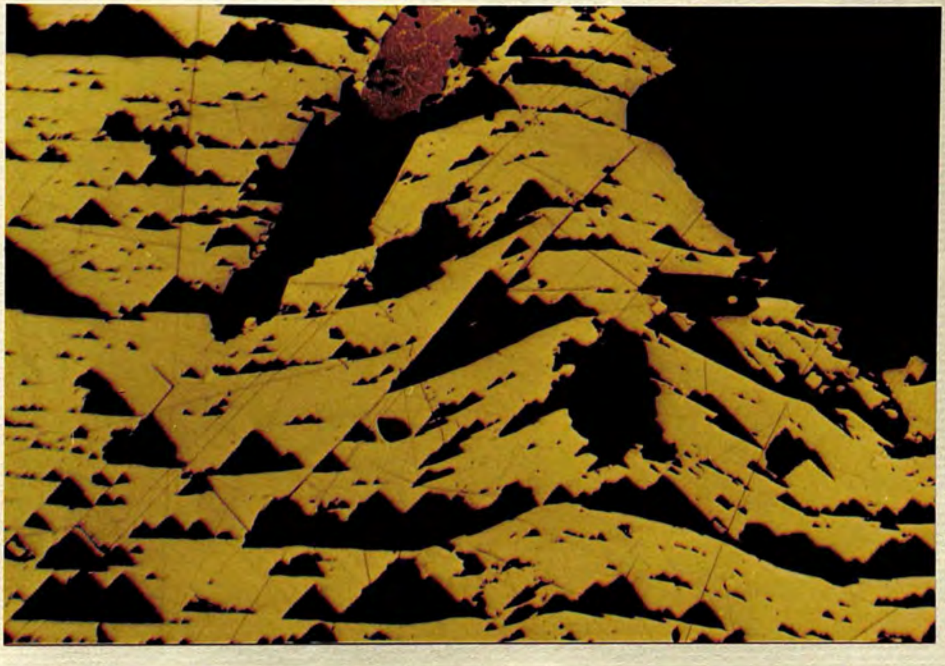


Plate 17. Polished section of brecciated ore (GL.15) showing deformed galena, containing sphalerite grain at the top.
Horizontal edges of the photograph ~ 0.5 mm.

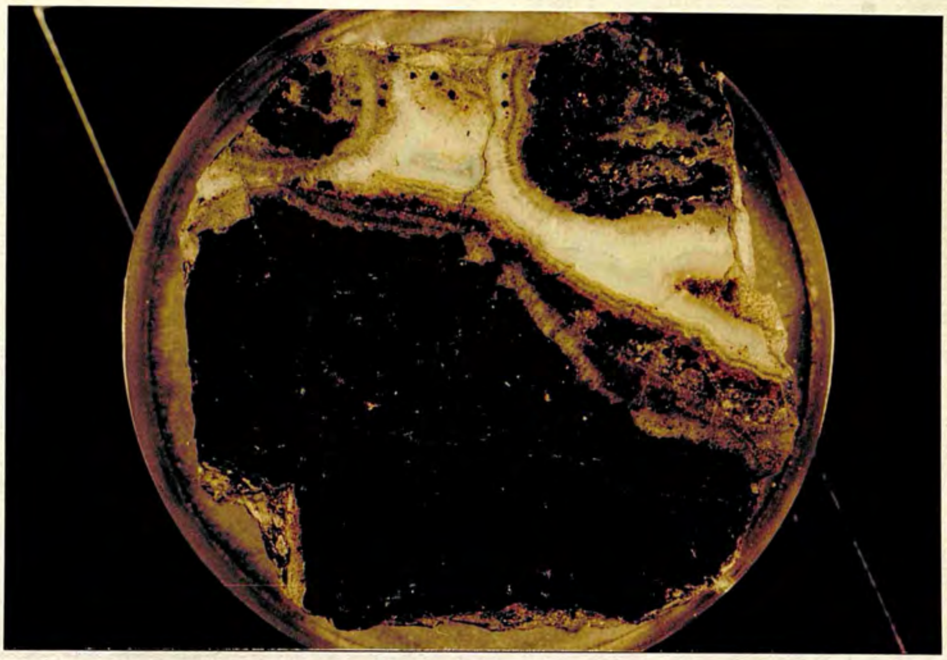


Plate 18. The features of brecciated ore (GL.4) showing a large fragment of sphalerite (dark brown), hostrock and quartz fragments contain chalcopyrite, pyrite and galena. The space between the fragments occupied by quartz forming a 'comb' structure.
Diameter of the mounting is 3 cm.

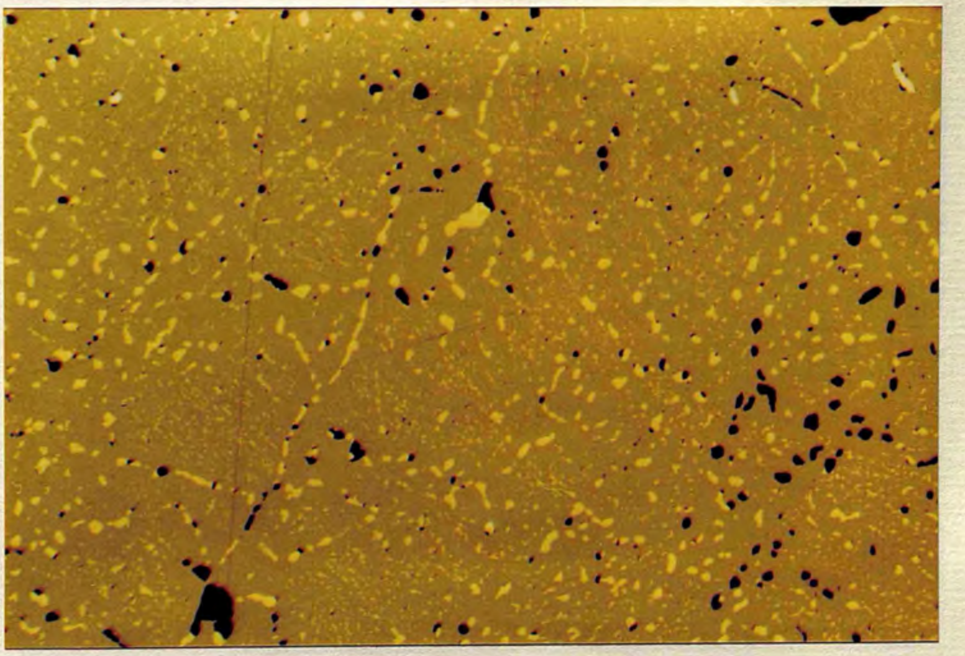


Plate 19. Polished section of sphalerite (GL.4) contains tiny lamellae and small blebs of chalcopyrite (yellow).
Horizontal edges of the photograph ~ 0.5 mm.

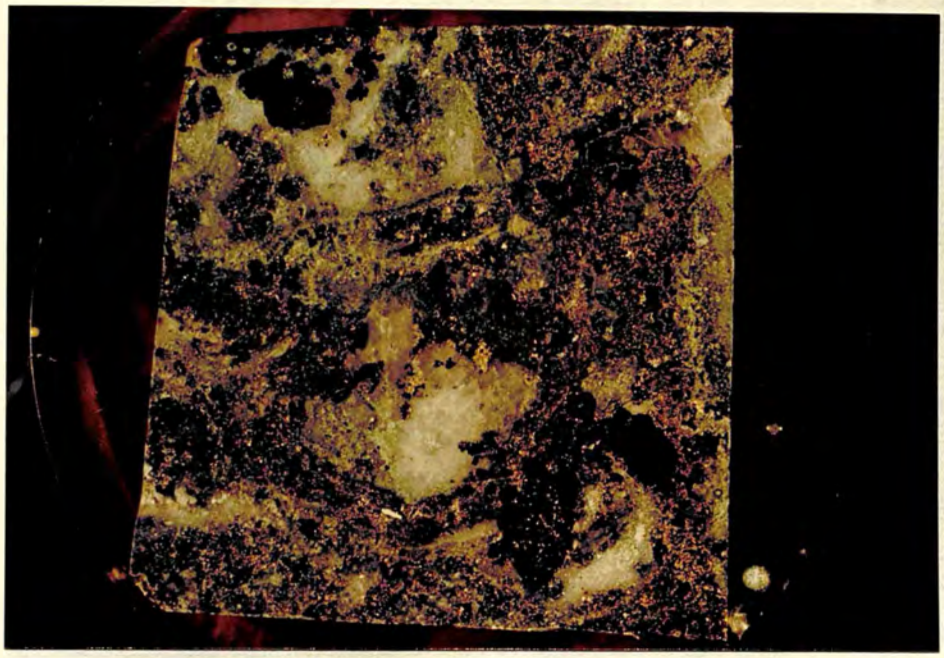


Plate 20. The feature of breccia-filling ore, showing a colloform texture of sphalerite (light brown) surrounding quartz and host rock fragments, associated with pyrite, chalcopyrite and galena (dark brown).
Diameter of mounting is 3 cm.

