UNITED NATIONS
Economic and Social Commission for Asia and the Pacific

# EPITHERMAL GOLD IN ASIA AND THE PACIFIC

MINERAL CONCENTRATIONS AND
HYDROCARBON ACCUMULATIONS
IN THE ESCAP REGION

Volume 6

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Cover: A crosscut of an orpiment chimney formed in silty lake sediment at Osorezan volcano in the Honshu arc of Japan. Amorphous arsenic sulfide is the latest precipitate. Idiomorphic barite and a radial aggregate of orange yellow orpiment crystals occur in black muddy material around the chimney. Since neutral pH chloride water with high $H_2S$ has high complexing capacity for Au, as well as As, Sb and Hg, a large-scale accumulation of arsenic sulfide may be a good indication of a Au deposit in the vicinity. (photo by Masahiro Aoki, Geological Survey of Japan)

ST/ESCAP/1023

Reference to "tons" is to metric tons, unless otherwise specified.

# FOREWORD

Over the past decade concepts regarding epithermal type mineral deposits, particularly as they relate to gold-silver ore bodies, have advanced considerably and this type of deposit has now become a central model in the search for mineral wealth in many parts of the world.

What is an epithermal precious metal deposit? As Takeo Sato points out in this volume, the essential elements include a shallow (less than 1,000 m) depth, an aqueous convection cell driven by a shallow volcanic or magmatic heat source, and an interactive process involving primary metal-bearing magmatic fluids and surface waters within the convection cell system having a temperature regime generally at less (and occasionally at much less) than 250°-300°C. Under these conditions, ore-bearing fluids undergo geologically rapid and intense physical changes in pressures, temperatures and gaseous activities over short distances. Metals are deposited through the combined agencies of boiling and related changes of pH, oxygen fugacity, temperature, and many other physico-chemical parameters of the hydrothermal fluid. The range of depositional styles encountered seems to reflect the varied evolutionary histories of such mineralizing fluids, which in turn reflect differing tectonic-magmatic environments. Some of these variations are the subjects of papers presented in this volume.

Why and how has this interesting type of deposit come to such prominence in the past decade? In retrospect, several historical factors appear to have combined to lead to this emphasis. First, the increase of the price of gold from its long-fixed level in the early 1970s made exploration for this metal once again attractive, after a long period in which exploration technologies had advanced. Prior to 1970 gold had not been a target of significant interest. Secondly, as a result of research on metal deposits over the past twenty years, volcanic-hosted mineral deposits in general are much better understood, and models of island arc and continental and plate-margin tectonism were developed (and are still evolving) in the wake of the plate-tectonic revolution. Investigations in geothermal fields, and the direct observation and sampling of ocean-ridge hydrothermal vents have led to an upsurge of scientific interest in near-surface thermal regimes and solution thermodynamics.

The term "epithermal" itself is by no means new, having formed part of the system proposed by W. Lindgren in his classification of ore deposits over 80 years ago. W.H. Emmons similarly used the term, and the expression appears to have been widely used among American economic geologists in the early decades of this century (viz. J.E. Spurr, T.B. Nolan, L.C. Graton). H.E. McKinstry in his Mining Geology (1948) gives a lengthy disquisition on the etymology of the term. It is interesting that modern economic geologists now return to the writings of these earlier observers, a number of whom gained their impressions of the epithermal environment through their work in the southwest of the United States of America, an area which today has become a foremost producer province of gold from deposits of this type.

On the Circum-Pacific rim, epithermal gold mineralization falls into two broad groups: one group is represented by a belt of deposits associated with subduction-related compressional tectonics and mafic to intermediate magmatic sources, and the second group, on the continental margins, is associated with intermediate to felsic igneous activity within an extensional tectonic framework. The former group is known for its gold-bearing copper deposits, gold-enargite deposits and many of the classic bonanza veins and stockworks (e.g. the Kyushu district of Japan). The latter group is characterized by the graben- or caldera-related precious metal deposits of the continental margins (e.g. the Geysers-McLaughlin area, California, and Queensland, Australia).

Working from these models, exploration geologists in South-East Asia have found the Circum-Pacific subduction zones and neighbouring continental margin zones to be particularly good target areas for the search for such deposits. Three main linear zones of subduction have attracted interest; (i) Bhutan - Myanmar - Sumatra - Java - Timor belt, (ii) Japan - Taiwan - Philippines - Sulawesi belt, and (iii) Sulawesi - Papua New Guinea - Fiji - New Zealand belt. Considering the continental margin areas as well, some eighteen or twenty countries and territories of South-East Asia, Oceania and Australasia are actual hosts of precious metal deposits of this group or are, geologically at least, potential hosts.

Because of their high potential for wealth creation and as developmental levers, mineral deposits of this type are of special relevance to the nations of this region, as the ESCAP Secretariat points out in its introductory paper. Consequently, ESCAP established in 1988 a programme on Epithermal Gold Mineralization. One of the major aims of this project was to provide opportunities for geoscientists from developing countries in the ESCAP region with potential for epithermal gold occurrences to familiarize themselves with the geology, tectonic settings and depositional regularities of these gold deposits. To this end, two major workshops were organized for regional participants.

The first workshop took place at Tsukuba, Japan and was hosted by the Geological Survey of Japan from 9 to 18 May 1989. Papers were presented over a period of four days, followed by a four-day guided field trip through the epithermal gold district of south Kyushu Island, Japan.

The second workshop was convened in the following year, for which the host organization was the Directorate of Mineral Resources of Indonesia. This meeting took place at Bandung, Indonesia during the period 10-13 September 1990, and was followed by a four day field excursion to the Kelian deposit of P.T. Kelian Equatorial Mining in East Kalimantan.

Whereas the first workshop was aimed primarily at the geologic settings, mineralogy and genesis of the deposits, the emphasis at the second workshop was more directed towards exploration technology, field recognition, and the applications of prospecting techniques. At both meetings, papers were presented by participants as exploration overviews, case histories and experience in their respective countries.

The present volume presents the collected papers from the two workshops. At each meeting, invited internationally recognized geoscientists with expertise in the field offered written papers. Participants from the region presented extensively researched papers, and contributed data and observations regarding deposits in their home countries. The latter are no less valuable for bringing case histories and observation data from little-known locales to international attention.

ESCAP believes that these papers will stimulate enquiry and further exploration for this important deposit type in South-East Asia, and will assist institutional geologists and exploration geologists both within and from outside the region in their continuing work on epithermal gold and related deposits.

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# PART 1

## GEOLOGICAL SETTINGS
## AND
## ORE GENESIS

# THE PRESENT GOLD RUSH

by
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## Introduction

In the 1980 edition of the authoritative United States Bureau of Mines publication "Mineral Facts and Problems", the author of the chapter on Gold, W.C. Butterman, states: "The last major gold rush was just prior to 1900 in Canada's Yukon and in Alaska". Ironically, when those words were being written, the present major gold rush was just about to begin.

This present day gold boom has its roots in developments in the financial markets of the early 1970s.

Before that time the gold market was shaped mainly by South African production and by the Bretton Woods Agreements of 1944. These contained *inter alia* agreements on set fixed exchange rates and a (previous) pledge by the United States of America to redeem, upon request, foreign holders of United States dollars in gold at the fixed price of $US35.- an ounce (Troy ounce-31.1 grammes), the same price at which it purchased all gold offered.

This dollar-gold convertability was abandoned in 1971 and from that point forward the price of gold was determined by the free market. Soon after 1971, currency devaluations, rising inflation, the first oil shock and political uncertainty were responsible for increased investment demand for gold in a market with only a limited supply for this type of demand. The effect was that, at first slowly, during 1971 to 1976, but then at an accelerated pace, the gold price improved from $US35/oz. in 1970 to well over $US600/oz. in 1980. Thereafter, during the early 1980s, it settled near the $US400/oz. level, around which it has fluctuated during the past eight years. Obviously the mining industry reacted to this ten fold-plus increase in the price for the commodity by trying to step up production, but it was not until after 1980 that these efforts were successful.

## Market Structure: Supply and Demand*

Gold supply comes from mine production, government's sales on the world market and recovery from such secondary sources as industrial scrap (from electronics) and old jewellery.

Structural changes in the mining industry may account for changes in supply. Examples are the sharp increases in output from mines on the Witwatersrand (South Africa) during the 1960s due to discovery and development of new high-grade districts. Another example is the present day increase in mine production related to developments in heap leaching technology and carbon-in-pulp recovery methods.

Total supply to the world market in 1987 was about 1800 tonnes, of which 1390 tonnes came from mine production and 325 from scrap recovery.

Demand for gold is made up of requirements for industrial use, for jewellery, for official gold purchases and for private investment. Of these, demand for jewellery is by far the highest; of the annual supply of gold reaching the market in 1987, jewellery accounted for 1200 out of 1800 tonnes or about 65 per cent.

Electrical and other industrial applications and dentistry account for 220 tonnes (12 per cent). Aside from a gradual rise in demand for jewellery and electrical applications and a decrease in requirements for dentistry, these demand factors remain fairly regular.

One specific aspect of the supply and demand sides is formed by the transactions, sales or purchases by central banks to or from official stocks. These transactions are not easily quantified and vary from year to year. Over the last eight years it is estimated that during 1983 and 1984 such official transactions amounted to net sales of between 50 and 150 tonnes, while in the remainder they amounted to net purchases, varying from about 50 tonnes in 1982 to as much as 200 tonnes in 1980 and 1986.

The "balance" of the available supply–an estimated 380 tonnes in1987–is "available to satisfy the appetites of investors around the world..." (Nichols, 1988). This "balance" is in part used for coinage (in the form of medals and bullion coins) and in part available for "bar hoarding".

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* In this discussion on gold supply and mine production it should be noted that a number of countries, amongst them the Union of Soviet Socialist Republics and China, do not officially release production and trade figures. The estimates in this paper are based on those in professional journals and statistical bulletins.

Bullion coin programmes have been initiated in the past decade in a number of countries and, in addition to South Africa's Kruger Rand, there are now bullion coins issued by Australia, Belgium, Canada, China, Japan, Mexico, the United Kingdom and the United States of America. Purchases for these coin programmes in 1987 amounted to 190 tonnes.

The final remainder is then available to those investors wishing to purchase bullion bars. This is a relatively small part of the initial supply to the market. It amounted in 1987 to approximately 190 tonnes or 10 per cent, but in the opinion of some analysts it does play a major role in establishing the price level of gold. Nichols (op.cit.) believes that the interest by investors for this surplus will either drive the price up if it is not sufficient to satisfy the demand or allow it to fall, if there is not sufficient interest to acquire it. The price developments at the end of the 1970s seem to support this view of the strong leveraging effect of bullion transactions.

The demand for gold for investment purposes is linked to a number of factors such as the performance of the United States dollar and other currencies, the price of oil, the rate of inflation and other economical and political indicators. This reflects the traditional value attached to gold as a store of wealth – often independent of the price – which has given the metal its reputation that it thrives on fear, anxiety and insecurity.

### World Mine Production (Figures I and II)

From the very early history to the present about 100,000 tonnes of gold has been mined and most of this is still "with us" in some form or another (Beunderman, 1988).

About 80 per cent of this has been produced since the beginning of the 20th century and about 50 per cent since 1950; approximately 1700 tonnes (say 1.5%) will be added to this total in 1989.

World mine output increased significantly from an estimated 900 tonnes in 1950 to a peak of 1500 tonnes in 1970. Most of this was the result of a massive production increase on the Witwatersrand in South Africa: from just under 400 tonnes/year at the end of the 1950s, this production rose to an all-time high of 1000 tonnes/year in 1970. At that time the country accounted for about 65% of the world's total output. This lasted until 1970 when the richer prospects had been mined out. From then on South African production began to slide and by 1980 it had dropped to just over 600 tonnes.

The South African increase coincided with a diminishing production level in the rest of the world, (presumably with the exception of the USSR), due mainly to the closure of many hard-rock underground mines unable to produce profitably at the fixed $US35/oz. level in the face of rising costs.

Production outside South Africa and the USSR came in those years mainly from alluvial operations, from high grade lode prospects and as by-products from (porphyry) copper and base metal (massive sulphide) ores. Specific gold prospects were not actively developed (or sought) at the unattractive price level of $US35/oz. Gold exploration came practically to a standstill and the scientific and technological advances in the geosciences and the mining industry were applied to other areas. It was the age of large iron ore deposits, porphyry coppers, massive sulphides and alluvial tin.

Aerial photography, airborne geophysics, atomic absorption analysis, IP and EM field methods, wire-line drilling, improved mining methods and leaching techniques were all developed and applied in those years. Geochemical exploration made it feasible to explore large areas at the grass-roots level and applied geophysics assisted considerably in locating mineral deposits of all kinds.

At about the same time the scientific community accepted and aggressively developed the theory of plate tectonics and related it to the formation of mineral deposits (notably in the cases of porphyry coppers and Kuroko-type deposits) and this, in turn, led to practical exploration methods.

In similar developments, the volcanogenic concept for greenstone-belt deposits led to an improved understanding of this mineralization mechanism and this in turn was also applied in exploration.

None of these developments was as yet specifically applied to gold exploration and exploitation but as soon as the price of gold started to rise during the 1970s and especially when, almost simultaneously with the peaking of the gold price, the base metal market collapsed in the early 1980s, the mining industry quickly re-targeted them to the specific problems of exploration for and mining of gold.

Soon developments in geologic modelling resulted in the recognition of the epithermal gold deposit type, flameless atomic absorption made rapid routine analysis of geochemical samples for gold possible, and thereby increased exploration efficiency. Efficient open-cast mining of low grade deposits was made profitable through breakthroughs in metallurgy with the heap leaching and carbon-in-pulp recovery techniques.

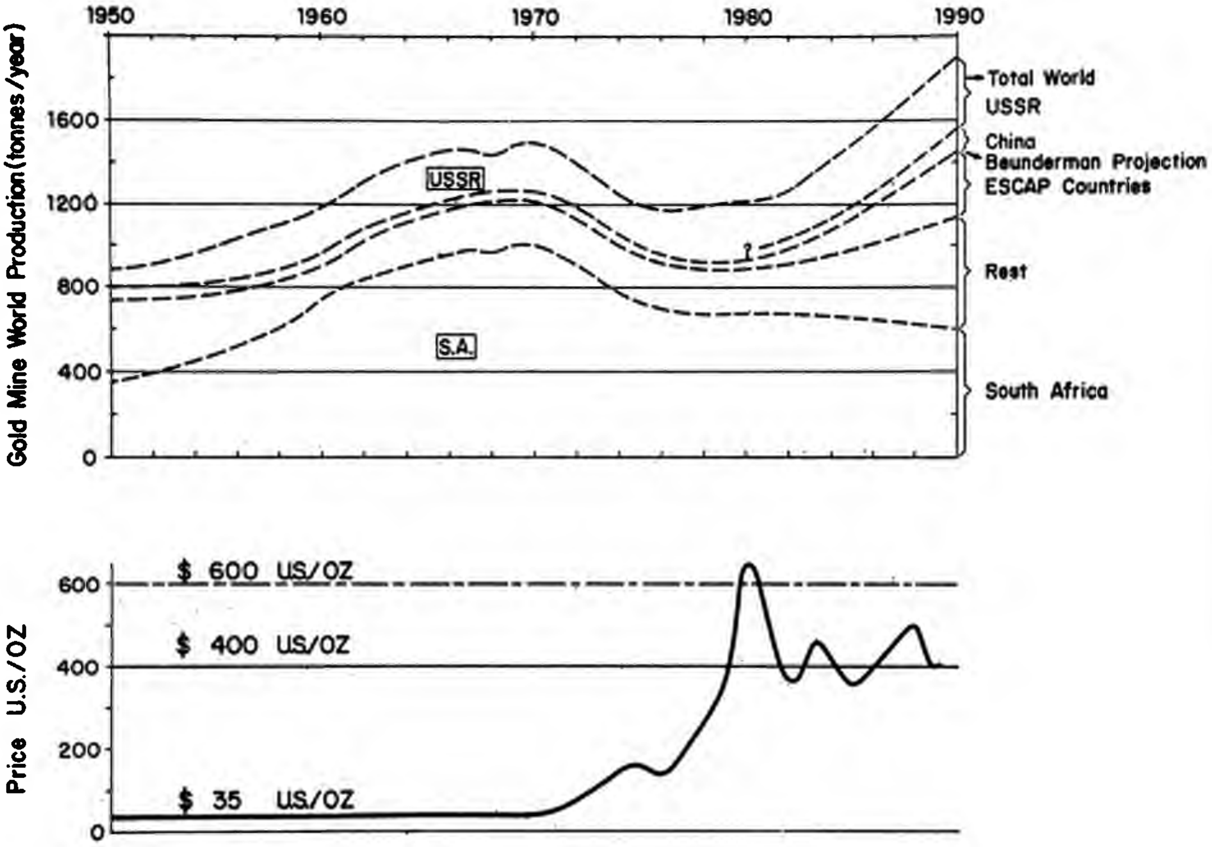

**Figure I. New gold production and price, 1950-1990.**

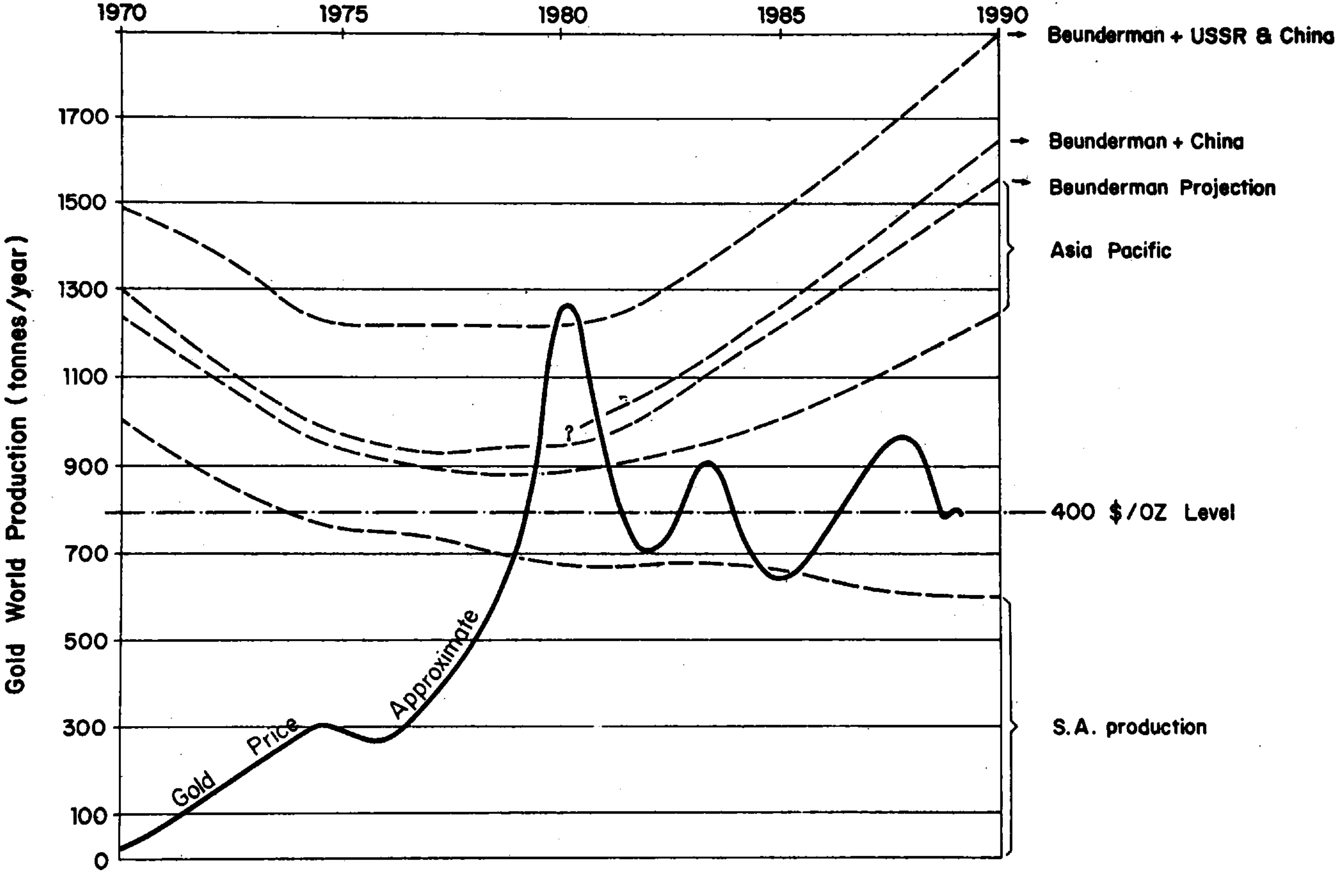

Figure II. New gold production and price, 1970-1990.

As could be expected, the results were not immediately apparent, but from 1980 onwards there was a marked increases in mine production. Notwithstanding the continued decline in South Africa, the total world production gained rapidly after 1980, and in 1986 the peak of 1970 was equalled. This was followed by further increases to 1650 tonnes in 1987 and to 1760 tonnes in 1988.

Forecasts beyond 1990 are difficult to make with any degree of accuracy but it seems very likely that as long as the price of gold does not go below $US300/oz. this upward trend will continue for some time. The reason for this is simple; most of the newly opened mines are low cost producers. Cash operating costs plus royalties in 1986/1987 were in the $US200-250/oz. range. With the price of gold fluctuating between $350-450/oz. the profits were handsome. Under these circumstances the industry will continue to step up production. That this will in the long run severely test the market is certain, but for the present time that market still seems flexible enough to absorb foreseen increases in supply.

Meanwhile during the period 1980-1987 several major producers (Canada, United States of America, Australia, amongst others) had more than doubled their output. Given the figures for these years and taking into account existing developments coming on-stream, Beunderman (op.cit.) projections for 1990 would put the world (minus China and the USSR) production level at 1570 tonnes. With estimates for China and the USSR at about 100 and 300 tonnes respectively, 1990 will see a total of over 1900 tonnes, up from just over 1200 tonnes in 1980.

## THE ROLE OF THE ASIA-PACIFIC REGION (Figure III)

In the Asia-Pacific region*, the major gold producers at present are Australia, China, Japan, Papua New Guinea and the Philippines. During the next decade they will be joined by Indonesia, Malaysia and possibly others. In 1990 the region will produce an estimated 400 tonnes of gold (or 20% of world output), up from 100 tonnes in 1980.

A review of mineral exploration activities in the region shows that especially those countries sharing the geologic setting of the Circum-Pacific belt are at present attractive for private industry. Australian-based companies in particular have ranged from home to actively engage themselves in the exploration scene in the Pacific islands, Papua New Guinea and Indonesia, all of which have become major exploration targets. The results of these activities will dominate Asia-Pacific gold production in the next decade.

## THE MAJOR PRODUCERS

### Australia

Australia is one of the traditional gold producers in the world. Early peak production levels were as high as 95 tonnes in 1856 and 120 tonnes in 1903. The years between 1950 and 1980 saw Australian production at levels between 20 and 30 tonnes with a low of 14 tonnes in 1975. It was in 1982 that the country stepped up production and from that time forward there has been a steady rise.

From 1985 to 1987, gold output more than doubled, reaching an estimated 108 tonnes in 1987. Estimates for 1988 are 140 tonnes, the highest output ever. Australia is the fifth ranking gold producer in the world and the largest in the region.

Forty-one new gold mines were commissioned between 1985 and 1987 and during 1988 plans were in hand to bring at least another fifteen prospects to production before 1990. The Kidston mine, which commenced operation in February 1985, is the major producer. Expansion of the treatment plant at Telfer to an estimated annual recovery rate of 8000 kg gold, and the commissioning of a mine at the large laterite-hosted gold deposit at Boddingtion are providing new competition.

Western Australia remains the leading gold-producing state and in 1987 accounted for an estimated 70 per cent of the national output.

Gold attracted an increasing percentage of the Australian private sector expenditure on mineral exploration. In 1987 the proportion of mineral exploration expenditure allocated to the search for gold was estimated to be more than half the total.

### China

An early 1988 "Review of Geological Survey and Mineral Development Activities in China (1985-1987)" reported that the results of gold prospecting have been "most impressive" and that a great number of gold prospects had been discovered in the review period. These discoveries had been in the Shandong, Hunan, Hebei, Heuilong Jiang, Guangdon and Sichuan provinces. The prospects include the exceptionally large deposits at Zhaoye

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* The Asia-Pacific region for the purpose of the Economic and Social Commission for Asia and the Pacific stretches from the Islamic Republic of Iran in the west to the Cook Islands far to the east in the Pacific, and from Mongolia in the north to New Zealand in the south.

The region occupies almost a quarter of the world's land surface.

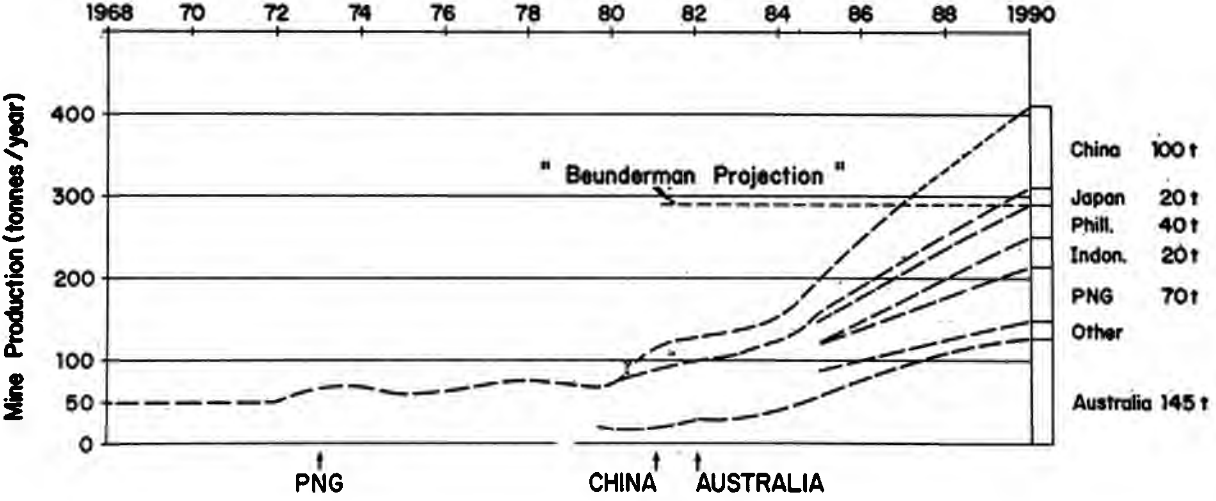

Figure III. ESCAP region gold production 1968-1990.

in the Shandong province and Carlin-type deposits in Xinshao in the Hunan province.

Government policy in China does not allow disclosure of the details of mining operations and production, nor is much known about the type of gold occurrences and their geological settings. It is presumed that gold comes from a variety of deposit types and that production is from large-scale operations, as base metal by-products and as production by small-scale miners. All gold from any production source has to be sold to the government which buys the gold at a price equivalent to $US270/oz. Total mine production is estimated to have increased from 40 tonnes in 1980 to about 75 tonnes in 1987. Production forecast for 1990 is 100 tonnes.

### Japan

During the 1950s Japan was an important producer of gold with an output rising from about 5 tonnes in 1950 to 10 tonnes at the end of the decade. The production came from numerous small copper-gold vein-type stockwork mines in the areas geologically characterized by the "green tuffs". As many as 400 small mines were in operation in those years.

Output increased after 1965 when the first Kuroko-type deposits came into production and a peak production of 21 tonnes was recorded for 1967. This dropped abruptly in 1968 after strict environmental legislation led to the closure of practically all small copper-gold mines; as a consequence during the 1970s gold production (at the level of approximately 5-8 tonnes a year) came mainly from the mining of Kuroko-type deposits from which it was recovered as a by-product. At present gold is produced mainly from the Hishikari mine, approximately 14 tonnes in 1986; this could rise to 20 tonnes by 1990.

Japan's total output of refined gold is about 60 tonnes. Most of this, however, is recovered as a by-product of imported ores and from scrap.

### Papua New Guinea

In Papua New Guinea, gold was of great interest in the period before 1940 but in the late 1960s and 1970s the then territories of Papua and New Guinea also became the object of exploration for porphyry-type copper deposits. Two such giant deposits, Bougainville Copper and Ok Tedi, were developed and others like Yanderra and Frieda River were discovered and evaluated. These deposits contain significant amouns of by-product gold. Bougainville, after it started producing (1972), increased Papua New Guinea's gold production from 600 kgs to almost 20 tonnes in 1973, just as the price of gold was significantly increasing. The leached cap over the Ok Tedi deposit, enriched in gold, initially produced an additional 20-25 tonnes gold per year. Annual gold production from Ok Tedi will decrease to 10-15 tonnes as this cap is mined out and gold is co-produced from the main copper ore body.

Over the last decade epithermal gold deposits have become the primary exploration target. A large number of these deposits and many occurrences have been discovered in recent years and a number of these have reached the production decision stage such as Porgera, Misima, Mt. Victory and Lihir. The reserves indicated in these prospects may well yield over 1000 tonnes of gold.

Papua New Guinea's production, at an annual level of approximately 35 tonnes in 1986 and in 1987, may well reach 70 tonnes in 1990 and possibly exceed 100 tonnes in the coming decade. Shearson (1988) formulates this as: "Exploration activity is prolific and we believe a mining boom is about to develop." This is very likely a correct observation.

### The Philippines

The Philippines has perhaps the oldest and strongest mining economy of all countries in South-East Asia in the modern era. The country produces a wide range of metallic minerals and counts at least five major native mining corporations.

Since 1981 gold production has increased by 60 per cent, and much of this gold (about 45 per cent) is produced as a by-product of large-scale copper-mining operations. The increase in the gold price gave these producers some critical revenue assistance in the depressed metal markets prevailing in the early years of the decade.

A large additional factor in the increase in gold output has been the greatly increased activity of small-scale miners and panners as one small gold rush after another brought hundreds of these operators into the field as new finds became known. Most of this has taken place in the southern island of Mindanao, and in the provinces of Surigao and Davao del Norte.

The Government has taken a number of steps to encourage and regularize small-scale mining, which is now estimated to employ 200,000 to 300,000 rural people who often are living in areas of high unemployment in the conventional economy. About 30 per cent of the annual gold production is won by these panners, who may sell their gold to the Government for a small premium above market price.

Lately the increased interest in epithermal gold deposits which has driven much of the activity of the international companies in East Asia has also had its effect in the Philippines.

Gold production in the Philippines stood at about 15-20 tonnes per year during the 1970s. Since then annual production has risen to about 40 tonnes in 1987. Additional potential outputs from the Longos and the Far South-East mines may push this up to about 50 tonnes per year in 1990.

## PROSPECTIVE MAJOR PRODUCERS

This group of countries not only merits separate discussion because of favourable geologic settings, but also for the favourable foreign investment climates which have been created for the mineral industry. The most notable members of this group at the time of writing are Indonesia and Malaysia.

### Indonesia

In South-East Asia Indonesia occupies a unique position, not only because of its size and the wide dispersal of the islands in the archipelago but also because of its geological setting at an area of interaction between three major plate tectonic units, which is the underlying cause for the widespread occurrence of epithermal gold according to our present understanding.

Although gold was mined in Java and Sumatra in historic times, and although as recently as 1941 about 2.5 tonnes of gold was mined, Indonesia had never been a great producer. Mining development in the country stagnated during the 1950s (Sigit, 1988) and it was not until 1983 that renewed interest for gold was experienced in the industry (Sigit, op. cit.). Renewed interest was made possible by Indonesia's Mineral Development Policy, the Foreign Capital Investment Law (1967), and the development of the "Contract of Work" (COW) concept. These, in combination with the recognition of the country's vast potential for epithermal gold have since 1985 led to an exploration boom in which over 100 COWs have been signed under which in excess of 100 million US dollars have been committed to exploration. Kalimantan, Sumatra, and Irian Jaya have been the main targets of this activity.

In 1987 Indonesia had a registered mine production of 3.5 tonnes, but export of gold from "unknown" sources was estimated to be well over 13 tonnes (Sigit, op.cit.). Recently the Government has announced that it plans to take action against this people's mining".

If future production reflects present exploration and development investment, Indonesia will become a major producer. Beunderman (op.cit.) estimates an output of 20 tonnes for 1990. Other estimates vary from 50 to 100 tonnes by 1995. Given a price in the $US400/oz. range, gold would rapidly replace tin as the premier non-fuel foreign exchange earner.

### Malaysia

In its drive towards diversification of the mining industry, the Government is now promoting development of gold and other commodities. Malaysia's potential for gold is significant. The central volcanic belt in Peninsular Malaysia and the States of Sarawak (notable the Bau district) and Sabah show special promise. There is increasing interest from private industry in undertaking exploration and the possibility of significant growth in output in the 1990s cannot be discounted.

In 1989 Malaysia produced about 3.5 tonnes of gold of which 2.5 tonnes is derived as a by-product from the Mamut copper mine.

### Thailand, Lao People's Democratic Republic, and Viet Nam

Virtually no gold production to date is officially known from Thailand, the Lao People's Democratic Republic and Viet Nam, although potential in all three countries has been recognized or inferred, and small-scale operations are known to exist.

Thailand's major prospects are in the northeastern Loei province. With government policy directed to development of gold mining and with the announced review of the royalty rates it may be expected that production in Thailand will materialize during the 1990s.

Historically Viet Nam has known gold production from Pac Lang, north of Hanoi and from Bong Mieu near Da Nang. Present production levels are low but it can be expected that, with the promulgation of the new foreign investment law in 1987, these and a number of other occurrences and deposits may attract interest from foreign investors.

In the Lao People's Democratic Republic there is no record of any organized production of gold although a number of gold showings are known. The country is underexplored and these showings are not considered representative of its potential.

### The Pacific

Gold output in the Pacific is relatively small although both Fiji and Solomon Islands have traditionally been producers. Fiji produced between 1 and 3 tonnes annually over the last decade, most of which came from the Emperor Gold Mine. In Solomon Islands, gold production could reach about 1 tonne by 1990 when newly installed capacity commences production. Other potential producers are Vanuatu, the Republic of Palau, the Federated States of Micronesia and the Commonwealth of the Northern Mariana Islands. Exploration is currently going on in all these islands.

New Zealand had been a modest producer but output has increased with the development of some new epithermal prospects. By 1990 production will stand at about 6-8 tonnes from newly opened mines at Martha Hill, Golden Cross and Macrea's Flat.

### South Asia

Countries of South Asia have a small output of gold. The main producer is India where production peaked with 8 tonnes in 1953. This has gradually come down to 2-3 tonnes annually during the last decade. Gold is produced from the Kolar gold field and from the Yeppamana mines in Andhra Pradesh. Recent new discoveries are in Karnataka and in the foothills of the Himalayas near the Uttar Pradesh-Mahdya Pradesh border.

Pakistan has no recorded significant production but when the Saindak porphyry copper project comes on stream, some 1-2 tonnes of gold will be produced annually as a by-product of that operation.

There is no geological reason to presume that the gold potential in South Asia is necessarily constrained at this low level; it is rather more likely that underexploration and other government priorities in mineral exploration may account for these low outputs.

In South Asia there is a very high sustained demand for gold (and silver) for jewellery. This demand can not be met from national mine production and recycling of scrap. As a consequence local market prices for gold can be as high as twice the world market price.

## CONCLUSION

There is indeed, worldwide and especially in South-East Asia and the Pacific, a gold rush going on. A gold rush in which this time the major players are not individual prospectors in great numbers but private companies, often as partners with governments in joint ventures. The tools of this on-going gold rush are not the prospector's hammer and the pan but innovative thought and successfully proven new technology. The outputs are high, the profits handsome and the benefits can be great, certainly if national mineral policy is premised on the view, as is in Papua New Guinea, that mines are useful not only for any direct benefits they may bring, but for the financial support they can provide for progress toward other national goals. It can also be pointed out that today's increased production does properly take into consideration the status of world market and supply needs and the pace of exploration is adapted to this in its role as the essential forerunner of mineral development. But exploration has another important role as a planning tool in more general terms, if only to provide the data necessary to establish a good and complete resource base. It is justified to intensify exploration for gold at a time while potential benefits are favourable. It is however unwise to neglect exploration for other commodities and it may be a wise policy to invest some of the profits in this effort. A more readily accessible resource information base benefits both investors and governments and, it can assist greatly in reducing the impacts of the mineral price cycles which periodically beset the industry.

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# WHAT IS "EPITHERMAL"?

by
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## 1. "Epithermal" is an Epidemic

Higher world market prices for gold combined with progress in low cost ore-processing techniques accelerated gold exploration in the world in the late 1970s, which resulted in discoveries of three major gold deposits in young volcanic terranes of the Circum-Pacific region in the period 1987 to 1981: El Indio, Chile (12.3 g/t, 40 tonnes Au), McLaughlin, California, United States of America (5.2 g/t, 93 tonnes Au), and Hishikari, Japan (80 g/t, 120 tonnes Au).

Encouraged by these highly successful gold discoveries, exploration activities targeting similar deposits spread, like an epidemic, throughout the Circum-Pacific countries, where young volcanics are extensively distributed. More recent discoveries include two gigantic deposits at Porgera (40 g/t, 335 tonnes Au) and Lihir (4.5 g/t, 360 tonnes Au), both in Papua New Guinea.

All these deposits are grouped in the category of epithermal gold deposits, although they have different morphologies, different mineral assemblages and different alteration patterns. Thus a question arises: What is "epithermal"?

## 2. Epitomizing "Epithermal"

The term "epithermal" was first used by Lindgren (1933) in his classification of mineral deposits, in which he defined epithermal deposits as "metalliferous deposits formed near the surface by ascending thermal waters and in genetic connection with igneous rocks" (p.444 in *Mineral Deposits*, fourth edition). They were thought to have been formed at low temperatures and low pressures.

Lindgren's definition is not erroneous even in the light of our present knowledge of epithermal deposits. We have reached a more detailed understanding of epithermal mineralizing systems, although it is a little frustrating to recall that while Kuroko deposits and porphyry copper deposits have emerged from Lindgren's mesothermal and hypothermal categories as independent deposit types with distinct genetic significance, so far a well-defined deposit group has yet to come forth from his epithermal category.

Our present knowledge on epithermal gold mineralizing systems as a whole can be epitomized in the following terms:

(1) The responsible system is driven by a shallow magmatic heat engine, and the economic gold mineralization takes place in a very small portion of the whole system, most commonly close to the surface where the fluid suffers intense physical and chemical changes.

(2) The fluid is dominated by meteoric water with varying degrees of incorporation of magmatic substances (water, sulfur, metals, chlorides, among other chemical species).

(3) Gold is transported most probably as bisulfide complexes, which are dissociated to precipitate gold most effectively by some combination of boiling, change of pH from near neutral, and oxidation.

Although the above characteristics are common to most epithermal gold deposits, it seems difficult to portray the great variety of the deposits in a single deposit model. A widely accepted classification of epithermal gold deposits is the following:

*(1) Volcanic-rock hosted:*

Low sulfidation type (adularia-sericite or quartz-adularia type)

High sulfidation type (acid-sulfate type)

*(2) Sedimentary-rock hosted (including Carlin type)*

Within each of the above classes, the hot-spring type and the bonanza type may also occur.

This range of epithermal gold deposits is thought to have arisen from various evolutionary histories of the mineralizing fluids, which in turn reflect varying tectonic-

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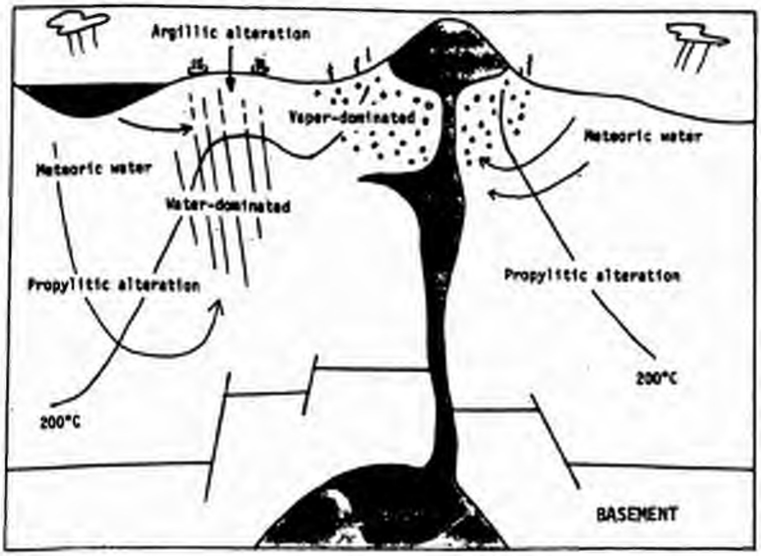

**Figure I. Deposit model of gold veins in the Hokusatsu district.**

magmatic environments. The above classification is by no means complete, however, as we may find when we try to classify a given individual deposit into one of three types. Indeed, many subtypes and intermediate types have been proposed in order to implement the above classification framework, or more properly, to make room for the "exceptional" deposits which seem to increase as studies progress. The great variety of epithermal gold deposits is due, at least in part, to their shallow origin which means they are greatly affected by local variations in host-rock lithology, thermal regime, topography, hydrology and even climate. This apparent complexity of epithermal mineralization hinders our clear-cut understanding of its real nature, but at the same time provides a fascinating field of attention for scientific research.

## 3. Epilogue for "Epithermal" Gold Exploration

It is most important in exploration for epithermal gold deposits to realize that gold mineralization is only one local aspect of a large-scale hydrothermal system possessing the general characteristics as cited above, and to predict the 'logical' consequences of such a system which is operated in a given geologic environment. The responsible fluids may have imprinted their more easily recognized conventional geophysical and geochemical signatures at some point very remote from the gold deposit. In order to locate gold deposits on the basis of such indirect showings, it is necessary to have a scientifically sound, but not too sophisticated, deposit model. For such a model to be effective, the local geologic, tectonic and geochemical characteristics of the target area must be carefully considered. Especially, the already known deposits in the area, if present, should be thoroughly studied as models to understand in which part of the total hydrothermal system the economic deposits were formed. An example will serve to demonstrate this point.

In the case of an exploration program conducted by the Metal Mining Agency of Japan in the Hokusatsu district, Kyushu, detailed studies of the Kushikino deposit and its surrounding area successfully resulted in the discovery of the high-grade Hishikari deposit in 1981. This extraordinary deposit, with at least 120 tonnes of gold in quartz-adularia veins averaging some 80 g/t Au, was located about 200 m below the surface by a pilot bore hole targeting an area below a low-resistivity anomaly and above a high-gravity, high-resistivity anomaly. The depth of the targeted ore veins was estimated from the measured filling temperatures of fluid inclusions in quartz collected from the waste of an abandoned mine in the area.

The deposit model adopted in this exploration program is shown in the Figure I. It may be criticized as being too simple by the standards of our present knowledge. But it is my belief that it worked because it was simple enough for "simple" exploration techniques to be easily applied.