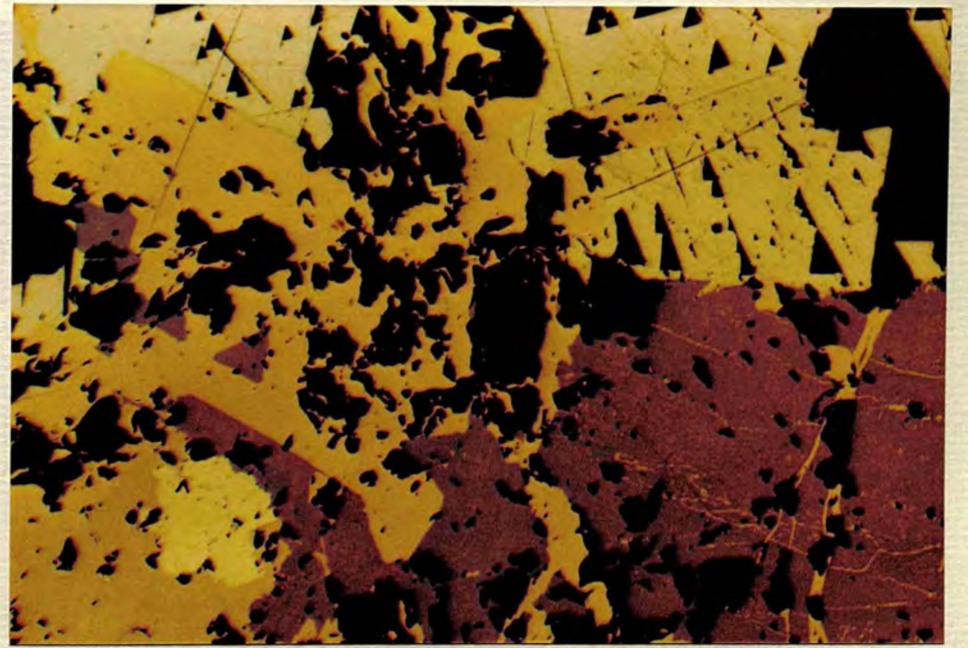


Plate 21. Polished section of breccia-filling ore showing pyrite (pale yellow) and chalcopyrite (yellow) enclosed in galena (with triangular pits) and sphalerite (light brown).
Horizontal edges of the photograph ~ 0.5 mm.

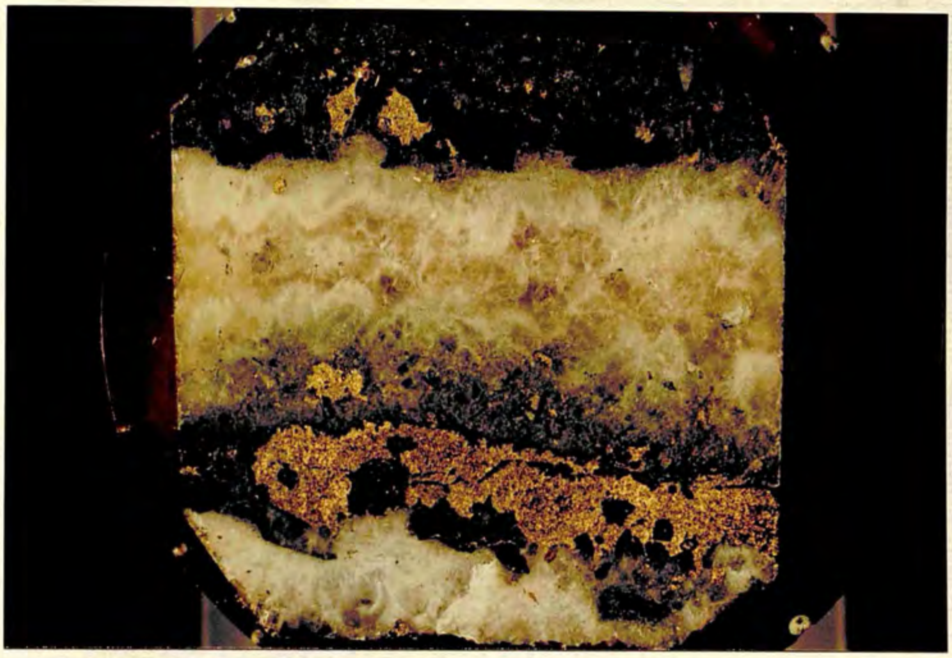


Plate 22. The feature of stratified ore, showing banded sphalerite (light brown) at the top and chalcopyrite (yellow) containing pyrite aggregate (dark brown/black); associated with quartz vein. Diameter of the mounting is 3 cm.

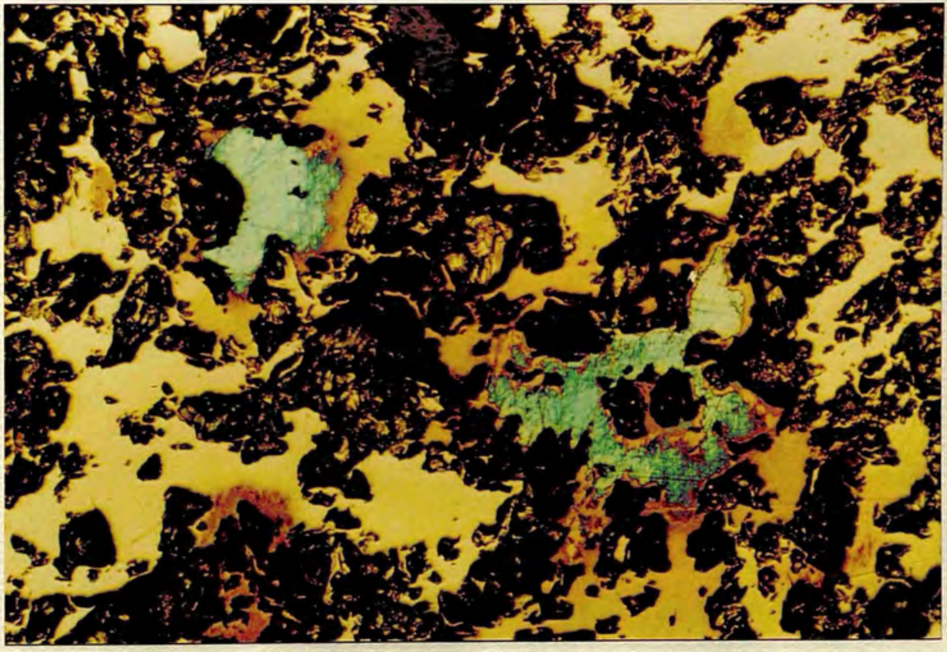


Plate 23. Lamellae chalcopyrite in the stratified ore, partly replaced by covellite (blue). Horizontal edges of the photograph ~ 0.5 mm.