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# MAGMATIC AND STRUCTURAL CONTROLS ON EPITHERMAL GOLD MINERALIZATION

by
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Research into epithermal mineralization in recent years has focused on the determination of the physical and chemical environment of precious metal deposition, using techniques such as fluid inclusion geothermometry, stable isotope analysis and the application of thermochemical theory as a method to estimate mineral stability relations. Thus the general chemical environment, involving relatively low salinity fluids at temperatures ranging up to 300°C or so, is now well understood. With time, greater confidence has arisen in the recognition of temperature ranges and other parameters of the ore environment based mainly on certain textures: thus pseudomorphs after bladed calcite may reliably indicate the transient occurrence of boiling conditions in a vein environment, and similarly the recognition of adularia (which requires a pH increase in the fluid phase due to gas loss) is also a reliable indicator of boiling. Fine laminations in vein quartz testify to rapidly changing temperature and or pressure conditions and in some cases quartz textures (e.g. chalcedonic quartz, euhedral quartz) may infer the temperatures of silica deposition. In themselves, however, such textures are not indicative of the gold potential of the environment.

Much recent attention has also been given to establishing the role of magmas in the formation of epithermal deposits. Stable isotope techniques have seldom been definitive often because of uncertainties caused by multiple stages in the hydrothermal evolution of deposits, but the growing body of field evidence is unequivocal: high level magmas are the source of gold and in most cases of the sulphur required for the transport of gold.

In the Taupo Volcanic Zone (New Zealand), gas-rich, gold-rich geothermal systems occur along a lineament which lies a few kilometers inside the boundary fault of the graben and coincident with the line of young (<100,000 years) andesite and dacite volcanos. New chemical data from these systems has indicated that they arise by interaction of conductively heated groundwaters with low salinity, probably vapor-phase magmatic fluids evolved at depths of 5 to 8 kilometers.

Using heat and mass-balance arguments, these data imply a magmatic source for gold in epithermal systems and provide a genetic link to subvolcanic porphyry-gold style systems and other intrusive-related deposits. Other similar subvolcanic environments may evolve tin deposits, confirming the concept that the origin and crystallization history of a given magma suite determines the character of the consequent mineralization developed during magmatic vapor-groundwater interaction. Other metals such as lead and zinc, whose crustal abundances are higher, may be derived from the host rock but are dependent on the salinity of the groundwater system for their transport and deposition elsewhere.

The role of degassing magmas in supplying metals is becoming more firmly established; Meeker (1988), for example, has shown that in December 1986 Mt. Erebus in Antarctica discharged daily about 0.1 kg Au together with 0.2 kg Cu, 200 tonnes HCl and 56 tonnes $SO_2$, – a rate of deposition equivalent to 360 tonnes gold per 10,000 years.

The differences between epithermal deposit styles may relate largely to their relative depths of intrusion. Thus the alunite-kaolinite type deposits are related to the degassing of high level magmas (e.g. rhyolite domes) with later hydrothermal flow driven by the larger, deeper magma system. The adularia-sericite type systems are related to deeper magma bodies (4-8 km) degassing into an overlying groundwater system. Convecting groundwaters serve to disperse the magma fluid. In highly permeable systems the dispersion may be so diffuse as to prevent the formation of an ore deposit even though a billion grams of gold may be released, only to form a large, disseminated low grade deposit in the upper few hundred meters of the system, as at Kawerau, New Zealand. In lower permeability host rocks, major structures may control and channel groundwater flow and thereby focus fluids to create a site of high level deposition, as at Hishikari, Japan.

Perhaps more important for exploration is the understanding of the controls on the fracture arrays within which epithermal deposits form. This has received only scant attention despite our modern ability to model the fracture response of rocks under stress. Indeed, the few data available on fracture geometry in epithermal deposits is to be found in the literature developed during the 1930's phase of gold exploration (e.g. McKinstry, 1941). Recently Sibson (1987) has focused attention on the relatively

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common association of epithermal deposits with dilational zones on large-scale primary or higher-order wrench structures. Examples include Waihi, New Zealand, and Camp Bird, Colorado, United States of America, Hishikari, Japan, and Golden Cross, New Zealand are also good examples in which high level, low grade mineralization gives way at depth to high grade vein sets. Sibson (1981) has also discussed the dynamics of fracturing in near-surface environments where the maximum principal stresses are not lithostatic. Under near-surface conditions a distinctive fracture array can develop which may commonly be associated with extensive hydraulic brecciation and hydrothermal eruption breccias at the surface. These eruption breccias are common features of hot-spring type epithermal deposits (e.g. McLaughlin, California, United States of America) and of active geothermal fields (e.g. Waiotapu, New Zealand).

Whilst the general characteristics of such structural settings are understood, the origins of the controlling stresses are not. These may relate to and be localized by magmatic processes, through caldera formation or doming, or to larger-scale regional tectonic events. Thus in Nevada, United States of America (e.g. the Walker Lane), Bolivia and elsewhere there are clear examples of links between the development of major crustal fractures related to plate geometries and the localization of magmatic intrusives and mineralization. Both Kelian, Indonesia and Lihir, Papua New Guinea are related to major crustal structures. Interestingly, in both these examples mineralization occurs within an extensive complex of phreatomagmatic breccia bodies and it is possible that during crystallization, reactivation of the structures which localized magmatism has been responsible for the magmatic brecciation which localized the later mineralization.

For exploration the recognition of the structural environment of epithermal mineral formation may be at least as important as the determination of chemical parameters. One of the most promising techniques for recognition of structural plays at an early stage in exploration is aeromagnetic survey. High resolution, low altitude surveys, combined with modern computing techniques and image processing are able to define structural patterns in poorly exposed terrain (e.g. below lateritic or jungle cover) and thereby focus follow-up geological or geochemical reconnaissance. Such surveys may also locate major lithologic associations (intrusives, etc.) and, through demagnetization anomalies, zones of alteration. The initial costs of such programs are relatively high but are rapidly offset against the comparative cost of conventional field programs which require more time and suffer from the limitations on exposure imposed by the terrain.

Recent exploration has focused on the search for near-surface deposits suitable to open-pit operations, but the future must lie in the exploration for deeper vein-type high grade targets similar to Hishikari. In 1989 the Hishikari deposit produced gold at a cost of $US30 per ounce, compared to costs of $US200 to 300 per ounce in other developed epithermal deposits. In many areas underground mining may also be environmentally more acceptable than open pit operations. As with oil exploration, the exploration for such deep targets is a high risk proposition but one with commensurate high rewards. The key to their exploration, as demonstrated at Hishikari, is a dedicated geophysical program combined with structural analysis, the very research area so badly neglected in recent years.

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# EPITHERMAL PRECIOUS METAL DEPOSITS ASSOCIATED WITH VOLCANIC SYSTEMS

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Epithermal precious metal deposits occur in a wide variety of volcanic systems which range in size, style of volcanism, and tectonic setting. The largest volcanic systems, and most explosive, are large Valles-type collapse calderas with diameters ranging up to 60 km. These systems release large volumes of magma in a short interval of time followed by a generally long interval (up to several million years) of small volume, less explosive volcanism. Smaller calderas and vent craters developed at the crest of shield and stratovolcanoes generally involve the eruption of a smaller volume of magma, and are followed by only a short interval of post-collapse volcanic activity. Volcanic domes and associated flows, dike complexes, and maars are the smallest volcanic systems associated with precious metal deposits and some of these systems develop within larger caldera systems.

Although gold deposits are spatially associated with each of these volcanic features, the deposits invariably form late in the evolution of the volcanic system and often are related to last phase of volcanic activity. The gold deposits may range in type from quartz-alunite (Nansatsu) deposits to quartz-adularia (Sado) deposits, both of which may have surface hot-spring sinter associated with them. Because the deposits occur in volcanic features formed at or very near the surface, temperature gradients extending from the magmatic heat source during the early stage of the hydrothermal system are large in relation to the small vertical extent of the deposits.

Development of large Valles-type calderas results from emplacement in the upper crust of large intermediate to felsic magma bodies which vent catastrophically, resulting in the collapse of large blocks of country rock into the evacuated magma chamber. After caldera collapse, resurgence of magma causes structural doming within the caldera and typically leads to emplacement of ring domes along the structural margin of the caldera.

Continued resurgence may lead to failure of the central structural dome and rapid venting of the resurgent magma chamber resulting in the development of another caldera nested within the large, older caldera.

Magmas associated with the development of caldera structures are typically zoned with the top part of the magma chamber consisting of a volatile-rich felsic melt which becomes more mafic and less volatile-rich with increasing depth. Because the early caldera eruption disperses the more silicic cap of the magma chamber, the residual magma responsible for resurgence can be more mafic in composition.

The last phase of volcanic activity in caldera evolution is the emplacement of intrusives and domes which are typically more intermediate in composition, ranging from dacitic to andesitic. Structural doming associated with this magmatic event is important in opening preexisting caldera ring- and radial-fractures and associated faults for fluid flow.

This last magmatic event also provides the heat source and possibly the metals for the hydrothermal systems which form gold deposits. Gold deposits of the quartz-alunite type, such as the Rodalquilar deposits in Spain, are spatially and temporally associated with these late stage magmas. Favorable sites of gold deposition occur along the ring-fracture faults of the caldera and radial and concentric faults and fractures developed just outside the collapse structure, as in the Rodalquilar deposits in Spain, especially where these structures are intruded by these late stage magmas. Permeable unwelded to partly welded intracaldera ash flow tuffs adjacent to these structures provide favorable horizons for ore deposition. Alteration zones may be strongly controlled by the permeability of volcanic units, with some unwelded tuffs and volcaniclastic units being strongly silicified for large distances from the feeder fault zones.

Volcanic craters and small calderas developed at the crest of stratovolcanoes and shield volcanoes may host large, high grade gold deposits of both the quartz-adularia type and the gold-silver-telluride subtype associated with alkalic volcanism. These caldera structures are small, generally ranging from 2 to 5 km, and are developed at the end-stage construction of large shield volcanoes, such as

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the Tavua caldera, Fiji, which hosts the Emperor gold-telluride deposits, or at the end-stage construction of stratovolcanoes such as the Luise caldera in Papua New Guinea, which hosts the Lihir deposit. In the Lihir deposit intracaldera fill deposits have been intruded by post-collapse intrusives and domes which are spatially and temporally associated with the gold mineralization. The deposits are young (0.3 m.y.), and are only restricted to the caldera because intrusion and dome emplacement did not extend outside the caldera structure.

Epithermal precious metal deposits associated with volcanic domes, flow-dome complexes, and dike complexes are of the quartz-alunite and quartz-adularia type. Volcanic domes unrelated to caldera systems result from the emplacement of small volumes of magma along a major extensional fault zone which is active throughout the volcanic event. Extensional fault zones associated with volcanic domes in the western United States of America (eastern Oregon, western Idaho, northeast California, and northwest Nevada) are relatively narrow, up to 25 km in width, in comparison to their strike length, which can be up to 200 km. The extensional fault zone may form at the crest of broad anticlinal structure which has developed as a result of structural doming of the near-surface in response to the emplacement of a shallow-level magma chamber. Total displacement across the fault zone is small, less than a km, and the volcanic domes are emplaced along the faults developed at the crest of the structural dome. Initial emplacement of the volcanic dome is reflected by a vent-clearing phase in which tuff breccias composed dominantly of country rock fragments are explosively erupted and deposited outward from the vent, forming a tuff ring. Juvenile magmatic inclusions comprise a subordinate amount of the tuff breccia. After clearing of the vent, the eruption consists dominantly of juvenile magma which vesiculates in the vent and is deposited as pumice lapilli tuffs and air-fall tuffs with only a minor lithic component. The resulting tuff cone is subsequently intruded by less volatile-rich magma which forms a dome within the original vent. Continued eruptions may produce small-volume lava flows, debris avalanches, and ash flow tuffs. Continued movement on faults along which the volcanic domes were emplaced is important in providing pathways for hydrothermal fluid flow through the dome and vent complex, as seen in the volcanic domes within the De Lamar deposits, Idaho, United States of America.

Dike complexes, like dome complexes with which they are often associated, are generally emplaced along extensional fault zones and individual dikes may extend along strike for several km. Epithermal mineralization is localized along the brecciated margin of the dike and in the adjacent country rock, such as is seen in the Castle Mountain gold deposit, California, United States of America.

Hot-spring type precious metal systems associated with volcanic domes are strongly zoned, with cinnabar mineralization occurring in the sinter and acid-leached zones in the uppermost part of the dome, such as at Quartz Mountain, Oregon, and Buckskin, Nevada, United States of America. Quartz-adularia gold veins, localized along faults as stockwork veins and as hydrothermal breccias, occur at deeper levels within the dome and in adjacent country rock. Exceptionally high grade (greater than 300 grams per ton gold) bonanza veins such as at the Sleeper deposit, Nevada, United States of America are typically associated with these systems. The narrow veins, generally less than 1 m in width, are developed along the faults which controlled the initial emplacement of the dome and were subsequently reactivated after dome emplacement. Stockwork veining and hydrothermal breccias characterized by stibnite, quartz, and a high silver-to-gold ratio cut the earlier high-grade gold veins at the Sleeper deposit. Disseminated, low-grade mineralization can occur in tuff breccias and pumice lapilli tuffs which form the tuff cone, such as at Quartz Mountain. Impermeable clay zones formed from altered air fall tuffs which were deposited on top of the volcanic dome such as at the De Lamar deposit, United States of America, can be important in localizing mineralization. On a district scale, localization of ore bodies is strongly influenced by the coincidence of volcanic vents with recurrent faulting along extensional structural zones.

# MINERALISATION OF VOLCANOGENIC HYDROTHERMAL SYSTEMS IN THE CIRCUM - PACIFIC, AND THEIR RECOGNITION

by
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## INTRODUCTION

Epithermal ore deposits hosted by volcanic rocks and formed by volcanic-related hydrothermal systems have become important gold producers in the Circum-Pacific following many recent discoveries (Hedenquist, 1987; Hedenquist et al., 1990). There is much potential for further discoveries, particularly in poorly known and explored regions of the southwest Pacific.

One such type of epithermal deposit, termed low sulfidation, is characterized by reduced sulfur in the ore-forming fluids; this deposit type is also referred to as adularia-sericite (Heald et al., 1987). This style of mineralisation formed in an environment analogous to many active geothermal systems (Henley and Ellis, 1983), with the ore-forming fluids having a near-neutral pH.

The alteration mineralogy reflects the near-neutral-pH fluids (Heald et al., 1987), with surficial steam condensates causing the restricted development of advanced argillic (acid) mineralogy. Although these convecting systems may have a magmatic component contributed at depth, it has been fully neutralised during ascent (Figure 1).

A contrasting style of epithermal gold mineralisation is reviewed here, in which the ore-forming fluids

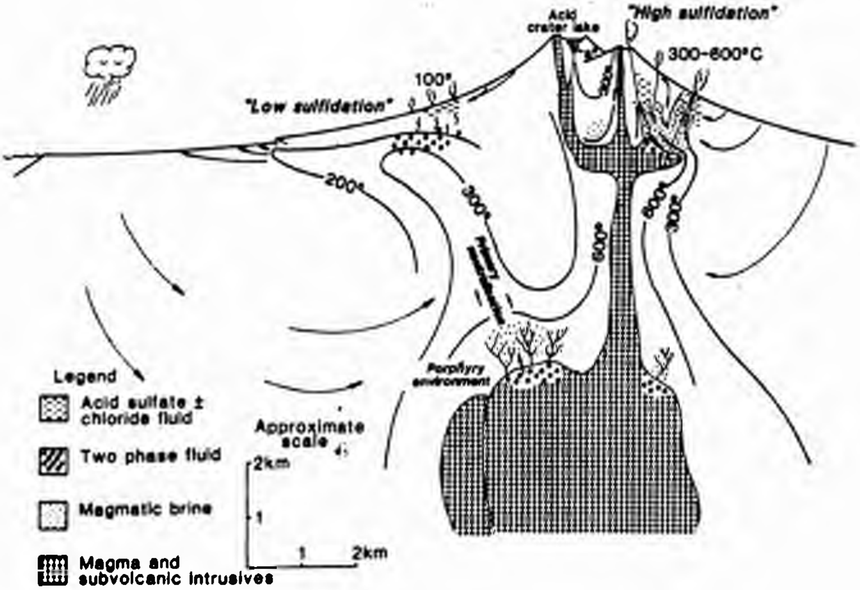

**Figure 1.** Schematic representation of the relationship between high and low sulfidation hydrothermal systems, and their volcanic setting. The relief shown is not necessarily typical; development of these systems in lower relief terrane will result in lower hydraulic gradients and less lateral flow. Advanced argillic alteration is present in both systems, but is more intimately related to the mineralising fluids in the high sulfidation situation. Epithermal gold mineralisation is most favoured in zones where temperatures are <300°C.

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were relatively oxidizing and acid. They are termed high sulfidation, to refer to the high oxidation state of the sulfur in the primary fluid (Hedenquist, 1987); they have also been referred to as the Goldfield type (Bethke, 1984) and the acid sulfate type (Heald et al., 1987). This style is somewhat enigmatic because they are poorly studied, both in terms of deposit examples and active analogues (in contrast to the low sulfidation, geothermal style of mineralisation). However, indications are that their formation is closely related to an acid fluid evolved from a high-level magma (Bethke, 1984; Henley, 1985; Stoffregen, 1987; Hedenquist, 1987). They can be closely related, both in time and space, and possibly also in genesis, to porphyry copper systems (Sillitoe, 1983, 1987).

## HIGH SULFIDATION SYSTEMS

### Characteristics

Gold mineralisation in high sulfidation ore deposits is generally associated with enargite (or its lower temperature dimorph, luzonite); in places it is associated with pyrite, tennantite-tetrahedrite, covellite, chalcocite, and/or alunite and barite. These minerals are commonly (though not always) hosted by a vuggy, silica-rich rock, which is the product of extreme hydrolytic base-leaching by highly acid fluids.

The ore zones, which often are strongly localized by structural features (Sillitoe, 1983) and associated with hydrothermal brecciation, have a ubiquitous though narrow alteration halo (generally less than tens of meters across). The gradation is from the ore zone (including leached, residual silica, if it is present) outward to quartz-alunite, quartz-kaolinite (±dickite, diaspore, and pyrophyllite), clays (illite and interstratified illite-smectite), and into a district scale zone of propylitic style of alteration. A late, overprinting alteration (sometimes supergene) may be present, including goethite, alunite and native sulfur.

The advanced argillic alteration assemblage intimately associated with the high sulfidation mineralisation contrasts with that observed in low sulfidation deposits. In the latter situation, the acid sulfate waters occur at shallow levels over and adjacent to the upflows of mineralising fluids. These surfical acid sulfate waters are relatively low temperature, and result in alteration blankets of kaolin clays, pyrite, cristobalite and native sulfur, sometimes overprinting the underlying alteration and mineralisation. Where these acid fluids descend along fractures and are heated, such as in high-relief Philippine geothermal systems, they may develop higher temperature acid minerals (e.g. pyrophyllite, diaspore). It is important to distinguish the acid alteration signature of high sulfidation systems, directly related to the mineralising fluid, in contrast to the ephemeral acid condensates overlying (or overprinting) mineralisation in the low sulfidation systems.

### Examples

The type example often used of the high sulfidation style of mineralisation (Bethke, 1984) is Goldfield (Nevada, United States of America ); other similar deposits include Summitville (Colorado, United States of America), Pueblo Viejo (Dominican Republic), Laurani (Bolivia), Pilzhum (Ecuador), Jarhuarazo, Julcani, Cerro de Pasco, Morococha, Yauricocha, Huaron, Colquijirca, Quiruvilca and Hualgayoc (Peru), El Indio and Tambo (Chile), Temora (Australia), Mount Kasi (Fiji), Nena, Wafi River and Frieda River (Papua New Guinea), Motomboto (Indonesia), Lepanto and Nalesbitan (Philippines), Chinkuashih (Taiwan Province of China) and Nansatsu district (Iwato, Kasuga, Akeshi), Ugusu and Teine (Japan). This list is not exhaustive, particularly as new deposits are being found or others are being reinterpreted; it may not be completely correct, either, as some of the deposits listed are poorly known, and may in fact be of another mineralisation style.

Not all these deposits have residual (vuggy) silica present (e.g. El Indio), suggesting that either the fluids were not acid enough to mobilize aluminium or the fluids did not interact with the wall rock (due to strong fracture control of flow). Several of the deposits have an elongate nature, due to structural control (e.g. El Indio, Lepanto, Goldfield), while others have mushroomed ore bodies where the fluids flowed into host rocks possessing aquifer properties (e.g. Iwato, Lepanto, Pueblo Viejo). In the case of Summitville, hydrothermal breccia pipes and fractures host most of the mineralisation.

Several are spatially associated with intrusives, some being related to porphyry copper mineralisation, either above or marginally (e.g. Summitville, El Indio, Lepanto). Others are close to low sulfidation epithermal gold mineralisation (Chinkuashih, Ugusu, Lepanto). A lack of precise age-dating for mineralisation of most deposits precludes an unambiguous determination of the timing of related mineralisation. More extensive references are available in Sillitoe (1988) and Hedenquist (1987).

### Mineralising fluids

Mineralogic and fluid inclusion studies of some high sulfidation deposits (e.g. Summitville, Pueblo Viejo, El Indio, Mount Kasi, Chinkuashih and the Nansatsu district) indicate that temperatures related to mineralisation are most commonly 180 to 270°C. This and the commonly deduced shallow depths of emplacement qualify many of these high sulfidation deposits to be considered as epithermal.

Fluid inclusion studies are few, and those available generally indicate a dilute fluid, though it should be noted that these inclusions are often in late-forming, vug-filling quartz crystals. Occasionally some inclusions are observed with daughter minerals and/or low ice melting temperatures, indicating the presence, at least periodically, of a brine.

The origin of the water in the systems studied to date appears most often to be meteoric (Rye et al., 1989; Stoffregen, 1989; Hedenquist et al., 1990). Although in some situations this may be due to an overprinting of an early magmatic fluid by a later meteoric water, it is possible that magmatic water is not significantly involved in early convection either. In contrast, sulfur isotope studies (Bethke, 1984) indicate that the sulfur was originally $SO_2$ of a magmatic source; upon cooling to <300°C, the $SO_2$ disproportionates to $H_2SO_4$ (and $H_2S$). This sulfuric acid, along with magmatic HCl and HF, causes the extensive rock leaching and development of the acid alteration mineral assemblage.

Despite the dominance of meteoric water, the magmatic signatures of the reactive components and the common spatial assocation with porphyry copper-gold mineralisation argues for a magmatic source of the metals.

### Mineralisation

In both Summitville (Stoffregen, 1987, 1989) and Nansatsu (Urashima et al., 1981; Hedenquist et al., 1990), gold mineralisation is associated with vuggy silica produced by acid leaching of the original volcanics. It appears that this strong leaching greatly increased the vertical permeability, such that fluid flow was focussed into these zones.

The exact cause of gold deposition is not well understood at present. However, evidence from several deposits suggests that the system evolved from a highly reactive fluid to one that was less acid and oxidizing. This may have occurred as the magmatic components to the convection system waned (Figure II), or possibly due to an increase in the reaction path, resulting in a greater degree of rock interaction and neutralization.

## EXPLORATION GUIDELINES

The potential for discovering further high sulfidation gold deposits in young volcanic terrane of the Circum-Pacific is very good. Extremely high-relief stratovolcanoes are probably not good potential hosts due to strong hydraulic gradients, unless mineralisation occurred quite deep; the meteoric convection cell would drain away too rapidly and not condense magmatic volatiles (and metals) as readily. Of greater potential are lower relief calc-alkaline terranes in proximity to volcanic vents (one to several kilometres), similar to that deduced for the Nansatsu district. The potential for high sulfidation systems to occur above and marginal to (and within) porphyry systems has been dis-

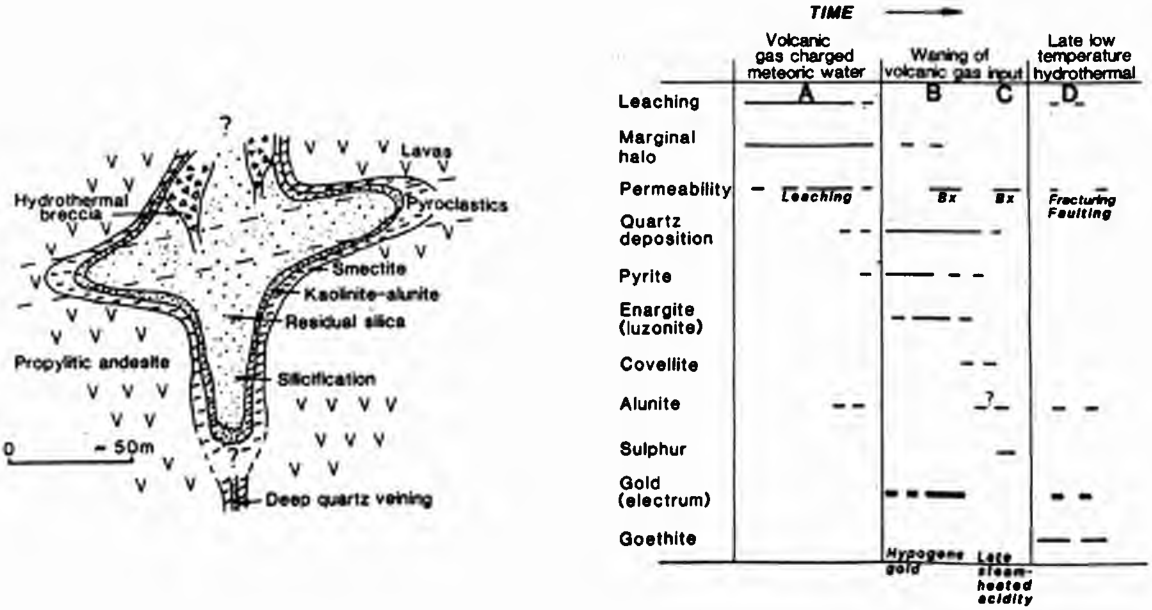

**Figure II.** (Left) Schematic cross-section of an Iwato ore body, modified from Urashima et al., 1981. (Right) Deduced paragenesis and evolution of Nansatsu mineralisation (Hedenquist et al., 1988).

cussed by Sillitoe (1988), who also mentions geologic features favourable for their development.

Distinction must be made in exploration between the advanced argillic alteration associated with mineralised high sulfidation systems and that simply due to solfataric alteration (magmatic fumarole condensates), without involvement of a convecting hydrothermal system. The latter maybe somewhat restricted and closely related to volcanic vents; however, there may be some metal anomalies (e.g. Pb, As) due to vapour-phase transport and fixation in sublimates. Advanced argillic alteration can also be related to low sulfidation systems and supergene processes (the latter without fresh sulfides), though they will not have associated metal anomalies unless they overprint previous mineralisation.

Structural trends are important, both regionally and locally; the potential for tonnage development will be improved where there are permeable stratigraphic units (e.g. unwelded pyroclastic and airfall tuffs) and/or syn-hydrothermal breccias. In addition to acid alteration, leaching and (commonly) residual silica, mineralised high sulfidation systems will have evidence of subsequent sulfide and quartz deposition. Alteration and grade are commonly regular in zonation, and surface geochemical anomalies will include gold, silver and arsenic (copper is usually leached by weathering).

In my experience, discovery of a fossil system is not as difficult as assessing its type (and therefore being able to imply possible characteristics) once found, and then determining local controls on mineralisation and the degree to which the system is mineralised. The ability to better assess individual high sulfidation systems will only come as we improve our overall understanding of the volcanogenic hydrothermal environment. Research drilling into hydrothermal systems that are present on the flanks of active volcanoes (e.g. White Island, New Zealand; Giggenbach et al., 1989) will help to provide this understanding.

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# EPITHERMAL GOLD MINERALIZATION IN KYUSHU, JAPAN

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## INTRODUCTION

Kyushu, with an area of about 41,000 km$^2$, is one of the four largest islands of Japan and is known as one of its most important gold-producing areas. Particularly, recent discovery of the Hishikari deposit (120t Au) has drawn mining attention to this area. The total production of gold from the Kyushu mines in this century is about 200 tonnes. Most of the gold deposits are of the epithermal type, being related to relatively young volcanism of Pliocene to Pleistocene age. Some of these young deposits, for instance the Hishikari deposit (0.9 Ma), are associated with outflow of thermal waters, indicating continued mineralization by geothermal systems active to the present day.

The epithermal gold deposits in Kyushu can be classified in two distinct types primarily on the basis of their vein and alteration mineralogies: the adularia-sericite type, and the acid-sulfate type (Heald et al., 1987; Hayba et al., 1985), also known as the low sulfidation type and high sulfidation type (Hedenquist, 1987). This paper will summarize the geologic setting of the epithermal gold mineralization in Kyushu, the geologic and mineralogic characteristics of these two distinct types of mineralization, and the intimate relationship of the gold mineralization to volcanic hydrothermal systems.

## GEOLOGIC SETTING

Kyushu is located at the junction of two island-arc systems, the Ryukyu arc and the Southwest Japan arc, along which late Cenozoic volcanic activity continues to the present. Figure 1 shows the distribution of gold deposits and their spatial relationship to the late Cenozoic volcanic and present-day geothermal fields. The continuing geothermal activity clearly shows an intimate relationship with active volcanoes, and epithermal gold deposits are distributed in the areas of quiescent volcano-geothermal systems.

The epithermal gold deposits occur in three main clusters, the North Central Kyushu, the Hokusatsu, and the Nansatsu districts, which correspond to the two zones of volcanotectonic depressions (Figure 1). Subaerial andesitic volcanism of calc-alkaline character commenced in the Hokusatsu and Nansatsu districts about 9 Ma ago, and in the North Central Kyushu district about 6 Ma ago. Large scale pyroclastic flows have erupted repeatedly since the late Pliocene. Lake sediments are intercalated in the volcanic piles. The epithermal gold mineralization is dated at 5.0 to 0.9 Ma in the Hokusatsu and Nansatsu districts, and at 3.6 Ma (and younger) in the North Central Kyushu district (Table 1). In the Hokusatsu and Nansatsu districts, the epithermal gold deposits are progressively younger toward the east, indicating the eastward migration of volcanic activity with time, so that present-day active volcanoes and geothermal fields are distributed from north to south along the eastern margin of the area. Similar spatial migration of volcanic activity and gold mineralization is also observed in the North Central Kyushu district, where epithermal gold deposits of Pliocene age are distributed along the northern margin of the volcano-tectonic depression, while the present-day active volcanoes and geothermal fields are on the southern margin (Figure 1).

Basement rocks of the North Central Kyushu district consists of segments of metasediments of Carboniferous to Triassic age and granitoid intrusives of Cretaceous age, while those of the Hokusatsu and Nansatsu districts consist mainly of sedimentary rocks of Cretaceous-Paleogene age (the Shimanto Supergroup). Several occurrences of high gold concentrations (137 ppm the highest) have been reported for shales from the Shimanto Supergroup (Ishihara et al., 1986), although the distribution of gold deposits as a whole seems to be independent of the type of basement rocks.

## EPITHERMAL GOLD DEPOSITS

Table 1 summarizes the ages, types, and gold and silver productions of the major epithermal gold deposits of Kyushu. Of the 23 deposits listed in Table 1, only five

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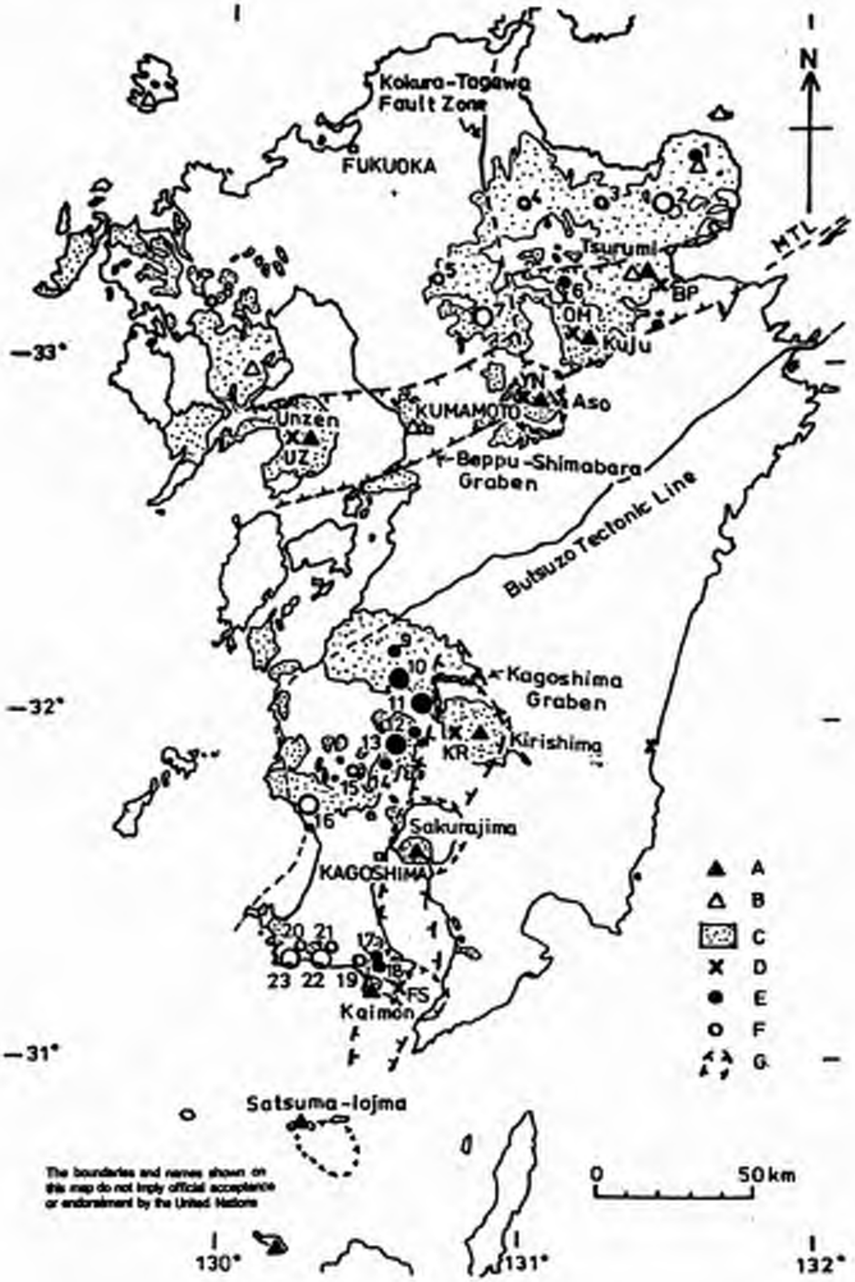

Figure I. Distribution of gold deposits in Kyushu and their spatial relationship to the Late Cenozoic volcanic activity and present-day geothermal fields. A, active volcanoes: B, middle to late Pleistocene volcanoes: C, areas of late Cenozoic vocanic activity: D, major geothermal fields; E, Pleistocene gold deposits: F, Pliocene gold deposits: G, volcano-tectonic graben. Large circles indicate gold production larger than 5 tonnes. Numbers 1 through 23 are referred to the numbers of gold deposits listed in Table 1 (Izawa and Urashima, 1987).

**Table 1. Major epithermal gold deposits in Kyushu (Izawa and Urashima, 1987)**

| No.* | Gold deposit | Age Ma | Type | Ag/Au | Year | Production (t) Au | Production (t) Ag | Ref. |
|---|---|---|---|---|---|---|---|---|
| (North Cental Kyushu) | | | | | | | | |
| 1 | Magane | (Q) | en-qv | 8-50 | - | - | - | |
| 2 | Bajo | - | asp-qv | 10 | 1912-1950 | 13.0 | 70.7 | S |
| 3 | Usa | - | st-ad-qv | 10 | - | - | - | |
| 4 | Yamakuni | - | ad-qv | 20 | 1904-1953 | 1.1 | - | M |
| 5 | Hoshino | - | ad-qv | - | 1896-1942 | 2.9 | - | M |
| 6 | Kusu | (Q) | qv-(stw) | 1-2 | 1912-1942 | 0.6 | 0.8 | # |
| 7 | Taio | 3.6 | ad-qv | 4 | 1905-1966 | 35.4 | 154.6 | S |
| 8 | Hasami | - | (ci)-qv | 4 | - | - | - | |
| (Hokusatsu) | | | | | | | | |
| 9 | Fuke | 1.4 | (ad)-qv | 0.7 | 1896-1947 | 2.4 | 1.5 | M |
| 10 | Okuchi | 1.1 | ad-qv | 0.7 | 1896-1966 | 17.7 | - | M |
| 11 | Hishikari | 0.9 | ad-qv | 0.8 | 1985-1986 | 11.2 | 8.7 | # |
| 12 | Onoyama | (Q) | ze-cr-qv | 0.4 | 1935-1962 | 1.8 | 0.8 | M |
| 13 | Yamagano | (Q) | (ze)-qv | 1-4 | 1640-1953 | 28.4 | 28.3 | M |
| 14 | Ora-Takamine | 1.8 | ad-qv | 4-7 | 1894-1943 | 1.5 | - | M |
| 15 | Iriki | - | qv | 5 | - | - | - | |
| 16 | Kushikino** | 4.0 | ad-qv | 7-12 | 1865-1986 | 55.2 | 456.2 | M,# |
| (Nansatsu) | | | | | | | | |
| 17 | Kuronita | 1.3 | (ad)-qv | - | - | - | - | |
| 18 | Hanakago | 1.1 | ad-qv | 7-10 | - | - | - | |
| 19 | Iiyama | 1.5 | si-(ad) | - | - | - | - | |
| 20 | Kago | - | qv | 1.4-4 | 1888-1948 | 0.6 | 0.3 | T |
| 21 | Akeshi | 3.7 | si-(al) | 0.6 | 1912-1984 | 4.7 | - | # |
| 22 | Iwato | 4.4 | si-(al) | 2 | 1938-1986 | 6.6 | 12.7 | # |
| 23 | Kasuga | 5.0 | si-(al) | 0.6 | 1929-1986 | 6.7 | - | # |

*Number indicates the location in Figure I.

**Including Arakawa, Serigano and Hioki.

Age data from Torigoe (1984) and Urashima and Ikeda (1987); (Q) indicates Pleistocene mineralzation. qv: quartz vein, stw: stockwork, si: massive silicified rocks, ad: adularia, al: alunite, asp: arsenopyrite, ci: cinnabar, cr: cristobalite, en: enargite, st: stibnite, ze: zeolite, ( ): minor occurrence. Ref.- S: Saito (1967), M: Miyahisa and Wakabayashi (1972), T: MITI (1985), #: mines' data and this study.

(Hishikari, Kushikino, Akeshi, Iwato and Kasuga deposits) are in operation. The Iriki deposit (No. 15) is being operated as a kaolin deposit. The Hishikari and Kushikino deposits in the Hokusatsu district are of typical adularia-sericite type, while the last three deposits in the Nansatsu district are of the acid-sulfate type (described as massive silicified rock-alunite type in Table 1). The epithermal gold deposits of the adularia-sericite type, in which gold occurs as bonanza quartz veins, have been recognized as the major source of gold in Japan, and the discovery of the Hishikari deposit confirmed this view. While this may be true, investigation and development of the acid-sulfate type deposits (known in Japan as the "Nansatsu type" because of its typical distribution in the Nansatsu district, will provide a wider spectrum of exploration targets, and also a better general understanding of the hydrothermal systems responsible for gold mineralization.

## A. Adularia-Sericite Type Deposit

### a) Kushikino deposit

The ore deposit of the Kushikino mine (No. 16 in Figure I) occurs as fissure-filling epithermal veins in Tertiary andesitic volcanic rocks. The Kushikino No. 1 vein, which is the largest vein at this site and has produced more than 80% of its precious metals, extends for 2,600 m with a NE-SW strike, dips 35° to 45° to the southeast and has an average width of 40 m. The veins consist of gold- and silver-bearing quartz and calcite with minor amounts of smectite, adularia, sericite and sulfides. Major Au-Ag minerals are electrum, naumannite-aguilarite and selenian polybasite with pyrargyrite. The end of the main mineralization stage is marked by the deposition of a large amount of barren calcite. The average ore grade over the past one hundred years has been calculated as 6.7g/t Au and 61g/t Ag.

Alteration minerals in the andesitic host rocks near the veins (within 5 m from the veins) are zoned with respect to the appearance of sericite and kaolinite. Kaolinite occurs only near the surface in the central zone of the vein system and rapidly diminishes downward. Quartz, K-feldspar, plagioclase, chlorite, and smectite occur commonly throughout the area. There is a high-temperature silicified zone in the Kammuridake area 2 to 3 km east of the vein system. Homogenization temperatures of fluid inclusions (200° to 230°C at the mineralization stage) increase toward the silicified zone. The Kushikino deposit is assumed to have formed in a fracture system which developed in the margin of a Pliocene geothermal system.

### b) Hishikari deposit

The Hishikari deposit (No. 11 in Figure I) is an adularia-sericite type epithermal gold-silver deposit, consisting of 5 major veins and numerous veinlets. The vein system was first discovered in 1981 by drillholes aimed to explore a deep target of combined geophysical anomalies (high gravity and low electroresistivity) and a possible extension at depth of a hydrothermal alteration zone. The geological reserve is estimated to contain about 120 tonnes of gold at an average grade of 80g/t Au.

The local gravity high corresponds to the uplift of the basement rocks composed of Cretaceous shales and sandstones (the Shimanto Supergroup). The vein system is developed at a depth near the unconformity between the basement Shimanto Supergroup and the overlying Pleistocene andesitic rocks. The veins strike N50°E in general and dip steeply to the north at 70° to 90°. Vein widths are usually from 1 to 3m (8m at maximum) with strike-lengths of 300 to 400m.

The veins show a banding structure, generally symmetric from both walls. The major constituent ore minerals are electrum, naumannite, chalcopyrite, pyrite and marcasite. Gangue minerals include quartz, adularia, smectite, and kaolinite with minor amounts of calcite, rhodochrosite, siderite, wairakite, laumontite and truscottite. Wall rocks in the upper levels of the vein system show hydrothermal alteration effects more intensive than those at lower levels. Specifically, the rocks occurring at levels 50 to 100 m above the vein system show a wide horizontal zone of smectite and pyrite alteration.

K-Ar dating of adularia taken from the veins indicates 0.8 to 1.1 Ma as the mineralization age. The Au-Ag mineralization may have taken place in a hydrothermal system established by and related to dacite magmatism of Pleistocene age. A large volume of NaCl-bicarbonate type thermal waters with a temperature of 65°C still exists in the vein system.

### B. Acid-Sulfate Type Deposits

This type of deposit (the Nansatsu type) is typically developed in the Nansatsu district, southern Kyushu (No. 21 Akeshi, No. 22 Iwato and No. 23 Kasuga in Figure I). Mineralization is both disseminated and fracture-controlled in acid-leached, strongly silicified (>95% $SiO_2$) volcanic rocks. The average ore grade ranges from 3.2 to 5.0g/t Au. The Ag/Au ratio is close to unity.

The silicified bodies (100 to 200m across) are distributed in clusters along an arc structure in andesitic lava and pyroclastic rocks of upper Miocene age. The silicified body is usually enveloped by a narrow (1 to 2m wide) argillic zone consisting of kaolinite, alunite and smectite, which shifts sharply to a propylite zone on the outward side. In the mineralized zone, silica has been introduced, while aluminum and most of other components have been leached away. The principal metallic minerals are pyrite, goethite and native gold (and probably electrum) with minor enargite and luzonite. Covellite and native sulfur are also present. Native gold is often intimately associated with goethite.

Geologic setting and alteration mineralogy suggest that this type of mineralization is related more directly to high-temperature, acid volcanogenic fluids, in contrast to the typical epithermal deposits of the adularia-sericite type. It is observed, however, that the salinity of fluid inclusions in quartz deposited in later stages is generally less than 1 wt% NaCl equivalent. Thus, high-temperature acid fluids containing magmatic gas components may be responsible for the intensive acid leaching and kaolinite-alunite alteration of the early stages. Then the hydrothermal system may have evolved to a neutral-pH type through reaction with surrounding rocks. These later stage, evolved thermal fluids may be responsible for the silicification and additional quartz deposition, and for the gold mineralization. The intimate relationship of the gold-rich zone with goethite also suggests reworking and re-deposition of gold under oxidizing conditions at a later stage.

## MINERALIZATION AND GEOTHERMAL SYSTEMS

Geothermal fields are distributed along the active volcanic terrains, which are the manifestation of present-day volcanogenic hydrothermal systems (Figure I). Some of these present-day geothermal systems have the potentiality for mineralization. Their mineralizing fluids are of

NaCl-type, neutral-pH thermal waters of deep origin, rising up to shallower levels through fracture systems. To apply the analogy of geothermal system to epithermal mineralization in geologic time, it seems important to make an effort to reconstruct the whole hydrothermal system that once existed in this region.

We have only a few limited examples of active systems which resemble the acid-sulfate type, or the Nansatsu type mineralization. Judging from the geology of the Nansatsu district, this type of mineralization seems to be related to resurgency of calderas. The hydrothermal systems may have formed in close connection, both in time and space, with the doming-up of magma within a caldera. On the other hand, the adularia-sericite type gold-bearing quartz veins seem to have formed in fracture systems developed by uplifting of basements. Although the uplift of basements itself may have been caused by rising magma or tectonic movement related to magmatism, the field of this type of mineralization seems farther from magma as compared with the acid-sulfate type. Fracture systems developed in peripheral areas of caldera also seem to accommodate the adularia-sericite type epithermal deposits.

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# ACTIVE GOLD MINERALIZATION IN AN EVOLVING VOLCANOGENIC HYDROTHERMAL SYSTEM AT OSOREZAN, JAPAN*

by
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The Osorezan area has long been noted among Japanese as a place of mystical significance. Within the precincts of an old temple named Osorezan-Bodaiji there is a famous area of steaming ground; it is often crowded with sightseers (among them, perhaps a few curious geologists) at almost all times of the year.

From the geological point of view, Osorezan is a composite volcano having a caldera lake and resurgent domes of hornblende dacite. It is located on the eastern margin of the volcanic front of the northern Honshu arc. Though the volcanic activity has greatly declined from its peak, many fumaroles and hot spring vents are still active particularly in areas surrounding the latest dacite domes. The surface around the venting hydrothermal system has been strongly altered in an acidic environment formed by low-pH steam condensate and low-pH hot spring water, chemically modified from the near-neutral-pH deep-seated fluid by near surface oxidation.

Recent geological and geochemical study of this area by the Geological Survey of Japan has revealed that the hydrothermal system is a spectacular example of an active gold depositional environment. The concentration of gold in the hot spring precipitates in an ancient hydrothermal eruption crater exceeds 400 ppm (max 6500 ppm) locally. This may be "a Guinness book grade" for recent hot spring precipitates at the surface. Notwithstanding the many technically qualified visitors who have seen the Osorezan steaming ground, the high grade gold mineralization had not previously been recognized. The entire mineralized body is nearly completely preserved and is now open to *in situ* observation of the ore forming process, through geochemical examination of the actively circulating hydrothermal fluid, the various precipitates, and the surrounding geological terrane. The results of this research work will serve as a useful guide in the exploration for young epithermal gold deposits.

An inferred evolutionary process for the hydrothermal system, as studied from surface features such as hydrothermal rock alteration, petrography, mineralogy and isotope geochemistry of hydrothermal eruption debris, is proposed as follows:

1. A hydrothermal convection cell was initiated consequent upon the shallow intrusion of dacite magma; this magma acted as a source of heat and acid gaseous components. An extensive acid alteration halo, composed mainly of porous residual silica, alunite and kaolinite, was formed by ascending acid fluids, derived from the magma, as they worked their way to the surface.

2. Extrusion of dacite magma then occurred in the northern part of caldera. The early-formed alteration halo, including some surface country rock was destroyed by the strong deformation caused by the upward movement of viscous magma. Some eruption craters may have been formed during this stage.

3. Evolution of the hydrothermal fluid continued with the formation of near-neutral-pH chloride water with high sulphide concentrations. Epithermal elements (Au, As, Sb, Hg, etc.), having been vigorously remobilized within the porous acid alteration halo, formed an overprint of mineralization. Banded quartz veins (with sphalerite, galena, chalcopyrite, tetrahedrite and pyrite, with the occasional association of adularia and gold) formed at depth (Au values up to 1.5 ppm, Ag up to 250 ppm), while stibnite-chalcedony veins formed at shallower levels, penetrating the acid-alteration halo.

4. Hydrothermal eruption took place due to overpressuring which resulted from fracture-sealing by silica or carbonate. The trigger for the eruption is not yet well understood. Decrease in the water level of the

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caldera lake which had covered the fracture system, or a later, shallow intrusion of magma, may have been responsible. The eruption brought fragments of the mineralized portions of the hydrothermal system to the surface.

5. The eruption crater thus formed beneath the lake was subsequently flooded by ascending hydrothermal fluid with near-neutral-pH and carrying Au, As, Sb, Hg and Te dissolved as sulfide complexes. This ascending fluid mixed with relatively cold water of the acid sulfate type. A large amount of hot spring precipitate rich in orpiment ($As_2S_3$), coloradoite (HgTe), krennerite ($AuTe_2$) and another unknown Pb-Sb sulfi
formed during the course of solution
crater along with clastic debris. Loc
precipitate, in which sphalerite, jor
the major minerals, was formed i
hydrothermal eruption.

6. Hot spring water of ne
$H_2S$ concentration is still forming s
arsenic sulfide and Au in small pool
now-filled crater.

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6. Hot spring water of neutral pH with a high $H_2S$ concentration is still forming sulfur deposits rich in arsenic sulfide and Au in small pools at the surface of the now-filled crater.

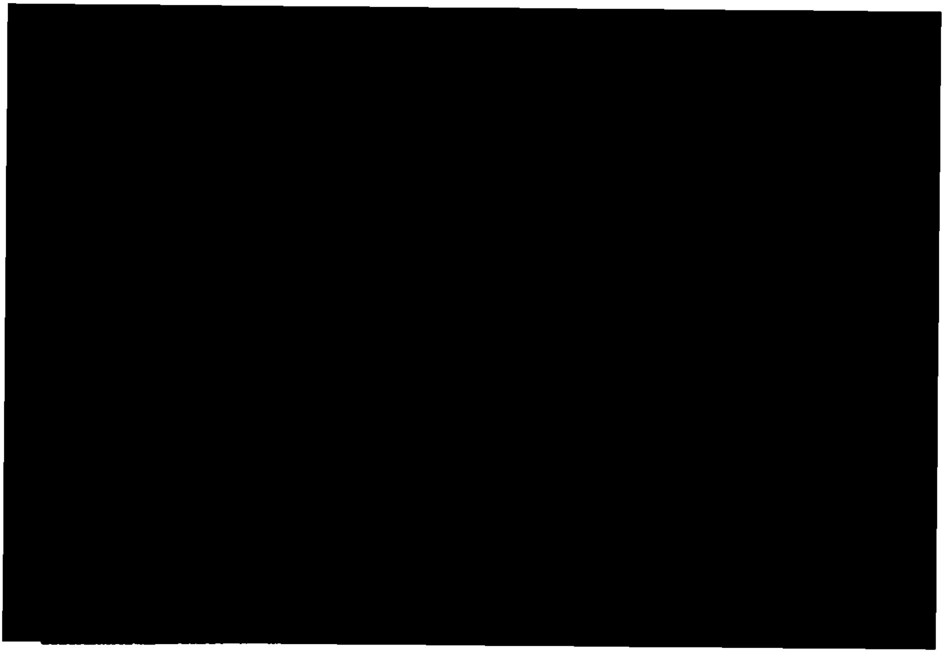
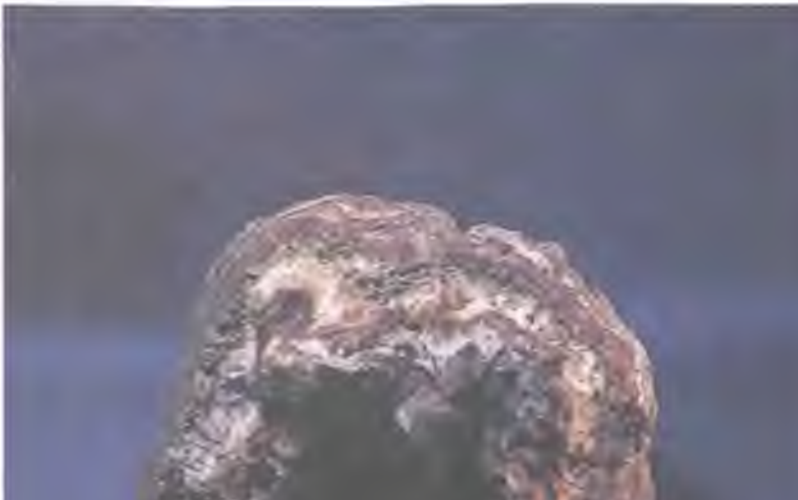


**Photo. 1.**

**A distant view of Osorezan caldera from the south rim. The caldera has a lake (about 2 km in diameter) in its central part and many resurgent domes of dacite on its northern margin. The bright area just beyond the lake is the steaming area where a high grade Au deposit is now forming.**

Photo. 2.

Extensive acid-alteration halo has been covered with silica sinter precipita
boiling neutral-pH, high-chloride water. There are some hydrothermal erup
ters, old and new, of which the younger ones can easily be identified from th
surface topography, the distribution pattern and the systematic change in thi
the eruption debris. This photograph shows a young shallow crater erupted
bottom of a silica sinter.



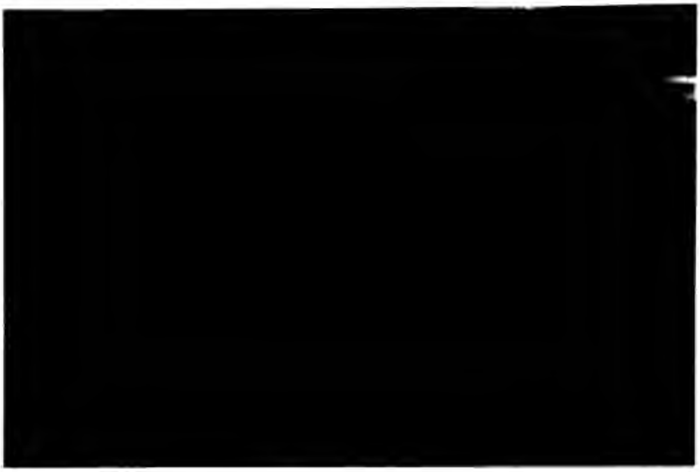


Photo. 2.
Extensive acid-alteration halo has been covered with silica sinter precipitated from boiling neutral-pH, high-chloride water. There are some hydrothermal eruption craters, old and new, of which the younger ones can easily be identified from the concave surface topography, the distribution pattern and the systematic change in thickness of the eruption debris. This photograph shows a young shallow crater erupted from the bottom of a silica sinter.

Photo. 3.
Silica sinter is a most common spring precipitate in this area; the spatial arrangement of springs looks to have been controlled by several fracture systems. Occasionally banded amorphous silica occurs in hot spring vents, showing an intermittent deposition of amorphous Sb-As-Tl sulfide and stibnite.

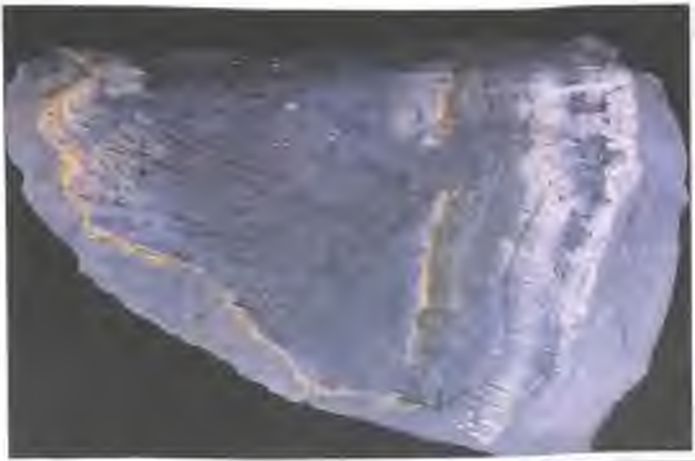


Photo. 4.

Eruption debris contains
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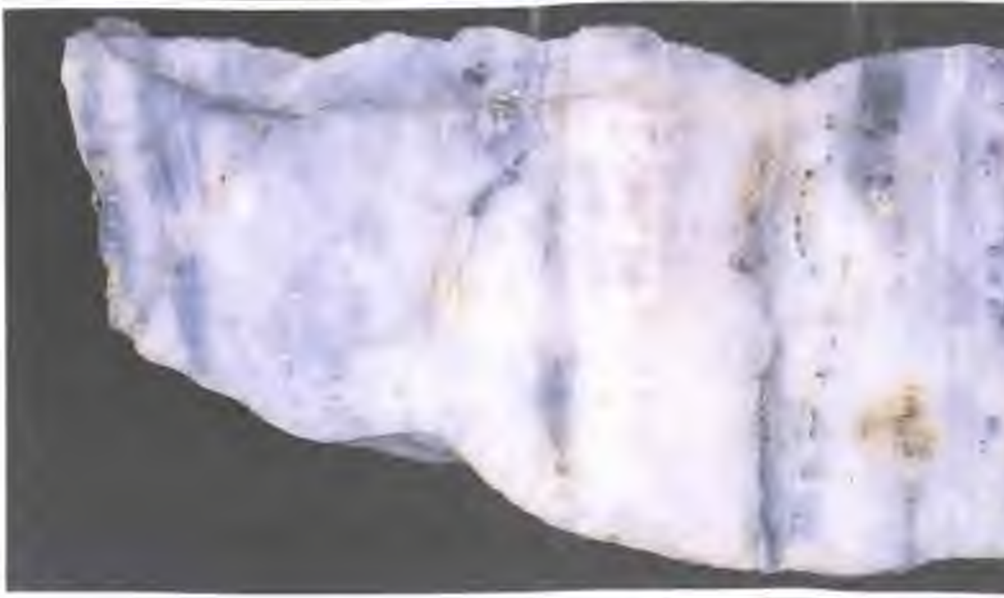

Photo. 5.

Banded quartz vein with sphalerite, galena and tetrahedrite. A subtle variation in tone is due to the difference in the grain size and crystal orientation of quartz, indicating repeated cycles of supersaturation.

Photo. 4.

Eruption debris contains various kinds of mineralized rock fragments, indicating that the hydrothermal eruption broke out from a zone of mineralization. This plate shows a fragment of a stibnite - chalcedony vein.

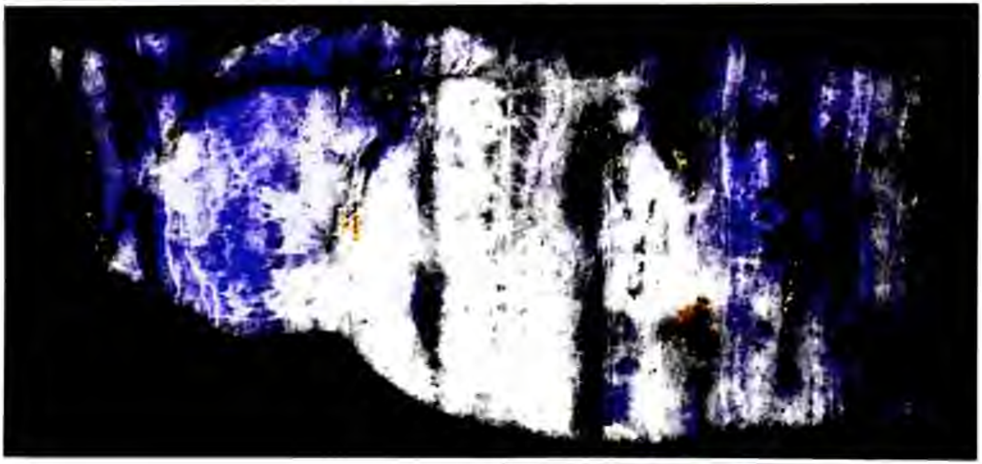

Photo. 5.

Banded quartz vein with sphalerite, galena and tetrahedrite. A subtle variation in tone is due to the difference in the grain size and crystal orientation of quartz, indicating repeated cycles of supersaturation.

Photo. 6.

Disseminated gold mineralization (7.3 ppm Au) in massive silicified pyroclastics with intimately associated alunite and pyrite. This may be correlated with the "Nansatsu-type gold ore". A large fractionation of sulfur is present between the alunite and pyrite, and indicates a possible contribution of magmatic fluid.

Photo. 7.

Discharge of deep fluid is apt to be focussed in the eruption vent when the hydrology of the system is such that this is the most permeable conduit. Hot spring precipitates may be effectively accumulated in the crater. If there is a drastic drop in fluid pH, through mixing of deep fluid with surficial acid sulfate waters, suilfide complexes of As, Sb, Hg and Au will be destabilized, resulting in the precipitation of their sulfide minerals as well as native gold. Scientific drilling undertaken to investigate the accumulated material in the ancient crater was conducted in October 1988; boreholes successfully penetrated high grade accumulates of Au and Hg, together with As and Sb sulfides, as predicted. In this photograph, the surface of the ancient eruption crater has been completely filled by hot spring precipitates and clastic material. There are many spring vents discharging neutral-pH chloride water with high $H_2S$ content. It is frequently observed that ascending transparent water precipitates orange-yellow to creamy-white material mainly composed of arsenic sulfide and sulfur, during periods of rain fall due to the influx of acid materials picked up from the surface nearby.

Photo. 8.

Scientific drilling, boring from the top of the silica sinter in the center of the ancient crater to 40m depth, penetrated the zones of amorphous silica, orpiment-rich mud, Au and Hg telluride-rich mud, sphalerite-lead antimony sulfide-rich mud, and strongly silicified fallback debris in the order of increasing depth. A geyser-like discharge of superheated water was unexpectedly encountered at a depth of 12m from the surface while drilling this hole. The

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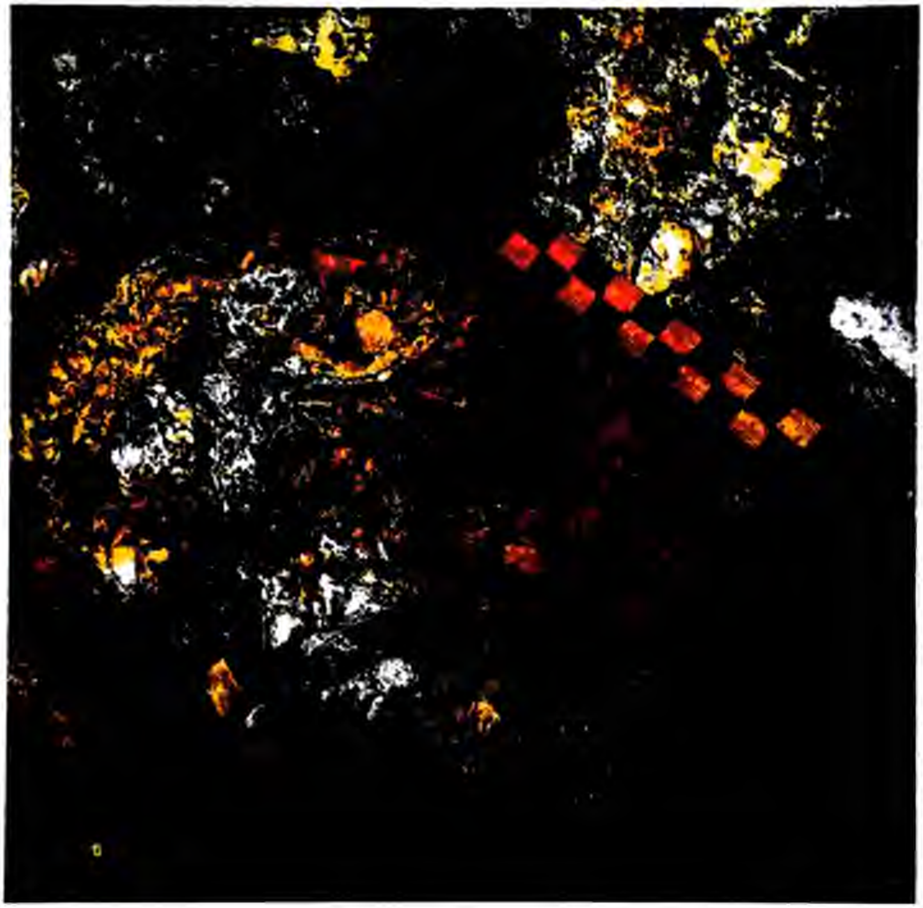
Photo. 9. (Cover photo)

A crosscut of an orpiment chimney formed in silty lake sediments with amorphous arsenic sulfide as the latest precipitate. Idiomorphic barite and a radial aggregate of orange yellow orpiment crystals occur in black muddy material around the chimney. Since neutral pH chloride water with high $H_2S$ has high complexing capacity for Au, as well as As, Sb, and Hg, a large-scale accumulation of arsenic sulfide may be a good indication of a Au deposit in the vicinity.



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# DISTRIBUTION AND GRADE-TONNAGE RELATIONS OF AU-AG DEPOSITS IN JAPAN

by
**Masaharu Kamitani and Yasuo Kanazawa**
**Geological Survey of Japan**[1]

More than 500 gold-silver deposits are located in the Japanese Islands. Mining of some of these deposits, notably in the Kitakami and Tajima areas, have been active since the Asuka age (7th century A.D.). The total gold production since this early period is estimated at approimately a thousand tonnes.

In this paper, the distribution, ages of formation and grade-tonnage relations of the Japanese gold deposits are discussed. A tentative evaluation for Au-Ag resources of Kitami and Northeast Hokkaido areas is also presented.

## DISTRIBUTION AND OCCURRENCE OF AU-AG DEPOSITS

Gold and silver in Japan have been produced mainly from vein-type epithermal deposits located in Neogene Tertiary to Quaternary volcanic terranes. The principal deposits are at Sado, Konomai, Kushikino and Hishikari. The major nine areas which include the majority of all significant deposits are in the Kitami, Southwest Hokkaido, Kitakami, Fukushima, Sado, Izu, Hita and Kagoshima districts (Figure I).

The age of formation of almost all Japanese Au-Ag deposits is either (1) late Cretaceous to Paleogene or (2) Neogene Tertiary to Quaternary.

### (1) Late Cretaceous-Paleogene Group

Kitakami and West Hyogo are representative of districts related to magmatic activity during late Cretaceous to Paleogene Tertiary time. There are several types of gold-bearing deposits in these districts including skarn and meso-epithermal types. The Ohya mine, Kitakami district, produced over 16 tonnes gold during the period 1917 to 1975, accompanied by low silver values. A considerable amount of arsenic, tellurium, bismuth and tungsten accompanies some veins. In the San-yo district, several Au-Ag vein-type deposits occur in weakly sericitized areas adjacent to the Mitsuishi pyrophyllite deposits, which have been dated at 80 to 90 Ma.

### (2) Neogene Tertiary to Quaternary Group

The majority of Au-Ag deposits occur in the "green tuff" regions of the Miocene and Plio-Pleistocene volcanic belts (Figure I).

*Kitami district;* more than 50 deposits are known in this district. Among them, the Konomai mine is representative, having produced 71.4 tonnes Au and 1,200 tonnes Ag during the period 1917-1974. Most of the deposits formed within the green tuff beds. K-Ar ages from Konomai, Sanru and Ikutahara indicate late Miocene mineralization (Sugaki and Isobe, 1985; Maeda, 1989). In general, quartz-adularia-calcite are dominant in the veins, and Ag/Au ratios range from 10 to 20.

*Southwest Hokkaido district:* Chitose, Todoroki and Teine are the representative deposits, with about 50 tonnes of gold produced from this district. The age of mineralization is estimated to be Miocene to Pliocene as determined by K-Ar dating of sericite and adularia in the mineralized veins.

*Sado district:* the Sado mine is a famous Au-Ag vein-type deposit in Japan; the production since 1542 is reckoned to be approximately 83 tonnes of gold and 2,400 tonnes of silver. There are three large-scale vein structures: the Aoban, the Ohdate and the Ohgiri-Torigoe. The largest of these is the Aoban vein, which extends in an E-W direction for 2,100 m, dips to south, and has an average thickness of 6 m. Its calculated geological reserve is about 17 million tonnes with average grades of 6 g/t Au and 60 g/t Ag, respectively.

*Izu district;* The Izu peninsula is a quite different in terms of geologic terrane from other parts of Honshu Island, because it belongs to the northern most edge of Philippine plate. The collision between these two masses began during the Toyooka magnetic-pole period (2 to 6 Ma). Gold-silver mineralization took place in connection with compressional fracturing related to the collision. The Seikoshi, Tohi, Mochikoshi and Rendaiji deposits were formed during the period 1 to 2.5 Ma. Since 1914 this district has produced about 50 tonnes Au and 1,000 tonnes Ag.

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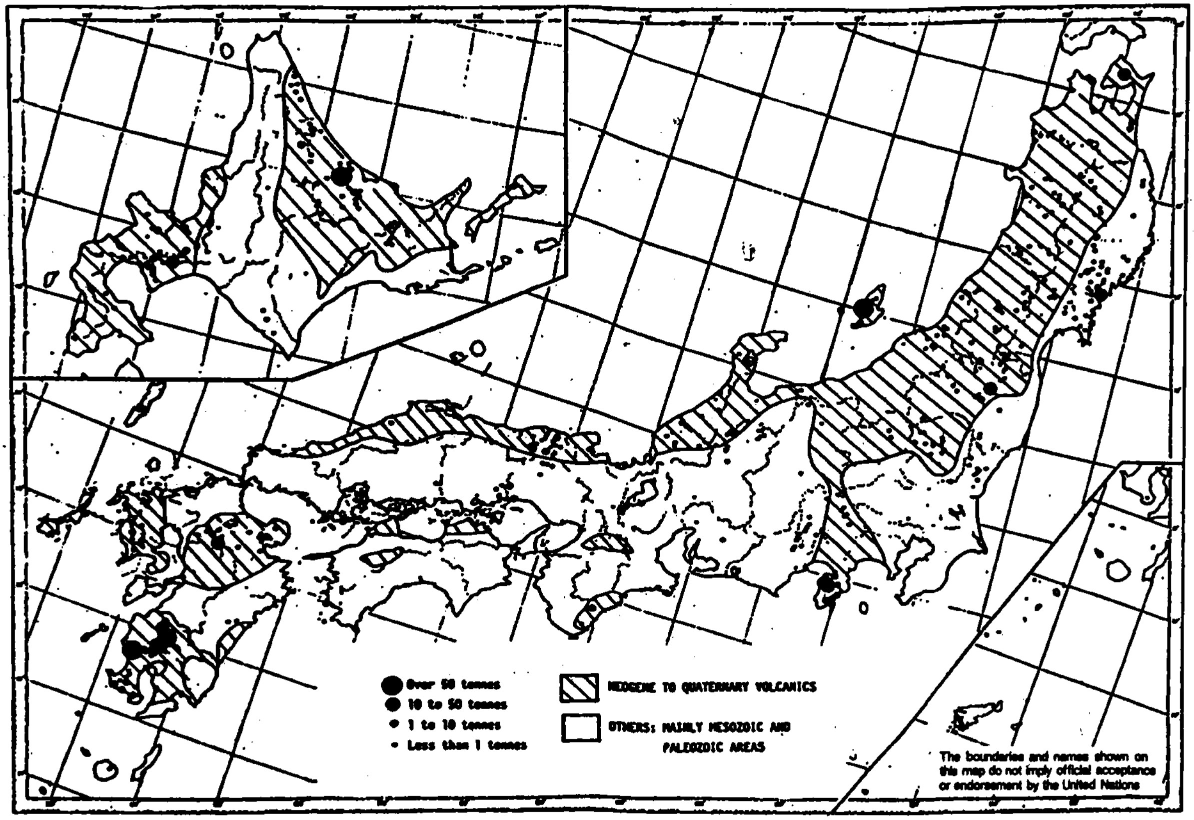


The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

**Figure I. Distribution map of Au-Ag deposits in Japan.**

*Hita district;* The Taio and Bajo deposits were first developed in the 16th and 17th centuries, and have produced more than 55 tonnes Au. The mineralization occurs mainly in Miocene volcanics and partly in Pliocene sediments. K-Ar dating of a quartz-adularia vein in the Taio mine indicates a Plicocene age (3.6 Ma.).

*Kagoshima district;* more than 150 tonnes of gold have been produced from this district. Among them, the Hishikari deposit has the highest-grade ore reserve; it now produces about 6 tonnes Au annually.

There are two types of epithermal deposits in this district; the Hokusatsu type, consisting of quartz veins with adularia and calcite, and the Nansatsu type, of mushroom-shaped silicified rocks related to acid alteration. The former are usually of higher grade than that of the latter. The mineralization ranges from middle Miocene to Pleistocene with a regional variation in which deposits are progessively younger toward the east (Izawa and Urashima, 1987).

## GRADE-TONNAGE RELATIONS OF JAPANESE AU-AG VEIN-TYPE DEPOSITS

There are many Au-Ag mineralized districts in Japan as shown in Figure I. We have outlined their size and quality distribution using grade-tonnage diagrams, based on published data which included the average grade and size of each vein.

In general, grade and tonnage relations show a rough negative correlation, as seen in Figure II. However some large-scale veins carry very high-grades and consequently contain a large amount of gold-silver. For example, the No. 5 vein of the Konomai deposit, Kitami district, has a theoretical ore reserve calculated to be about 13 million tonnes with an average grade of 4.9 g/t Au, indicating that about 64 tonnes Au are contained in that single vein system.

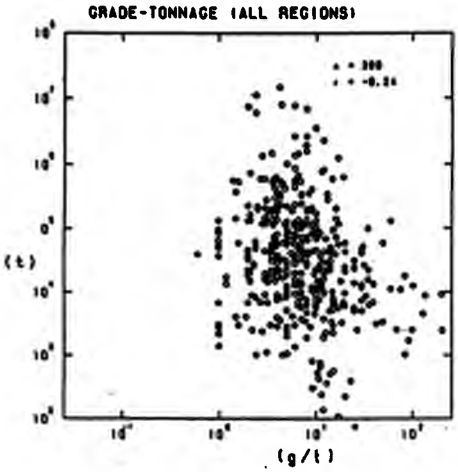


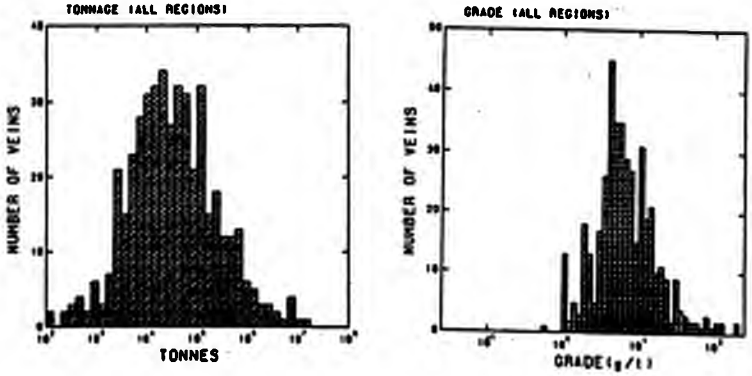
**Figure II. Grade-tonnage relation of all the Japanese Islands.**

Considering all deposition in the Japanese Islands, the distribution frequencies of tonnage and grade for veins are quite well approximated by a log-normal distribution, as shown in Figures III(a) and III(b), in which the median values are 6.8 g/t for grade and 30,000 tonnes for bulk tonnage.

The tonnage distribution over the principal mineralized districts varies widely because several very large-scale vein systems occur in two districts (Kagoshima and Hita). Conversely, the tonnage of the Kitakami district, an area representative of late Cretaceous magmatism, shows a much smaller median value for tonnage. In general, large-scale veins occur in the green tuff regions of Miocene age, the veins of Plio-Pleistocene are intermediate in size, and the Cretaceous veins are comparatively smaller than either of the former two classes.

## A TENTATIVE EVALUATION FOR AU-AG DEPOSITS IN THE KITAMI DISTRICT

A tentative resource evaluation of the Kitami district has been made utilizing the geologic, geophysical and grade-tonnage relationship data. There are many copper-lead-zinc, gold-silver and mercury deposits in this district, sited mainly in the Miocene green tuff formation (Figure IV), though some minor deposits were also formed in the Pliocene. Thick Plio-Pleistocene volcano-sedimentary piles cover the Miocene green tuff and Jurassic-Cretaceous sediments. Almost all the Au-Ag deposits so far developed occur in the green tuff rather than in the Plio-Pleistocene units.



(a)

(b)

**Figure III. Distribution frequencies of grade and tonnage of all the Japanese Islands.**

A mineralization model is proposed for this district (Figure V). Several calderas are postulated, based on the observed geologic structures and low gravity anomalies. Two major basin-like structures with NNW-SSE trends are roughly conformable to the distribution pattern of the Au-Ag deposits (Figure VI), i.e. the ore deposits are distributed around these basins. An overlay of the aeromagnetic anomalies on the geology and mineral distribution maps clearly indicates that most deposits are developed surrounding positive magnetic anomalies (Figure VII). These positive anomalies may originate from magnetite-series intrusives which occur underneath the Plio-Pleistocene piles.

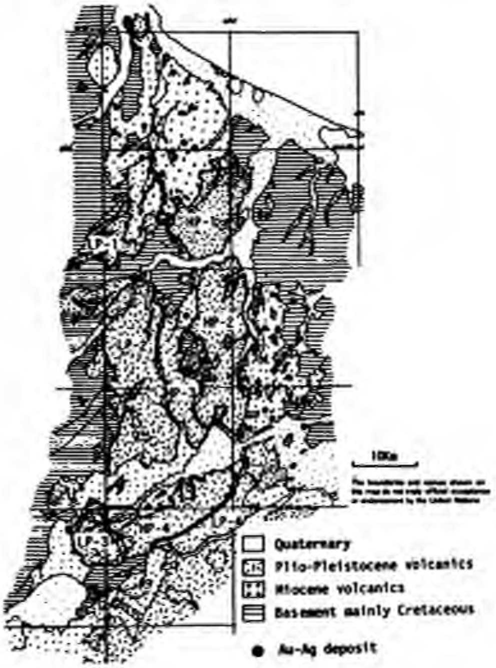


**Figure IV.** Geology and distribution of Au-Ag deposits in Kitami district, Hokkaido.

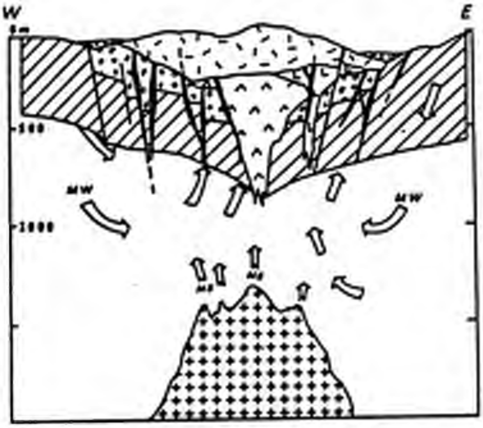


**Figure V.** Au-Ag mineralization model of Kitami district.

**Figure VI.** Gravity map of Kitami district.

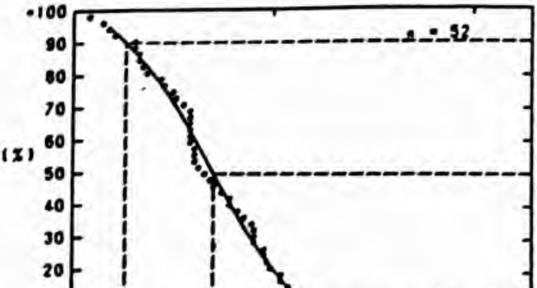
Figure VII. Aeromagnetic anomaly map of Kitami district.

Based on the above data, the distrib outcrops of green tuff was calculated, tha number of veins per square kilometer (Ta potential areas were identified and their t was computed. We divided the potentia categories of high and low potential: HP high in potential and the other 4 areas are

### Table 1. Number of expected vein district

| | *Potential Area (km²)* | *Number of Vein* |
|---|---|---|
| HP-1 | 105.6 | 14 |
| HP-2 | 185.2 | 24 |
| HP-3 | 99.2 | 13 |
| HP-4 | 132.4 | 17 |
| LP-1<br>LP-4 | 318.0 | 41 |
| Total | 840.4 | 109 |

Approximately 12 million tonnes are calculated to exist in the high potential the grade-tonnage diagram for this district. would indicate that 14 comparatively la hold about 11 million tonnes reserve, cont Au. An additional million tonnes of ore six tonnes of gold, yielding a total of 12 containing 61 tonnes Au for the high indicated (Table 2).



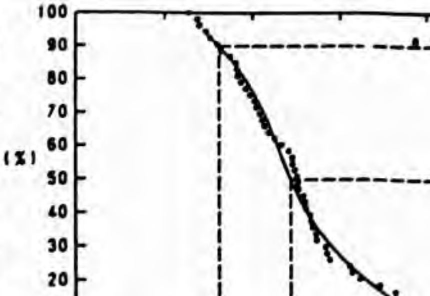


Table 2. Resources potential of Kitami district

| | | *Number of veins* | *Ore Reserve (t)* | *Grade (Au;g/t)* | *Content (Au;kg)* |
|---|---|---|---|---|---|
| High-Potential Area | Large-scale veins (20%) | 14 | 11 067 098 | 5.0 | 55 335 |
| | Intermediate-scale veins (60%) | 40 | 1 078 800 | 5.0 | 5 394 |
| | Small-scale veins (20%) | 14 | 59 402 | 5.0 | 297 |
| | | (68) | (12 205 300) | (5.0) | (61 026) |
| Other Area | Large-scale veins (20%) | 8 | 6 324 056 | 5.0 | 31 620 |
| | Intermediate-scale veins (60%) | 25 | 674 250 | 5.0 | 3 371 |
| | Small-scale veins (20%) | 8 | 33 944 | 5.0 | 170 |
| | | (41) | (7 032 250) | (5.0) | (35 161) |
| Total | | 109 | 19 237 550 | 5.0 | 96 187 |

For the other areas judged as low in potential, 7 million tonnes ore reserve with a total of 35 tonnes Au were determined (Table 2). The total potential ore reserve for the Kitami district as determined by our method is therefore approximately 19 million tonnes of ore car
96 tonnes Au.

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# GEOLOGICAL CHARACTERISTICS OF THE SEDIMENT HOSTED, DISSEMINATED GOLD DEPOSITS IN THE WESTERN UNITED STATES OF AMERICA: AN OVERVEIW

by
Yukio Togashi[1]
Geological Survey of Japan[2]

## INTRODUCTION

In late 1986, a deep-seated gold deposit, at present called the Deep Post orebody of the Gold Strike mine, was discovered in northern Nevada. The currently announced total ore reserve of Deep Post, Betze and Oxide Post orebodies of the mine, which are collectively called the Gold Strike deposit in this paper, is about 140 million tonnes with average grade of 3.54 g/t Au, giving a total gold content of more than 500 tonnes (Mining Magazine, October 1989). This mega-deposit is hosted by calcareous marine sediments, in which gold occurs as disseminated micron- to submicron-sized grains. Many similar gold deposits occur in the surrounding districts, and are called sedimentary-hosted, disseminated, or "Carlin-type" gold deposits.

The Gold Strike deposit is located in a relatively narrow mineralized belt which extends northwesterly nearly 80 km and with a width of only 8 km. This belt is called the "Carlin trend", and some 21 economic deposits, including Gold Strike, Carlin and Gold Quarry deposits as majors, have been discovered since the early 1960s. Total gold resources of the Carlin trend at present are reported to be 1,735 tonnes Au, and the total mineable reserve remains more than 1,000 tonnes Au, with some 180 tonnes Au mined up to 1988 (Mining Magazine, October 1989).

Mine production of gold in the world has been continuing to grow for many years. Mines in the non-communist world produced 1,538 tonnes Au in 1988, while the United States of America, producing 205 tonnes Au, moved to the second rank in the non-communist world and the third in the whole world (Gold 1989, Consolidated Gold Fields, Plc.). In the same year, Nevada produced about 60% of the total output of the United States. The Carlin trend is one of the major gold belts in Nevada, and is inevitably the center of the present-day gold rush by explorationists. Stimulated by the discovery of the Gold Strike deposit, the Carlin-type deposits currently are their most important exploration target.

In this paper, a comprehensive attempt is made to introduce the geological characteristics of the Carlin-type gold mineralization, especialy in the Carlin trend and the surrounding districts in northern Nevada. Examples of carbonate-hosted gold deposits in Asia are also introduced. Some suggestions are also presented on the exploration of Carlin-type gold deposits.

## TECTONIC AND STRUCTURAL SETTING

Most Carlin-type gold deposits in the western United States are located in the Great Basin, which is the northernmost division of Basin and Range province. The eastern half of the Great Basin is underlain by miogeosynclinal sediments composed mainly of Ordovician carbonates, while the western half is underlain by eugeosynclinal volcanic sediments of Jurassic to Permian age. The western limit of Precambrian crystalline basement beneath the North American continent strikes northerly near the center of the Great Basin as determined by 0.708 and 0.706 isopleths of strontium isotopes (Cunningham, 1988) (Figure 1).

Three distinctive trends of the Carlin-type gold mineralization have been recognized in central northern Nevada; the Carlin, Cortez (or Battle Mountain-Eureka) and Getchell trends (Figure 1). Each of these trends is considered to reflect the alignment of intrusive activity of Cretaceous felsic plutons. Prior to this intrusion, the Antler orogeny took place in this region in late Paleozoic, forming the low-angle Roberts Mountains Thrust (RMT). Due to movement on the RMT, Ordovician siliceous rocks (chert, shale, etc.) were shifted eastward by more than 150 km, covering Siluro-Devonian calcareous rocks (Figure 1). Uplift by the Cretaceous plutonic intrusions eroded some parts of the allochthonous western assemblage ("upper plate") above the RMT, causing outcrops of the autochthonous eastern assemblage ("lower plate") to appear as windows through the upper plate. This is the basic geologic structure of the Carlin and Cortez trends. Most

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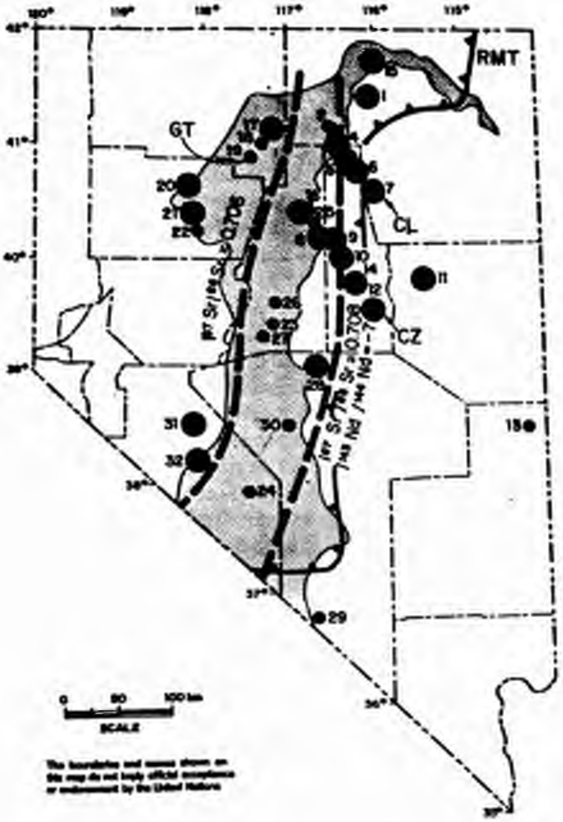

**Figure I. Map of Nevada showing sedimentary-hosted, disseminated Au-Ag deposits, lines bounding the areas containing granitic plutons with initial $^{87}$Sr/$^{86}$Sr of 0.708 and 0.706 and initial $^{143}$Nd/$^{144}$Nd of -7, and the location of the regional paleothermal anomaly (in light grey) as shown by conodont color alteration. Large circles are deposits and districts containing more than 12 tonnes Au, and small circles are for those with 0.3 to 12 tonnes Au. 1) Jerritt Canyon; 2) Dee, Boulder Creek; 3) Bootstrap; 4) Blue Star, Gold Strike, Genesis; 5) Carlin, Bullion Monarch; 6) Gold Quarry, Maggie Creek; 7) Rain; 8) Cortez; 9) Horse Canyon; 10) Tonkin Springs; 11) Alligator Ridge: 12) Windfall; 13) Atlanta; 14) Gold Bar; 15) Sammy Creek; 16) Hilltop; 17) Getchell; 18) Pinson; 19) Preble; 20) Standard, Florida Canyon; 21) Rochester; 22) Antelope Springs; 23) Quito; 24) Weepah; 25) Gold Acres, Tenabo; 26) Sumich; 27) Toiyabe; 28) Northumberland; 29) Sterling; 30) Manhattan; 31) Santa Fe; 32) Candelaria. CL, Carlin trend; CZ, Cortez trend; GT, Getchell trend; RMT, Roberts Mountains Thrust. (modified from Cunningham, 1988)**

gold deposits of these trends have been discovered in and around these windows, and in both upper and lower plates.