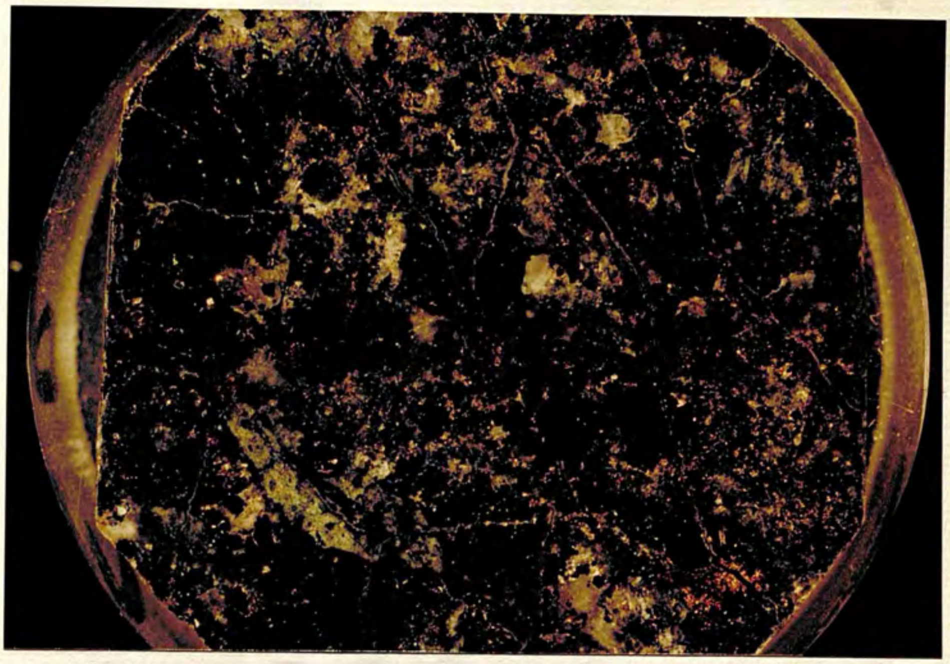


Plate 24. The feature of another type of brecciated ore (GL.12), showing sphalerite grains (dark brown), chalcopyrite (brownish yellow) and wall rock fragments (greenish white).
Diameter of the mounting is 3 cm.

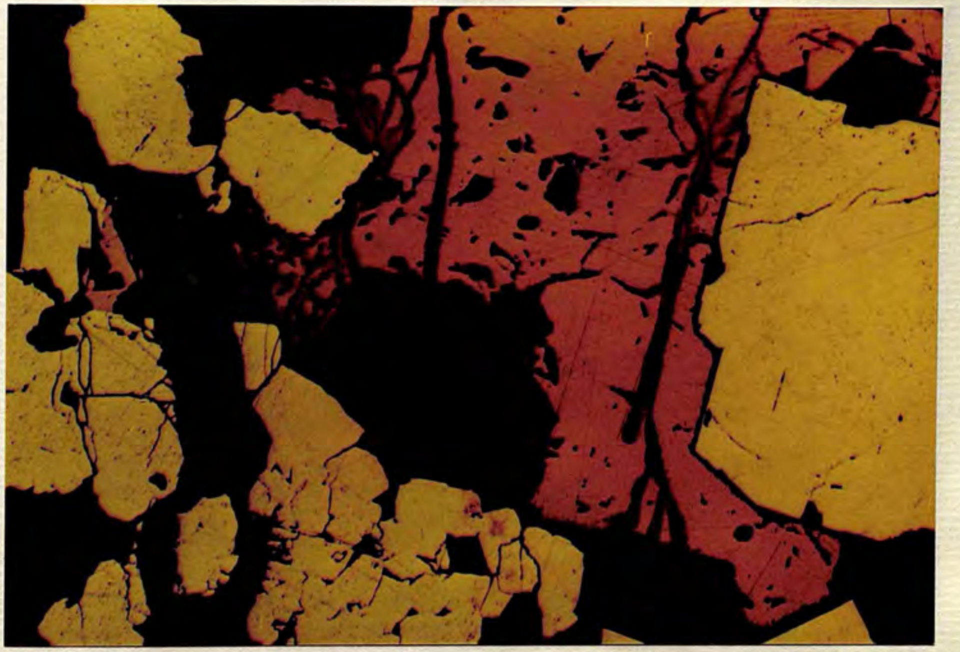


Plate 25. Polished section of brecciated ore, (GL.12) showing euhedral pyrite (pale yellow) enclosed in chalcopyrite (yellow). The edge of the chalcopyrite crystal is replaced by chalcocite.
Horizontal edges of the photograph ~ 0.5 mm.

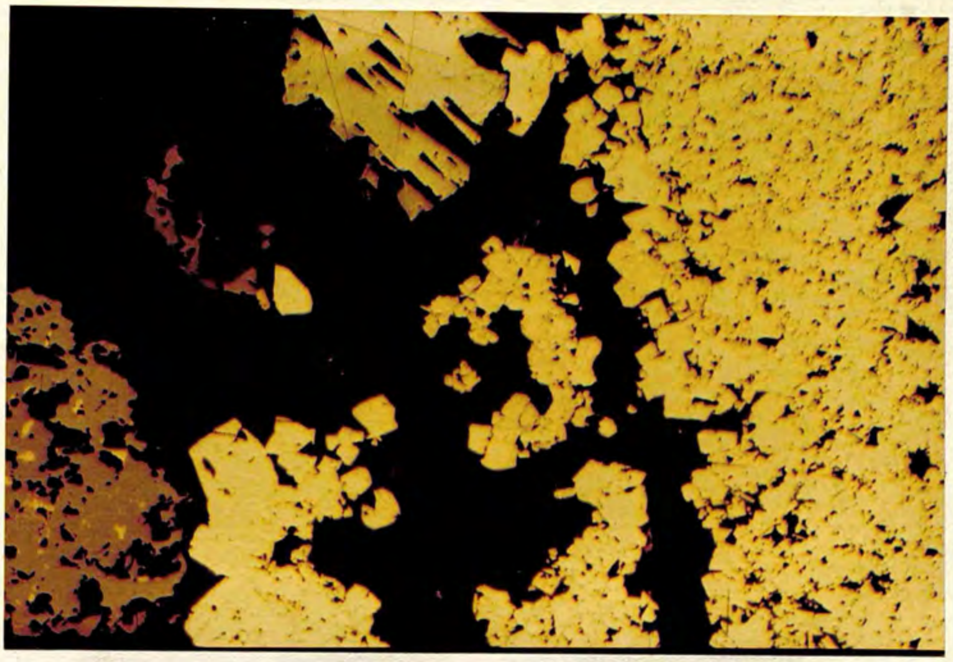


Plate 26. Polished section of brecciated ore, (GL.17) showing cubic crystals of pyrite surrounding framboidal pyrite, and a grain of galena (with triangular pits) and grains of chalcopyrite, associated with quartz.
Horizontal edges of the photograph ~ 0.5 mm.

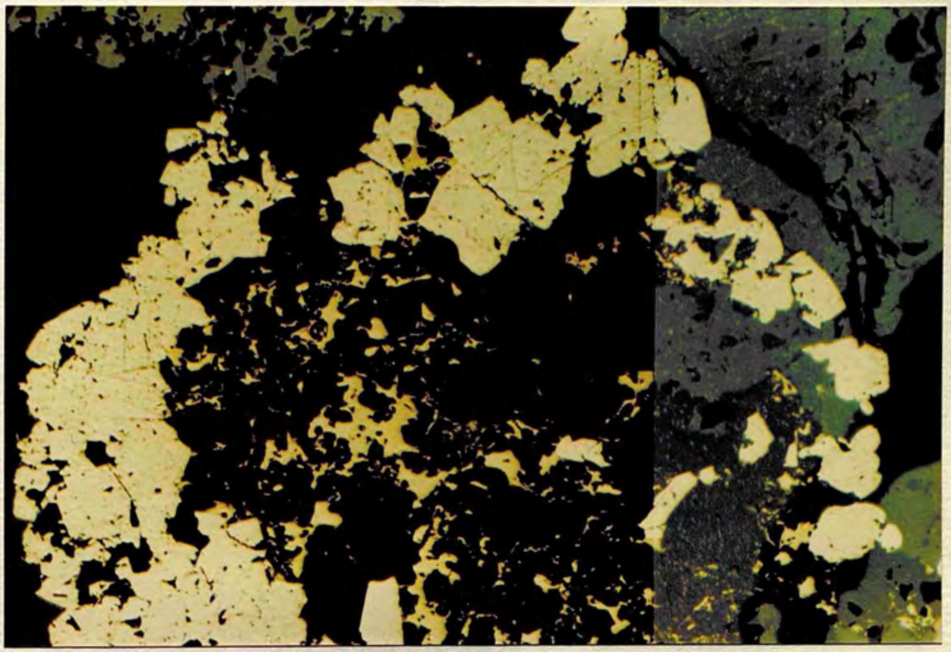


Plate 27. Polished section of brecciated ore, (GL.21) showing chalcopyrite surrounded by euhedral grains of pyrite.
Horizontal edges of the photograph ~ 0.5 mm.