The Getchell trend on the other hand is located on the western flank of the Antler orogenic belt, showing a different geologic setting from the other two trends. The Osgood Mountains, where the Getchell trend is located, are composed of Cambrian quartzite and phyllite, late Paleozoic carbonate and shale, Cretaceous plutonics and Tertiary volcanics. Gold deposits of the Getchell trend are controlled by NNE trending fault zones striking along the eastern flank of the Osgood Mountains.

Extensional tectonic movement, related to the present-day physiography of the Basin and Range province, began 17 million years ago and culminated around late Miocene, forming many northerly or NNE-trending high-angle normal faults. Outcrops of felsic intrusives from Cretaceous through mid-Tertiary age are rather limited, but it has been recognized that the high-angle faults are associated with most known Carlin-type deposits.

## DEPOSIT SCALE GEOLOGY

Although the Carlin-type gold deposits display considerable variation in their geologic characteristics, the following have been recognized as common features at the deposit scale (Radtke, 1985; Bagby and Berger, 1985; Percival et al., 1988; Bonham, 1989; Berger and Henley, 1989).

### Host Rocks

The most common types of host lithology are thinly-bedded, silty dolomites and limestones, while siltstone, sandstone, conglomerate, argillite and interbedded clay and shale sequences also host the Carlin-type deposits in northern Nevada. Sedimentary rocks of any lithology can host the mineralization provided that the porosity and permeability are sufficient to allow penetration by hydrothermal fluids. Massive, thickly bedded limestones and dolomites are not favorable host rocks for the mineralization (Percival et al., 1988). Carbonaceous matter is more abundant in silty carbonate rocks and shales compared to siliceous, clastic sediments.

Ages of host rocks in known Carlin-type deposits range from Cambrian to Jurassic, and the majority are early to middle Paleozoic age (Ordovician to Devonian).

### Structures

Positions of orebodies within an individual deposit are strongly controlled by high-angle faults. In all of the known deposits, high-angle faults are critical features in the formation of the orebodies, and in the Carlin deposit, for example, high-angle, siliceous orebodies formed within the high-angle faults (Radtke, 1985).

Thrust faults and/or low-angle faults also served as important ore controls in several deposits. Tectonic brecciation and brittle fracturing resulted in zones of increasing permeability and of gold deposition. Mineralization in general is most remarkable at brecciated intersections between sets of high-angle faults, and between high-angle and low-angle faults.

Antiformal structures, both of regional and local scale, are also important ore controls in providing sites of fluid movement within the hydrothermal environment. Fold hinges and axial-plane cleavages provided open space for increased permeability and for reaction between sedimentary rocks and hydrothermal fluids.

### Igneous Rocks

Almost all of the known Carlin-type deposits are spatially associated with intermediate to silicic igneous rocks in the form of intrusions whose mode of occurence may include plutons, stocks, plugs, dikes and sills. They have suffered intense hydrothermal alteration, and are not commonly mineralized, although a few deposits (including Gold Strike) contain significant tonnages of ore in the intrusive bodies.

Ages of the igneous rocks, which may be understood to have a close general relation to mineralization ages in most deposits, range from Cretaceous to mid-Tertiary, although the details of the timing between the intrusive event and the mineralization event have not been established for most deposits.

## MINERALIZATION

Carlin-type gold mineralization is characterized by the disseminated mode of occurrence of micron- to submicron-size gold in the calcareous host sediments. Localization of orebodies is basically controlled by high-angle normal faults and thinly-laminated calcareous formations. Thus typical orebodies of the Carlin-type deposits are stratiform or stratabound, and lenticular or tabular, and some are accompanied by a relatively narrow, high-angle "root" at deeper levels.

High Au:Ag ratio also characterizes the deposits. In most deposits, including such major deposits as Carlin, Gold Quarry and Gold Strike, the ratio is within a range between 10:1 to 20:1. No economic recovery of silver has been recorded in the three trends in northern Nevada, although a few silver-rich variations of the Carlin-type deposits, represented by the Taylor and Candelaria deposits in central Nevada, have been described (Bagby and Berger, 1985).

### Ore Deposits

The Carlin deposit, the best documented among all the known sediment-hosted, disseminated gold deposits, was discovered in early 1960s, and its initial ore reserve was 22 million tonnes with a grade of 8 g/t Au (Wilkins, 1984). The orebodies occur as a continuous chain of at least four ore zones having a stratiform or tabular shape (Radtke, 1985). The ore zones are hosted within the upper 250 m of stratigraphic horizon of the "lower plate" Robert Mountains Formation (laminated dolomite, dolomitic limestone, calcareous shale, etc.) (Figure II). Most mineralized portions of the Main ore zone are located at intersections of normal faults of northerly or northeasterly trends. The thickness of stratiform orebodies of the Carlin deposit ranges from 20 m to over 90 m, while the width of vein-like orebodies ranges from 1 m to 10 m.

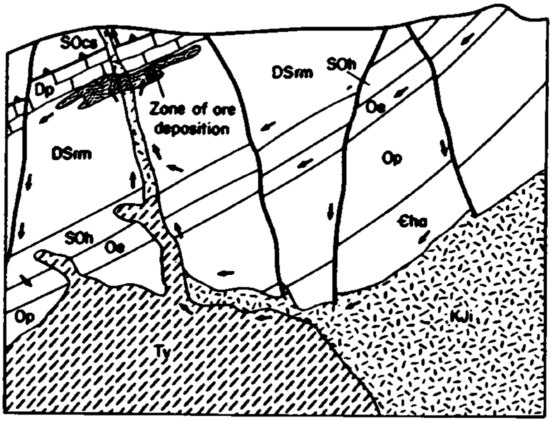

**Figure II.** **Hyrothermal system inferred for formation of the Carlin gold deposit. Arrows show paths of solution movement. DSrm, Roberts Mountains Formation (dolomite and limestone); Dp, SOh, Oe, Op, and Cha, other "lower plate" formations (limestone, dolomite, sandstone and quartzite); SOcs, "upper plate" formation (chert and shale); KJi, Jurassic-Cretaceous intrusive igneous rocks (quartz diorite, diorite and granodiorite); Tv, Tertiary volcanic rocks (Radtke, 1985).**

Shallow levels of most Carlin-type deposits in the western United States are generally oxidized. In the case of the Carlin deposit, the base of the oxidized zone extends to about 120 m below the present surface, creating 7 million tonnes of oxidized ore (Radtke, 1985).

Little secondary gold enrichment in the oxidized zone has been reported (Table 1).

**Table 1. Average concentrations of trace elements in the Main ore zone of the Carlin gold deposit**

| *Element* | *Unoxidized zone* | *Oxidized zone* |
|---|---|---|
| Au | 7.1 ppm | 9.0 ppm |
| Ag | 0.4 * | 0.7 * |
| Cu | 36 | 25 |
| Pb | 49 | 30 |
| Zn | 193 | 95 |
| As | 490 | 380 |
| Sb | 106 | 95 |
| Hg | 20 | 18 |
| Tl | 40 | 20 |
| Ba | 500 | 1500 |
| Mo | 7 | 3 |
| W | 17 | 12 |
| Se | 0.9 | 0.4 |
| Te | 0.4 | 0.2 |
| Organic carbon | 0.38 wt.%<br>(locally 1.5 to 5.0 wt.%) | 0.07 wt.% |

* value for whole deposit (compiled from Radtke, 1985)

Percival et al. (1988) summarized the average scale of the Carlin-type deposits as having a tonnage of 5.1 million tonnes and a grade of 2.5 g/t Au, with a subsequent metal content of about 13 tonnes Au (Figure III).

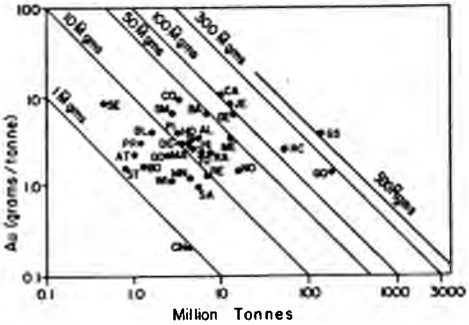

Figure III. **Gold grade versus tonnage for several sediment-hosted, disseminated gold deposits. AL, Alligator Ridge; AT, Atlanta; BA Bald Mountain; BL Blue Star; BO Bootstrap; CA Carlin; CN Candelaria; CO Cortez; DE Dee; GE Getchell; GO Gold Acres; GQ Gold Quarry; GS Gold Strike; HI Hilltop; HO Horse Canyon; JE Jerritt Canyon; MA Maggie Creek; ME Mercur; MN Manhattan; PI Pinson; PR Preble; RA Rain; RC Rabbit Creek; RE Relief Canyon; NO Northumberland;SA Santa Fe; SE Sterling; SM Sammy Creek; St Standard; TO Tonkin Springs; WI Windfall. The diagonal lines indicate total contained gold in millions of grams. Modified from Percival et al., 1988.**

## Type of Ores

Most ores from the Carlin-type ore deposits look like unaltered sedimentary rocks because of the relatively low grade and disseminated occurrence of gold. In general it is only possible to discriminate ore from waste by gold assay.

At the Carlin deposit, five types of primary unoxidized ores have been recognized; including oxidized ore, six types have been described (Radtke, 1985):

(1) *Normal ore:* Mainly composed of dolomite, illite and quartz, with minor amounts of kaolinite, sericite and some remnant calcite. This ore type forms over 60 per cent of known unoxidized ores in the Carlin deposit. Hydrothermal sulphides other than pyrite are uncommon in this ore type. Hydrothermal pyrite usually occurs as dispersed cubes and as clusters of small framboidal microspheres. Gold grade is within a range of 5 to 12 g/t Au. Content of carbonaceous matter is about 0.5 weight per cent, which is about twice that of fresh calcareous members of the Robert Mountains Formation.

(2) *Siliceous ore:* Dominated by quartz which replaced carbonates, it is essentially the same as jasperoid. Quartz is associated with subordinate sericite, kaolinite and dolomite, and a small amount of carbonaceous matter. Gold grains are usually encapsulated by the hydrothermal quartz.

(3) *Carbonaceous ore:* Characterized by high amounts (1 to 6 weight per cent) of organic carbon. Otherwise, this ore type is almost equivalent to the normal ore.

(4) *Pyritic ore:* Pyrite content is 3 to 10 weight per cent, which is much more than the average of other unoxidized ore types (0.5 to 3). Pyrite occurs as euhedual to semihedral cubes with a maximum size of 0.4 mm, and is associated

with minor framboidal aggregates. Sulphides other than pyrite include a minor amount of realgar, stibnite, cinnabar and sphalerite, which are disseminated in the ore. Gold occurs as films or coatings on pyrite, and is accompanied by Hg, As and Sb. Gold content of this ore type is relatively high (about 20 g/t Au).

(5) *Arsenical ore:* Contains 0.5 to 10 weight per cent As, much more abundant than in other ore types. Arsenic occurs mostly as orpiment, realgar and various sulfosalts, filling small fissures and cavities. Extremely high gold grades (70-130 g/t Au) and anomalous As, Sb, Hg, Tl and Ba are associated with this ore type. In limited places of the Carlin deposit, these minerals, with other rare As-Sb-Hg-Tl-S minerals, occur in a mode of "telescoping" and are nicknamed "garbage can orebody".

(6) *Oxidized ore:* Occurs in oxidized zone at upper levels of the deposit or along high-angle faults at lower levels. Oxidized ore is composed of quartz, sericite and dolomite, associated with minor kaolinite and montmorillonite. Mineral composition is comparable to the unoxidized normal ore, but oxidized ore commonly contains much less carbonaceous matter (0.03 to 0.35 weight per cent ), giving a bleached appearance to the ore. Sulfides and carbonates are very minor constituents, while goethitic aggregates, sometimes amorphous, are sporadically present. Gold is present in association with quartz, limonite or clays, with a grain size in general coarser than that in unoxidized ores (Bakken et al., 1987).

### Age of Mineralization

It is commonly accepted that the Carlin-type mineralization in the western United States is generally related to the Cretaceous to mid-Tertiary intrusions (Bagby and Berger, 1985; Percival et al., 1988; Berger and Bonham, 1990), although the age of mineralization of individual deposits is usually not obvious, mainly due to the lack of reliable age determinations for the intrusions. Some deposits on the Getchell trend are indicated to have formed in Cretaceous time, on the basis of K-Ar ages of ore-related intrusions. The high-angle normal faults related to mid-Tertiary extensional tectonics are considered to have played an important role in the mineralization of most deposits, but the Cretaceous mineralization still remains the probable primary period for several deposits. In general, no specific time ranges appear necessary for this mineralization, provided that other geologic conditions (extensional tectonics, an associated heat source, carbonate hosts, etc.) were prepared.

## HYDROTHERMAL ALTERATION

ized by progressive dissolution of calcite by
tion, followed by a moderately intense d
associated with gold precipitation, with argilliz
sericitization) and silicification accompan
alteration. Dissolution of calcite resulted i
crease of volume of limestones and subsequ
brecciation and deformation of the rocks.
hydrothermal alteration, $TiO_2$ and $Al_2O_3$ were i
CaO and MgO were largely removed. On th
the $SiO_2$ content increased significantly.

Decomposition of carbonaceous matt
of pyrite to amorphous iron-oxides, and local re
of calcite took place during weathering. K
alunite found in oxidized zones of several
deposits are mostly Miocene, suggesting th
due to weathering.

Jasperoid is the term for a massive sil
formed by silica replacement of calcareous
one of the characteristics of hydrothermal alt
ciated with Carlin-type mineralization. Gold
tion in jasperoid is mostly subeconomic,
strong relief in many places of the arid p
western United States, providing good landm
eralized areas, and serving as the most appro
rial for geochemical analysis as well.

## GEOCHEMISTRY

The behavior of trace elements associ
Carlin deposit was studied by Radtke (198
overall geological framework. As, Sb, Hg, an
as Au, are the most common minor elements.
ing description is for this deposit unless othe

Gold shows highest values where it
with pyrite. Some 500 ppm Au was re
monomineralic sample of pyrite. In terms
arsenic ore is richest in Au, showing 130
maximum value.

Silver is negligible, with average con
1 ppm in most Carlin-type deposits. Eighty
reported at the Gold Quarry deposit, an e
high value for gold-rich type deposits (Rota
1988).

Arsenic is highest in concentration a
called "epithermal" elements, with 2.5 weig
a maxium value for arsenical ore. The con
normal ores ranges 400 to 500 ppm.

epithermal elements, Sb concentrations do not vary appreciably in terms of ore type.

Mercury, of all the epithermal elements, shows the most positive correlation with Au, with Hg:Au ratio varying within a relatively limited range of 4:1 to 2:1 (3:1 on average). A value of 280 ppm Hg was observed in an arsenic ore, while the average value for all unoxidized ores is 20 ppm Hg. Mercury is said to have been recovered economically from the Carlin deposit, but no details are available.

Thallium is concentrated in arsenical ores at levels up to a maximum value of 150 ppm, while the average of total unoxidized ore is 40 to 50 ppm Tl. The Tl content of fresh rocks around the mineralized district is 3 ppm.

The barium content in unoxidized ores is 400 ppm on average, which represents an increase by 2 to 3 times over that of fresh, unmineralized rocks. Ba values are not positively correlated with Au values in the mineralized zones, presumably because dissemination and veining of barite took place after the mineralizing stage of gold.

Characteristic trace elements associated with the Carlin-type deposits commonly differ between individual deposits. Jones (1989) indicated that, among seven deposits in the Carlin trend, including the Carlin deposit, As is associated with 6, Sb and Hg with 4, Zn and Ba with 3, and Ag, Tl, Pb with 2 deposits respectively.

Holland et al. (1988) and Nelson (1990) discussed the usefulness of multielement geochemistry to evaluate jasperoids as devices for regional exploration and prospect evaluation. In particular, Nelson (1990) stresses that careful sampling and consistent analysis of jasperoid samples are essential for the results to be meaningful. By using a discriminant function based on a database from known deposits, it is possible to increase the confidence in interpreting samples related to economic mineralization. In Nevada, there appears to be a correlation of elements enriched in the local marine shales (Li, P, Mn, Ba, Mo, Cr, Co, V, Cd, N, U, Zn and Pb) with Carlin-type deposits.

Oxygen isotopes of jasperoid and other altered rocks may be correlated to the degree of evolution of mineralizing fluid and to the subsequent extent of gold deposition (Hofstra et al., 1987, 1990; Holland et al., 1988).

## ORE FORMING PROCESSES

### Stable Isotope and Fluid Inclusion Studies

Ore forming conditions of only a few deposits such as Carlin, Mercur and Jerritt Canyon have been studied by means of stable isotope and fluid inclusion studies.

Summarizing the data on the Carlin reported by Radtke (1985) and Rose and Kuehn (1987), the Mercur by Jewell and Parry (1988), and the Jerritt Canyon by Northrop et al. (1987) and Hofstra et al. (1987; 1990), it is concluded that the ore-forming hydrothermal fluid is highly evolved meteoric water, which encountered normal meteoric water at shallow levels (Figure II). Temperature of the "deep" fluid was measured to be 185° to 235°C and salinity was 2 to 4 wt.% (NaCl equiv.) during the main mineralizing stage of the Carlin deposit (Radtke, 1985; Rose and Kuehn, 1987), although considerable temperature variations have been recognized in all of the above deposits. Fluid inclusions from Jerritt Canyon were shown to contain several gas components, dominated by $CO_2$ (4 mol.%). Sulfur isotope data on pyrite of the Carlin deposit indicate that the origin of sulfur is diagenetic pyrite in beds of the Roberts Mountains Formation (Radtke, 1985).

A positive correlation of oxygen isotope composition ($\delta^{18}O$) of jasperoid from Jerritt Canyon with its gold content was indicated by Northrop et al. (1987), suggesting that both parameters are closely related to the degree of interaction between hydrothermal fluid and host rocks. Holland et al. (1988) also pointed out that higher $\delta^{18}O$ values of jasperoids from many localities in northern Nevada are closely associated with a suite of ore-related trace elements.

### Ore Forming Model

The ore forming model of the Carlin-type gold deposits accepted by most explorationists at present may be summarized as follows, on the basis of the above genetic studies as well as of many descriptive studies (Figure II).

The hydrothermal system was generated in close association with the intrusion of igneous rocks of Cretaceous or mid-Tertiary age. The origin of the hydrothermal fluid was evolved meteoric water with basinal characteristics. The fluid was weakly acidic and was rich in $CO_2$ and $H_2S$. Metals in the fluid were scavenged from the host sedimentary rocks.

Ascending through high-angle faults, the hydrothermal fluid encountered reactive and permeable calcareous formations, and resulted in decalcification, brecciation, silicification (jasperoid formation) and argillization (kaolinization and sericitization) of the rocks during the upflow and lateral outflowing through the calcareous beds. Subsequently, the fluid mixed with meteoric water, and was cooled, diluted, and oxidized. These processes resulted in deposition of gold and associated elements represented by As, Sb, Hg, and Tl.

Gold deposited mainly with pyrite, most of which formed by replacing dispersed, small aggregates of reactive iron in the sedimantary rocks. This produced the characteristically small grain size and disseminated mode of gold occurrence (Hofstra et al., 1990).

The features of the Carlin-type mineralization outlined above may be understood as forming under epithermal conditions, as presently accepted by most geologists. However, recent development of the Gold Strike deposit revealed that high-grade gold mineralization is spatially associated with deep-seated Cretaceous granodiorite stocks and their accompanying skarns. The occurrence of skarns has been reported at some other deposits, although the genetic relation with gold mineralization has not been established in all deposits. On the basis of the above facts, Sillitoe and Bonham (1990) proposed a new model in which the Carlin-type gold deposits are considered as distal products of magmatic-hydrothermal systems around intrusions.

## SEDIMENT-HOSTED, DISSEMINATED GOLD DEPOSITS IN ASIA

### *Yata, Guizhou Province, China*

Cunningham et al. (1988) reported that several gold deposits in southern Guizhou Province have many similar characteristics to the Carlin-type gold deposits in the western United States. This may be the first recognized case of a Carlin-type gold mineralization outside the United States published in a journal of world-wide distribution.

Gold deposits at Yata and four other districts are disseminated within calcareous rocks of Permian to Triassic age, which cover the southern periphery of the Precambrian Yantze craton. Deposits are located along the crests of antiforms, and are controlled by high-angle faults. Each deposit is 4 to 5 g/t Au in grade, and contains up to 5 tonnes of gold. The grain size of gold is less than 1 mm, and occurs as disseminations. The Au:Ag ratio is high, and Au is associated with the suite of As, Sb, Hg and Tl. Silicification (jasperoid formation), decalcification, argillization and pyrite dissemination are common. Homogenizing temperature of fluid inclusions ranges between 120° and 240°C, and salinity is less than 5 wt.% (NaCl equiv.). Mineralization age is estimated to be about 100 Ma, a period in which extensional tectonics of the Yanshanian orogeny prevailed in this terrane.

### *Bau District, Sarawak, Malaysia*

Sillitoe and Bonham (1990) introduced the gold deposits of the Bau mineralized district, Sarawak, Malaysia, as the most appropriate example for their proposed model that Carlin-type gold deposits formed as distal products in magmatic-hydrothermal environments around progenitor intrusions.

In the Bau district, where some 40 tonnes of total gold output has been recorded, intrusive bodies and gold deposits are aligned in a north to northeast trend ("Bau trend"), at least 30 km long and about 8 km wide (Percival et al., 1990; Sillitoe and Bonham, 1990). Gold deposits are hosted by Late Jurassic to Cretaceous limestones and calcareous shales, intruded by stocks, sills and dikes of Late Miocene microgranodiorite and dacite porphyry. All principal gold deposits, represented by the Tai Parit deposit (2 million tonnes, 6 to 9 g/t Au), are located on the periphery of the mineralized district, while low grade Cu-Mo-Au mineralization and calc-silicate skarns are associated with intrusions in the center of the mineralized district. Pyrite, arsenopyrite, realgar and stibnite are associated with the gold deposits. Mineralization is controlled by high-angle faults, and host rocks are decalcified, brecciated, silicified and argillized.

### *Siana and Placer, Surigao del Norte, Philippines*

The Siana deposit in the northeastern Mindanao is one of the major gold operations in the Philippines. The deposit is stratabound and is hosted by calcareous sedimentary rocks termed the Siana Beds, overlain and underlain by pillow lavas and basaltic clastics of the Late Oligocene to Early Miocene Bacuag Formation (United Nations, 1987). These rocks are intruded by andesite porphyry of 3.2 Ma (Middle Pliocene), which is considered to be genetically related to the mineralization.

Two types of gold ores are recognized in the Siana deposit. The first and major type is disseminated gold ore. The ore zones of this type consist of black carbonaceous and pyritic clays within which recrystallized and brecciated limestones are present as rounded boulders and blocks. Gold is closely associated with pyrite framboids of micron-size within the black clays. The average grade of this ore type is 4 g/t Au, with a Au:Ag ratio of about 1:3. This ore type contributes about 80 per cent of total gold production from this deposit.

The second type is a gold-bearing massive sulfide ore of irregular shape within limestone, consisting of pyrite, sphalerite, galena and subordinate chalcopyrite. The length of individual ore lenses is up to 7 m. Gold grade is usually up to 30 g/t Au, but the maximum recorded value is 641 g/t Au (Mercado et al., 1987). Gold grains are 30 to 120 µm in diameter. The Au:Ag ratio is comparable to the disseminated ore.

United Nations (1987) has suggested that the "fossil soil" horizon of the Placer deposit, another major gold operation in Mindanao about 15 km north of the Siana mine, is also a carbonate-hosted stratabound gold mineralization. The "fossil soil" ore occurs replacing calcareous units of the Bacuag Formation and consists of banded chalcedonic silica associated with pyrite, orpiment, realgar, stibnite and cinnabar.

Although these gold deposits inMindanao differ in some features from the well-documented Carlin-type deposits in the western United States, and although more detailed information is needed to establish a specific model for these deposits, they are especially useful as comparative examples of sedimentary-hosted, disseminated gold deposits in very mobile island-arc systems.

## SUGGESTIONS FOR EXPLORATION

On a crustal scale, the Carlin-type gold deposits in the western United States are distributed in a terrane overlying the western limits of Precambrian crystalline basement. Extensional tectonics have prevailed since mid-Tertiary time in this terrane, forming the well-known Basin and Range physiography. Regionally, mineralized districts in this terrane are underlain by calcareous sedimentary rocks intruded by alignments of Cretaceous to mid-Tertiary igneous rocks. Crests of antiforms caused by the intrusions may be the target of regional exploration. Remote-sensing images from satellites may be useful at an early stage of exploration.

In the Carlin and Cortez trends in northern Nevada, lower plate formations of the low-angle Roberts Mountains Thrust crop out in windows seen through the upper plate formations. These windows are usually associated with magnetic and/or gravity anomalies (Ponce, 1990), and have proven to be the most promising target zones of exploration, since many gold deposits have been discovered in and around them.

Jasperoid is in general resistant to erosion, and often provides a good landmark for mineralized districts in arid regions. Furthermore, jasperoid usually contains trace levels of Au and associated "epithermal" elements. Thus the evaluation of geochemical characteristics of jasperoids is extremely important in order to discriminate between mineral-related jasperoids and barren jasperoids. Statistical analysis of multielement geochemical data, sometimes coupled with oxygen isotope analysis, may be effective for this discrimination, as shown by Hofstra et al. (1987), Holland et al. (1988) and Nelson (1990).

Polytpye and crystallinity of the sericite/illite commonly associated with Carlin-type mineralization varies systematically with distance from the orebody (Hauff et al., 1990). Closer to the orebody, 2M polytype increases relative to 1M, while the degree of crystallinity, which is reversely correlated with content of expandable smectite layers, decreases. This mineralogical variation may also be useful for district scale exploration.

The mineralized belt which is at present called the Carlin trend used to be a mining district for placer gold, vein Cu-Au, copper oxides, antimony, barite and turquoise, although the operations were of small-scale nature. Manifestation of such minerals at the surface may also be a good indicator of larger-scale mineralization.

The recent discovery of the Gold Strike deposit on the Carlin trend, in which the mineralization shows features of rather deep levels relative to other known Carlin-type gold deposits, suggests that estimation of erosion level, or in other words, proximity to the related intrusion, may be another important aspect for exploration, as proposed by Sillitoe and Bonham (1990). More evidence to be revealed by further development of the Gold Strike deposit may contribute to improvement of the exploration model of the Carlin-type gold deposits and help explain variations of the original model.

These suggestions are largely based on the setting of the western United States, where the Carlin-type gold deposits are best understood. The reader is strongly advised to bear in mind that models vary from place to place and, though models are useful and necessary, they must be tailored to suit the geological terrane encountered in each new exploration area.

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# GOLD-ALUNITE AND BASE METAL VEIN MINERALIZATION WITHIN THE RODALQUILAR CALDERA COMPLEX, SPAIN.

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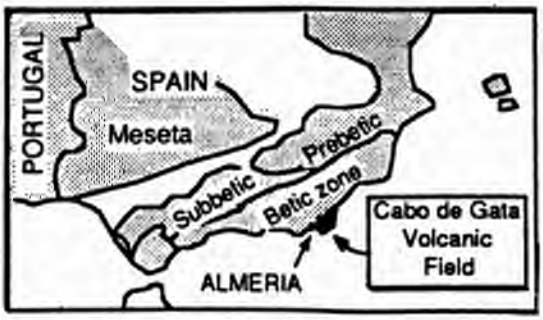
## INTRODUCTION

The Miocene Cabo de Gata volcanic field occurs along the southeastern coast of Spain and is the only extensive area of Tertiary volcanic rocks within Spain that hosts epithermal precious- and base-metal deposits. The volcanic field is separated from the Betic Alpine fold belt (Paleozoic and Mesozoic rocks which comprise most of southeastern Spain) by a left lateral strike-slip fault (Figure I). The volcanic field extends for 150 kilometers along the Mediterranean coast, and in the western part of the volcanic field, regionally extensive rhyolite to dacite flow tuffs and andesitic stratovolcanoes and cones are present. Three collapse calderas occur in the western part of the volcanic field and include, from oldest to youngest, the Los Frailes, the Rodalquilar and the Lomilla calderas (Rytuba et al., 1988). The calderas retain much of their original morphology notwithstanding their Miocene age. Gold deposits of the quartz-alunite type (Nansatsu type) and associated base metal vein systems occur within and adjacent to the Rodalquilar and Lomilla calderas. Advanced argillic alteration is widely distributed within the calderas, and several alunite deposits have been mined.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure I. Location of the Cabo de Gata volcanic field, Spain.

The Los Frailes caldera is the oldest caldera and resulted from the eruption of a hornblende dacite ash-flow tuff about 14.4 million years before present. The caldera has a diameter of 5 kilometers and has been partly eroded by the Mediterranean Sea (Rytuba et al., 1988). The Rodalquilar caldera resulted from the eruption of the Cerro Cinto ash-flow tuff and is an oval collapse structure having a maximum diameter of 8 km in an east-west direction and a minimum diameter of 4 km in a north-south direction (Figure II).

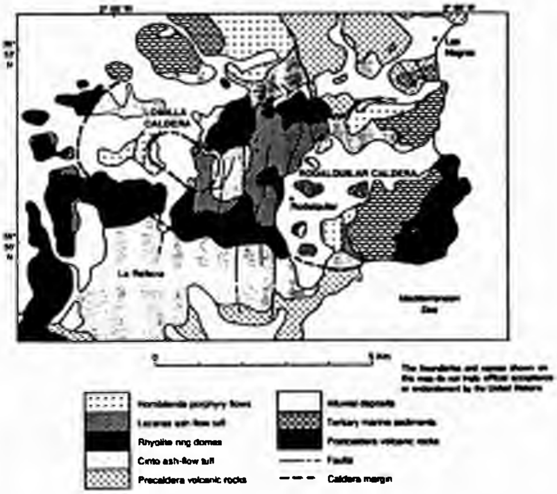


Figure II. Geology of the Lodalquilar caldera complex, Spain.

## CALDERA DEVELOPMENT

The morphology of the Rodalquilar caldera is well preserved despite its Miocene age. The south topographic wall of the caldera is defined for a strike length of about 5 km by a fault scarp which separates gently dipping ash-flow tuffs vented from the Los Frailes and Rodalquilar calderas from intracaldera rocks. the topographic wall of the caldera is exceptionally well exposed along the sea coast where unwelded Cerro Cinto ash-flow tuff is depos-

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ited on precaldera andesite flows. This contact is gently dipping and reflects erosion of the oversteepened structural wall of the caldera by extensive landsliding of precaldera andesite into the caldera. Large blocks of precaldera andesite are locally incorporated within the Cerro Cinto ash-flow tuff and indicate concurrent eruption of the Cinto ash-flow tuff with caldera collapse. The northern structural margin of the caldera is well exposed for a distance of 2 km and consists of a single, nearly vertical fault that separates precaldera domes forming the well of the caldera from intracaldera Cerro Cinto ash-flow tuff and interbedded collapse breccias (Rytuba et al., 1988).

Six ash-flow tuff cooling units are exposed outside the Rodalquilar caldera and are part of a regionally extensive ash-flow volcanic field. The large number of cooling units which comprise the Cerro Cinto ash-flow tuff indicates that it is a composite sheet and that multiple collapse events occurred during formation of the Rodalquilar caldera. The ash-flow tuffs range from unwelded to welded and from lithic to pumice rich. Near the caldera margin the size and abundance of pumice and lithic fragments increases.

Within the caldera more than 200 m of intracaldera collapse breccias and intracaldera Cerro Cinto ash-flow tuff occur. The individual collapse breccia beds thicken toward the margin of the caldera, and clasts within the breccia reach up to 30 m in diameter. The matrix of breccia consists of pumice and ash from the Cerro Cinto ash-flow tuff. Each breccia bed records a repeated failure of the oversteepened caldera wall as the eruptions of the Cerro Cinto ash-flow tuff occurred.

Shortly after collapse of the Rodalquilar caldera, resurgence of the central part resulted in uplift and structural doming of intracaldera tuffs and breccias. Development of the resurgent structural dome was followed by emplacement of volcanic domes along the southern and northern structural boundaries of the caldera. These rhyolite ring domes consist of massive, flow-foliated rhyolite which is typically mantled by a carapace of debris avalanche deposits. These domes retain their original morphology and some of the domes attained sufficient height to extend above the top of the southern caldera wall. In these areas, debris avalanche deposits derived from the rhyolite domes flowed over the rim of the caldera and were deposited on the top of out-flow facies of the Cerro Cinto ash-flow tuff. The ring domes emplaced along the southern margin of the caldera extended into the caldera for a distance of about 1.5 km. Ring domes emplaced along the northern margin of the caldera are associated with flow-domes from which massive flows extend into the caldera.

Continued resurgence of the central part of the Rodalquilar caldera resulted in the catastrophic failure of part of the central resurgent dome and eruption of the Lazaras ash-flow tuff. The Lazaras tuff was ponded within the moat of the Rodalquilar caldera, where it reaches a maximum thickness of about 90 m. Eruption of this tuff resulted in the formation of the Lomilla caldera, an oval collapse structure with a maximum diameter of 2 km, which is nested within the central part of the larger Rodalquilar caldera. The eastern topographic wall of the Lomilla caldera is very well preserved and defined by an arcuate scarp with over 100 meters of vertical relief. The wall of the caldera is composed of Cerro Cinto ash-flow tuff and interbedded collapse breccias, and ring domes emplaced along the margin of the Rodalquilar caldera. Arcuate and radial fractures cut the wall of the Lomilla caldera and developed in response to caldera collapse.

After eruption of the Lazaras ash-flow tuff, the moat of the Rodalquilar caldera was filled by a lacustrine sedimentary sequence consisting of thin bedded shales and diatomite. Overlying the lacustrine sequence is lithic-rich ash flow which is highly silicified and has a maximum thickness of about 6 meters, which apparently flowed out onto the nearly flat floor of the Rodalquilar caldera moat. At the time of eruption, the lake which had filled the moat of the Rodalquilar caldera had largely evaporated leaving deposits of gypsum and fine grained clays, though some residual waters within the moat sediments of the caldera reacted with the tuff resulting in its extensive silicification.

Overlying the silicified ash-flow tuff is a sequence of hornblende andesite flows, which range from a few meters to more than 50 meters in thickness. Because the flows were deposited on a soft sediment surface, fine-grained sediment is often incorporated within the matrix of flow breccias. Intrusive plugs and dikes of hornblende andesite are present in the wall of the Lomilla caldera and are closely associated in time and space to epithermal gold mineralization within the caldera.

Late-stage resurgence within the Rodalquilar caldera occurred near the final stage of emplacement of the hornblende andesite magma, evidence for which is the tilting and doming of the Lazaras ash-flow tuff, the caldera fill and volcaniclastic sediments, and the earliest flows of hornblende andesite. The main locus of this late-stage doming was in the south central part of the caldera, where the Cerro Cinto ash-flow tuff and its interbedded collapse breccias show the steepest tilts. This late stage of resurgence was important in opening faults and fractures which later formed the fluid pathways critical to the development of the large hydrothermal systems now seen within the caldera.

The eastern and western margins of the Rodalquilar caldera are covered by a thick sequence of marine sediments. Incursion of sea water into the caldera and deposition of marine limestone occurred after the late-stage resurgence. The last event within the caldera was the emplacement of pyroxene andesite flows along the eastern part of the Rodalquilar caldera. These flows are unaltered and are postmineralization in age.

## THE SETTING FOR MINERALIZATION

Gold-alunite and base metal deposits within the Rodalquilar caldera complex are closely associated with a zone of extensive advanced argillic alteration which trends east-west across the caldera complex. This zone of alteration is well delineated by Landsat Thematic Mapper data in which color-ratio composite imagery produced from TM5/7, TM5/4 and TM3/1 band ratios are projected as red, blue and green, which allows the zones of intense alteration to be observed as white and yellow areas (Rytuba et al., 1988). A strong aeromagnetic high trends east-west across the Rodalquilar caldera, essentially coincident with the zone of alteration. A strong gravity high is also coincident with this zone. The gravity and aeromagnetic highs reflect the presence of the dioritic magma body emplaced at the base of the volcanic pile late in the caldera cycle, the extrusive equivalents of which are the hornblende andesites which concluded the cycle of volcanic activity in the caldera, and whose emplacement was responsible for the last stage of caldera resurgence. This magma is regarded as the heat source responsible for the large hydrothermal cells developed within the caldera (Cunningham et al., 1989). K-Ar age dating of the sericite and alunite at 10.8 Ma indicates that the hydrothermal event developed within a half million years or less after formation of the Lomilla caldera (Rytuba et al., 1989).

## ORE DEPOSITS

Ore deposits within the Rodalquilar caldera complex consists of gold-alunite, alunite, and base metal vein deposits. The alunite deposits consist of massive replacement bodies that are localized in the collapse breccias and the intracaldera Cerro Cinto tuff along the northeast margin of the Rodalquilar caldera and on the east flank of the resurgent dome of the Rodalquilar caldera. Both the lithic clasts and matrix of the breccias are replaced by alunite. The base metal vein deposits, consisting of Pb, Cu, Ag and Au-bearing quartz veins, occur along north-south trending faults which transect all volcanic units except the youngest pyroxene andesite flows. The Triunfo vein, which cuts the Lazaras tuff in the north-central part of the Rodalquilar caldera, is typical of these. Barren, supergene alunite veins and veinlets are present throughout the caldera and are the youngest vein deposits (Arribas et al., 1988). The gold deposits consist of chalcedonic veins ranging up to 1.5 m in width which are localized in ring and radial faults and in fractures present in the east wall of the Lomilla caldera. In the 1930s about 5 metric tons of gold were produced from these deposits and current reserves consist of 650,000 tons of ore averaging 2.5 grams per ton. Highest gold grades occur in black (pyritic), banded chalcedony which fills preexisting openings and fractures. A younger, late stage white chalcedony commonly has a lower gold content (Arribas et al., 1988). Very high grade gold veins, up to 1 m in width, extend into the ring domes located along the southern margin of the Rodalquilar. caldera.

Hydrothermal alteration associated with the gold mineralization persists to a depth of over 860 m and is typical of acid-sulfate systems. A deep sericitic zone grades upward into argillic, advanced argillic, and silicic zones, with gold occurring in the highest part of the system where the silicification and advanced argillic alteration are most intense. Hypogene, high sodium alunite within the central part of the alteration zones extends to a depth of 230 m and occurs with zunyite and aluminum phosphate-sulfates (Arribas et al. 1988).

Stable isotope data on hypogene alunite from the ore zone ($\delta^{34}S=26\pm4‰$, $\delta^{18}O_{SO_4}=7\pm‰$, $\delta D=-25\pm5‰$) indicate formation of the alunite in a magmatic-hydrothermal environment (Rye et al., 1988) by disproportionation of $SO_2$ derived from the degassing dioritic magma associated with late-stage resurgence in the caldera. Late, supergene alunite-jarosite veins unrelated to gold mineralization have significantly lighter sulfur and oxygen isotopic signatures indicating that they formed from the oxidation of $H_2S$ in a steam-heated environment (Rye et al, 1988) that in some places was superimposed on the advanced argillic assemblage as the hydrothermal system collapsed (Arribas et al. 1989). Deuterium isotopic evidence indicates that seawater was probably an important component of the water in the ore forming hydrothermal fluid (Arribas et al, 1988, 1989). Incorporation of sea water into the hydrothermal system is consistent with the stratigraphic evidence that indicates sea water incursion into the eastern and western part of the Rodalquilar caldera occurred just after emplacement of the hornblende andesites.

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# THE EPITHERMAL GOLD DEPOSITS IN THE CIKOTOK AREA, WEST JAVA, INDONESIA

by
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## ABSTRACT

The Cikotok gold mine district has been known since 1936. It is one of the most significant mineralized districts in the Bayah Dome area, South Banten, West Java, Indonesia.

Gold deposits are typically of quartz-vein type hosted by propylitized Oligo-Micoene volcanic andesite.

The structures developed by the domal system are strongly correlated with the vein formation, with NNE-SSW, N-S and E-W trends. Several phases of known gold mineralization are deposited in fault breccia zones, which act as epithermal reservoirs.

The ore types are comprised of crustifications, cockade and banded quartz veins bearing base metal sulphides, pyrite, argentite and electrum. Rhodonite and rhodochrosite are the essential gangue minerals. Ag/Au ratio of the ores varies from 6 to 97, and the gold occurs as electrum.

The mean homogenization temperatures of fluid inclusions are within the range of 143 to 320 degrees centigrade, and freezing point measurements yield salinity estimates of 0.0 to 2.4 wt percent NaCl. These temperatures and salinities are typical of fluids within a epithermal environment.

New evidence of gold mineralization in this area indicates that sedimentary rocks which underlie and are lateral to the propylitized andesite may also be mineralized.

## INTRODUCTION

The Cikotok mining area is located in the sub-district of Bayah in southern part of Lebak district, West Java Province, Indonesia, approximately 250 km south-west of Jakarta (Figure I).

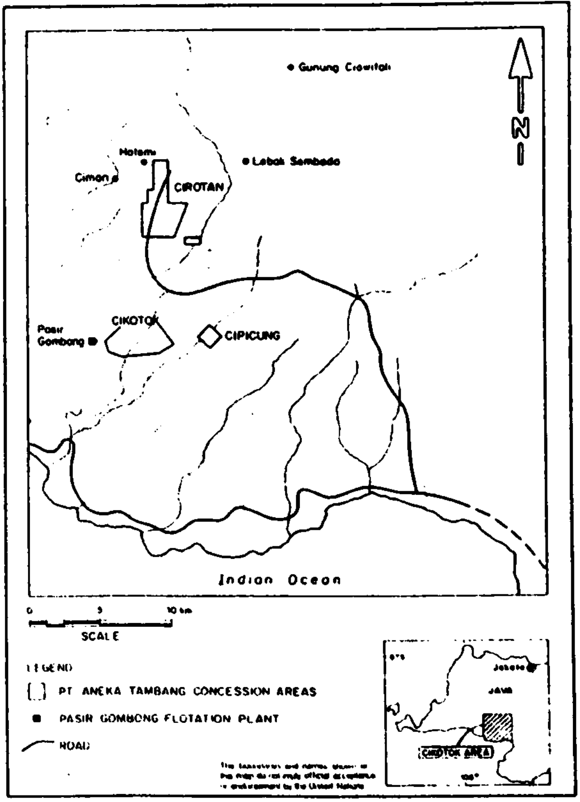

Figure I. Access to Cikotok gold mining area, South Banten, West Java.

The occurrence of gold and silver in the sulphide mineralization in the Cikotok area was discovered during the last century, but the first mining only started about 1936. The extraction by underground mining used cut-and-fill methods with temporary timbering supports. Drifts were developed at several levels below the surface following the strike of the veins (Figure II). Ores were mined from a number of mining sites, namely Cikotok, Cirotan, Cimari, Hatemi, Lebak Sembada, Cipicung and

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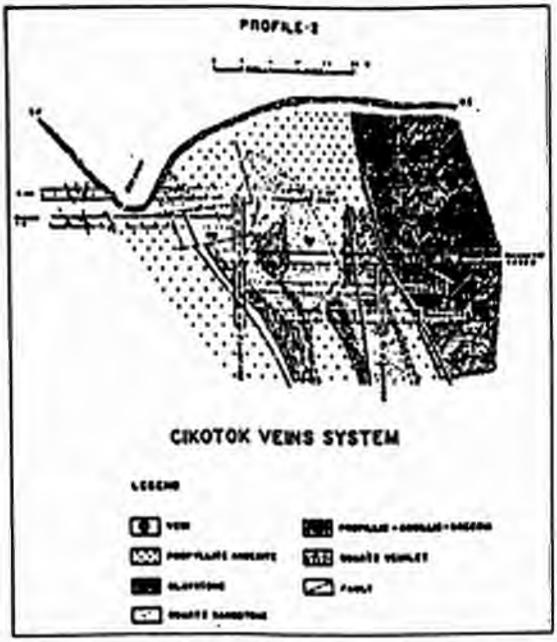

Figure II. A profile of the Cikotok vein system.

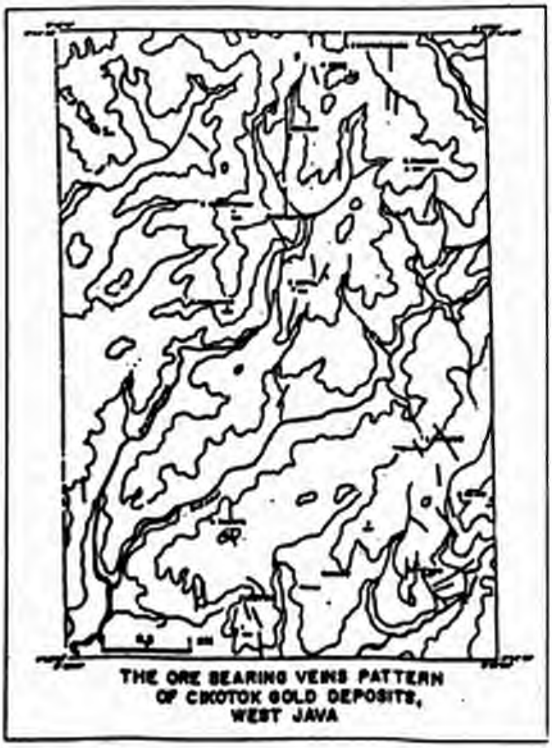

Figure III. Ore-bearing veins pattern of the Cikotok gold deposits.

Cipanggleseran (Figures I and III). The total annual production of gold and silver metal from mining sites in the Cikotok area has decreased during the last decade, apparently related to decreasing high grade reserves. Only low grade ores (1-2 g/ton of Au, amounting to about 400,000 ton) are currently being mined (Gandataruna, 1988), and the ore-dressing methods in use may not be the most appropriate for such low grade ores.

A "crash" exploration programme is being carried out in the Cikotok area to identify reserves to cover operations for the next 5-8 years. New evidence based on recent field data in the area has suggested a redesign of the exploration concept toward the epithermal model based on gold-silver-base metal associations in quartz vein deposits hosted in the volcanic rocks, similar to Cikotok deposits, but also directed toward other possibilities of gold and silver hosted in the sedimentary rocks.

## PREVIOUS INVESTIGATIONS AND MINING HISTORY

Extensive exploration for precious metal and other economic minerals in the Cikotok area was done by Zeigler (1918). Between 1924 and 1929 Dutch geologists explored and discovered gold-bearing quartz within the area, and suggested that the andesite may be the important host rock for the mineralization (Zeigler, 1931). Koolhoven (1933) produced the earliest systematic geologic map of the area (scale 1: 100,000, Sheet 14, Bayah area). De Haan (1954) concluded that the veins occupied shear fractures formed by stresses which originated from the south.

Mining in the Cikotok area commenced in 1936 and was continued until 1939 by the N.V. Mijnbouw Maatschappij Zuid Bantam (MMZB) organization, who built a milling plant at Pasir Gombong, approximately 5 km from West Cikotok. During the Japanese occupation period from 1942 to 1944, the gold mine was taken over by Mitsui Kosha Kabushiki Company whose principal interest was the lead ores from the Cirotan mine. In 1954 the owner, NV. Perusahaan Pembangunan Pertambangan, established the NV. Tambang Emas Cikotok (The Cikotok Gold Mining Unit) which was the operator of mine until it was recently transferred to the supervision of the government company P.T. Aneka Tambang Ltd.

## TECTONIC FRAMEWORK

Western Indonesia is considered to be a part of the Sunda Shelf of the Eurasian continent (Palunggono, 1985) and is bordered by an island arc (the Sunda Arc) marked by a row of active volcanoes. The development of the arc-trench system in western Indonesia was most intense during the early Tertiary. It was accompanied by the emplacement of granitic intrusions along the west coast of Sumatra and in Java (Katili, 1973). Lavas from Java and Bali are typical of a normal island arc, and are dominantly basaltic-andesitic composition containing up to 55% silica (Whitford et al., 1979).

The general tectonic framework of west Java, and the Bayah dome in particular, has apparently been affected by both local and regional tectonic episodes. The dome has an elongated NW-SE axis (Figure III). The southern and northern parts of the dome have similar tectonic patterns which probaly were derived as a result of NNE-SSW-trending regional stresses (Katili and Koesoemadinata, 1962).

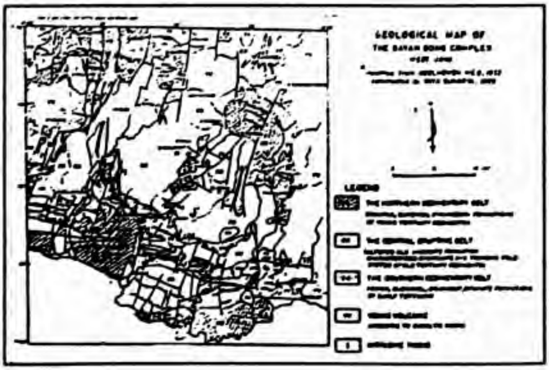

**Figure IV. Geological map of the Bayah dome complex.**

Faulting occurred over wide stratigraphic ranges, but folding developed only within a restricted number of lithological units. North-south compressional stress appears to have generated folding and thrust-faulting. Strike-slip faults developed particularly near the center of the dome, oblique to the long axis and with a trend of N 30°E during the doming period.

## STRATIGRAPHY

The stratigraphy of the area is summarized in Figure V.

The oldest basement consists of carbonate sedimentary rocks (Bayah Formation), the propylitic extru-

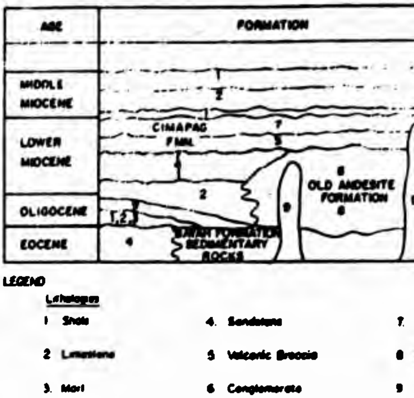

**Figure V. Schematic stratigraphic diagr Banten area (Sheet 14) showing and mineralization. After Kool and Koesoemadinata (1962), r by Sunarya (1989).**

The Bayah Formation, occupying the s of the Bayah dome, was deposited in the E The central part of the Bayah dome is con nantly of the Oligo-Miocene Old Andesit bordered by the Cimapag Formation slightly The Old Andesite Formation consists of pr and breccias, whereas the Cimapag Formati less altered lapilli and brecciated andesitic r these formations also contain sedimentary indicating marine depositional environments. flank is covered by younger volcanic and formations.

The intrusive rocks consist of granoc diorite and dacite that intrude the lithologic and were probably the heat sources for the n in the area.

## MINERALIZATION

In this area, sulphide-bearing quart monly fill deformation zones in the propyli (Figure VI) and may contain base metal s precious metal minerals but often are barre veins are mostly seen in the andesite rocks found in the Eocene sediments of the Bay and in the arcuate sediments which are late to the andesite. These wall rocks have unde degrees of alteration including chloritization, carbonatization, silicification and argillizat

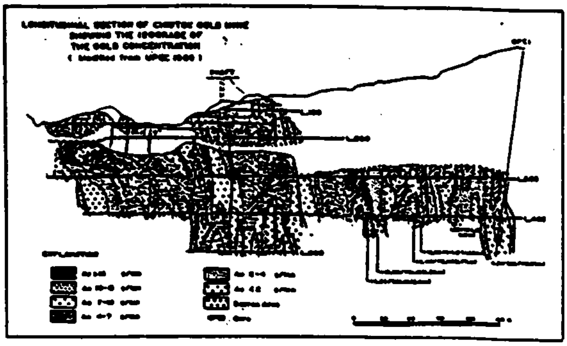

Figure VI. Longitudinal section of the Cikotok gold mine showing the isograde of gold concentration.

times with colloform structures. The breccia veins contain angular fragments of earlier vein materials and show repeated silicified banding. These textures indicate an epithermal environment where abundant fluid movement and brecciation due to hydraulic fracturing alternated,- favourable conditions for gold deposition.

In general, the ores can be distinguished into two groups, the oxidic and the sulphidic ores. The oxidic ores are low in base-metal sulphides (for example, ores from Cikotok and Cipicung Mines) and high in precious metals. The sulphidic ores contain high base-metal sulphides (for example, ores from Cirotan, Cimari-Hatemi and Lebak Sembada) plus precious metals.

## PETROGRAPHY AND ORE MINERALOGY

In general, the wall rocks of the quartz veins have undergone various degrees of alteration characterized by the occurrence of chlorite, sericite, carbonate, argillite, quartz and pyrite. The andesite host rock has typically a porphyritic texture and occasionally exhibits a glomeroporphyritic texture, and is sometimes fractured by deformation with chlorite, sericite or calcite filling the fractures. The phenocrysts of plagioclase are often zoned with the core more calcic in composition. The pyroxene is clinopyroxene and thought to be primarily augite. The groundmass consists of micro-crystalline plagioclase. It exhibits a sub-parallel alignment suggesting a flow texture. The tuffaceous rocks are commonly altered to argillite or are silicified. The sedimentary rocks include sublitharenite, tuff shale and slate. Locally, these rocks often contain pyrite and chalcopyrite.

Pyrite is the most abundant sulphide mineral and often forms layers within breccia ore. Other sulphides are galena, chalcopyrite, sphalerite and bornite. Veinlets of galena often crosscut the pyrite, as do some very thin veinlets of chalcopyrite.

The precious metal minerals are thought to be very fine-grained argentite (up to 200 microns) and electrum (less than 100 microns), associated with iron-oxides which occur as secondary minerals (Soeharto, 1987). The lateral and vertical distributions of ore minerals are quite irregular.

## FLUID INCLUSIONS

A fluid inclusion study (Maunder, 1988) noted that the salinity ranges from 0.0 to 2.4% (normal pure-water system at shallow depth) and homogenization temperatures ranges between 130 to 335°C. The study also concluded that, as in most hydrothermal systems, multiple episodes of mineralization have occured and these have been affected by post-mineralization aqueous activity.

## APPROPRIATE EXPLORATION CONCEPT

Recent geochemical exploration beyond the immediate mining concession area has revealed that the mineralization in the Bayah dome was strongly structure-controlled and restricted to the propylitized andesitic rocks. Free gold and cinnabar grains have been found in pan-

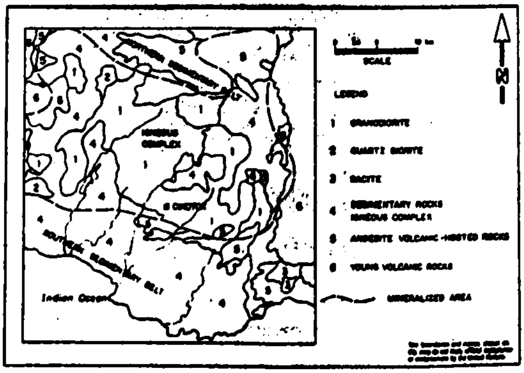

Figure VII. Primary gold mineralization zone in the Bayah dome complex, West Java. After Koolhoven (1932), modified by Sunarya (1989).

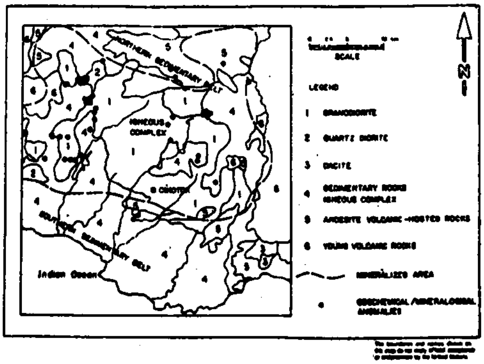

Figure VIII. New discoveries of gold mineralization indicators, in and near the Bayah dome complex, West Java.

concentrates confirming and correlating with the gold mineralization in the area (Figure VIII).

There are also skarn and massive sulphide deposits hosted by carbonate sedimentary rocks found in the area. Re-study of the geology in the Cikotok Mine has shown that mineralization has occurred in both volcanic and sedimentary rocks, and consequently has suggested a new model for mineralization. The gold mineralization may be generalized into two types: the base metal association (within the Cikotok mining area), surrounded by the free gold system (beyond the Cikotok Mining Concession). However, the free gold mineralization discoveries seem to be rather lower grade ores. It is concluded that, instead of seeking gold geochemical anomalies in soils, free gold and cinnabar found in pan-concentrates are the essential method to localize the low-grade type of epithermal gold mineralization in preliminary exploration stages.

## ORE TREATMENT

Since the begining of operations, the milling plant has produced about 6.9 tons of gold, 206 tons of silver, 3,726 tons of lead (concentrate), and 5,536 tons of Zn (concentrate).

The change of the ore characteristics from oxidic to sulphidic types has meant that the distribution and mineralogical composition of gold and silver in the ore has also changed. As a result the extraction recovery rate has decreased, and the reagent consumed has increased. Some modification in the milling techniques could increase the recovery, whereby 4 g/ton ore sould be successfully treated. The company has plans underway to treat ores with grades between 2 and 4 g/ton.

## CONCLUSIONS

The geological setting of the Bayah dome gives promise of a favourable environment for mineralization in a district which is intimately related to an island arc system at a convergent plate boundary.

Previously, all known mineralization was found in the old andesite domain, whereas recent exploration results reveal that prospective mineralization may also occur in sedimentary rocks.

The epithermal gold mineralization concepts reasonably fit the area, where the granodiorite, quartz diorite and dacite intrusions are considered as the heat sources for the mineralization. Fluid inclusion studies support this view. The nature of the quartz veins and the textures of the polymetallic ores suggest a multiphased mineralization. The main aspects of the mineralization model are listed in the Table 1. The free (visible) gold and cinnabar found in the pan-concentrates were an important field indication for gold mineralization, which in turn contributed to the local geochemical anomaly which decided the prospect area.

Since the high grade ore reserve at Bayah are waning, mining strategy must shift to new, lower grade exploration targets and a modified beneficiation technology will be required to extract the metals from lower grade ores, both old and new.

## ACKNOWLEDGEMENTS

We are indebted to Mr. Salman Padmanagara of DMR for his kind permission, and to Mr. Fachri Mahmud, the Chief of Techical Cooperation Division for his encouragement to present this paper in the First Workshop on Epithermal Gold Mineralization. We would also like to express our sincere gratitude to Aneka Tambang Co. Ltd., for providing additional data and facilities, to Dr. N. J. Page for his assistance, and to all our colleagues in DMR for their help during the preparation of this paper.

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## Table 1. DESCRIPTIVE MODEL OF THE CIKOTOK EPITHERMAL GOLD DEPOSITS

by Yaya Sunarya and Simpwee Soeharto

**ORE TYPE** : Epithermal gold, polymetallic quatz veins.

**DESCRIPTIVE** : Pyrite, galena, sphalerite, chalcopyrite, argentite and electrum in quartz vein.

### GEOLOGICAL ENVIRONMENT

**Rock Type** : Oligo-Miocene propylitic andesite and older carbonaceous host rocks intruded by granodiorite, quartz diorite and dacite.

**Textures** : Porphyritic, lava and breccia.

**Age Range** : Early Tertiary.

**Depositional Environment** : Calc-alkaline volcanism in epicontinent of island arc in subductive plate margin zone.

**Tectonic Setting:** Compressional E-W fold developed in sedimentary rocks and N-S tensional strike-slip faults related to the doming to form resurgent-like structures.

### DEPOSIT DESCRIPTION

**Mineralogy** : Pyrite, galena, sphalerite, chalcopyrite, argentite and electrum.

Gangue minerals are quartz, rhodochrosite, rhodonite, chlorite, sericite, calcite, kaolinite and adularia.

Secondary minerals are pyrite, malachite, bornite and limonite.

**Texture and Structure** : banded vein, open-space filling, stockworks, colloform texture and cockade structure.

**Alteration** : Regional propylitic, silicified, carbonatized, sercitized and argillized.

**Ore Control** : N-S tensional fractures. High grade ore associated with up-thrusting faults.

# MINERALOGIC, ALTERATION AND FLUID INCLUSION STUDIES OF EPITHERMAL GOLD VEINS AT THE MT. MURO PROSPECT, CENTRAL KALIMANTAN (BORNEO), INDONESIA

by
**Stuart F. Simmons[1] and Patrick R.L. Browne[1]**
**Auckland University, New Zealand**

The Mt. Muro prospect contains numerous steeply dipping, gold-bearing quartz veins that formed within an epithermal environment during mid-Tertiary calc-alkaline volcanism of Central Kalimantan (Figure I). The two centers of mineralization studied,Gunung (Mt.) Baruh and Luit, are approximately 10 km apart, and represent the upflow zones of former geothermal systems (Figure II). Gold mineralization throughout the region is structurally controlled, and grades are unevenly distributed within veins.

The Kerikil veins at Gunung Baruh are characteristic of the mineralization style and are one of the most extensively drilled targets. These vein structures trend north-northwest and extend discontinuously over a 1000 m strike along the west flank of Gunung Baruh (Figures III and IV). Host rocks consist of porphyritic andesite flows, a hypabyssal basaltic andesite intrusion, and volcanic breccias.

Primary sulfide mineralization within the Keriki veins occurred in four distinct stages related to hydrothermal brecciation and open-space filling (Figures Vand VI); the highest gold contents are associated with a hydrothermal breccia (stage II), and local occurrences of laminated quartz-sulfide veins(stage IV). Quartz is the predominant gangue mineral throughout, with subordinate adularia, calcite, and rhodochrosite. Electrum and acanthite are fine-grained (≤ 30 μm) and associated with minor disseminated pyrite, sphalerite, galena, chalcopyrite, and covellite. Bleached zones of quartz-illite-pyrite envelop the mineralized veins, but where host rock was less permeable, a weak alteration assemblage of epidote-chlorite-albite formed instead. Fluid inclusion studies (Figure VII) indicate that mineralizing solutions were dilute, ≤4.1 eq. wt. % NaCl, <4.0 wt. % $CO_2$ (Figure VIII), and ranged between 207° to 253°C. These alteration and fluid inclusion features are characteristic of deeply convecting, near-neutral-pH, alkali-chloride fluids found in active geothermal systems. Fluid inclusion and mineralogic evidence suggests that fluids were boiling under conditions which favored gold deposition; however, most gold mineralization appears restricted spatially and temporally to the timing of hydrothermal brecciation. Mineralization at Luit is similar, although exposed veins here apparently formed at greater depths and higher temperatures (238°-262°C; Figure IX); gold grades diminish sharply with depth.

During the late collapse of the geothermal system, shallow acid fluids (produced from steam condensate) descended preferentially down structures and reacted with adjacent host rocks to produce a late kaolin overprint. These same fluids also partially digested vein carbonate, adularia and rock fragments, forming enhanced secondary permeability within the vein structures. This secondary permeability was important in the development of later supergene oxidation, which locally extends to 100 m below the present surface.

Erratic supergene gold enrichment is mostly restricted to depths less than 25 m below the present surface and is closely associated with iron and manganese oxides; however, comparison of Au, Ag, Mn, Fe, and combined Cu+Pb+Zn contents between oxide and sulfide zone samples does not show significant trends. Microprobe analyses of supergene electrum indicate an average composition of 71 wt.% Au and, 29 wt.% Ag, which is very similar to the average composition of primary electrum associated with sulfides (Figure X). These compositions suggest that thiosulfate complexes in ground waters acted as transporting agents for remobilization of gold during oxidation. Gold and silver adsorption onto amorphous oxides was ultimately important for their reprecipitation; however, where steeply dipping veins transect steep terrain some gold may have been lost through dispersion into nearby soils and subsequent erosion. A three stage model summarizing main stage hydrothermal mineralization, late stage collapse of the hydrothermal system, and subsequent erosion are shown in Figure XI.

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Figure I. Map of Borneo showing the major gold prospects of Central Kalimantan, plus the salient tectonic and geologic features which formed during mid-Tertiary subduction beneath the northwest coast of the island.

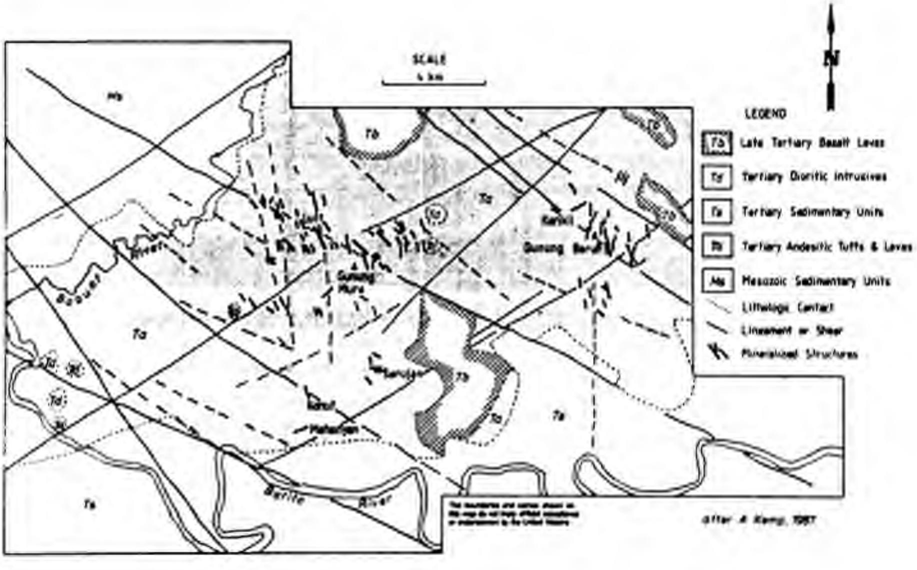


Figure II. Geologic sketch map of the Mt. Muro prospect.

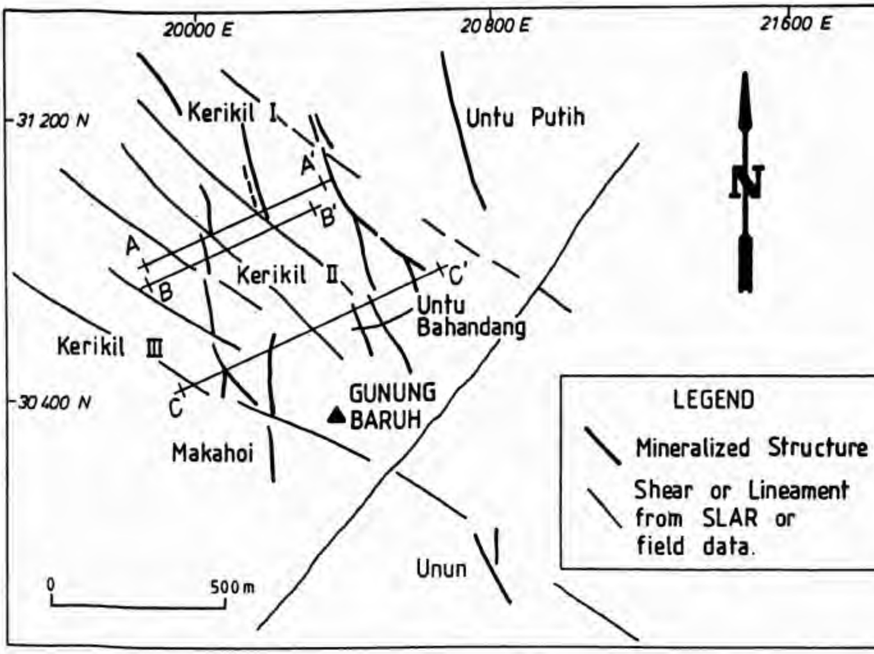
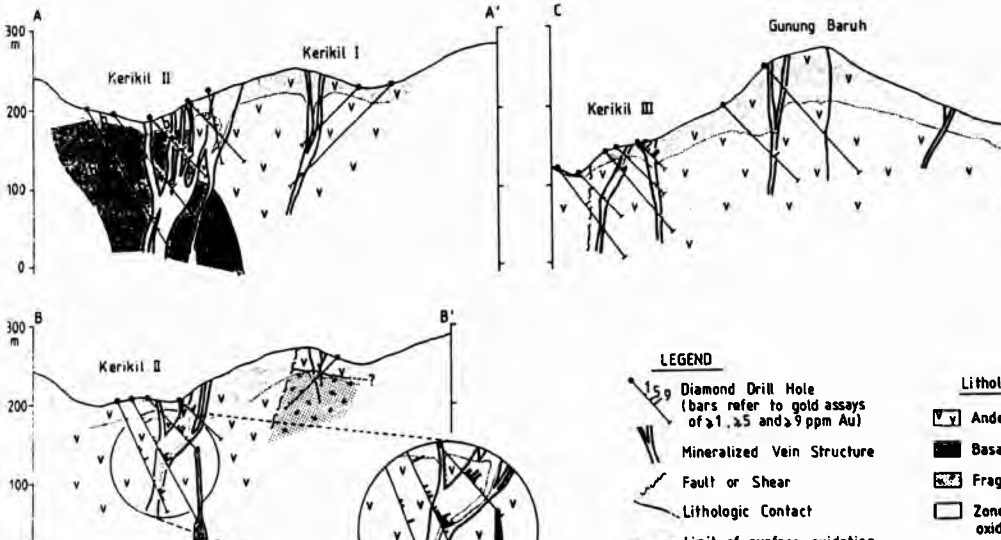


**Figure III.** Location of the Kerikil, Untu Bahandang and Untu Putih vein structures along the f
Baruh. Note position of sections A-A', B-B' and C-C' shown in Figure IV.



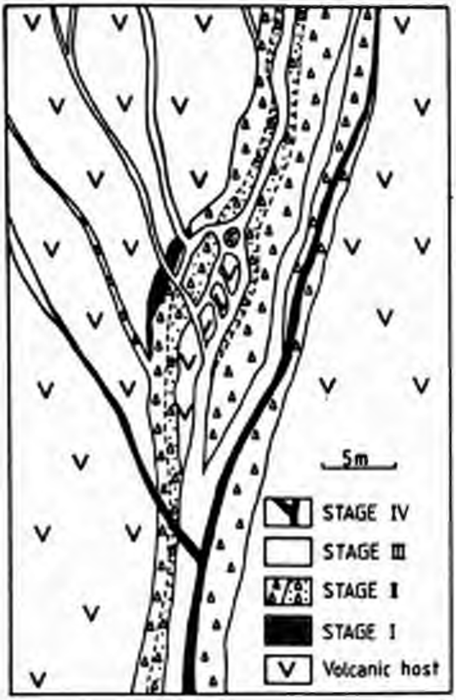


**Figure V.** Schematic diagram of a mineralized intersection from the Kerikil veins. Four crosscutting stages of mineralization are depicted and show the complex vein relationships which are characteristic of many vein intersections. Note that stage II is a polyphase breccia where triangles plus dots represent hydrothermal breccia, and triangles represent hydraulic and vein breccias.

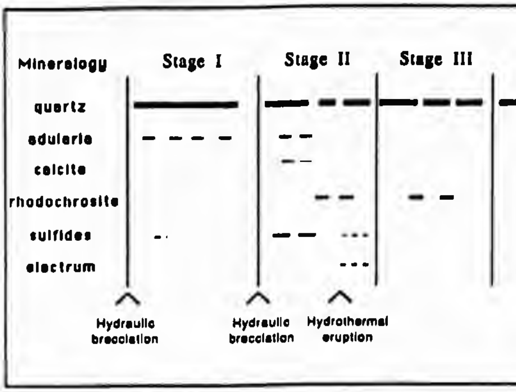


**Figure VI.** Schematic paragenesis for the Ke

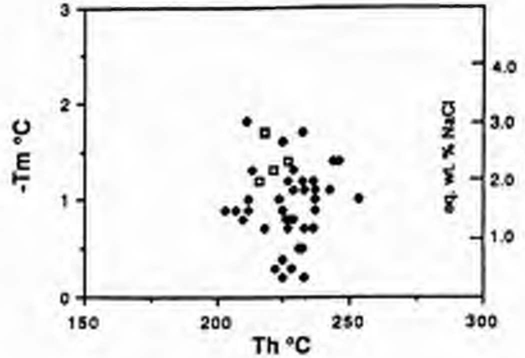
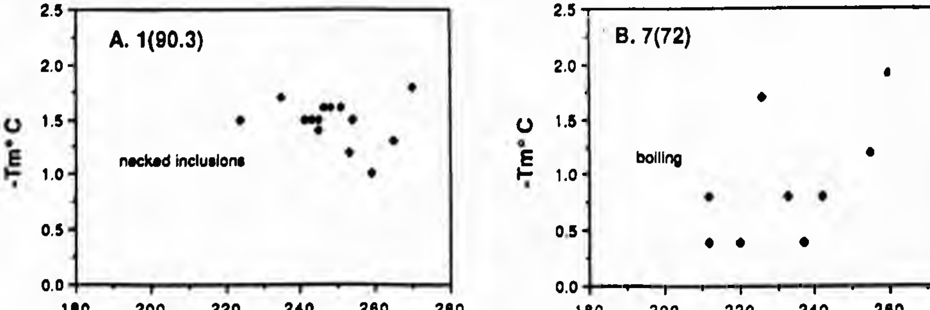


**Figure VII.** Average temperature of melting (Tm, ec
plotted versus average temperature of ho
(Th) for genetically related populations of f
from the Kerikil, Untu Bahandang an
veins.



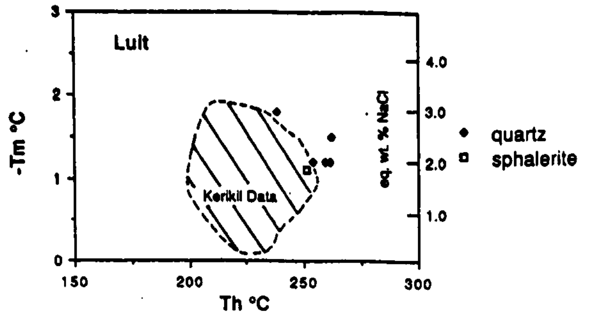


Figure IX. Average temperature of melting (Tm, eq. wt. % NaCl) plotted versus average temperature of homogenization (Th) for individual populations of fluid inclusions from Luit area veins. The region of Kerikil fluid inclusion data is shown for comparison.

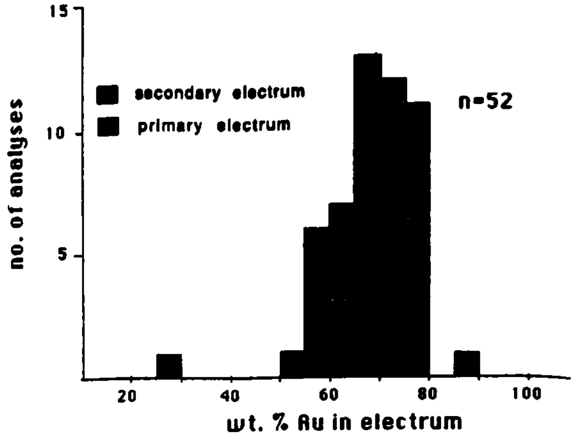
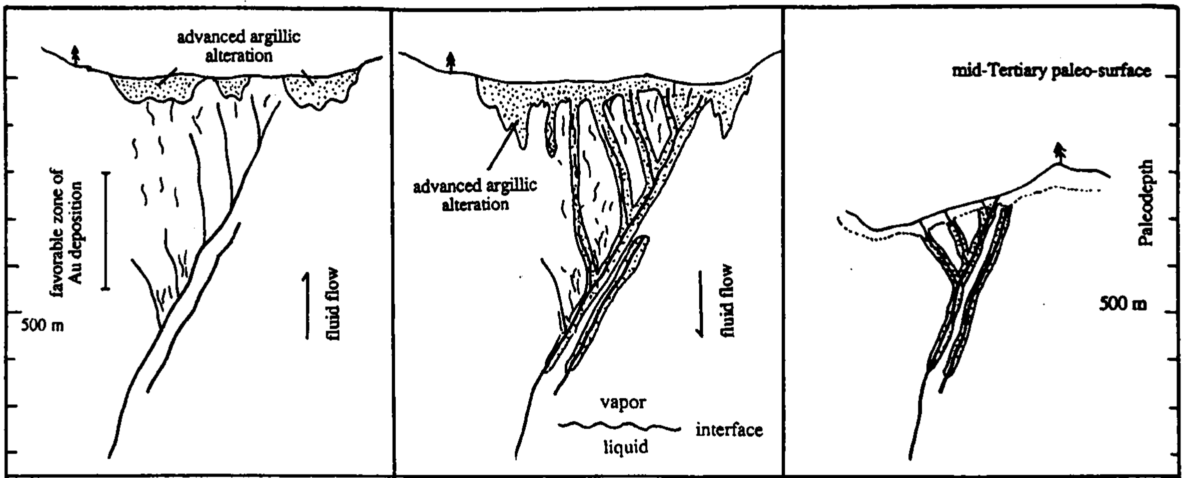


Figure X. Histogram showing the compositions of primary and secondary electrum grains determined by microprobe analysis.



Primary Mineralization

- mineralizing fluids ascend under boiling conditions and deposit precious metals in favorable zone
- quartz-illite-pyrite alteration envelopes form around permeable structures at depth
- advanced argillic alteration forms in the presence of acid fluids near the surface

Collapse of Geothermal System

- acid fluids descend down mineralized fractures and form kaolin overprint on quartz-illite-pyrite alteration
- vein carbonate and rock fragments partially digested by acid fluids and enhance permeability within veins

Weathering and Erosion - Present Day

- oxidation and supergene enrichment of gold in the near surface environment
- permeability in vein structures extends depth of oxidation locally to deeper than 50 m below the surface

Figure XI. Schematic diagram demonstrating the evolution of Gunung Baruh vein structures from primary mineralization (left) through to late stage collapse of the geothermal system (center), followed by weathering and erosion (right). The final frame depicts the present day level of erosion.

# MINERALIZATION AT THE KELLY GOLD MINE, BAGUIO DISTRICT, PHILIPPINES: FLUID INCLUSION AND WALLROCK ALTERATION STUDIES

by
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## ABSTRACT

Mineralogical and fluid inclusion studies on the gold-quartz veins at the Baco-Kelly Mine suggest the existence of two major types of hydrothermal fluids that permeated the fractures at Baco-Kelly area, each of which is characterized by distinct fluid inclusion content and alteration assemblages. These two major hydrothermal pulses included an earlier low-sulfur neutral-pH chloride-carbonate fluid which is recorded in low salinity fluid inclusions, essentially of the liquid type that homogenized in the temperature range of 175°C to 230°C, and a much later and significantly more saline high-sulfur acid fluid that overprinted earlier veins. Fluid inclusions representing the later fluid consists of liquid, gaseous and polyphase types. Liquid inclusions homogenized at a temperature range of 215°C to 270°C while polyphase inclusions record temperatures greater than 350°C. Coexisting gaseous inclusions in both liquid and polyphase types suggest boiling of the high-sulfur acid fluid at temperatures from 260°C to 385°C. These fluids formed two distinct alteration assembages as they reacted with the wallrock namely: phyllic alteration (illite + muscovite) resulting from the reaction with low-sulfur neutral-pH carbonate fluid and advanced argillic alteration (pyrophyllite + diaspore + alunite), a product of the reaction with high-sulfur acid fluid.

The precipitation of free gold and base metal sulphides (sphalerite-chalcopyrite-galena) as well as the quartz-calcite-illite veins averaging 2-3 g/t Au was initiated by the earlier low-temperature, less saline hydrothermal fluid which is responsible for the development of phyllic alteration assemblages. The overprinting high-temperature, high-salinity, boiling hydrothermal fluids carried significant amounts of metals, further enriching the gold content of certain portions of earlier veins. This later phase is also responsible for the precipitation of gold-bearing copper sulfosalts (tetrahedrite-tennantite-bornite) in some parts of the mine. Finally, the genetic affiliation of this high-sulphur type system with porphyry copper deposits permits speculation on the presence of a potential porphyry gold-copper mineralization at depth.

## INTRODUCTION

Fluid inclusions and alteration assemblages associated with epithermal gold mineralization are among the major parameters defining recent genetic models of epithermal systems. The recognition of the significant differences between many Au-Cu epithermal deposits termed "high sulphidation" (Sillitoe, 1973,1975; Wallace, 1979) and low-sulphur epithermal systems is largely based on these parameters. Distinct differences between the two systems generally reflect diversity in fluid composition.

The purpose of this paper is to chararcterize the nature of the hydrothermal fluids that once permeated the fractures at the Kelly Gold Mine of Benguet Corporation in the Baguio District, Philippines, based on fluid inclusions contained in quartz occurring with various specific assembages of alteration minerals and to relate these findings to current genetic models of epithermal mineralization.

## GEOLOGIC SETTING

The Kelly Mine area is located in Bo. Gumathdang, Itogon, Benguet Province, approximately five kilometers southeast of Baguio City (Figure I). The area lies between geographic coordinates 16° 23'-16° 24' North latitude and 120° 38'-120° 39' East longitude. The Kelly Mine occupies the northern half of a complex of gold vein systems and lies adjacent to the Baco (Atok) Mine which is also operated by Benguet Corporation. Towards the north lies the Baguio Gold Mine while the Antamok Mine is situtated just east of the Kelly Mine area.

In the Kelly-Baco Mine area, a thick sequence of early Middle Miocene porphyritic andesite-dacite volcanic flows (Zigzag Formation/Middle-Upper Keratophyre Series) is capped by the Lower Miocene Klondyke Forma-

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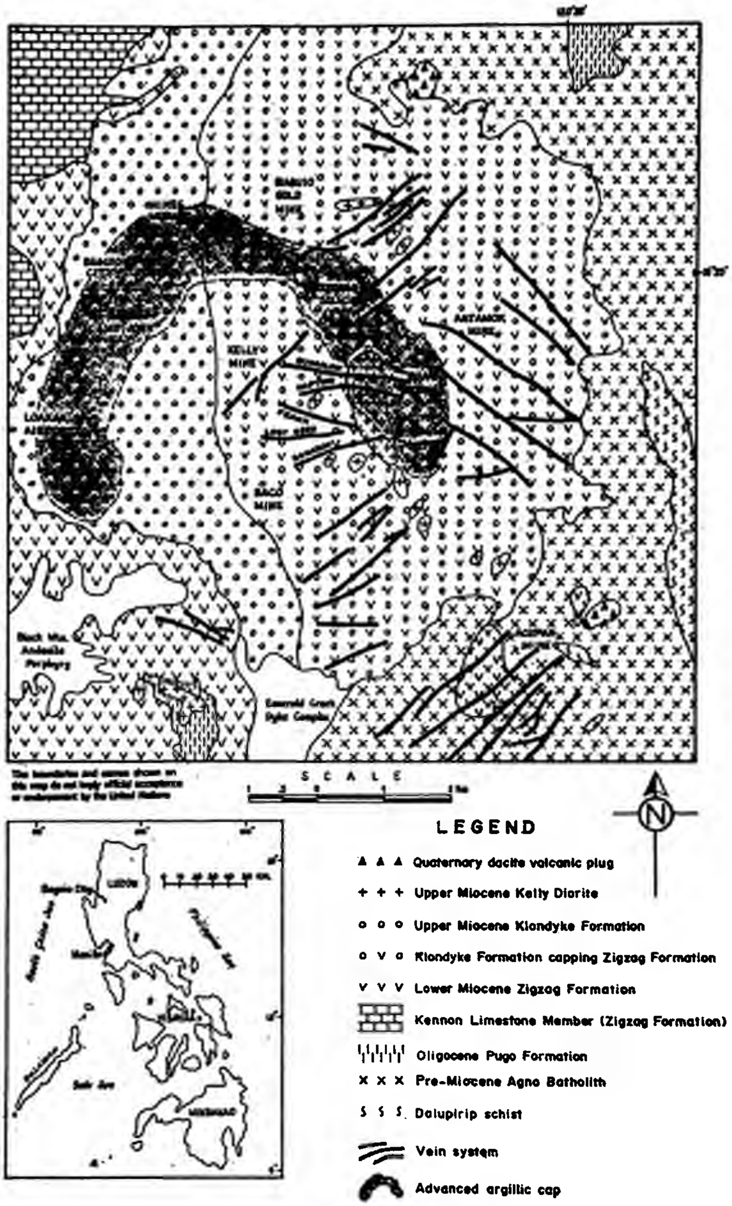


**Figure I.** Generalized geologic map of the Baguio District, Phillippines (modified from UNDP, 1987, and Benguet Corporation File).

tion consisting of conglomerates and pyroclastic deposits. The andesite component to the volcanic flow is typically porphyritic with large andesine prisms set in a cryptofelsitic to felty matrix. The rock consists of 38-70% plagioclase; 3-20% hornblende (altered to chlorite-epidote and/or tremolite-actinolite); 3-8% secondary quartz; 3-5% opaques (pyrite) with traces of sphene, leucoxene, ilmenite and rutile. Regional metamorphism is manifested by granulation, resorption, embayment, and intense propylitic alteration of the volcanic units. Late Miocene igneous activity is represented by the emplacement of the Kelly Diorite, a north-trending hypidiomorphic granular pluton that intruded both the Zigzag Formation as well as the Klondyke Formation (UNDP, 1987). The typical composition of Kelly Diorite is 52-85% plagioclase; 7-32% hornblende (altered to tremolite-actinolite, epidote and chlorite); 1-12% secondary quartz; 4-7% opaques (primarily pyrite) and traces of sphene, rutile, leucoxene and apatite.