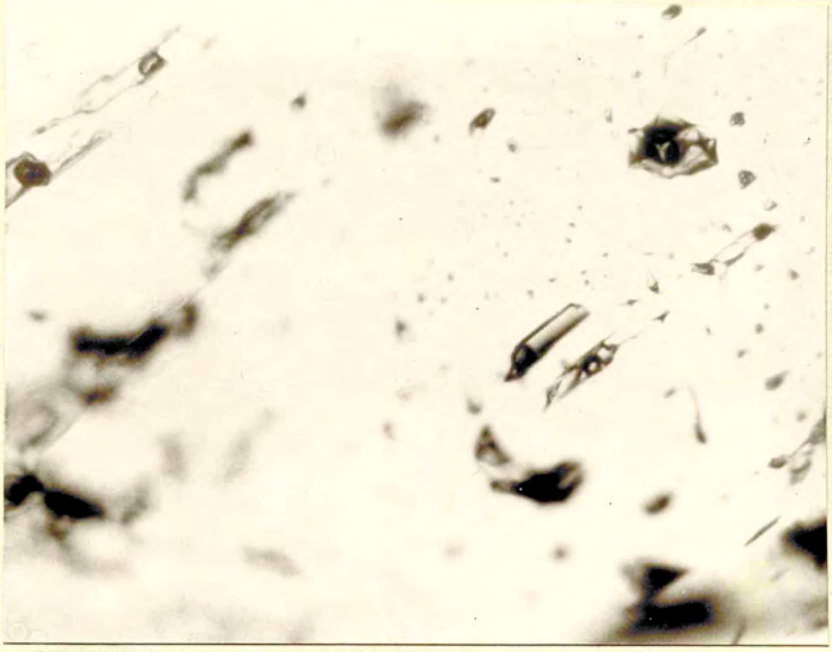


Plate 28. Photomicrograph of fluid inclusions within sample GL.10, showing oriented primary fluid inclusions. Some of the inclusions contain solid phases.
Horizontal edges of the photagraph ~ 300 μm.

Plate 29. Photomicrograph of some fluid inclusions within sample GL.10, showing 'necking down'.
Horizontal edges of the photograph ~ 300 μm.

Plate 30. Photomicrograph of fluid inclusion within sample GL.26, containing solid phases as daughter minerals.
Horizontal edges of the photograph ~ 300 μm.

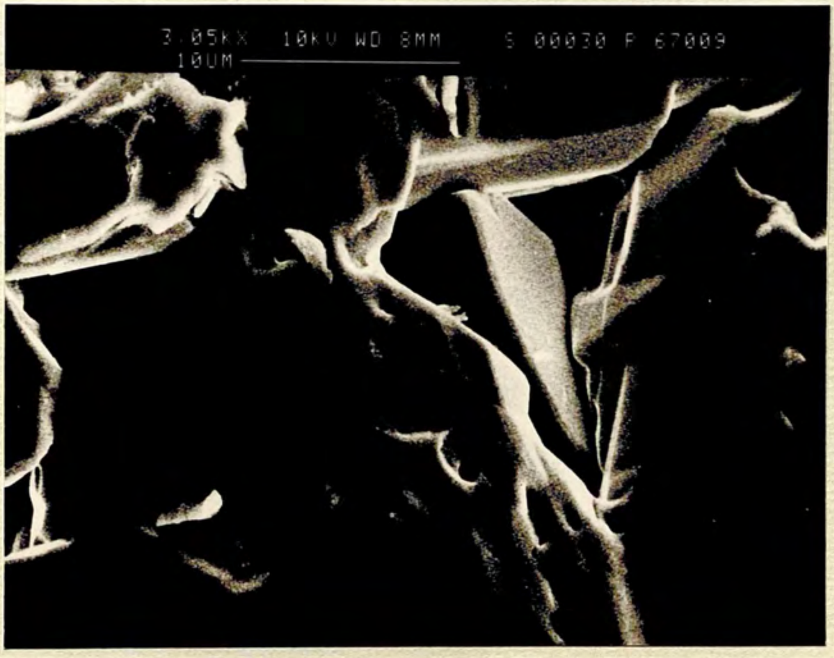


Plate 31. SEM view of opened inclusion within sample GL.30, showing a Cu-Fe sulphide crystal. (Probably chalcopyrite).

Plate 32. SEM view of opened inclusion within sample GL.30, showing several small un-identified solid phases.

APPENDIX A

X-Ray diffraction

X-Ray diffraction is a powerful technique for the identification of a crystalline compound. It is invaluable in all material research relating physical and chemical properties to crystalline state.

Ideally all possible orientations of all possible latice planes are present in a powdered sample. If a beam is passed through a powder of randomly oriented grains there will be sufficient to produced diffracted X-Rays from each set of planes with a characteristic d-spacing. If the diffraction angles (2θ) are recorded, the d-spacing can be calculated and arranged in sequence with the relative intensities also indicated. Minerals can be identified by their sequence of d-spacing and intensities, without consideration of the orientation of the sets of planes of atoms. The d-spacings of layers of atom which produce each diffracted X-Ray can be calculated from the Bragg equation:

$$n\lambda = 2d\sin\theta ,$$

where λ = wavelength of the incident X-Rays.

The diffractometer consists of a goniometer for measuring the diffraction angle, and various electronic circuits for determining intensity of the X-Rays at any angle. The goniometer employs a large flat sample combined with parafocusing arrangement to increase the intensity of diffraction, and an X-Ray counter tube to detect the diffracted radiation.

The X-Ray optical system of the diffractometer is shown in Fig. 27 below.

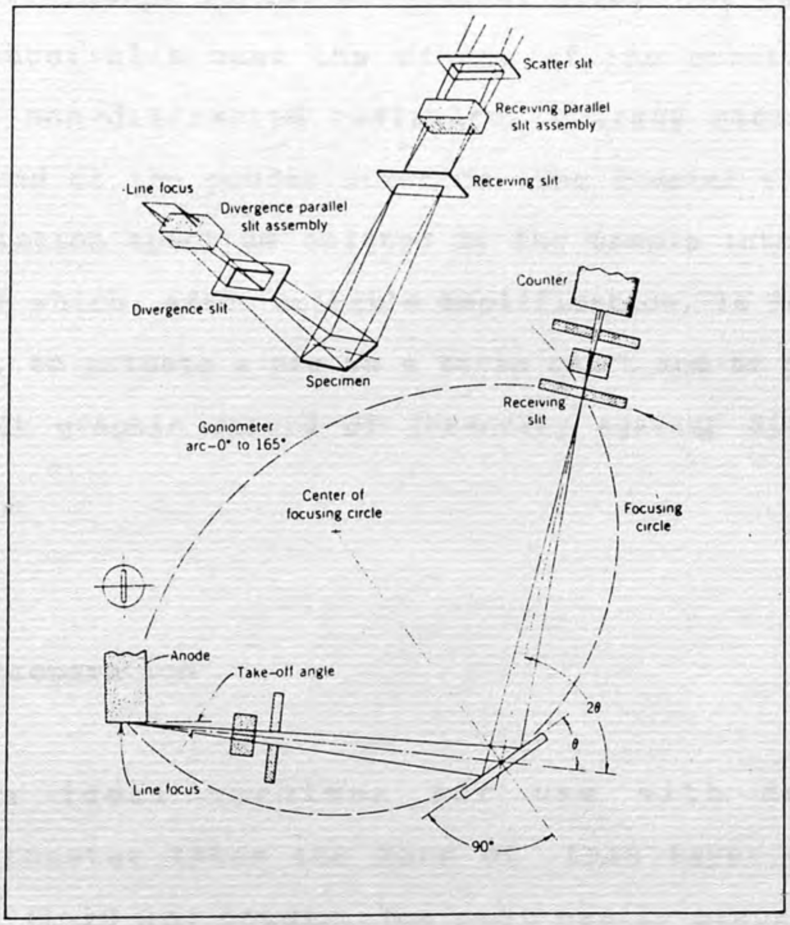


Fig. 27 X-Ray optical system of the diffractometer (After Parrish, 1954)

The goniometer enables the crystal and detector to be moved together so that they are always at angles of θ and 2θ, respectively, to the disvergence parallel slit assembly.