The Kelly Diorite and the andesitic volcanic flows of the Zigzag Formation are the primary hosts of the gold-sulphide vein mineralization in the Kelly-Baco Mine area.

## HYDROTHERMAL WALLROCK ALTERATION

The wallrocks adjacent to the mineralized veins at Kelly have suffered varying degrees of alteration. The general types of hydrothermal wallrock alteration recognizable within the Kelly Mine and its immediate environs consist of low temperature and high temperature propylitic, potassic, illitic-phyllic and argillic types, and low temperature and high temperature advanced argillic alteration (Figures II and III).

At Kelly Mine, propylitic alteration, which may be originally related to deep-seated regional metamorphism, is still pervasive at depth, possibly even below the lowest level of the mine. Propylitization is represented by the breakdown of plagioclase feldspar and hornblende and their replacement by chlorite, epidote and tremolite-actinolite. Propylitized rocks are traversed by later gypsum, anhydrite, and calcite veinlets.

A major stage of mineralization and alteration is defined by quartz-calcite-pyrite veins with illitic-phyllic

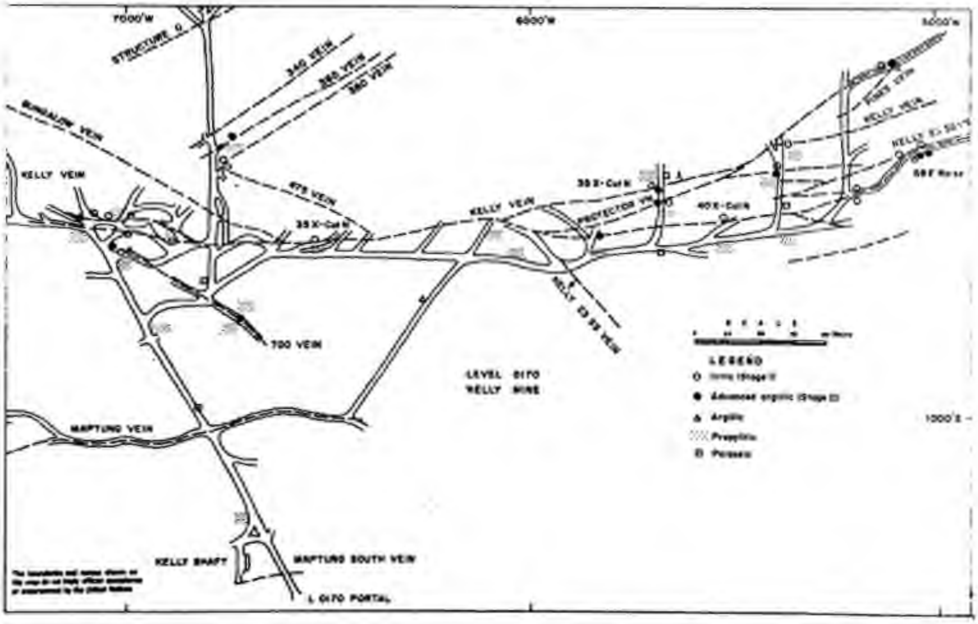
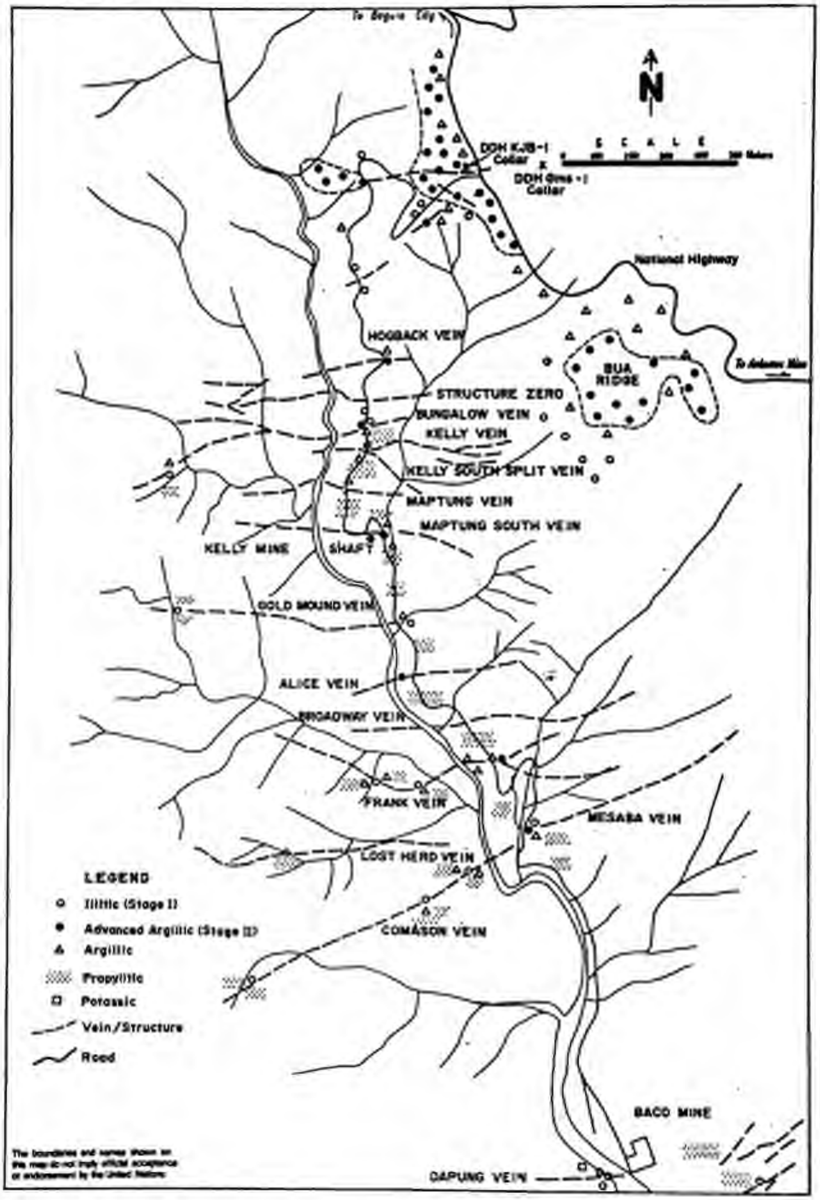


Figure II. Underground schematic alteration map of the Kelly Mine based on petrographic and XRD analyses.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

**Figure III.** Simplified surface alteration map along the Kelly-Baco road and vicinity based on combined petrographic and XRD analyses of samples.

alteration envelopes. Illitic-phyllic alteration in the Kelly Mine is defined by significant amounts of illite (or its crystalline equivalent, muscovite), as replacement of plagioclase and as interspersed grains with chlorite after hornblende. It generally overlies the propylitic horizon underground. In surface exposures, it becomes more pervasive towards the south (Figure III). Widespread illitic-phyllic alteration is presently observable along the Kelly Road up to the national highway to Baguio and around Bua Ridge (Figure III). Not all of this pervasive phyllic alteration may be related to the generation of quartz-calcite-pyrite veins, however, especially in cases where the veins are in sharp contact with propylitized host rocks below and within the phyllic zone. In the propylitic zone, illitic wallrock alteration, when present, is confined to the immediate hanging wall and footwall host rocks and extends only 10 cm to 1 m into the walls (Villones et al., 1987). It is also interesting to note that the major vein systems generally characterized by the occurence of illitic alteration also show portions with incompatible advanced argillic alteration in smaller stringers and wallrock (Figures IVand V).

Both low-temperature and high-temperature advanced argillic alterations are present in Kelly Mine. The low-temperature subtype, being more widespread, exends towards the vicinity of the mine, i.e. in Mines View Park, Tuding Silica Pit, Loakan Airport and near Camp John Hay. It also occurs at the present highest erosional surface in the mine. The alteration assemblage consists of quartz-alunite-kaolinite-iron oxide. Secondary acid sulphate deposition (acid leaching) from circulating groundwater may be responsible for the pervasive and widespread occurrence of this particular assemblage.

The high-temperature (primary) advanced argillic alteration is characterized by the presence of pyrophyllite + diaspore + alunite + tourmaline. It generally follows the same major structures containing the quartz-calcite veins with illitic alteration. There are even cases where the two types of alteration coexist at the same sampling point (Figures IV and V). In the Kelly 35 South Split Vein, for instance (Figure VI), this incompatibility is manifested by the common occurrence of illitic-phyllic alteration in the major vein and advanced argillic alteration in the immediate wallrock. This may be a result of a later introduction of sulfate-rich acid fluids along the borders of an earlier quartz-illite vein and hence implies the overprinting of primary acid-sulphate assemblage over the earlier neutral chloride assemblage. Similarly, the ascent of hot primary acid-sulphate fluids towards a shallower setting is also implied by the local occurrence of primary advanced argillic alteration zones that cut through the widespread acid-leached horizons.

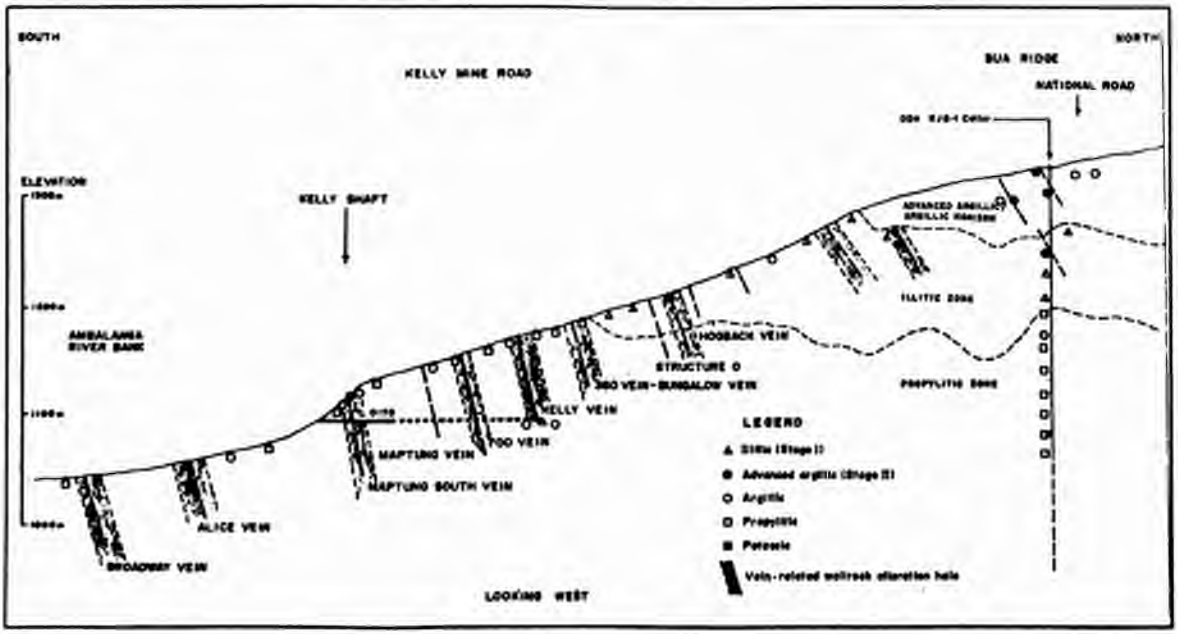


**Figure IV.** **Schematic cross-section showing vertical hydrothermal alteration zonation and vein systems at Kelly Mine.**

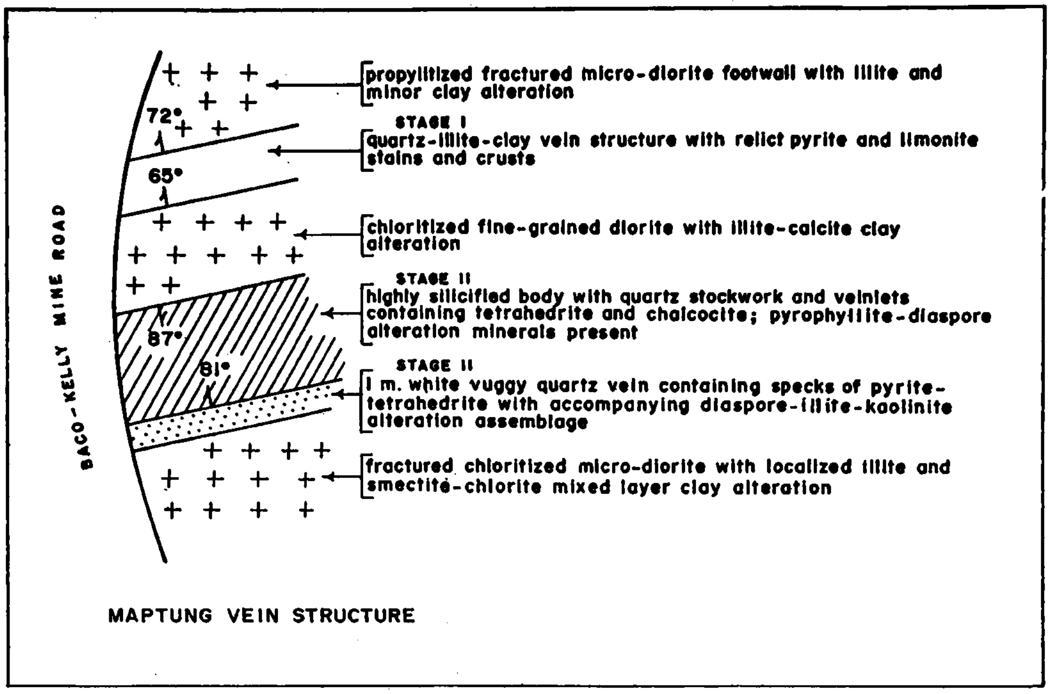


**Figure V.** **Schematic plan of vein and wallrock alteration of a surface outcrop of Maptung Vein, Kelly Mine, showing the occurrence of both illitic and advanced argillic altered quartz veins (from detailed surface paragenetic mapping of Benguet Corp., 1987).**

The argillic assemplages are dominated by smectite, mixed layer clays, kaolinite and allophane. The zone of argillic alteration immediately adjacent to the veins is relatively wide in surface exposures, extending from less than a meter to 5 meters and becoming narrower underground. From the vein, argillic alteration grades outward to phyllic and propylitic alterations and also envelopes the advanced argillic assemblage, if the latter is present. The development of argillic alteration could have been enhanced by a low temperature degradation of mineral assemblages due to collapse of a hydrothermal system and later weathering/oxidation that resulted in the widespread and pervasive argillic and secondary advanced argillic zones especially in surface exposures along Bua Ridge towards Mines View Park in Baguio City (Figure III).

Potassic alteration in the Kelly Mine occurs sporadically and is characterized by the presence of incipient secondary biotite after tremolite-actinolite of the propylitized rocks. Patchy occurrences are observed in the lowest underground level. It is more developed towards the south especially in the Maptung Vein, occurring even in surface exposures. The occurence of potassic alteration may mark the transition into a deeper environment of deposition and may indicate a previous heat source that intruded the country rocks during Miocene time, possibly a magmatic body at depth.

## MINERALIZATION

Precious and base-metal sulphide-sulphosalt mineralization in the Kelly Mine is confined to parallel easterly-trending quartz veins. The major vein systems are: (a) Kelly Group, including Main Kelly Vein, Bungalow Vein, Kelly 35 South Split Vein, and Hogback Vein; (b) Maptung Vein; (c) Alice Vein; (d) Comason Vein; and (e) Dapung Vein (Figures II, III and IV). The veins range in width from 0.5 to 2 m and consist of quartz, calcite, sulphide/sulphosalt minerals and free gold. At least two texturally different varieties of quartz can be recognized, each belonging to a particular stage of mineralization and alteration. The first type is contained in tight quartz-calcite-pyrite veins with associated illitic-phyllic alteration. Main vein structures are dominantly filled by this type of quartz. Quartz in this veining episode is typically microcrystalline and turbid owing to incipient rutile disseminations and associated illitic alteration.

Coarser, clearer and more transparent quartz aggregates belong to another recognizable episode and are present in some portions of the Kelly 35 South Split and Comason Veins. These vuggy varieties, which are conspicuously not associated with the usual illitic alteration, are intergrown with copper sulphosalts/sulphides such as tetrahedrite-tennantite, bornite, and free gold. The second veining episode carrying these vuggy quartz crystals is confined to stringers and relatively smaller veins following the main vein structures characterized by the first-stage quartz (Figures V and VI). This later episode is related to high-temperature advanced argillic alteration. The vuggy nature of this quartz suggests deposition at a shallower depth under dominantly hydrostatic pressure after much of the overburden present during the formation of the earlier quartz-illite veins had been eroded.

The ore minerals consist of pyrite, sphalerite, galena, chalcopyrite, bornite, tetrahedrite-tennantite, arsenopyrite and minor magnetite. Free gold is associated with these minerals. Gold values normally assay 2-7 g/t Au. Local enrichment yields values of 8-18 g/t Au.

Pyrite is the dominant mineral, occurring as anhedral to subhedral aggregates or, less frequently, as rectangular disseminations. It tends to be idiomorphic along voids. In the vuggy quartz veins, gold occurs as medium-grained free gold in close association with bornite. The paragenetic sequence of mineralization is summerized in Figure VII. Pyrite is replaced by anhedral galena commonly occuring along its extremeties. Galena is in turn fringed by sphalerite. Pale yellow exsolution blebs of chalcopyrite are enclosed in spharlerite. Late chalcopyrite also fringes sphalerite and bornite. Copper sulphosalts (tetrahedrite-tennantite) occur as continuous irregular masses masked by abundant lamellar to minute micrographic exsolution blebs of bornite. Spicules of free gold occur in fractures of bornite crystals. Chalcopyrite occurs as intricate networks in fractured pyrite. In bornite it occurs as exsolutions arranged in triangular sagenitic pattern and as later stringers that invade and fringe bornite crystals. Covellite after chalcopyrite and chalcocite after bornite represent supergene alteration and enrichment which have affected the hypogene assemblage to some extent.

## FLUID INCLUSIONS

Five hundred and eleven fluid inclusions in quartz representing two stages of mineralization and alteration were analyzed by heating and freezing runs. The results are summarized in Figures VIII and IX. In the microcrystalline

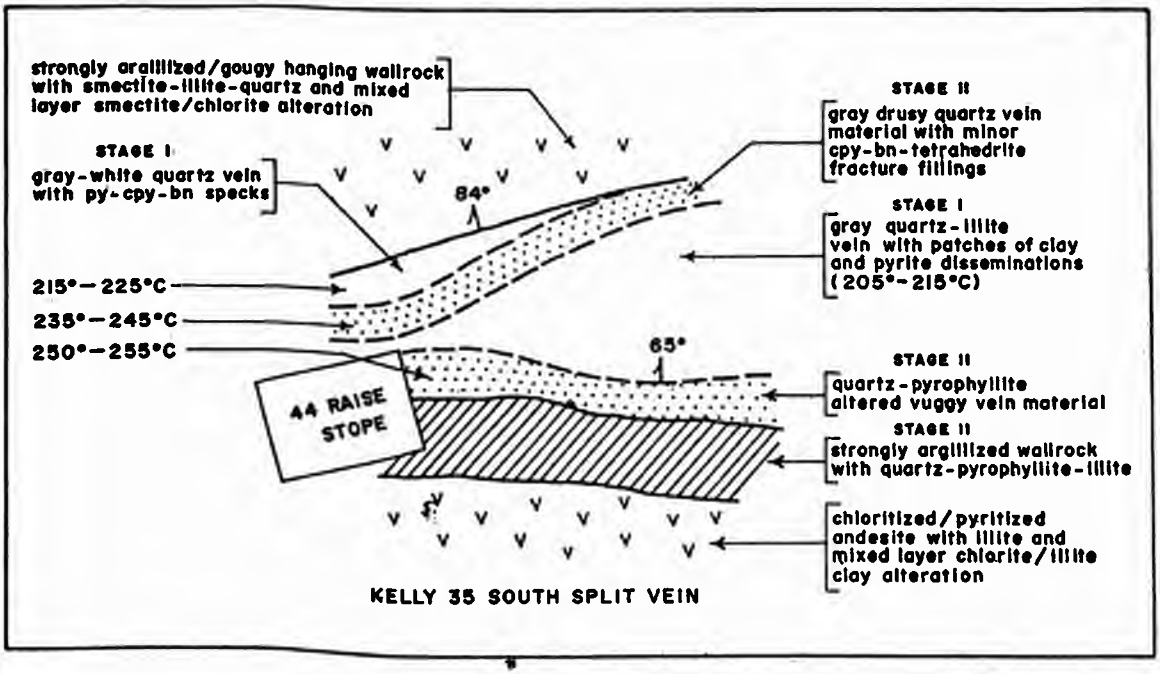


**Figure VI.** Schematic plan of vein and wallrock alteration of Kelly 35 SS Vein along 9th Floor, 44 Raise/Stope, L 0170, of Kelly Mine, showing typical overprinting of advanced argillic-altered veins (230°C-270°C) on earlier quartz-illite vein structures (190°C-235°C) (From detailed underground paragenetic mapping of Benguet Corporation, 1987).

quartz, abundant two-phase fluid inclusions which homogenize into liquid upon heating, are observed. These liquid inclusions are very minute, ranging in size from 6 to 35 microns, usually semi-negative to negative, and are aligned parallel to visible growth zones in quartz. They occur in clusters or as solitary inclusions. The vuggy, more transparent quartz aggregates which apparently belong to a later veining episode characteristically contain coexisting liquid, vapour, and polyphase inclusions that homogenize over a wide temperature range. Polyphase inclusions contain daughter crystals of halite (NaCl), sylvite (KCl) or hematite ($Fe_2O_3$). This particular fluid inclusion assemblage is relatively abundant in the Kelly 35 South Split and Comason Veins where it is observed in quartz veinlets and stringers that invade and follow the same major vein structures. In the Comason Vein, three samples were found to consist of coexisting liquid, gaseous, and polyphase inclusions.

## HEATING RUNS

Figure VIII presents the homogenization temperatures of fluid inclusions of the two recognizable episodes of quartz deposition, mineralization and alteration. The composite data show the presence of at least four populations which can be significantly related to the distinction between types of inclusions and episodes of quartz deposition in the Kelly Mine.

The first population is a well-represented normal population ranging in temperature from 170°C to 230°C. These values represent a minimum-temperature range estimation, as no evidence of boiling was found in this first set of inclusions, and hence the temperature estimation has to be corrected due for the effect of pressure. Assuming that the maximum thickness of the overburden during the time of mineralization, based on stratigraphic reconstruction, was not over 900 meters which is the thickness of the Klondyke Formation (UNDP, 1987), then the maximum necessary pressure correction to be added to the homogenization temperature readings should not be over 10°C (Potter, 1977). This correction is relatively minor, and therefore the homogenization temperature readings are quite close to the trapping temperature. These data and these inclusions represent the two-phase liquid type which is present in quartz associated with illitic-phyllic alteration and the first-stage base metal sulphide/gold deposition.

The second population, which also shows a more or less mormal distribution, records a tempeature range of between 215°C to 285°C. This population represents liquid inclusions present in the later-stage quartz associated

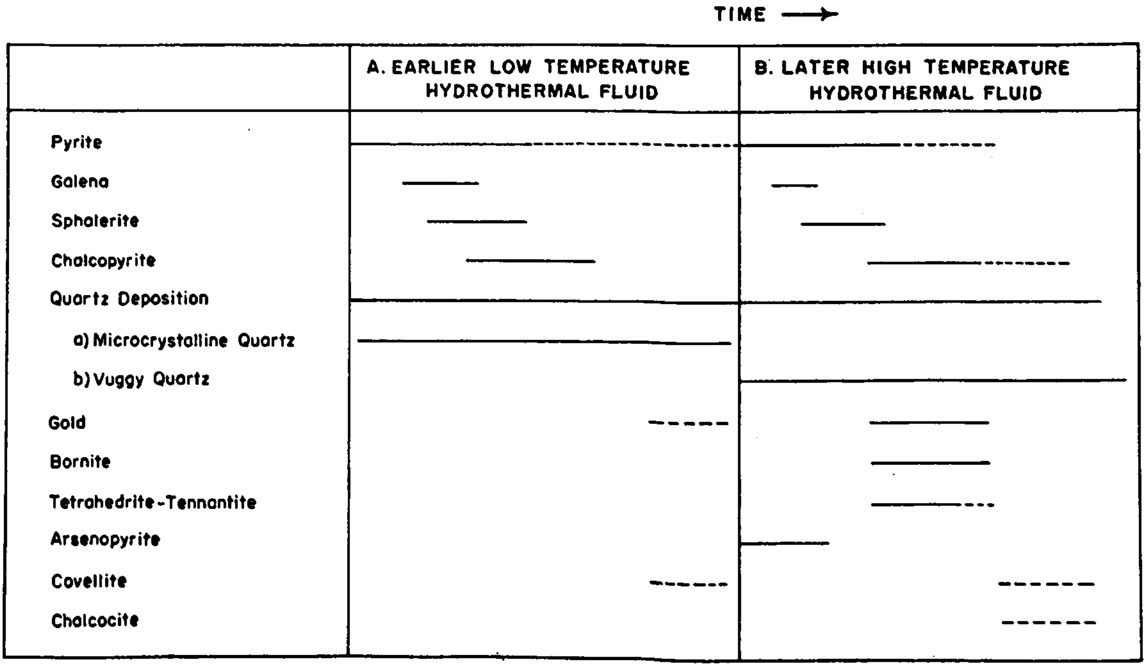


Figure VII. Deduced paragenetic sequence of the Kelly mineralization.

with high-temperature advanced argillic alteration, base metal sulphides/sulphosalts and secondary gold deposition. Coexisting gaseous and polyphase inclusions, often found to occur with the liquid inclusions of this second population, are represented in the last two sub-populations in the histogram. Polyphase inclusions homogenize at temperatures greater than 350°C. The temperature range of salt disappearance is from 305°C to 410°C for NaCl and from 275°C to 295°C for KCl, indicating a high salinity fluid. The salinity based on salt dissolution is in the range of 38.6 to 46.9 weight per cent NaCl equivalent. Boiling of this latter fluid is manifested by gas-rich inclusions homogenizing at temperatures of 260°C to 385°C. Assuming boiling conditions and a dominantly hydrostatic confining pressure (as indicated by the vuggy nature of the quartz veins) the depth from the surface during quartz deposition and mineralization can be estimated at about 700 meters (Haas, 1971). Further, if boiling has indeed occurred during the trapping of the fluid, then the vapour pressure of the solution should have been equal to the confining pressure at the time of trapping and therefore pressure correction need not be applied to the homogenization temperature readings. That is, the homogenization temperature of the second stage quartz may be regarded as the trapping temperature.

Figure IX shows the homogenization temperature plots at various levels of the Kelly Mine over a vertical distance of 400 meters. The average homogenization temperature in each level is more or less consistent with elevation such that the high temperature average defines the lowest elevation and the low temperature average characterizes the surface elevation. The high-temperature inclusions related to primary advanced argillic alteration are notably present even at the lowest mine elevation, indicating the presence of acid-sulphate fluids at deeper levels.

## FREEZING RUNS

Salinities of liquid inclusions were determined by ice melting. All inclusions studied underwent supercooling to temperatures of -60°C to-80°C prior to ice formation. Freezing runs were conducted in quartz belonging to both first and second veining episodes. The overall range of ice-melting temperatures (except one sample from the Comason Vein) corresponds to the same low-salinity range of less than 5 wt.% NaCl equivalent, implying very dilute fluids. There appear to be two groups of ice-melting temperatures within this range (Figure X). The two groups may be related to the differences in vein samples and types of quartz analyzed. Quartz associated with the first veining episode characteristically contains inclusions with ice-melting temperatures of -0.2 to -0.3°C. In vuggy quartz of the second veining episode, there are liquid inclusions with ice melting temperatures of -0.3°C (quartz intergrown with tetrahedrite-tennantite) and there are those with a relatively higher ice-melting temperature range from -1.4°C to -2.2°C.

Figure X is a plot of homogenization temperatures versus salinities/ice-melting temperatures. Three groups of inclusions are apparent, namely : (a) a high-temperature, high-salinity group of polyphase inclusions beloning to

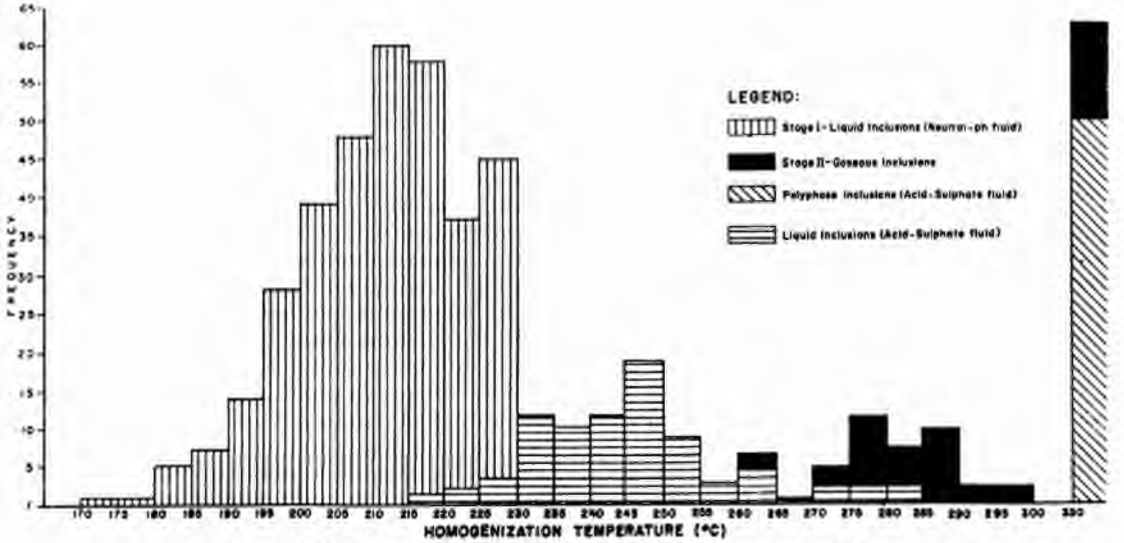


Figure VIII. Filling temperatures of quartz veins from Kelly Mine.

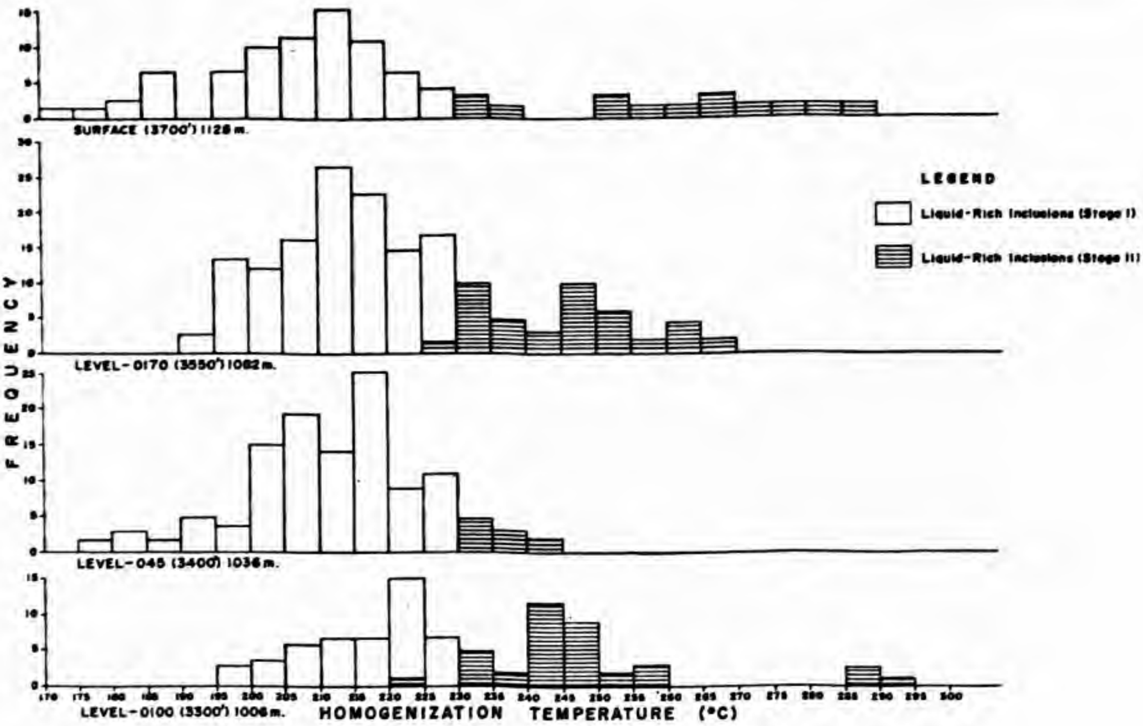


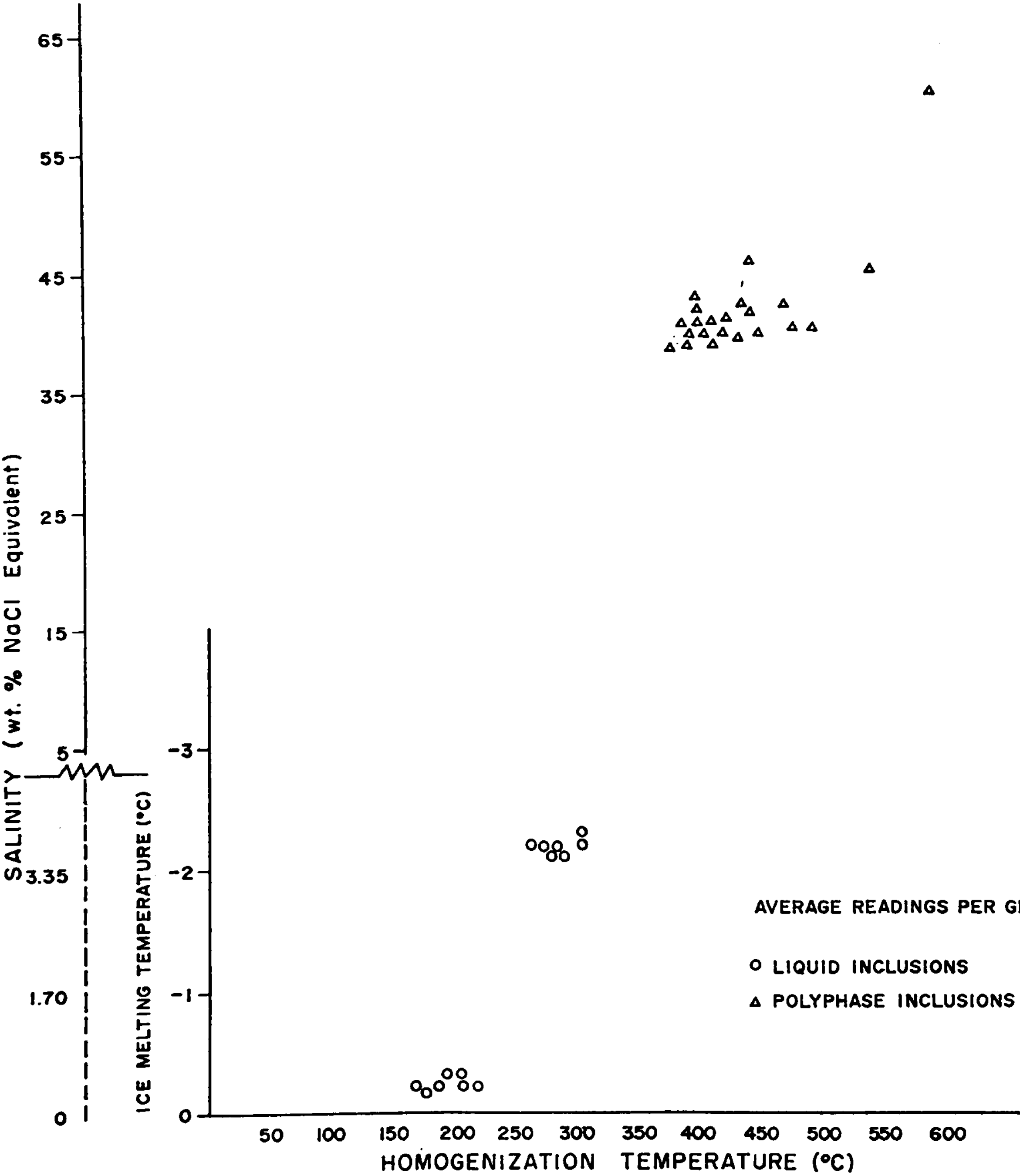
**Figure IX. Filling temperature of quartz vein at various levels of Kelly Mine.**

the second veining episode, (b) a moderately high-temperature, low-salinity group of liquid inclusions belonging also to the second veining episode, and (c) a low-temperature, low-salinity group of liquid inclusions of the first veining episode.

## SUMMARY AND CONCLUSION

Fluid inclusion and wallrock alteration data indicate that there were at least two very distinct fluid types present during mineralization at the Kelly Mine : (1) an earlier low-temperature, low-salinity near-neutral pH fluid responsible for the deposition of epithermal gold/sulphide-bearing quartz veins at temperatures from 170°C to 230°C with accompanying illitic-phyllic alteration, and (2) a much later, high-temperature, more saline, acid hydrothermal fluid that partially transected and overprinted the earlier epithermal mineralization, depositing base metal sulphide/sulphosalts and free gold, with accompanying high-temperature advanced argillic wallrock alteration. Deposition temperatures of the latter fluid range from 215°C to more than 250°C.

The earlier quartz-calcite-illite veins with low salinity liquid inclusions and associated neutral-pH chloride-carbonate fluid alteration type may have been evolved from an originally low-sulphur type hydrothermal fluid, i.e. diluted by meteoric waters as has been observed in a majority of the gold deposits in western Pacific island arcs (Sillitoe, 1988). Fluid circulation and deposition of epithermal gold-sulphide bearing quartz veins were made possible by a heat source generated by Pliocene-Quaternary intrusive bodies at depth. The later hydrothermal fluid, on the other hand, is markedly different in chemical composition. The generation of a highly saline fluid such as this may only be possible by: (a) direct exsolution from underlying magmas, (b) magmatic gas contamination of circulating meteoric waters in hypogene environments, or (c) by boiling of less saline fluids in a hypogene system. The last mechanism would require the supply of a large amount of heat in order to volatilize the less saline water and produce a fluid with a minimum salinity of 40 weight percent NaCl equivalent (Ahmad and Rose. 1980). In all three mechanisms, a close relationship of the high-salinity fluid to magma is required, either as a source of fluid itself or as a nearby source of heat or high-temperature vapours.


SALINITY (wt. % NaCl Equivalent)
65
55
45
35
25
15
5
3.35
1.70
0
ICE MELTING TEMPERATURE (°C)
-3
-2
-1
0
50
100
150
200
250
300
350
400
450
500
550
600
HOMOGENIZATION TEMPERATURE (°C)
AVERAGE READINGS PER G
○ LIQUID INCLUSIONS
△ POLYPHASE INCLUSIONS

Also, in all three cases, a genetic relationship with a porphyry copper-gold deposit at depth is implied (Sillitoe, 1983, 1985). The formation of acid-sulphate plumes from descending acid fluids (UNDP, 1987) seems unlikely to produce a fluid with a salinity of a high as 47 weight per cent NaCl equivalent. The low-salinity liquid inclusions associated with the second veining episode may well represent a dilute equivalent of this fluid, a product of mixing with circulating ground water. Similar types of inclusions have been reported by Balce (1987) in the Lepanto Mine, Mankayan Mountain Province, Philippines, a porphyry-related high sulphidation system. Isotopic studies could shed more light on the nature of these two fluids at the Kelly Mine.

The two major hydrothermal pulses at Kelly both deposited gold and base metal sulphide/sulphosalts. The earlier quartz-calcite-illite veins deposited sphalerite, chalcopyrite, galena and free gold (2-5 g/t) while the later acid fluids preipitated smaller veins carrying copper sulphosalts (tetraheadrite-tennantite) and bornite with associated free gold. The overprinting by the later acid fluids may have appreciably enriched the gold content to as much as 7 to 18 g/t Au.

The high-salinity, high-temperature acid fluid may be directly or indirectly related to a porphyry gold-copper mineralization at depth below Kelly or proximal to its downward projection. The patchy potassic alteration at the deeper levels, which is more discernible in the southern part of the area, may indicate the direction towards the said source. It may also be possible, however, that this inferred southward source represents an older system distinct from that which generated the hydrothermal system at Kelly. The polyphase, gaseous, and liquid inclusions in the Comason Vein, several killometers south of the Main Kelly Vein, may possibly be remnants of this old hydrothermal system.

## ACKNOWLEDGMENTS

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# GEOLOGY AND EPITHERMAL GOLD MINERALIZATION OF THE CHUNGM AREA IN THE SOUTHEAST PART OF THE REPUBLIC OF KORE

by
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## ABSTRACT

The Tongyoung epithermal gold deposits and the Mireugdo epithermal volcanogenic hydrothermal deposits are well-known epithermal gold mineralizations in the Republic of Korea.

The Tongyoung epithermal gold deposits are embedded in late Cretaceous andesite and andesitic pyroclasitcs, which are related to a quartz porphyry intrusion. There are four major mineralization stages, namely Stages I, II, III and IV marked by tectonic breaks, and Stages II can be further divided into Stages IIA and IIB due to local tectonic breaks. In the mineralization Stages I, pyrite is associated with chalcopyrite, sphalerite, galena, argentite and gold-silver bearing minerals of Au-Ag-Te-Sb-S system.

In mineralization Stage IIA, rhodochrosite, rhodonite and calcite were crystallized. In the Stage IIB, so-called "Ginguro", silver-bearing sphalerite and calcite were formed. In the mineralization Stage III, barren quartz, calcite and rhodonite were formed, and in the last stage, Stage IV, barren calcite and ankeritic rhodochrosite were formed.

The Mireugdo alteration zone has epithermal volcanogenic-hydrothermal deposits which are both disseminated and veinlet type of sulfides in andesitic lapilli tuff with some rhyolitic tuff in a zone of 300 m width and 1 km length of alteration. These deposits are not yet prospected in detail.

## A. TONGYOUNG DEPOSITS

The Tongyoung gold mine, or
epithermal gold deposits in the cou
1920. The ore deposits are embedde
andesite and andesitic pyroclasitcs, w
quartz porphyry intrusion. The Ton
contain rhodochrosite as a gangue m
common in the other gold mines. Thi
to 150 tonnes of crude ore (Au 8.4g/t,
The geology and ore deposits of th
investigated by Kato (1923), Park (19
(1988), among others.

The Mireugdo alteration zo
volcanogenic-hydrothermal deposits
nated and veinlet-type sulfides in a
with some parts of rhyolitic tuff, 300
in length (alteration zone). This depo
and not workable at this moment. Th
zation and drilling of this alteration
by Hwang and Kim (1988).

### General Geology

Geology of the mine area is
ceous andesite, lapilli tuff andesite, t
crate, sandstone and shale, which ar
Cretaceous quartz porphyry.