The actual angular aperture of the beam is determined by the width of a divergence slit. The length of the specimen irradiated by the X-Ray through a given slit increases with decreasing angle of incidence (2θ). The diffracted X-Rays are controlled by a slit to produce a line-focus X-Ray, and the parallel slit assembly is used to limit divergence in the horizontal plane. The purpose of the scatter slit near the window of the counter is to exclude non-diffracted radiation, thereby reducing the background of the powder spectrum. The counter transforms the radiation spectrum emitted by the sample into a pulse spectrum which, after suitable amplification, is fed into a circuit, to actuate a pen on a strip chart and to produce a permanent graphic record of intensity against diffraction angle.

Sample preparation

The ideal specimen for use with an X-Ray diffractometer takes the form of thin layer of fine-grained (1-10 μm) powder. The most easily prepared, and therefore most commonly used specimen mounting is a smear on a glass plate. A microscope slide of suitable dimension is used as a base for spreading a thin layer of powdered specimen. A slurry of powder can be prepared in acetone and this settles and is left behind when the acetone rapidly evaporates. If a more permanent mount is desired, a little 'Durofix' or similar glue can be mixed with the acetone.

APPENDIX B

X-Ray Fluorescence Spectrometry

X-Ray Fluorescence Spectrometry (XRF) is a physical method of analysis which involves the measurement of the fluorescent intensity due to a particular element in a sample, using an X-Ray spectrometer.

The components of an X-Ray spectrometer are shown in Fig. 28 below.

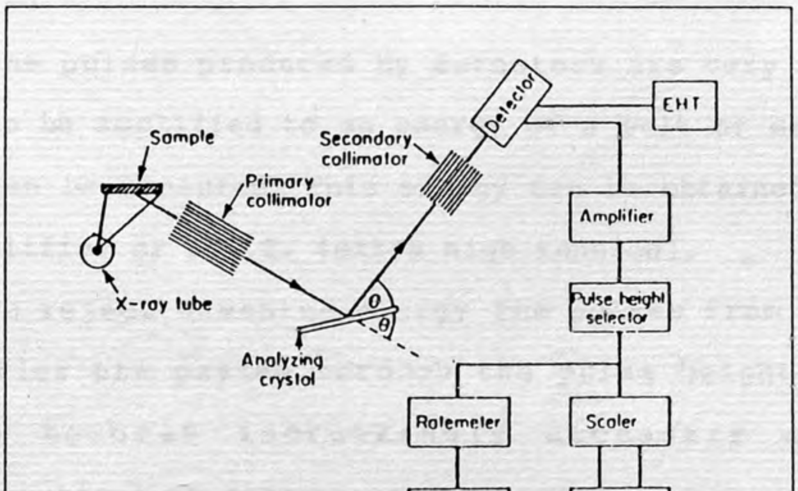


Fig. 28 Components of an X-Ray spectrograph (After Norrish and Chappel, 1967)

The fluorescent radiation is produced by directing X-Rays from an X-Ray tube, which is operating with a stabilised power supply on the sample to be analysed. A small proportion of the fluorescent radiation emitted by the sample is selected by a primary collimator or slit and allowed to pass on to the flat surface of a crystal.

The X-Rays are diffracted by the crystal according to Bragg's equation (see Appendix A for the equation).

A secondary collimator is placed at an angle 2 θ to the primary collimator and the X-Rays pass through this secondary collimator to the detector or counter, whose function is to convert the energy of individual X-Ray photons into pulses of electrical energy that can then be measured.

The pulses produced by detectors are very small and need to be amplified to an energy of a volt or more before they can be measured. This energy can be obtained by using an amplifier or E.H.T. (extra high tension).

To reject unwanted energy the pulses from the linear amplifier are passed through the pulse height selector, which becomes increasingly necessary as lower concentrations of elements are measured.

The pulses passing through the pulse height selector may be recorded as an intensity on a rate meter which is usually connected to a pen-recorder. This can then record the spectrum of a sample as the goniometer moved through a selected angular range. A scaler counts the pulses arising from individual X-Ray photons and is operated in conjunction with a time device (timer).

The results of the measurement can also be processed by computer and the results outputted on to teletype or visual display unit (VDU).

Sample preparation

For major and minor element analysis, the samples are prepared in fusion beads or glass discs.

To make glass discs, approximately 2 g of each sample are dried overnight at 110° C in a clean glass bottle. 0.7 g of dried rock powder are weighed accurately into numbered platinum crucibles. The crucibles (covered with lids) are then ignited in a furnace at 1100° C for 20 minutes. This releases the volatile material (H_2O, CO_2, etc).

After ignition, the crucibles are cooled on steel blocks for about 5 minutes and reweighed. This enable the volatile-free sample weight to be calculated.

Next the correct amount (6X sample weight) of flux (Spectro-flux 105 - i.e. lithium tetra-borate + lithium oxide + lanthanum oxide) is added, plus about 0.02 g extra to compensate for the volatile in the flux. The crucibles are then fused at 1100° C for about 20 minutes, covered with lids. Then they are allowed to cool on steel blocks (still covered by the lids). The crucible are reweighed and extra flux is added to each to make up to the calculated total. Then the mixture is swirled to ensure homogenity, and the disc are cast using Al-platten and plunger on a hot plate at a maximum temperature.

The discs are then removed, and numbered on the lower side, i.e. the side in contact with Al-platten. The discs are now ready for analysis.

APPENDIX C

Electron Probe Microanalysis

Electron probe microanalysis provides the means for determining the chemical composition of selected regions (of the order 1 μm diameter) at the surface of polished mineral mounts and petrological thin sections. The name derives from the essential features of a fine electron beam or probe, that is directed at the target to be analysed. The elements present (in the target) generate characteristic X-Rays with intensities which are an approximate linear function of the concentration.

An electron micro-analyser consists of:

(1) An electron optical system which focuses an electron beam onto an area about 1 μm diameter on the surface of the specimen.

(2) A stage on which the specimen and standards are mounted.

(3) A microscope which allows the area of interest to be selected and positioned with respect to the electron beam.

One or more Bragg spectrometer are normally used to select the characteristic radiations of the elements to be determined, and their intensity is measured with a proportional counter.

The schematic diagram of the electron probe microanalyser can be seen in Fig. 29.

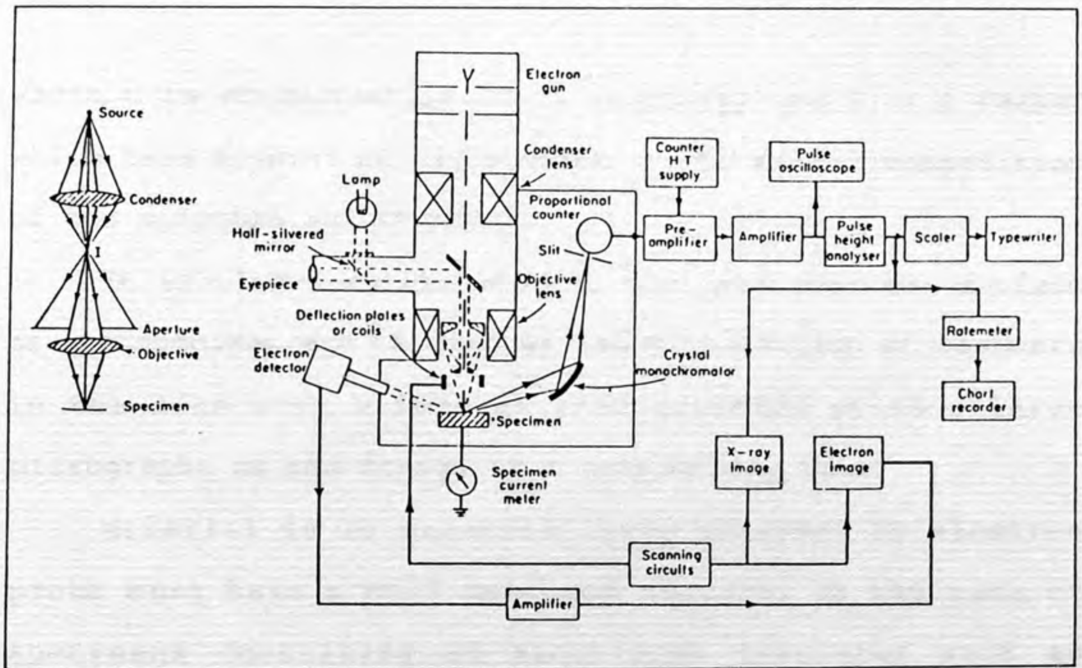


Fig. 29 Schematic diagram showing components of an electron probe analyser and their raypaths in the electron optical system (After Long, 1967)

Because of its simplicity of operation, electron probe microanalysis has found increasing application in both qualitative identification of un-known phases, and quantitative analysis of minerals. For quantitative analysis, the basic measurement is a comparison of the intensity of the characteristic line of the element, with the corresponding intensity generated at the incident electron current in a standard of known composition. Intensities and concentration are related according to the equation:

$$C\ \text{specimen} = C\ \text{standard} \;.\; \frac{I\ \text{specimen}}{I\ \text{standard}} \;.\; F\ ,$$

where C is concentration, I is intensity and F is a factor which take account of differences in the matrix composition of the specimen and standard.

It is also possible to scan the beam over the surface of the specimen and to display the distribution of elements in the scan area either as line profiles or as enlarge micrographs on the screen of a cathode-ray tube.

Material to be quantitatively analysed by electron probe must have a well polished surface. In the case of specimens containing an electrical insulator such as silicates, the polished surface must be coated by a conducting film in order to carry away the specimen current to the ground. The most commonly employed coating for mineralogical work is a vacuum-evaporated film of carbon of the order of 200 Å thick.

To make a good contact between the specimen surface and the stage, the specimen must be connected to the stage by 'painting' colloidal graphite or colloidal silver.

It is well worthwhile, if identification of minerals to be analysed relies on examination in reflected ligt, to prepare photomicrographs or skethes before coating.

APPENDIX D

Inductively Coupled Plasma Source Emission Spectrometry (ICP)

ICP is an emission method that involves the measurement of the wavelength and intensity of visible and ultra violet light radiation emitted as electrons of an atom refill the outer-electron orbitals which have emptied by ionisation in the intense heat ofa plasma. The measurement of the wavelength of the emitted light enables the operator to identify the atom, and hence the element, and the measurement of the intensity of the light of this particular wafelength gives the quantity of this element in the sample.

The ICP has a stream of argon atoms which have been heated by inductive heating using a radio frequency (RF) coil. The inductive heating strips away the electrons from the argon atoms to produce plasma argon ions. This plasma is ignited by a high frequency T Spark, and has an operating temperature of between 6 - 10,000 ^{o} K.

ICP methods analyse aqueous solutions. The solution to be analysed is pumped by a peristaltic pump into a spray chamber where a flow of pure argon gas converts a proportion of solution into aerosol, which is then sprayed into the centre of the plasma. The very high temperature within the plasma flame is enough to dissociate chemical bonds in the individual atoms and excite a very large number of spectral lines. The light emitted is then focussed and diffracted onto a bank of photomultipliers or so called polychromators, and the wavelengths and intensities are measured. The information is processed by computer and the results produced on a teletype, or a visual display unit (VDU)

The schematic diagram of the ICP can be seen in the figure below.

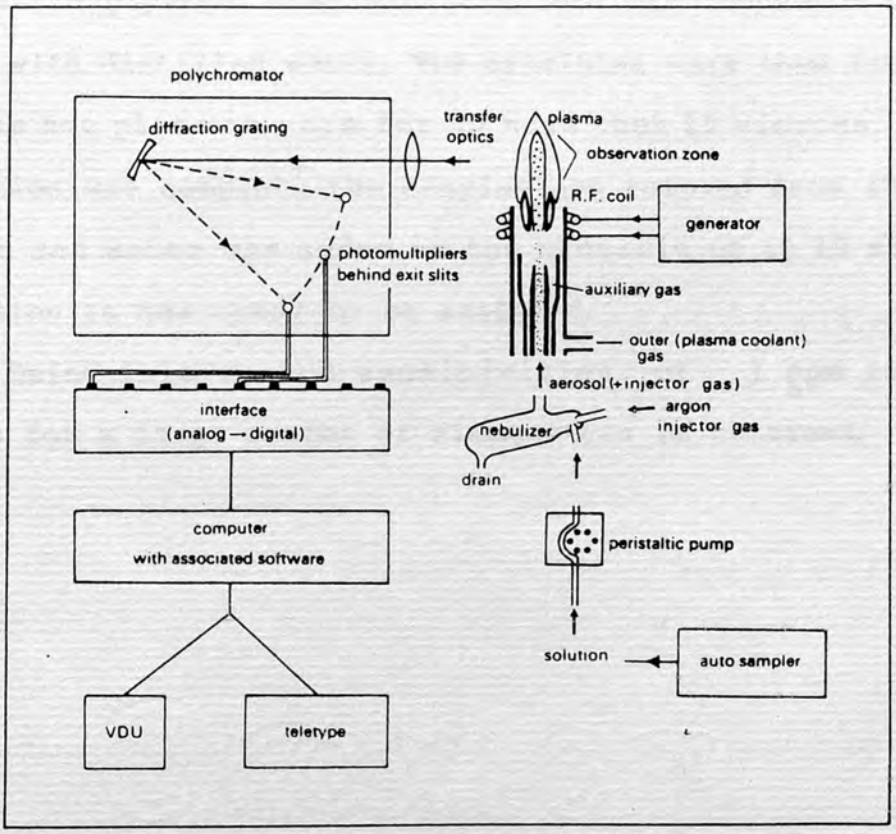


Fig. 30 The schematic diagram of the ICP (After Thompson and Walsh, 1983)

To make a solution for analysis, 0.1 g of rock powder is weighed into a PTFE crucible, with an accuracy of 0.01 g. The samples are then dissolved in acid.

An acid solution was made up containing 100 ml of perchloric acid ($HClO_4$) and 200 ml of hydrofluoric acid (HF). 3 ml of this acid were then added to the sample with an automatic pipette. The crucibles were then placed on a hot plate and evaporated to dryness. They were then removed from the hot plate and allowed to cool. 1 ml of hydrochloric acid was then added to each crucible with the automatic pipette. Then each crucible was topped-up to 3/4 full with distilled water. The crucibles were then returned to the hot plate to warm for no more then 15 minutes. After solution was complete the samples are removed from the hot plate and water was added to the crucible up to 10 ml. The solution is now ready to be analysed.

Using this method sensitivities of 1 ppm (in the rock) for a large number of elemens can be obtained.

APPENDIX E

Ocupan gold deposits, Buagio, Luzon, Philliphines

(K.J. Callow and B.W. Worley Jr, 1965)

The Ocupan gold deposits are of epithermal vein type, and are composed of tellurides associated with sulphides (sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, etc). The veins occur in Tertiary diorite, quartz diorite, granodiorite, andesite and sediments.

The youngest sediments are lower-Miocene, and consist of conglomerate, sandstone, shale and limestone. These sediments are intruded by diorite, granodiorite, quartz diorite and andesite porphyry which occur along the crest line of the major batholith, stocks and dikes which extend almost to the northern tip of Luzon island. The Ocupan gold bearing veins are genetically related to these intrusive rocks.

The plutonic intrusives began with diorite, followed at an interval by quartz diorite and lastly granodiorite and andesite. The intrusion are very closely related and they may have originated from the same magma. The igneous activity is suggested to have started in early-Tertiary time, continuing until Pliocene or later.

Within a few feet of the veins, the quartz diorite is highly altered. All feldspar is completely altered to sericite, and ferromagnesian minerals are altered into small granules of quartz and epidote. All magnetite is replaced by pyrite.

The absence of pyrhotite and the presence of sphalerite containing chalcopyrite particles (blebs) indicate that the initial temperature of deposition of sulphides was somewhere around 350°-400° C.

The Ocupan veins can be regarded as typical of deposition at a shallow depth, relatively close to the magmatic source.

Toyoha deposits, Hokkaido, Japan

(J. Yazima and E. Ohta, 1979)

Ore deposits of the Toyoha mines are epithermal vein (fissure filling) type deposits which mainly consist of pyrite, sphalerite, galena and important amounts of silver. The deposits are composed of more than 15 veins which are arranged in two major directions, E-W and NW-SE. The veins were formed in two stages; most of the E-W fissures were mineralised at the first stage and those of the NW-SE fissures system largely of second stage.

The veins were deposited at depths less than 1000 m (450-900 m), in pyroclastic rocks of Miocene to Pleistocene age. The mineral deposits were related closely to the quartz pophyry intrusion which is considered to be one of

Tertiary granitoids composed of such rock facies as granite porphyry and granodiorite porphyry.