The tuffaceous conglomerate,
belongs to the Cretaceous Jangyeong
strikes N40°-60° W and dips 15°-20°

The andesites are tinged with
Phenocrysts of the rocks commonly c
and pyroxene, and the matrix is of l

an epithermal gold style ore deposit. The strike of ore veins is N45°-60°W and they dip 70°-85° south-westward and 75°-85° north-eastwards. The veins are 1.5-2m width, 320m depth and about 800m in length.

The base-metal sulfides are pyrite, chalcopyrite, arsenopyrite, pyrrhotite, sphalerite, galena and argentite.

The Au-Ag-Sb-bearing sulfides are hessite, Ag-bearing tetrahedrite, pyrargyrite, argentite-acanthite and electrum.

The gangue minerals are quartz, rhodochrosite, rhodonite, manganocalcite, calcite and ankeritic rhodochrosite.

## Mineralization Stages

The ore deposits were formed through four major mineralization stages, namely Stages I, II (A and B), III and IV, which are classified according to the tectonic breaks as seen by trensecting, brecciating, crushing and intersecting relationships.

*Stage I :*

Quartz, pyrite and chalcopyrite are precipitated in this Stage I; quartz is white and milky-white color, penetrated in and along the fractures in the country rock. A rhythmical band form of chalcedony is seen.

The base-metal sulfides are sphalerite, galena, arsenopyrite, pyrrhotite and argentite. The Au-Ag bearing minerals are electrum, hessite, pyrargyrite, Ag-bearing tetrahedrite and argentite-acanthite.

The ore veins of Stage I are cut or penetrated by manganese ore veins (II A), Pb-Zn-quartz veins (II B) and calcite veins (III and IV).

*Stage II:*

Ag-bearing ore veins which were formed during mineralization Stage II are worthy of development economically.

Rhodochrosite, rhodonite and so-called "Ginguro" were formed in Stage II. "Ginguro" means sphalerite and galena associated with pyrite, chalcopyrite, Ag-bearing tetrahedrite and argentite. Rhodochrosite shows banded

ore minerals but has cut the ore veins of S
II, and also filled along the boundary bet
Stage II.

*Stage IV:*

Calcite and ankeritic rhodochrosite v
in Stage IV, and calcite veins of banded t
cutting the veins of Stage I and Stage II.

## Minerals

*(A) Base-metal sulfides*

(1) Sphalerite

Sphalerite is associated with
chalcopyrite and pyrrhotite in Stages I an
pyrite blebs were formed whithin sphale
tion or reaction of copper in FeS solution

(2) Galena

Galena has replaced sphalerite,
quartz and country rock, and also is asso
bearing tetrahedrite.

(3) Arsenopyrite

Arsenopyrite was formed during
grained massive form and has included
galena.

(4) Pyrite

Primary cataclastic pyrite is intergrov
and sphalerite. Fine-grained pyrite is
quartz of Stage II and also appears as a th

(5) Chalcopyrite

Chalcopyrite was formed in Sta
disseminated or bleb-type in sphalerite, and a
with pyrite and galena.

*(B) Manganese minerals*

Manganese minerals were formed

microscope rhodochrosite is seen to have been replaced by quartz which is associated with sphalerite and galena.

(2) Manganocalcite

Under the microscope manganocalcite is shown to be associated with rhodochrosite and replaced by quartz.

(3) Rhodonite

Rhodonite is associated with rhodochrosite in Stage II as relatively coarse grains with needle-like, colloform and zonal textures. The rhodonite shows chemical zoning, in which Mn and Ca compositions change from center to margin in colloform texture rhodonite, while Ca composition was changed from center to margin in zonal texture rhodonite.

*(C) Au-Ag minerals*

The Au-Ag minerals were formed in mineralization Stages I and II; in Stage I electrum is associated with hessite, Ag-bearing terahedrite, pyrargyrite and argentite-acanthite. In Stage II, so- called "Ginguro", Pb-Zn minerals of argentite and Ag-bearing tetrahedrite were crystallized in and along the fissures.

(1) Electrum

The electrum was formed in mineralization Stage I in paragenetic relation with galena and sphalerite, as crystals of fine grain size (less than 5μm) included in pyrite and chalcopyrite.

The composition of electrum (Ag 50.98-64.05 atomic per cent and the ratio of Au/Ag in the 1.44-1.79 range) coincides with the epithermal gold mineralization types of

(5) Argentite-Ac

Argentite-aca
has infilled chalcop

**Chemical Composi**

Sphalerite wa
I and II, and assoc
chemical compositi
FeS in Stage I and 2.
mole per cent MnS i
II, rather a high MnS
MnS is less than 1
mineralization (Shik
had generally very

**Fluid Inclusion**

In the minera
tains fluid inclusions
Fluid inclusions are
fluid. The filling tem
Tongyoung mine w
(equivalent to NaCl)
1.2-3.8 wt per cent;
cent range.

The relationsh
and salinity of fluid
higher homogenizat
the increasing high

**Conclusion**

Of the gold-silver-bearing minerals, electrum is 50.98-64.05 atomic % of Ag and the ratio of Au/Ag is 1.44-1.79 range.

Regarding the chemical composition of sphalerite which is associated with the Au-Ag-bearing minerals, FeS proportion varies with mineralization stages. MnS is relatively high which is very important to identifying the origin of the ore solution.

Filling temperature of fluid inclusions in quartz ranges was from 134 to 223°c and salinity ranges from 1.2 to 3.8 weight % equivalent to NaCl.

## B. MIREUGDO GOLD MINERALIZATION ZONE

### Location

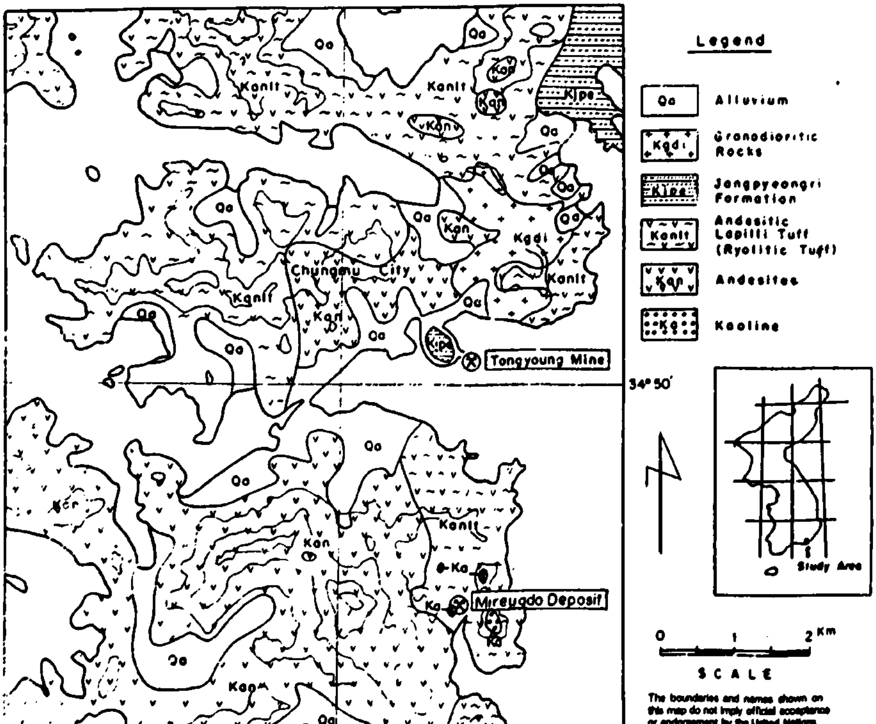
The Mireugdo epithermal gold mineralization area is located bordering Chungmoo city in the southeastern part of the Korean Peninsula (Figure I).

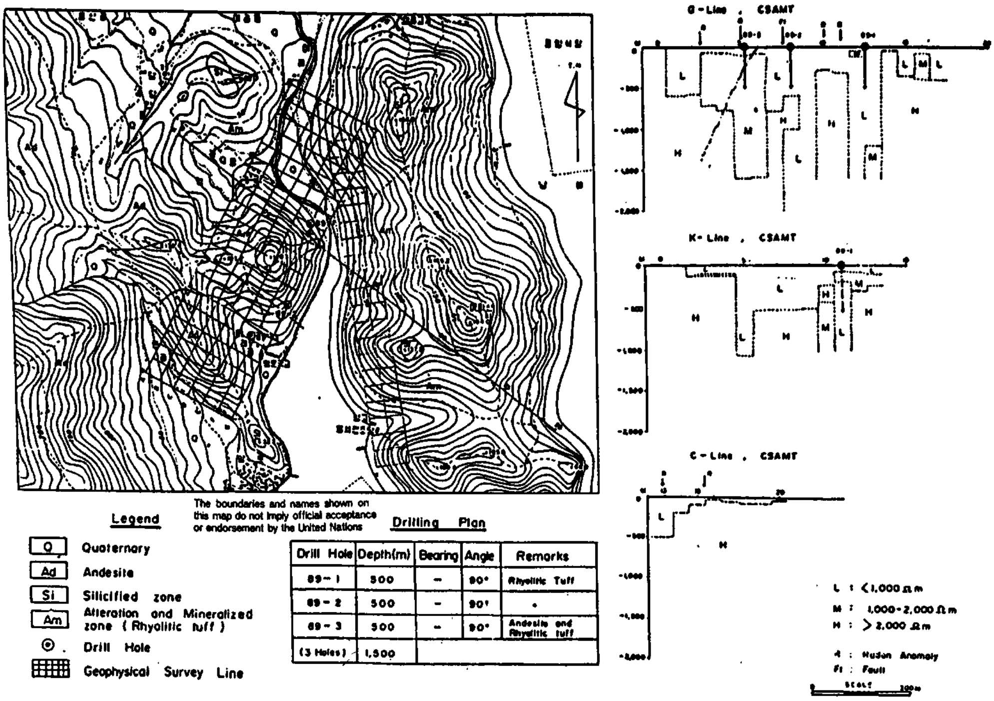
### General Geology

Geology of the Mireugdo epithermal vo
hydrothermal area consists of Cretaceous a
lapilli tuff andesites with some rhyolitic tuff.
are dark greenish color and consits of plagoclas
quartz and iron oxides. Rhyolitic tuff was alte
and kaolin on the surface by weathering, and to p
and alunite by hydrothermal solutions below
zone.

### Ore Deposits

The epithermal volcanogenic-hydrother
which are most abundant are the dissemina
sulfides (especially pyrite, chalcopyrite, galean an
in lapilli tuff andesites with some parts in rh
These are situated in an alteration zone marked by p
alunite, silica and kaolinized tuff. The zone st
-75° W, has a width of about 300m and a leng
1 kilometer (Figure II).





| Drill Hole | Depth(m) | Bearing | Angle | Remarks |
|---|---|---|---|---|
| 89 - 1 | 500 | - | 90° | Rhyolitic Tuff |
| 89 - 2 | 500 | - | 90° | 〃 |
| 89 - 3 | 500 | - | 90° | Andesite and Rhyolitic tuff |
| (3 Holes) | 1,500 | | | |

Figure II. Drilling plan map of alteration zone in Mireugdo.

There are two different types of ore deposits in the area; first is the disseminated gold-pyrite deposits seen in the hydrothermal alteration zone and the second type is the sulfide vein deposits which were discovered in the deeper zones by diamond drilling (Figure III).

The ore minerals are galena, sphalerite, chalcopyrite, bornite, pyrite, hematite, and gangue minerals are quartz and calcite. There are four sulfide veins which are embedded, steeply deeping, in and along the alteration zone.

## Alteration Zone

The alteration zone is developed in the rhyolitic tuff of the Yucheon group as the result of hydrothermal activity. The bedding in the rhyolitic tuff shows gentle dips of about 30° to the northeast. This alteration zone can be divided into two different mineral assemblage zones; an "upper" silicified kaolinite-quartz zone, more resistant than the country rocks, and a "lower" alunite-kaolinite-pyrophyllite-diaspore zone which contains fine pyrites of disseminated type and also very small grains (several microns to 3 mm size) of chalcopyrite, galena, sphalerite and tennantite, an assemblage which is similar to the "Nansatsu- type" gold deposits in Japan.

The alteration zone can be divided into three spatial zones, namely, main alteration zone (400m x 450m), east alteration zone (900m x 2,000m) and north alteration zone (350m x 350m). Quartz-clay-feldspar and kaolin-sericite-montmorillonite diagrams of the clay normative minerals show the dominance of quartz, clay, kaolinite and sericite in each samples, which are definite evidence of hydrothermal alteration.

## Chemical Composition of Sulfide Minerals

The assay results of the massive pyrite disseminated ore zone and vein zone which was explored by drilling show Au trace-0.3 g/t and Ag 1-7 g/t. The average Cu value of 189 drill core samples is 58 ppm which is six times higher than that of the fresh rhyolitic tuff (Cu 10

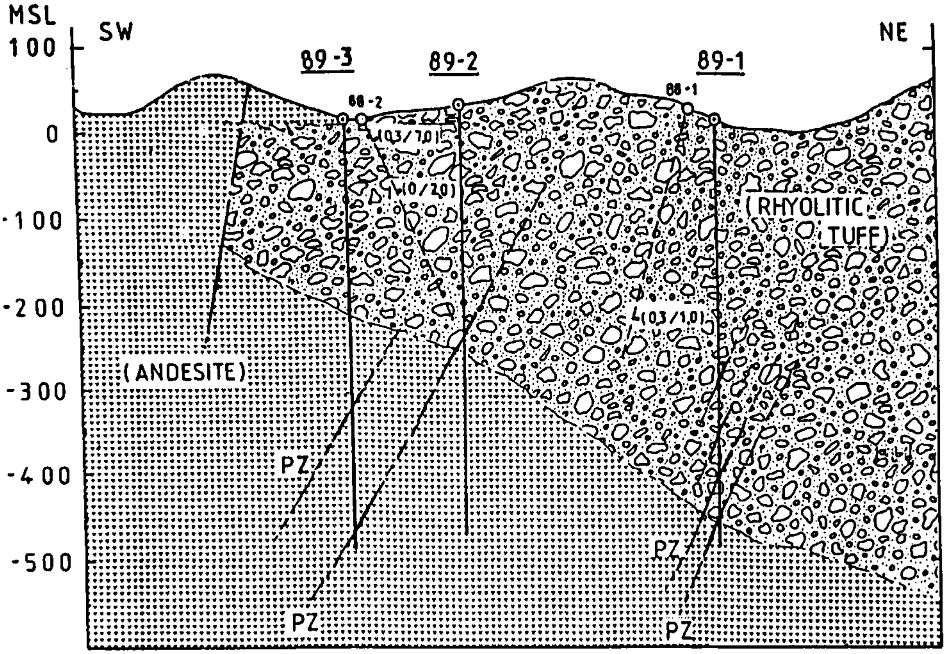


**Figure III. Drilling section of Bore hole 89-1, 89-2, and 89-3 of Mireugdo area (PZ = Sulphide vein).**

ppm). Sphalerite in massive disseminated deposits contains a little higher Au, Ag, Cu and Fe composition than that in vein deposits, but Zn composition is low-about 30%.

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# PART 2

# EXPLORATION METHODOLOGIES

# EPITHERMAL GOLD MINERALIZATION AND EPITHERMAL EXPLORATION IN THE CIRCUM-PACIFIC RIM

by
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Australia

The close association of epithermal precious metal ore deposits and volcanic rocks has been recognized for a long time but it is only recently that new steps have been taken in understanding these relationships. These steps have come from a series of integrated geoscience studies on active geothermal systems in the volcanic terranes of the Pacific Rim during their exploration and development as energy resources. In some of these systems gold deposition is known to be occurring and the mechanisms for gold deposition are now well understood.

Combined with the increase in the world price of gold in the early 1980s and lower cost extraction methods, this better understanding of the relation between gold deposits and high level magmatism has focused recent exploration on the young volcanic terranes of the circum-Pacific region. There have been a number of major new discoveries (e.g. Lihir Island, Papua New Guinea (167 Mt at 3.4 g/t), Hishikari, Japan (1.5 Mt at 80g/t), progressive exploration of earlier-developed prospects (e.g. Kelian, Indonesia (>40 Mt at 2g/t) and Porgera, Papua New Guinea (80 Mt at 3.7 g/t + 5.2 Mt at 25.5 g/t in Zone 7)) and redevelopment of epithermal deposits mined earlier this century (e.g. Waihi (14 Mt at 3.5 g/t) and Golden Cross (5 Mt at 4.4 g/t), both in New Zealand). Gold deposits in deeper but related volcanic environments are also important and include porphyry deposits such as Bougainville (625 Mt at 0.46 g/t) and porphyries with associated skarn deposits, such as Ok Tedi (351 Mt at 0.59 g/t), both in Papua New Guinea.

Present reserve estimates for epithermal and porphyry-type gold deposits in the Southwest Pacific indicate some 2100 tonnes of gold compared with a total past, cumulative production of about 600 tonnes. Such reserves are important in the socio-political evolution of nations in these regions just as the epithermal districts of northern Greece and Romania were influential in the establishment of ancient empires.

Epithermal precious metal deposits form near the earth's surface in the upper few hundred meters of large hydrothermal convection systems in volcanic terranes. Most commonly, vein and disseminated deposits are hosted by rocks altered to sericite/clay -K-feldspar assemblages. Gold deposition is in many cases interpreted to be the result of boiling, and is accompanied by abundant silica and adularia. Well known examples include Round Mountain, Nevada, McLaughlin, California, and Hishikari, Japan. A second common association exists between gold-copper (often as enargite) ores and zones of high-temperature advanced argillic alteration. In these cases the advanced argillic alteration has been seen as the product of volcanic gases and later this mineral assemblage may act as a 'chemical trap' for metals subsequently introduced by a long-lived aqueous convective system. Examples of such alunite-kaolinite (or acid-sulfate type deopsits) would include Goldfield, Nevada, Iwato, Japan and El Indio, Chile.

Modern exploration for epithermal deposits follows the methodology developed in the 1960s and 1970s for porphyry deposits and volcanogenic massive sulphide deposits. Thus regional geochemistry and the mapping of alteration in bedrock or float material are of prime importance.

Geochemical stream sediment and soil surveys are proving increasingly useful although their utility as a cost-effective exploration method has been highly dependent on the development of sub-ppm carbon-rod atomic-absorption techniques. The bulk cyanide leach technique has also been developed as a qualitative and inexpensive tool for regional gold surveys. Arsenic, antimony and mercury are covariant with gold and may be used as additional pathfinders, and base metals and copper may be useful indicator elements for some deposit styles. Thallium and tellurium may be useful as discriminants but are generally precluded as routine exploration tools by the difficulties and costs of this chemical analysis.

The majority of large epithermal systems are characterized by large, intense alteration haloes consequent on widespread destructive reactions affecting feldspars and ferromagnesian minerals, followed by silicification and pyritization. Other observed characteristics of epithermal systems include the transfer of potassium into the upper

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few hundred meters of the system and, due to the presence of reduced sulphur, the widespread demagnetization of host rocks. These features allow that airborne magnetic, radiometric and resistivity surveys can be usefully employed in locating epithermal systems. The methods have been very successful in epithermal exploration throughout eastern Australia. Such surveys also provide basic geological information and, depending on suitable flight-line orientation, may locate major regional and related structures which can provide a fundamental control on the location of ore districts. The recognition of possible regional structures is also aided by satellite thematic mapper and SLAR radar imagery.

At the *prospect* scale geochemical surveys using gold as its own indicator are obviously of great importance in locating ore zones. Where outcrop is sufficient or pilot drilling has been completed, alteration mapping (backed by X-ray diffraction and petrography) are both important although the distinction between a hypogene or supergene origin for kaolinite and alunite may often be impossible. Recognition of multiple alteration stages may be very important. Similarly mapping of breccia types provides an important guide to mineralization style and possible targets. Fluid inclusion thermometry is useful in characterizing deposits but *only* if great care is taken in selecting suitable samples and interpreting homogenization data.

Strong variations in electrical properties within hydrothermally altered rocks allow conductive clay-pyrite zones and resistive silicified zones to be mapped in detail by standard resistivity methods. Controlled Source Audio-Magnetic-Telluric (CSAMT) has been used with varying success in targetting capricious vein systems at depth and in detecting resistive quartz-rich zones or conductive clay-pyrite zones (Austpac, 1988).. In many epithermal districts, recognition of the original geomorphology provides clues to the paleohydrology which may in turn aid in developing exploration targets. At Creede, Colorado, for
example, the silver-base metal vein distri
outflow portion of a much larger epithermal
upflowed several kilometers to the north
fracture of the San Luis caldera, where it de
high grade gold mineralization.

No single technique provides the key
exploration. Rather, the combination of ca
in conjunction with geophysics and geochem
be used to lead to the recognition of good
drilling as always is the ultimate test. The di
Hishikari bonanza deposit, for example, wa
a five-year combined geological and geo
gramme. Exploration drilling then teste
airborne electromagnetic and ground-surv
anomalies which were found to be coinc
basement gravity high . Drilling also teste
mentary concept of the deeper extensions o
andesite-hosted veins.

Such recent discoveries in the youn
gions of the Pacific Rim demonstrate the ef
modern exploration concepts and methods
phasize the potential for further major di
should however be stated that discoveries
gold decopsits are not confined to such yo
terranes. In eastern Australia, for example
veins (e.g. Pajingo and Wirralie, 12.5 Mt
3.65 Mt at 2.75 g/t gold respectively) we
during systematic exploration of upper Pa
volcanics in northern Queensland. Simi
deposits of presumed epithermal origin are a
tion in South Carolina, U.S.A.

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# EXPLORATION SRATEGY FOR EPITHERMAL GOLD DEPOSITS IN JAPAN

by
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## INTRODUCTION

The most important precious and base metal mineralizations in Japan are situated in the late Cenozoic magnetite-series metallogenic province. This province is characterized by intensive submarine and subaerial volcanism and intercalated sediments. Mineralization includes massive sulfide deposits of Kuroko type containing such recoverable metals as Au, Ag, Pb, Zn and Cu, and vein type deopsits which are distinguished generally into Au-Ag, (Ag-)Pb-Zn, Cu(-Pb-Zn), $MnCO_3$ (-Pb-Zn) and Hg-HgS assemblages. This classification is reflected in regional divisions of mineralization types (Figure I).

Progress in geological studies and in development of exploration techniques applied to this metallogenic province over the past ten years has demonstrated the necessity of revising our exploration thinking concerning epithermal gold deposits. In this paper, new ideas on exploration will be presented based on modern data from epithermal gold areas, especially of eastern and southwestern Hokkaido, and central and southern Kyushu.

## HOW YOUNG GOLD DEPOSITS CAN WE FIND?

Precious metal and base metal vein-type mineralizations of the late Cenozoic volcano-plutonic province in the Northeast Japan arc have been considered to be coeval with Kuroko mineralization, i.e., 11-13 Ma. Recent K-Ar dating, however, has revealed that the age of gold mineralization in Ryukyu, Japan and Kurile arcs varies widely from 22 Ma to 0.5 Ma, but tends toward younger ages than those related to Kuroko mineralization (Figure II).

This fact implies that exploration for epithermal gold deposits should be expanded toward Quaternary volcanic areas. One of the youngest deposits in southern Kyushu is the Hishikari deposit, concealed below the present surface with the topmost part of the deposit located about 130 m deep. Its age is 0.9 Ma. Another very recent (0.5 Ma) deopsit of quartz-adularia type at Noya in central Kyushu was found during drilling for geothermal exploration purposes at a depth of 150-210 m below the present surface.

These are the youngest gold-quartz vein deposits so far found in Japan. Much younger ones may possibly be discovered; the associated high heat flows present serious obstacles for mining operations, however. The Hishikari vein and fracture system is filled up with 70°C hot water, while the Noya drill hole logged a temperature of 175°C at the mineralized depth. Thus, only the relatively cool parts of the volcanic areas along the present volcanic front should be considered for the exploration.

## IS FRESH BASEMENT NECESSARY?

Figure II may be considered to show a positive correlation between the mineralization age and the distance between plotted ore deposits and the present volcanic front. That is, older deposits tend to occur further from the volcanic front.

This is very clear in the gold district of southern Kyushu. Here (Figure III), magnetite-series granitoids occur in the westernmost Koshiki Island where the age of the magmatism is older than 7.6 Ma. On the main Kyushu Island, diorite-porphyrite is the major plutonic unit and is presumably the heat and sulfur source for the Kushikino gold vein system; this intrusive plug gives an age of 4.0 Ma. Ore deopsits further east are 1.8 Ma old, and the youngest Hishikari deposit (0.85 Ma) are located closer to the present volcanic front, which is represented by the Kagoshima Graben (Figure III).

The implication of this eastward migration of gold deposits in southern Kyushu is that the ore deposits were always formed at the then-current volcanic fronts, because felsic to andesitic magmatism has migrated in the same direction. Furthermore, trace amounts of gold in the upper mantle and crustal material were easily extractable, and not connected with the major rock-forming minerals and scavenged into hydrous magmas.

The initial $^{87}Sr/^{86}Sr$ ratio of the Shishimano dacite, whose intrusive plug is thought to be genetically

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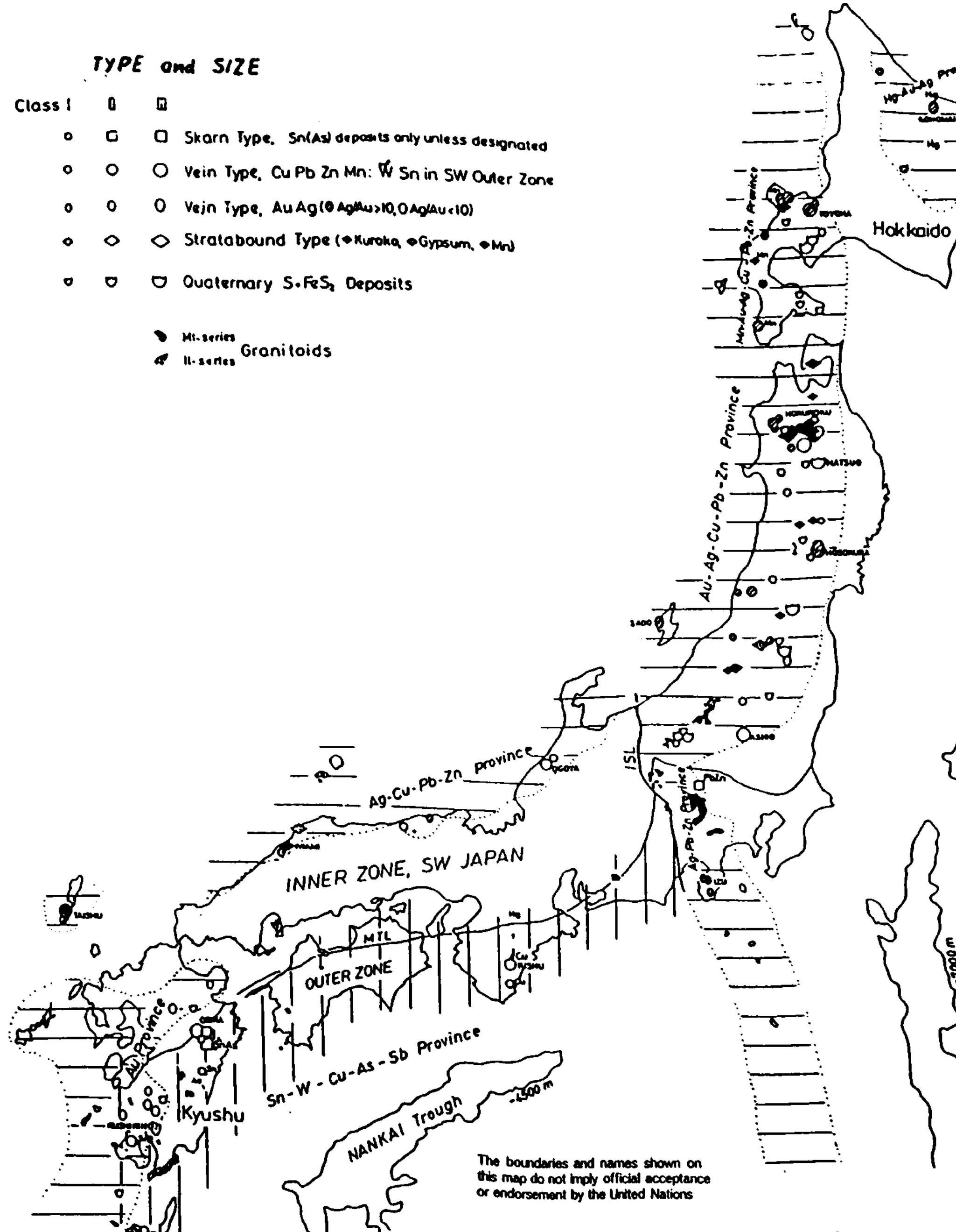

TYPE and SIZE
Class I II III
Skarn Type. Sn(As) deposits only unless designated
Vein Type. Cu Pb Zn Mn: W Sn in SW Outer Zone
Vein Type. Au Ag (Ag/Au>10, Ag/Au<10)
Stratabound Type (Kuroko, Gypsum, Mn)
Quaternary S·FeS2 Deposits
MI-series
IL-series
Granitoids
Hokkaido
Au-Ag-Cu-Pb-Zn Province
Ag-Cu-Pb-Zn province
ISL
Ag-Pb-Zn Province
INNER ZONE, SW JAPAN
MTL
OUTER ZONE
Au Province
Kyushu
Sn-W-Cu-As-Sb Province
NANKAI Trough
-4500 m
-3000 m
SADO
MATSUO
ASHIO
TSUSHIMA
Mn
Hg

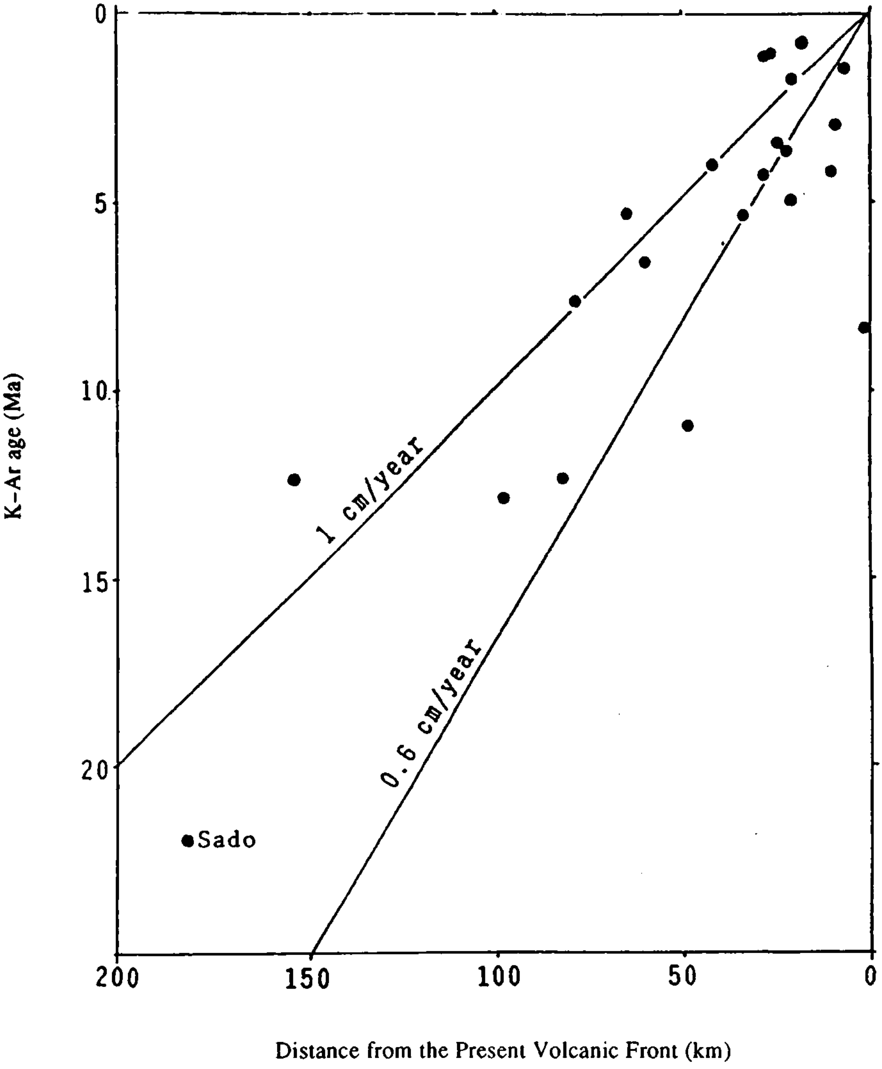


**Figure II.** K-Ar ages of vein-forming and alteration minerals from epithermal gold deposits in the late Cenozoic magnetite-series metallogenic provinces plotted against the distance of the ore deposits from the present volcanic front.

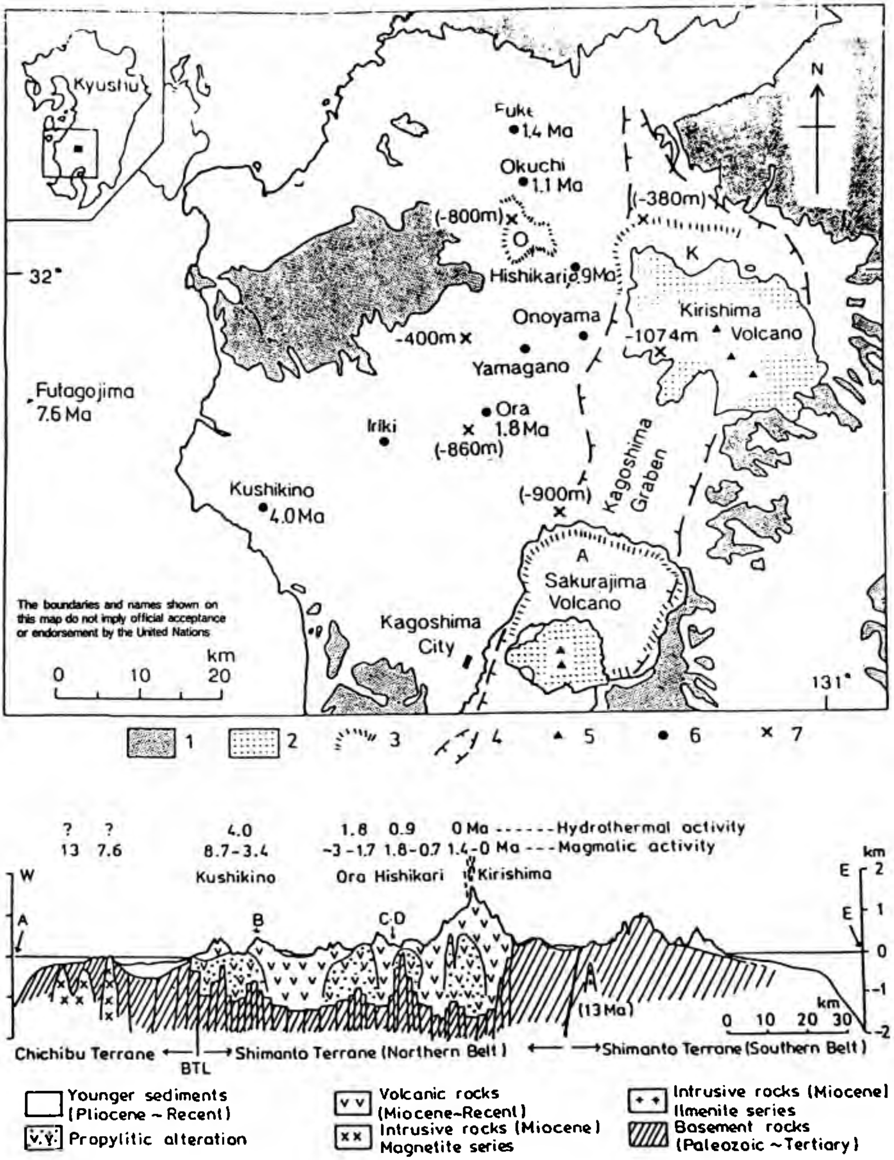
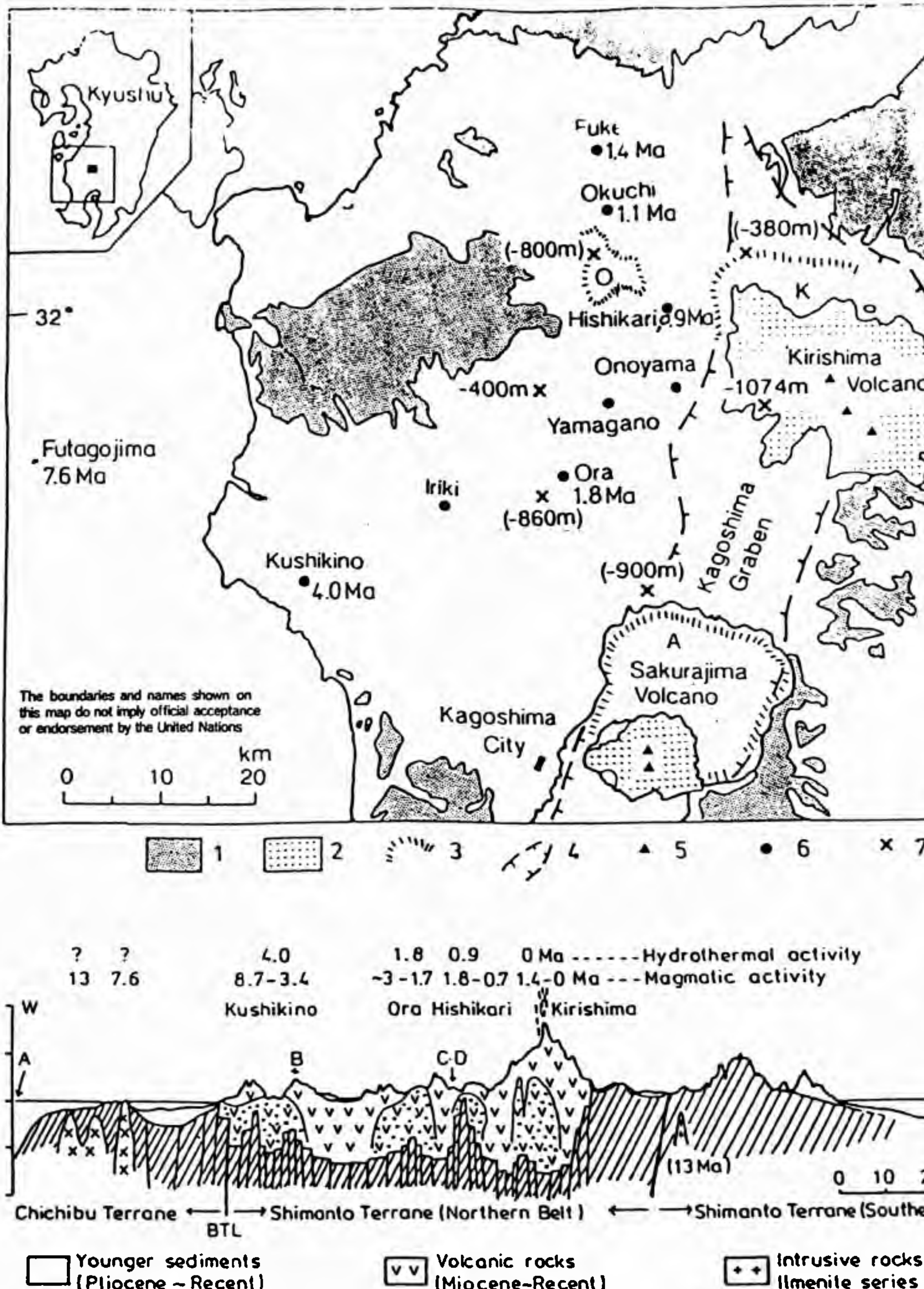


**Figure III.** Geological outline and K-Ar age of the Hokusatsu Au-mineralized district, southern Kyushu (top) and schematic E-W section (bottom). 1, Outcrops of the Shimanto Supergroup; 2, Holocene volcanic rocks; 3, Caldera and basin, O, Okuchi basin, K, Kakuto caldera, and A, Aira caldera; 4, Kagoshima graben; 5, Volcanic centers; 6, Gold deposits; 7, Deep drill holes with elevation of the top of the Shimanto Supergroup (parenthesis indicates that the drill hole did not reach the basement). After Izawa et al. (1990), partly revised.


Kyushu
Fukt
1.4 Ma
Okuchi
1.1 Ma
(-800m)
O
(-380m)
K
32°
Hishikari 0.9Ma
Onoyama
Kirishima
Volcano
-400m
-1074m
Yamagano
Futagojima
7.6 Ma
Ora
1.8 Ma
Iriki
(-860m)
Kagoshima
Graben
Kushikino
4.0 Ma
(-900m)
A
Sakurajima
Volcano
Kagoshima
City
The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations
km
0
10
20
1
2
3
4
5
6
7
? ? 4.0 1.8 0.9 0 Ma ------Hydrothermal activity
13 7.6 8.7-3.4 ~3-1.7 1.8-0.7 1.4-0 Ma ---Magmatic activity
Kushikino
Ora
Hishikari
Kirishima
W
A
B
C·D
(13 Ma)
0
10
Chichibu Terrane
BTL
Shimanto Terrane (Northern Belt)
Shimanto Terrane (Southe
Younger sediments (Pliocene ~ Recent)
Volcanic rocks (Miocene-Recent)
Intrusive rocks Ilmenite series

related to the gold mineralization, is as low as 0.70474-0.70486 (Ishihara et al., 1990), implying little contamination by crustal materials. $\delta^{34}S_{CDT}$ of the ore sulfur ranges from −1.1 to +1.8 ‰ and the average is +0.3‰. The same ratio of the basement sandstone and shale of the Shimanto Supergroup averages −12.0‰. Thus, the source of sulfur is not from the immediate basement but the much deeper materials of the source zone of the dacitic magma. Gold may have the same provenance as the sulfur (Ishihara et al., 1986). At any rate, virgin areas for any given volcanism may be prime target areas for exploration for epithermal gold deposits.

## GOLD VERSUS BASE-METAL DEPOSITS

In the late Cenozoic magnetite-series metallogenic provinces, gold deposits tend to occur in special areas like southern Kyushu, central Kyushu, Izu peninsula and eastern Hokkaido. Base metals are especially concentrated in the Hokuroku area of northern Honshu (Figure I).

These precious metal/base metal variations in ore deposits are the consequence of various geological factors such as differences in the magma types related to mineralization, and/or differences in the basement rocks, especially for copper (Ishihara and Terashima, 1974). Tectonic setting of mineralized areas is also important.

In Hokkaido, gold mineralizations are seen in the southwestern and eastern parts. In the southwestern part, both gold and base metal deposits occur in large numbers but in different zones: gold on the frontal side and base metal in the back-arc side. These ore deposits were formed in an E-W to NW-SE compressional tectonic setting during the Pliocene-Pleistocene (5.2-0.5 Ma) by ore fluid which passed through late Cenozoic sedimentary-volcanic sequence (i. e., Green Tuff formation).

The gold-rich subprovince of eastern Hokkaido, on the other hand, is characterized by mineralization which occurred in volcanic rocks related to three periods (12, 8-7, 4-3 Ma) of felsic volcanism along N-S subsidence zones, which may have been triggered by the opening of the Kuril Basin. Thus, as in Kyushu Island, extensional rifting appears to be a necessary condition for the volcanism related to gold mineralization in eastern Hokkaido.