The close affiliation between the quartz porphyry and ore of the Toyoha deposits is presented from a sulphur isotopic study.

The fluid inclusion studies show that the formation of the Toyoha deposits took place in the temperature range 150°-300° C, with salinity of fluid between 0.2%-4.2% wt NaCl equivalent.

From these temperature and salinity measurements it is suggested that the hydrothermal fluid related to the Toyoha deposits had originated from meteoric water which freely circulated through the fractures of E-W trend, mixed with saline waters of magmatic origin.

Deposits in the Tintic mining district, West United States

(H.T. Morris, 1974)

The Tintic mining district of Central Utah is one of the largest base- and precious metal ore fields in the Western United States. There is convincing evidence of ore deposition in this district, as a terminal phase of multiple volcanism.

The pre-volcanic rocks in the East Tintic Mountains range in age from late Pre-Cambrian to Permian, and mainly consist of quarzite and argillite (Pre-Cambrian); limestone, sandstone and shale (Palaeozoic).

After a period of orogenic activity of the region (Cretaceous), the volcanism began in the East Tintic Mountains during the middle-Oligocene.

The eruption terminated with the intrusion of the important, ore-related Silver City monzonite stock. Numerous monzonite porphyry plugs and dikes were also emplaced in a compound zone extending north-northeastward.

Shortly following the intrusion of the Silver City monzonite, great volumes of of acid, argillising solutions invaded the shattered rocks adjacent to the stocks, plugs and dikes, and moved outward from these area along high- and low-angle faults and along igneous and young sedimentary (mainly volcanoclastics) contacts. The solutions are believed to be chemically similar to groundwaters.

The latest pre-ore solutions deposited sericite (or orthoclase), crystalline quartz, pyrite, barite and rhodochrosite. With time metallic ions appear in these latest solutions, ore minerals began to be precipitated in the general vicinity of the stock and its satellitic plutons. The ore solution deposited galena, sphalerite, argentite, tetrahedrite-tennantite, enargite, calaverite, etc.

Chemical and isotopic studies indicate that the ore-depositing solutions were sodium and potassium-rich brines.

The ore deposition temperatures ranged from 100^{o}-400^{o} C. The ore solutions were the last solutions to flow in volume and were the terminal solutions related to the Oligocene volcanism in the East Tintic Mountains.

Caudalosa silver deposits, Central Andes, Peru

(F.J. Sawkins, R.O. Rye, 1974)

The entire area of the Caudalosa vein deposits is underlain by essentially flat lying volcanic units, consisting mainly of andesitic lava flows, tuff breccia and tuff units.

Intrusive bodies are not known in the area, but small plug and pipe like intrusive bodies have been recorded in east, south and west Caudalosa. No radiometric dates are available for the rocks in the immediate area, but dating of very similar, undeformed volcanic rocks in Hauchocolpa mining district (30 km to the northeast) has indicated a maximum age for this pulse of late-Tertiary Andean volcanism (10.5 m.y). The age of mineralisation at Caudalosa is almost certainly (by analogy with the additional K-Ar dates on shallow intrusive in Hauchocolpa district) be as low as 4 m.y.

The veins which represent hydrothermal infilling of fissure systems, strike in a predominantly E-W direction and vary in width from 10 cm to 3 m. Within them, a quarzose matrix contains variable amount of iron and base metal sulphides, accompanied by a variety of sulfosalts, many of them silver-bearing. In addition, ubiquitous quartz barite and carbonate are present in the vein system but their occurrence is sporadic. Hydrothermal alteration of wall rocks has produced chlorite and sericite assemblages.

Temperature and salinity data were obtained from the study of fluid inclusions in quartz and sphalerite crystals. The occurrence of daughter minerals in the fluid inclusions was restricted to an acicular birefringent phase in many quartz sample which was thought (from the optical properties) dawsonite.

The ore formation temperature range from 220^{o}-325^{o} C, with the salinity of solutions ranging from 4%-18% wt NaCl equivalent.

From the fluid inclusion studies it is suggested that the deposits were emplaced at depths of 1500-2000 meters.

The results of temperature and salinity studies, and the hydrogen isotopic determinations of fluid inclusions in quartz and sphalerite indicate that the hydrothermal solution originated from saline magmatic waters which sporadically being partially mixed with low salinity waters having D values essentially similar to modern meteoric waters.

REFERENCES

Ahrens, L.H., 1977 : Origin and distribution of elements. Proceedings of the second symposium, Paris. Pergamon Press.

Alderton, D.H.M., 1976 : The geochemistry of mineralisation at Pendarves, and other Cornish areas. A Ph.D Thesis, King's College, University of London. Unpublish.

Barnes, H.L., 1979 : Geochemistry of hydrothermal ore deposits. Holt, Rinehart and Winston Inc., New York.

Battey, M.H., 1981 : Mineralogy for students . Longman Inc. ,New York.

Bemmelen van, R.W., 1970 : The geology of Indonesia, Vol. II, Economic Geology. Martinus Nijhoff, The Hague, Netherlands.

Bemmelen van, R.W., 1970 : The geology of Indonesia, Vol. IA, General Geology. Martinus Nijhoff, The Hague, Netherlands.

Berry, L.G. and Thompson, R.M., 1962 : X-Ray powder data for ore minerals. The Peacock Atlas, Geological Society of America.

Bloss, F.D., 1971 : Crystallography and crystal chemistry: an introduction. Holt, Rinehart and Winston Inc., New York.

Borg, I.Y. and Smith, D.K., 1969 : Calculated X-Ray powder mineral pattern for silicate. GeologicalSociety of America. Memoir 122.

Boyle, R.W., 1979 : The geochemistry of gold and its deposits. Geological Survey of Canada, Bulletin 280.

Brown, J.S., 1948 : Ore genesis. Hopewell Press, New Jersey.

Brownlow, A.H., 1979 : Geochemistry. Prentice Hall Inc., Englewood, USA.

Callow, K.J. and Worley Jr., B.W., 1965 : The occorrence of telluride minerals at the Ocupan gold mine, Mountain Province, Phillipines, Econ. Geol., 60, 1965.

Cameron, E.N., 1966 : Ore microscopy. John Wiley & Sons Inc. New York.

CCOP, 1981 : Studies in East Asian Tectonics and Resources (SEATAR), Escap, Bangkok.

Craig, J.R. and Vaughan, D.J., 1981 : Ore microscopy and ore petrology.John Wiley and Sons, New York.

Djumhani, 1981 : Metallic mineral Deposits of Indonesia: A metallogenic Approach. Directorate of Mineral Resources, Department of Mines and Energy, Indonesia.

Evans, A.M., 1980 : An Introduction to Ore Geology. Blackwell Scientific Publication. Oxford.

Fang, J.H.and Bloss, F.D., 1966 : X-Ray diffraction tables. Southern Illinois University Press, USA.

Gazali, S.A., 1972 : Geologi daerah Gunung Gede, Jasinga, Bogor, Jawa Barat (Geology of the Gunung Gede area, Jasinga, Bogor, West Java). A graduate thesis in geology. University of Pajajaran, Bandung, Indonesia.Unpublish.

Geological Survey of Indonesia, 1977 : Geologic Map of Java and Madura, Sheet I (West Java) Scale 1:500,000.

Effendi, A.C., 1974 : Geologic Map of the Bogor Quadrangle, scale 1:100,000. Geological Survey of Indonesia.

Hamilton, W., 1979 : Tectonics of Indonesian Region. Geological Survey Professional Paper 1078. Washington.

Hatch, F.H., Wells, A.K. and Wells, M.K., 1983 : Petrology of igneous rock. George Allen & Unwin, London.

Howarth, R.J., 1983: Statistic and data analysis in Geochemical Prospecting. Elsevier Publishing Company, Amsterdam.

Jensen, M.L. and Bateman, A.M., 1979 : Economic Mineral Deposits. Third edition. John Wiley & Sons, New York.

Kadar, D. and Siregar, S.V., 1978 : Onshore sedimentary basin of Indonesia. Geological Survey of Indonesia.

Katili, J.A., 1974 : Geological environment of the Indonesian mineral deposits. A Plate Tectonic Approach. Directorate General of Mines, Department of Mines and Energy.

Kerr, P.F., 1977 : Optical Mineralogy. Mc Graw Hill.

Krauskopf, K.B., 1967 : Introduction to Geochemistry. Kogakusho Co., Tokyo.

Kwong, Y.T.J and Crocket, J.H, 1973 : Background and anomalous gold in rocks of an Archean greenstone assemblages, Kakagi Lake Area, Northwesten Ontario. Econ. Geol. Vol. 68.

Lagache, M. and Weisbord, A., 1977 : The system: Two Alkali Feldspars KCl-NaCl-H_2O at Moderate to High Temperature and Low Pressure. Contributions to Mineralogy and Petrology, Vol. 62, 77-110.

Long, J.V.P., 19.. : Electron Probe Microanalysis. In Zussman, 1967: Physical Method in Determinative Mineralogy. Academic Press, London

MacKenzie, W.S., Donaldson, C.H. and Guilford, C., 1982 : Atlas of igneous rocks and their texture. Longman Group Limited.

MacKenzie, W.S., Donaldson, C.H. and Guilford, C., 1982 : Atlas of rock forming minerals in thin section. Longman Group Limited.

Mantei, E.J. and Brownlow, A.H., 1967 : Variation in gold content in minerals of Marysville quartz diorite stock, Montana. Geocham. Acta. Vol. 31.

Marks, P., 1961 : Stratigraphic Lexicon of Indonesia. Science Publication No. 31. Directorate of Geology, Bandung.

Marmount, S., 1983 : The role of Felsic Intrusion in Gold Mineralisation. Ontario Geological Survey, Miscellanous Paper 110.

Meyer, H. and Hemley, J.J., 1967 : Wall rock alteration. In Barnes: Geochemistry of hydrothermal ore deposits. Holt, Rinehart and Winston, Inc.

Morris, H.T., 1974 : Volcanism and ore deposition in the Tintic mining distrct, West United States. In Varna: Problems of ore deposition, Fourth IAGOD, 1974. The Bulgarian Academy of Science.

Mueller, R.F. and Saxena, S.K., 1977 : Geochemical Petrology. Springer, New York.

Norrish, K. and Chappel, B.W, 19.. : X-ray Fluorescence Spectrography. In Zussman, 1967: Physical Method in Determinative Mineralogy. Academic Press, London.

Nuffield, E.W., 1966 : X-Ray Diffraction Method. John Wiley and Sons, Inc. New York.

Oelsner, O., 1966 : Atlas of the most important ore mineral paragenesis under microscope. Pergamon Press, Oxford.

Park Jr, C.F., Mc Diarmid, R.A., 1977 : Ore Deposits. Second edition. W.H. Freeman & Co., San Francisco.

Pearce, J.A., 1983 : Role of the subcontinental lithosphere in magma genesis at active continental margins. In: Hawkesnorth, J.A. and Norry, M.J. : Continental Mantle Xenoliths. Shiva Publishing Ltd., Norwich. p 230-249.

Phillips, W.J., Phillips, N., 1980 : An introduction to mineralogy for geologist. John Wiley & Sons, The Pitman Press, Great Britain.

Poldervaart, A., 1955 : Chemistry of earth's crust. Geol. Soc. Am., Spec. Paper 62, 119-144.

Potter, R.W.II, 1977 : Pressure corrections for fluid-inclusion homogenisation temperatures based on the volumetric properties of the system $NaCl-H_2O$. J. Res. U.S. Geol. Surv. 5, 603-607.

Pupilli, M., 1973 : Geological evolution of South China Sea area, tentative reconstruction from borderland geology and well data. Proceeding Indonesian Petroleum Association, Second Annual Convention 1973.

Putnam, G.W. and Burnham, C.W., 1963 : Trace elements in igneous rocks, Northwestern and Central Arizona. Geochem. Cosmochem. Acta, 27, 53-106.

Ramdohr, P., 1969 : The ore mineral and their intergrowths. Pergamon Press, Oxford.

Roedder, E., 1979 : Fluid inclusion as samples of ore fluids. In H.L. Barnes, 'Geochemistry of hydrothermal ore deposits'. Wiley Interscience, New York. pp 684-737.

Roedder, E., 1977 : Fluid inclusions as tools in Mineral Exploration . Econ. Geol. 72, 503-525.

Roedder, E., 1984 : Fluid Inclusions, Reviews in Mineralogy. Mineralogy Society of America. Book Craffer Inc., Chelsea, Michigan.

Rose, A.W., Hawkes, H.E and Webb, J.S., 1979 : Geochemistry in Mineral Exploration. Academic Press Inc, London.

Rusman, 1982 : Geologi daerah Cirangsad dan sekitarnya, Kecamatan Cigudeg, Kabupaten Bogor, Jawa Barat (Geology of the Cirangsad area, Cigudeg district, Bogor, West Java).A graduate thesis in geology. University of Pajajaran, Badung, Indonesia. Unpublish.

Russel, M.J. et al., : On the origin of the Aberfeldy celsian + barite + base metal deposits, Scotland. A paper. University of Strathclyde, Glasgow, Scotland.

Sawkins, F.J. and Rye, R.O., 1974 : Fluid inclusions and stable isotope studies on the Caudalosa Ag-Pb-Zn-Cu deposit, Central Andes, Peru. Econ. Geol., 69. 181-205.

Schouton, C., 1962 : Determination Tables for Ore Microscopy. Elsevier Publishing Company, Amsterdam.

Shepherd, T.J., Rankin, A.H. and Alderton, D.H.M., 1985 : A practical guide to fluid inclusion studies. Blackie & Sons Ltd, Glasgow.

Siegel F.R., 1974 : Applied Geochemistry. A Wiley Inc. Publication, John Wiley & sons, New York.

Sudharto, R.T., 1984 : Mineral Exploration in the Supayang area, Solok, West Sumatra, Indonesia. A project report. Unpublish.

Suprayitno, N., 1983 : Esplorasi daerah Gunung Limbung dan sekitarnya (Exploration in the Gunung Limbung and area). A project report. P.T. AnekaTambang, Jakarta, Indonesia. Unpublish.

Sukendar, A., 1974 : The geologic evolution of Central Java and vicinity in the light of new-global tectonics. Desertasi DR (a DR desertation). Institute Technology of Bandung. Unpublish.

Stanton, R.L., 1972 : Ore Petrology. Mc Graw Hill.

Steckeisen, A., 1976 : To each plutonic rock its proper name. Earth Science Review, 12, 1-33. Elsevier Scientific Publising Company, Asterdam, Netherland.

Steven, T.A. and Eaton, G.P., 1975 : Environment of Ore Deposition in the Creede Mining District, San Juan Mountains, Colorado. Econ. Geol., Vol. 70.

Takenouchi., S., 1980 : Preliminary studies on fluid inclusions of the Santo Thomas and Tapian porphyry copper deposits in Philippines. The Society of Mining Geologist of Japan, Tokyo.

Thompson, M. and Walsh, J.N., 1983 : The Handbook of Inductively Coupled Plasma Spectrometry. Blackie & Sons Ltd, Glasgow.

Tilling, R.I, Gottfried, D. and Rowe, J.J., 1973 : Gold abundance in igneous rocks: bearing in gold mineralisation. Econ. Geol. Vol. 68.

Turner, F.J. and Verhoogen, J., 1960 : Igneous and Metamorphic Petrology, 2nd edition. Mc Graw Hill, New York.

Uytenbogaardt, W. and Burke, E.A.J., 1971 : Tables for microscopic identification of ore minerals. Elsevier Publishing Company, Amsterdam.

Warman, R. and Thaib, J., 1973 : Ikhtisar Penyelidikan Logam-logam Dasar di Jawa, 1969-1973 (Summary of Base Metals Investigation in Java, 1969-1973). A project report. Exploration Division, Geological Survey of Indonesia.

Watanabe, M., 1979 : Fluid Inclusions in Some Neogene Ore Deposits in the Green Tuff Region, Japan. Mining Geology, 29 (5) 307-321.

White, D.E., 1957 : Magmatic, connate and metamorphic waters. Bull. Geol. Soc. Am. 68, 1659-1682.

Williams, F., Turner, F.J. and Gilbert, C.M., 1982 : Petrography, An introduction to the study of rocks in thin section. W.H. Freeman and Company, USA.

Yazima, J. and Ohta, E., 1979 : Two-stage Mineralisation and Formation Process of Toyoha Deposits, Hokkaido, Japan. Mining Geology, 29 (5), 291-306.

Zussman, J., 1967 : Physical Methods in Determinative Mineralogy. Academic Press Inc., London.