## GEOCHEMICAL AND GEOPHYSICAL EXPLORATION

For the exploration of very young concealed gold deopsits, studies of alteration haloes by mineralogical and geochemical means and field geophysics are seen to be indispensable. Some results from the Hishikari are given in Figures V to XII referring to Izawa et al. (1990) (Figures V and VIII) and MITI (1990) (Figures VI-VII and IX-XII). The activities are presently going on in central Kyushu and eastern Hokkaido. The purpose of these examples is to show some of the characteristic signals given by alteration patterns, district level geochemistry and geophysical methods in and near the Hishikari vein systems.

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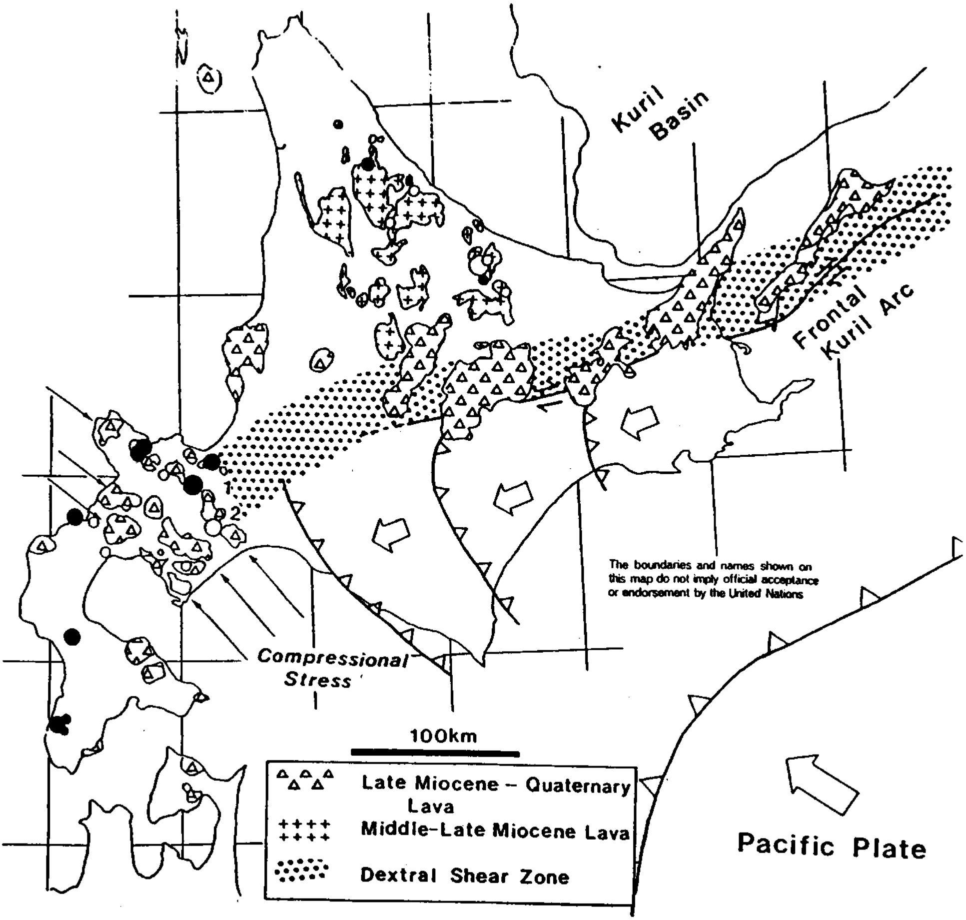
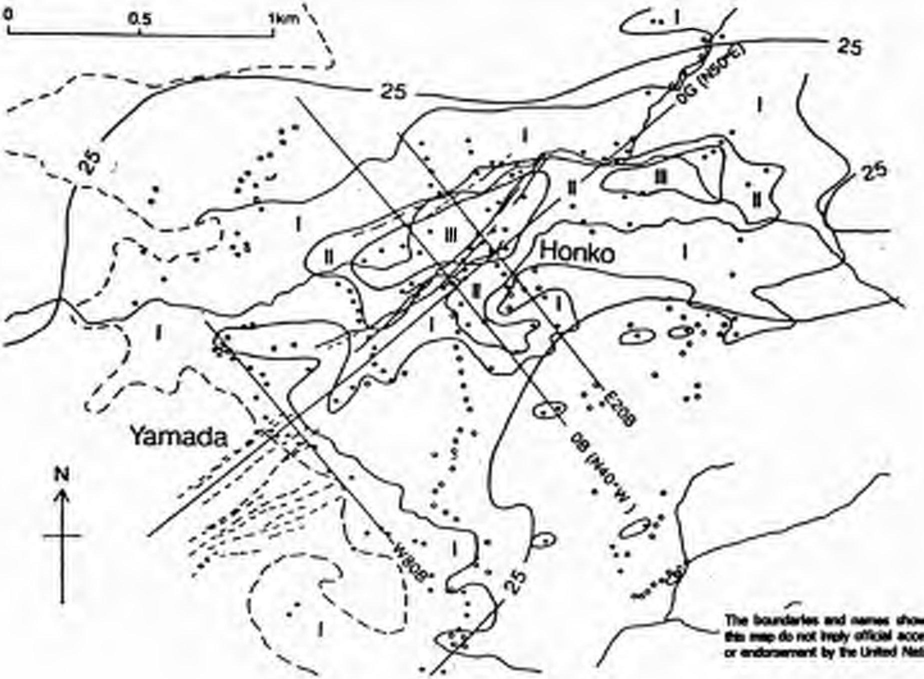
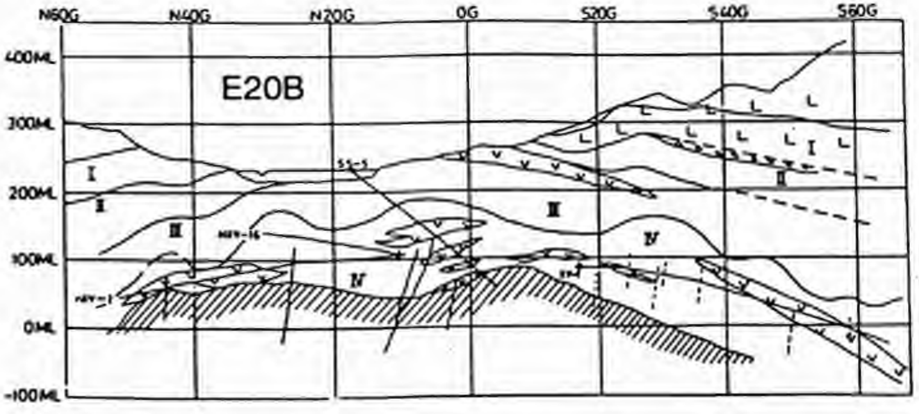


**Figure IV.** Outline of geotectonics and distribution of gold (open circle) and base metal (solid circle) deposits in Hokkaido. Only large ones, i.e., size category 1 to 3 of Igarashi (1979) and Kishimoto et al. (1979) are plotted. After Watanabe (1990), partly revised.



*I* = cristobalite-smectite zone; *II* = quartz-smectite zone; *III* = interstratified clay mineral zone. The western side of the dashed line is covered by young pyroclastic flow deposits. Small circles show sample locations; open circles denote the least altered rocks and solid circles refer to altered rocks. Light lines or dashed lines show the surface projection of the veins. Area of low resistivity (less than 25 ohm-m), determined by CSAMT (Kawasaki et al., 1986), is outlined by the heavy line.



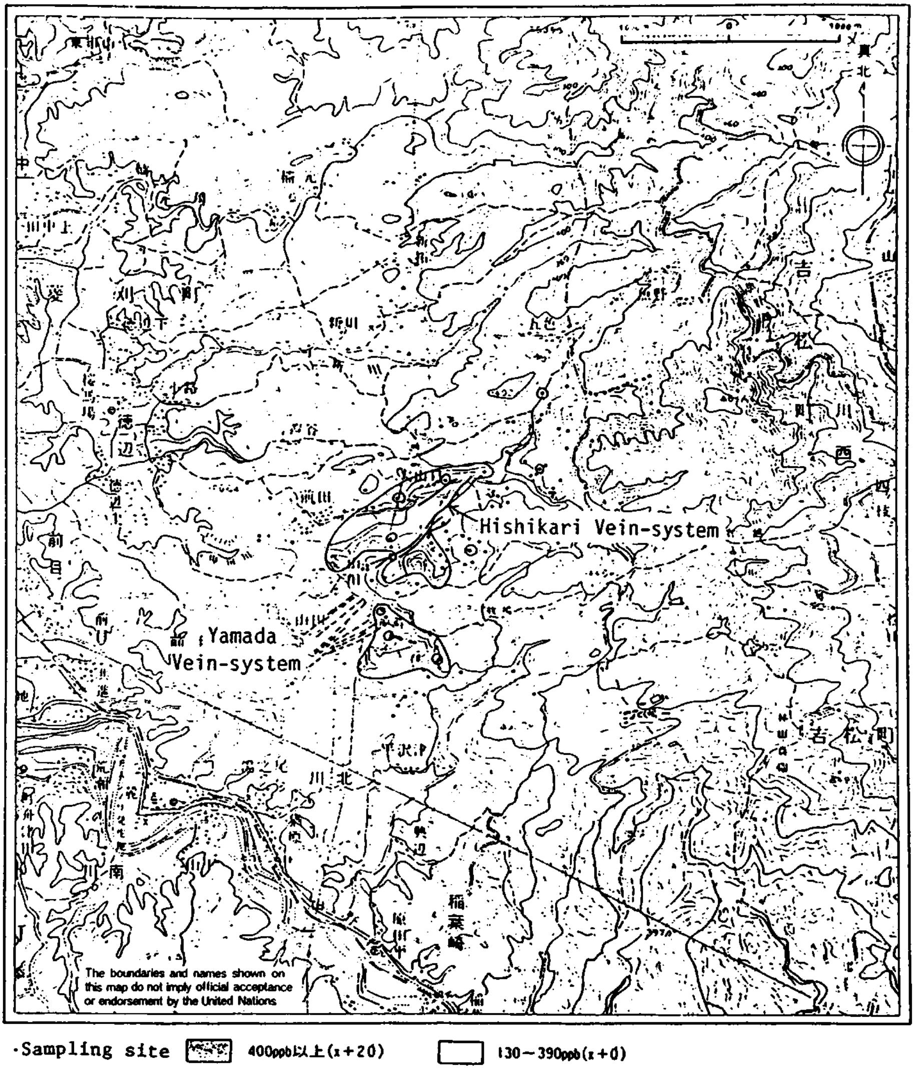


Figure VI. Mercury in rocks. Rock geochemistry for gold (X+ σ = 9 ppb, X+ 2σ = 42 ppb) shows almost no anomaly on the surface rocks. Mercury gives anomalous (X = 50 ppb, X+ σ = 130 ppb, X+ 2σ = 400 ppb) haloes above the vein systems. Hg is better indicator than Au, As and Sb.

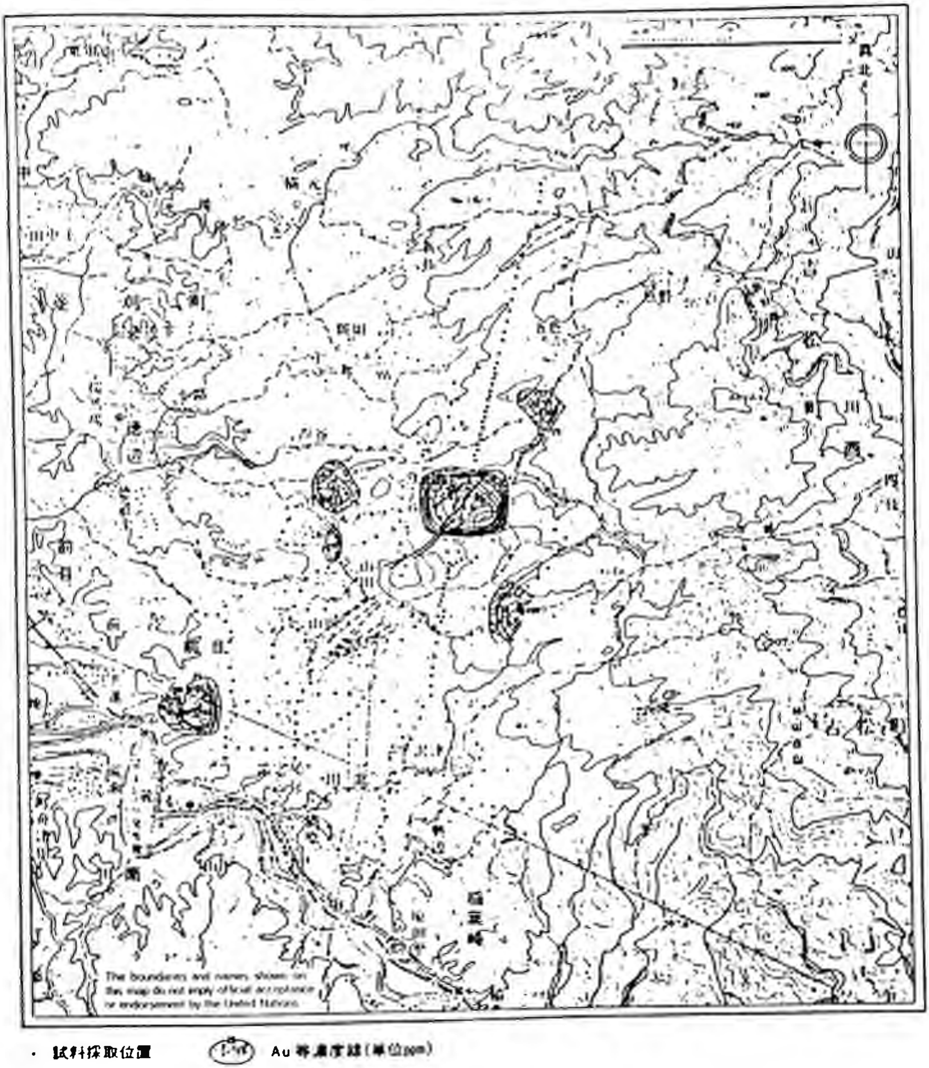


Figure VII. Gold in soil. In soil geochemistry, Au, As and Sb show anomalies (more than 25 ppb) above and near the ore deposits, thus Au is a good indicator.

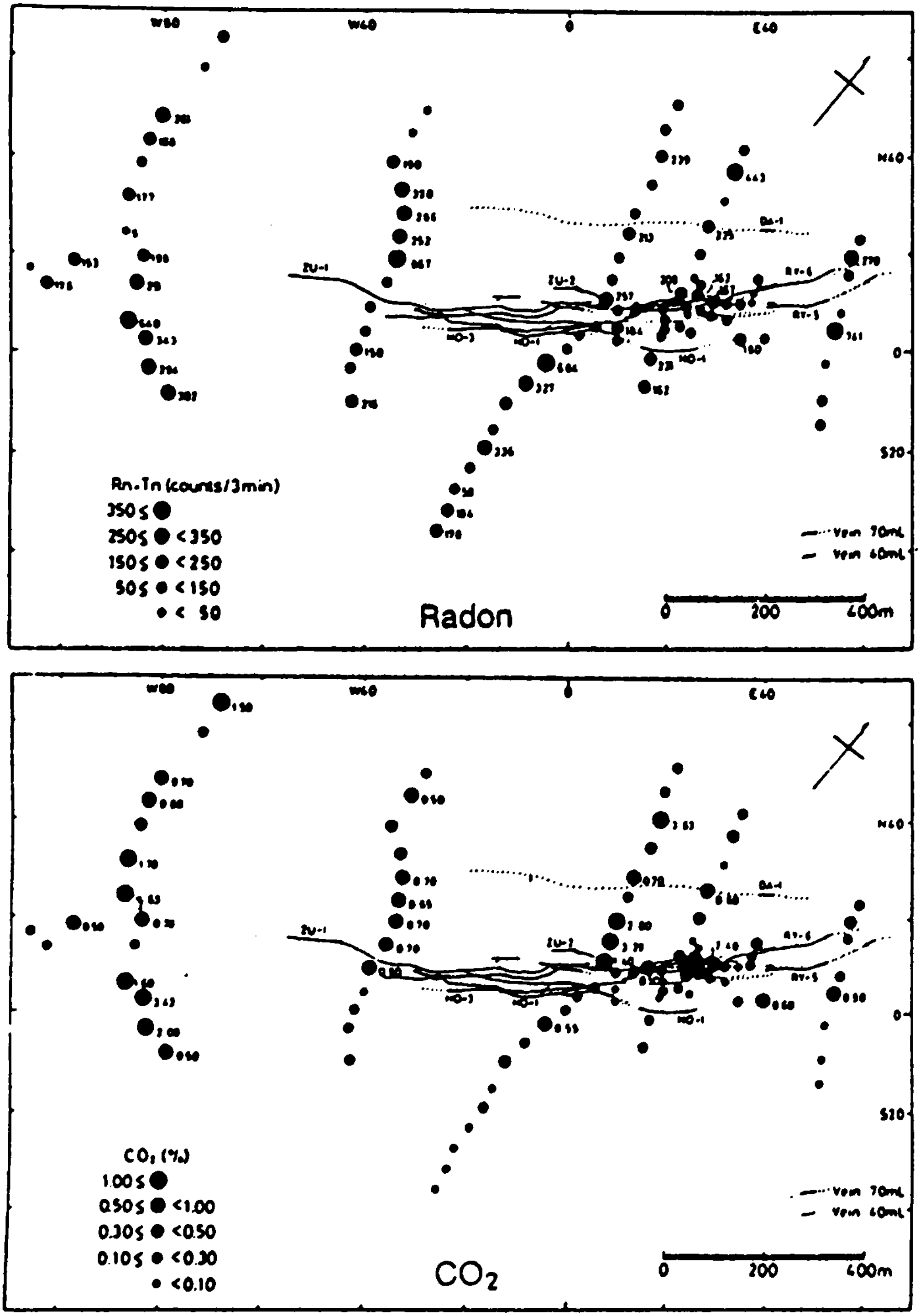


**Figure VIII.** Geochemical maps showing the distribution of radon (Rn + Tn), CO$_2$ and Hg in soil gas, and Hg in soil. The vein pattern was projected to the surface from 70 mL and 40 mL. The base line of the mine grid is parallel to the general strike of the veins (N50°E). Rn: the numbers with solid circles are total radon

Figure IX. Gravity survey, Hishikari mine area (D = 2.4 g/cm$^3$). The contour lines show generally an ENE-WSW elongation, which is that of Au veins, but a NW-SE direction is seen in the northwestern part. The Hishikari deposit is located in the higher anomaly zone over 13 mgal. Yamada satellite deposit is situated at the southern part. Refer Figures VI and VII for the better vein location.

Figure X. Magneto-telluric (MT) survey (100 Hz). MT method is useful to detect resistivity at depth (20 km) and is effective for analyzing the basement structure of this area. A NE-SW trending low resistivity zone (below 25 Ωm) was recognized in the studied area. Kawasaki et al. (1986) was able to propose a magmatic body at 8 km below the Hishikari mine.

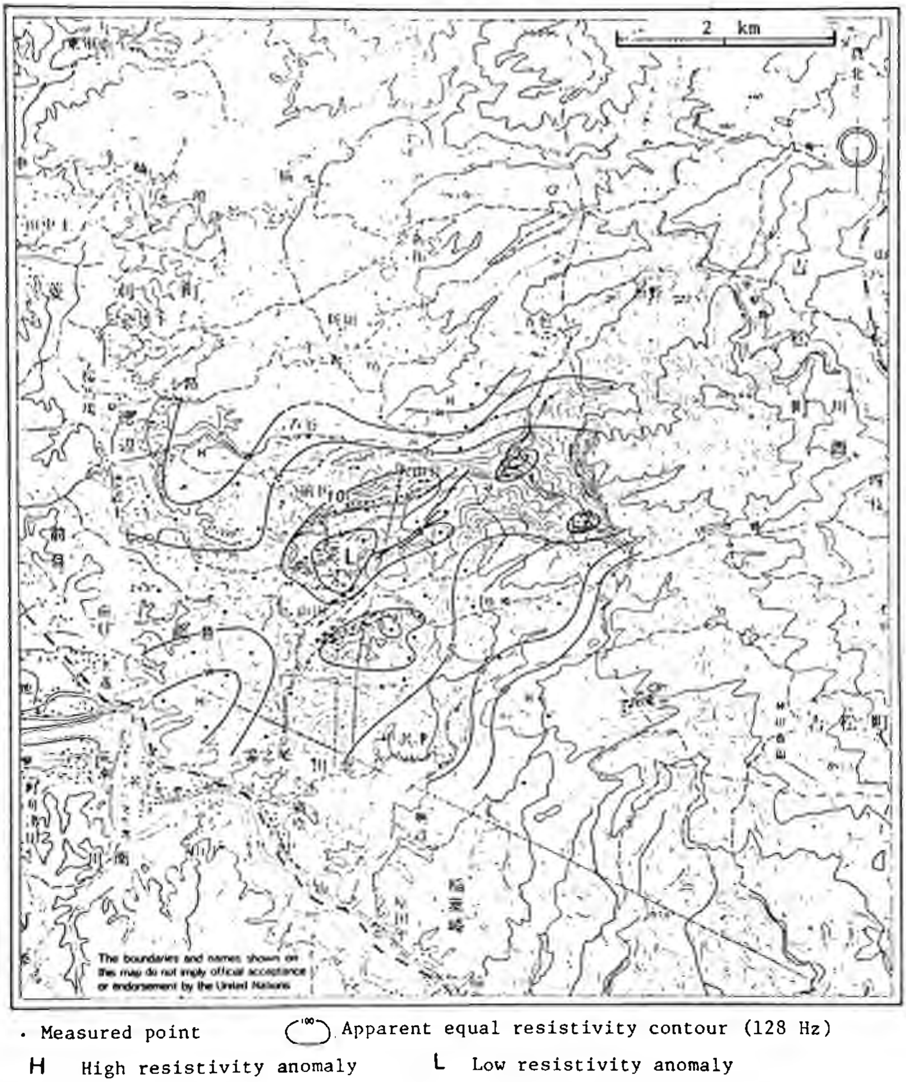
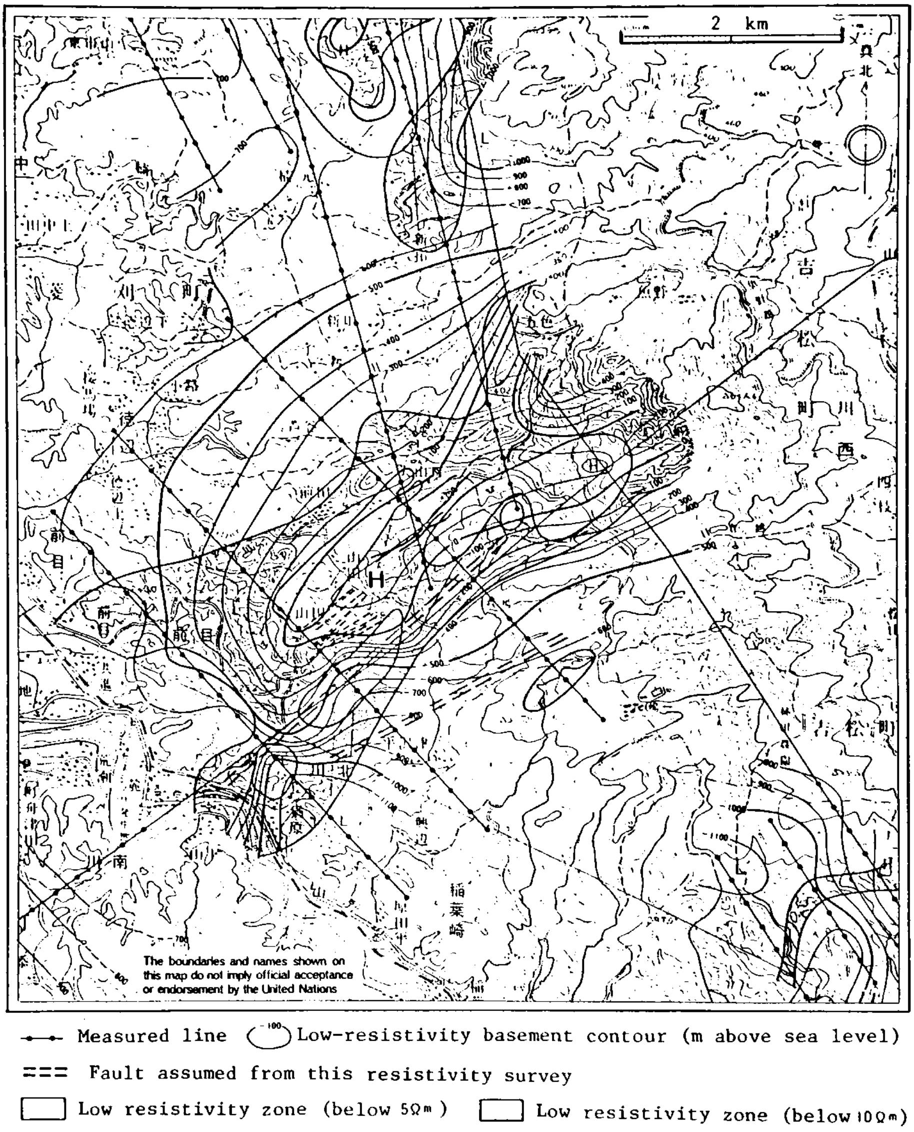


Figure XI. Controlled source audio-frequency magneto-telluric (CSAMT) survey. CSAMT method is efficient in operation time and has a high resolution vertically. Apparent low resistivity zone elongates also in an ENE-WSW direction around the Hishikari mine area, but the slope is gentle toward the south.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

**Figure XII.** Schlumberger soundings. High resistivity basement is seen in NE-SW direction around the Hishikari and Yamada Au vein deposits.

# PLANNING, STRATEGIES AND TECHNIQUES OF A GOLD EXPLORATION PROGRAMME

by
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## INTRODUCTION

The epithermal gold deposit is the model for a gold deposit which is hosted by volcanic rocks and is formed by a volcanic-related hydrothermal system.

This model has been selected for the discussions because it is of potential importance for ESCAP countries many of which are located on the Circum-Pacific Rim.

The exploration programme for the epithermal gold deposit at Gunung Ciawitali, West Java, Indonesia (Figure I) has been chosen as an example and will be presented as the actual model.

## GENETIC MODEL

Recently, economic geologists have had to reorganize, develop and refine their knowledge of the characteristics of the models for epithermal gold deposits hosted by volcanic rocks.

Two epithermal gold deposit models, as defined and controlled by type of host rock are known. These are:

1. The epithermal gold deposits hosted by volcanic rocks, which occur and have been discovered along the Pacific Rim.
2. The epithermal gold deposit hosted by sedimentary rocks, which is best known as the Carlin-type deposit, best developed in Nevada, United States of America.

The geological environments of most ESCAP countries are commonly situated on or adjacent to the active plate margins of the Pacific Rim. As such, epithermal deposits are commonly volcanic-hosted.

The epithermal gold deposit is usually developed in near-surface volcanic terranes. Lindgren (1933) defined the maximum depth of the deposit as about 1,000 m, and the grade of the ore rapidly decreases or completely vanishes below this depth. Therefore, study of erosion levels is very important, and the exploration target is quite ideal if the volcanic terrane has not been eroded below this critical depth. Buchanan (1981) and others provided two important models for estimating the level of the deposit in the exploration of epithermal gold.

## EPITHERMAL GOLD EXPLORALTION PROGRAMME

The exploration is an extremely high-risk, expensive and generally long-term activity, notwithstanding occasional lucky and accidental discoveries.

Explorationists have stated that the mineral exploration environment has observable economic characteristics, such that the recognition of these provides guidelines for exploration planning within the mining company. For its long-term survival, the mining company needs sound exploration planning to ensure successful exploration strategies. The important thing in exploration planning is to select the right exploration environments. These will enable the mining company to maximize exploration probabilities and to reduce risk conditions.

The strategic considerations consist of:

- The selection of commodities (as exploration targets),
- The geographic concentration of exploration effort,
- The structuring of an exploration programme, to optimize the economic benefit of the whole exploration investment.

The environment of mineral exploration involves:

- The distribution of undiscovered epithermal gold deposits,
- The exploration techniques, and
- The skill and experience available.

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The specific environments are expressed by the geological setting (for example, island arc model around the Pacific Rim), specific deposit model and geophysical signatures.

In general, explorationists conclude that to the purpose of the target search strategy is to eliminate the risk by recognizing the right exploration environments.

In general, four sequential exploration stages can be distinguished; these are:

1. Area selection,
2. Regional exploration,
3. Follow-up exploration, and
4. Detailed exploration.

As each exploration stage is continued, the information analysis at the end of each stage will or will not support the economic justification for further investment.

## SCHEME OF PROGRAMME DESIGN FOR EPITHERMAL GOLD EXPLORATION

A. Selection of the Promising Area

    a) Reading assignment
    b) Aerial photo and satellite imagery interpretations
    c) Data collection and other information
    d) Planning, regional and local area selection:
        1. Familiarization with the general geological setting of the projected areas
        2. Familiarization with the general concept and targets of epithermal gold prospects/deposits
        3. Selection of general target areas
        4. Initial site visit

B. Regional Exploration (Prospect Delineation)

    a) Geological and geochemical reconnaissance using topographic maps (or available maps) of 1:100,000 or 1:50,000 scale

    c) Laboratory work
    d) Data processing and report writin

C. Follow-up Exploration (Prospect Delin

    a) Semi-detailed geological and ge exploration within the prospect 10,000 scale
    b) Making topographic maps at 1:10
    c) Soil grids, saprolites or bedr concenrates (if necessary), trench pitting
    d) Delineating the alteration haloes
    e) Geophysical exploration
    f) Laboratory work
    g) Data processing and report writin

D. Detailed Exploration (Preliminary Eval

    a) Detail geological and bedrocks ge at 1:5,000, 1:2,500 or 1:1,000 sca
    b) Geological maping of mineralize and systematic rock sampling
    c) Trenching, with systematic sampl
    d) Geophysical investigation
    e) Geological test drilling
    f) Laboratory works
    g) Data processing and report writin

## A CASE HISTORY OF AN EPITHERMA DEPOSIT OF GUNUNG CIAWITALI, WE – INDONESIA

The cooperative work in gold explorat pursued by the Directorate of Mineral Resour of Indonesia and the Bureau de Recherches G et Minieres (BRGM – France) has been a exploration programme to search for new gold in the Bayah Dome Complex and Jampang Java. The aim of the mission has been to disc gold deopsit, in order to maintain and support t Cikotok Gold Mine, a government enterprise o

(1988 and 1989) it is now revealed that the Bayah Dome Complex offers more potential than the Jampang Area.

Based on the erosion level of the altered volcanic host rocks, the Bayah Dome Complex is better situated for potential primary gold mineralizations such as the Gunung Ciawitali Prospect. Apparently the altered volcanic host rocks in the Jampang Area are too deeply eroded, resulting only in very small-scale primary gold deposits and a number of remnant placer occurrences.

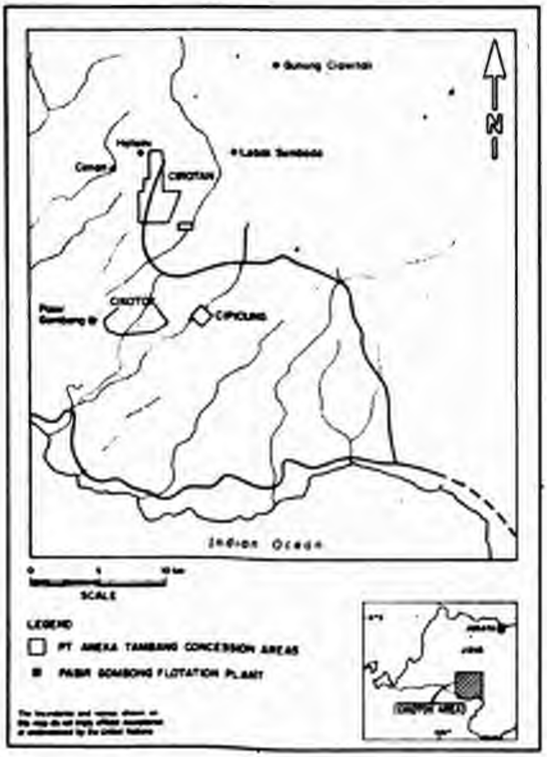

**Figure I.** Location of Gunung Ciawitali, Cikotok Area, West Java, Indonesia

## CONCLUSION

Delineating the scope for epithermal gold deposits in near-surface volcanic environment can be determined by key features such as:

Step 1 : Identification of the type of epithermal gold deposit for which one is searching in the area.

Step 2 : Delineating the tract by using the identifying features of the general epithermal gold deposit model, and recognizing the erosion level at which one is working.

Step 3 : By using exploration histories and detailed studies to place successive limits on the extent of the domain of search.

Epithermal gold exploration programmes organized and managed by careful planning, sound strategies and good techniques may reach a successful result, even for small-scale gold deopsits.

The geological and geochemical results may lead finally to the calculation of a preliminery grade-volume estimate, preparatory to a full feasibility study.

## ACKNOWLEDGEMENT

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# EPITHERMAL GOLD EXPLORATION: SOME EXPERIENCES AND PRACTICAL EXPLORATION TECHNIQUES

by
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Geological Survey of Papua New Guinea[2]

The purpose of this paper is to present a series of handy hints and techniques that are useful when exploring for, and evaluating, epithermal gold targets. These hints are intended for prospectors, inexperienced geologists, and old hand explorationists alike, and are based on many years of experience in the field by the author and by numerous other geologists and prospectors. The methods found to be of greatest use invariably have a strong scientific basis, which at times are clearly obvious even to the casual observer. Other methods that have been used by prospectors for years are known to be frequently successful, but their scientific basis may not be fully understood.

Much of what is presented here will be well known, and perhaps is being used on a daily basis by many. However, my intention in discussing practical exploration techniques is to remind us all that:

> **common sense comined with scientific knowledge help provide a pathway to successful mineral exploration.**

## BASIC PROSPECTING

Many people think of the gold prospector in general terms as a poorly educated laborer. However, experienced prospectors are frequently bright and industrious individuals who use common sense when confronted with problems and new situations. Their efforts often lead to the discovery of gold mineralisation, and whether lode or placer or whether economic or subeconomic at the time, the information on the location, size, and grade of these gold occurrences becomes very useful when integrated into modern day exploration programmes.

The first major discovery of gold in Papua New Guinea took place on Sudest Island in 1888. Approximately 0.3 tonnes (10,000 oz) of gold were produced from alluvial gravels before these deposits were exhausted. As production of gold from the alluvial gravels diminished, exploration for lode gold sources increased, and lode gold deposits on Sudest Island were eventually discovered and mined. Thus began a pattern of gold exploration and exploitation throughout Papua New Guinea in which rich alluvial gold deposits were discovered and mined first, followed by the exploration for lode gold deposits in the same districts.

This pattern of alluvial gold discovery and exploitation prior to exploration for lode gold deposits is com~~mon to~~ mining districts throughout the world. A recent example of the important relationship that alluvial prospecting has to modern day exploration programmes is the discovery of the Hidden Valley lode gold deopsit (Papue New Guinea). This deposit, containing 77.4 tonnes (2.5 million ounces) of gold, was discovered by CRA of Australia as a result of their investigations into the presence of gold placer miners working in the headwaters of the Watut River.

> **When planning regional gold exploration programmes the modern day geologist should rely heavily on reports detailing the loclation and production history of alluvial gold deposits.**

### Placer Gold Prospecting

Modern day lode gold exploration frequently relies on the use of heavy mineral pan concentrate samples. It should be noted that the presence of even minor quantities of oil can cause small flakes of gold to float out of the pan during washing. Oil frequently comes from the panner's skin while performing the arduous task of panning. As well, new metal gold pans generally come from the factory coated with a layer of oil to prevent rusting prior to their sale. Whenever fine gold is present and oils may become a problem, add a drop or two of liquid soap to the pan and its contents prior to washing. Oil is much more difficult to clean from wooden gold dishes (bateas) and hard plastic gold pans. A second drawback of the batea is presented by wood fibers on the surface, which along with any pits and cracks present may act to entrap small gold grains. Because of the small losses involved this is rarely a problem to a placer miner, but, the loss of even trace amounts of

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gold may make a significant difference to the conclusions which may be drawn by the explorationist who uses the pan as a prospecting tool.

> **When collecting pan concentrate samples the use of a metal gold pan is encouraged. But prior to its first use, and periodically thereafter, all metal pans should be heated over a fire to remove oil.**

### Sources of Alluvial Gold

Gold grains and nuggets recovered from alluvial deposits exhibit a wide variety of characteristics, some of which are useful in helping to determine the types of source deposit from which they were eroded. The size and morphology of gold grains, gold fineness, and inclusions and intergrowths of gangue minerals with the gold are not only a function of distance transported, but also reflect primary characteristics encapsulated within the gold grains during formation. Additionally, the relative size (extent) and richness of alluvial deposits may also provide information useful in determining the type of deposit from which gold was eroded.

## REGIONAL TARGETING

When looking for an area to prospect for gold the old saying "look for mangos on a mango tree" (i.e. look for gold in gold country) applies. Re-evaluation of old mining districts frequently leads to significant new discoveries by prospectors and exploration geologists alike. It is often the case however that within old mining districts the land may be tied up for years by individuals and companies who jealously guard their mineral rights. It is therefore important for the geologist to be able to identify new areas where the potential of epithermal gold mineralisation has not yet been fully explored.

During the early 1980s there was a goldrush for hot spring type epithermal deposits throughout the western United States of America. Company geologists were frantically exploring for any ground that showed siliceous sinter outcrop. The companies that were to successfully locate epithermal gold deposits, on the other hand, generally used in-house multiple factor exploration models to target regions that held the greatest potential. Included within those models are the presence of certain suites of industrial minerals and gold pathfinder elements.

### Industrial Minerals as Regional Exploration Guides

Common to many acid hot spring gold systems are a wide variety of hydrothermal alteration minerals, including clays, alunite, sulphur, silica, and others that are potentially useful as industrial raw materials. Because of this genetic tie between a variety of industrial minerals and near–surface hydrothermal activity, regional targeting of hot spring type gold systems is aided by the use of government maps or databases that indicate locations of industrial mineral sites and occurrences.

### Case History 1: Trinity Range, Nevada, United States of America

While exploring for hot spring type gold systems in Nevada the author noted that there was a coincidence of siliceous sinter occurrences with diatomite, and especially with the thickest sequence of diatomite beds within an area. In Nevada, basin-and-range faulting during the Tertiary has created a series of parallel graben basins, and within several of these fault basins large lakes have formed. Reasoning that since diatoms are microscopic organisms with siliceous exoskeletons, they should therefore be most abundant in lakes which had a high influx of nutrients and silica. This would especially be the case where hot springs issued from range-front faults either subaqueously, or along the shores of lakes. Inspection of outcrops adjacent to the Eagle Pitcher diatomite mine in the Trinity Range found that the highway cut through several outcrops of siliceous sinter. Sampling of these hot spring deposits in the highway cuts revealed up to 1.6 g/t gold in these outcrops.

### Case History 2: White River, Washington, United States of America

In the course of a literature search for potential regional epithermal gold targets in the western United States the author noted a report of a large occurrence of alunite along the White River in Washington State. Additionally, during the 1960s a small silica quarry had operated within the envelope of the alunite, and zones of sulphur mineralisation had also been located within the area. This information all suggested that the White River area held potential as a regional hot spring type gold target. Surface examination revealed a major zone of hydrothermal alteration extending over 300 km$^2$, and encompassing large zones and veins of coarsely crystalline hydrothermal alunite. An extensive silica capping, measuring 1.6 km by 5.6 km and up to 200 m thick marks the core of the system. Several zones of hydrothermal brecciation were located with outcrop samples assaying up to 0.25-0.45 g/t gold, and highly anomalous concentrations of mercury, arsenic, antimony and other gold pathfinder elements were also noted.

> **One of the keys to successful regional targeting of acid hot spring type epithermal gold systems is the use of certain industrial minerals (especially alunite, silica, clays, sulphur, and diatomite) as indicators of target areas.**

### Pathfinder Elements

In addition to the industrial mineral suite, there is also a suite of pathfinder elements that are frequently present in hot spring and other epithermal gold vein systems, notably mercury, arsenic, and antimony. In addition to being pathfinders for gold, both mercury and antimony in such systems can form sulphide mineral accumulations in minable abundances, and the location of mercury and antimony occurrences is frequently well documented in geologic literature of the region being investigated. Arsenic can also form sulphide minerals in high concentrations, though arsenic is less desirable as an economic mineral, and consequently is less likely to be reported in regional metallogenic publications.

### Case History 3: The McLaughlin Mine, California, United States of America

The company that is perhaps most responsible for much of the initial development and application of the hot spring type gold model throughout the United States is Homestake Mining Company. Using a company-developed gold target model, which relied heavily on the examination of mercury and antimony mining districts, they discovered the McLaughlin epithermal gold deposit during the late 1970s. This deposit contains over 100 tonnes of gold, with ore grade mineralisation cropping out as veinlets and vein-stockworks crosscutting siliceous sinter. Prior to Homestake's discovery of gold mineralisation on the property, *the siliceous sinter had been mined for mercury.*

### Case History 4: Buckskin Mt., Nevada, United States of America

During a literature search for regional epithermal gold targets the author noted the occurrence of an old mercury mine on Buckskin Mountain. The literature also indicated that small amounts of gold had been mined in the area. Ground examination revealed a mercury occurrence apparently formed in siliceous sinter above an epithermal gold vein system.

### Structure

Several aspects of geology and geochemistry could be addressed in this discussion of regional targeting, but none would be more important than structure. From regional-scale folding and faulting to district-wide basin and range faults, to deposit-scale vein stockworks and breccia zones, structure plays a key role in the location and localization of gold in epithermal deposits.

### Case History 5: The Carlin Gold Belt, Nevada, United Sates of America

There is perhaps no better example of structurally controlled mineral belts than in north-central Nevada, United States of America. Here, the Carlin, Getchell, and Battle Mountain gold belts host numerous gold deposits which are concentrated along three distinct structural trends (see Figure I). Collectively these deposits contain an incredibly large amount of gold — the Carlin trend itself has indicated resources of over 1,600 tonnes of gold (Philip, 1989).

Worldwide, it is the rule rather than the exception that mineral deposits form in clusters or groups. One of the key causalities of this phenomenon is regional tectonics.

> **_The early recognition of major structural patterns along which gold mineralisation is localized may be a principal key to the successful regional targeting of epithermal gold systems.**

## DISTRICT RECONNAISSANCE

Much of what has been said in the previous section can also be applied to district reconnaissance for epithermal gold mineralisation. Orebodies within any particular district frequently exhibit alteration and mineralisation characteristics which are so similar that the detailed study of one deposit frequently leads to the discovery of other local deposits or mineralised zones. District-level aspects which can have useful applications in exploration programmes include structure, pathfinder minerals and alteration suites, reactive host rocks and favorable host environments, groundwater flows, intrusive magma types, and hydrothermal fluid boiling levels, among other physical and chemical variables.

### Vertical Limits of Mineralisation

It is often observed that economic mineralisation within a given epithermal mining district exhibits well-defined vertical limits of deposition. Without knowing the details of physical and chemical variables which may have caused mineralisation to occur only within distinct vertical limits the geologist or prospector can use this information to advantage during district-wide gold exploration.

### Case History 6: Wild Dog, Papua New Guinea

The Wild Dog gold-silver-telluride copper-sulphide epithermal vein prospect is located on east New Britain. Discovered and evaluated by D. Lindley, he quickly rec-

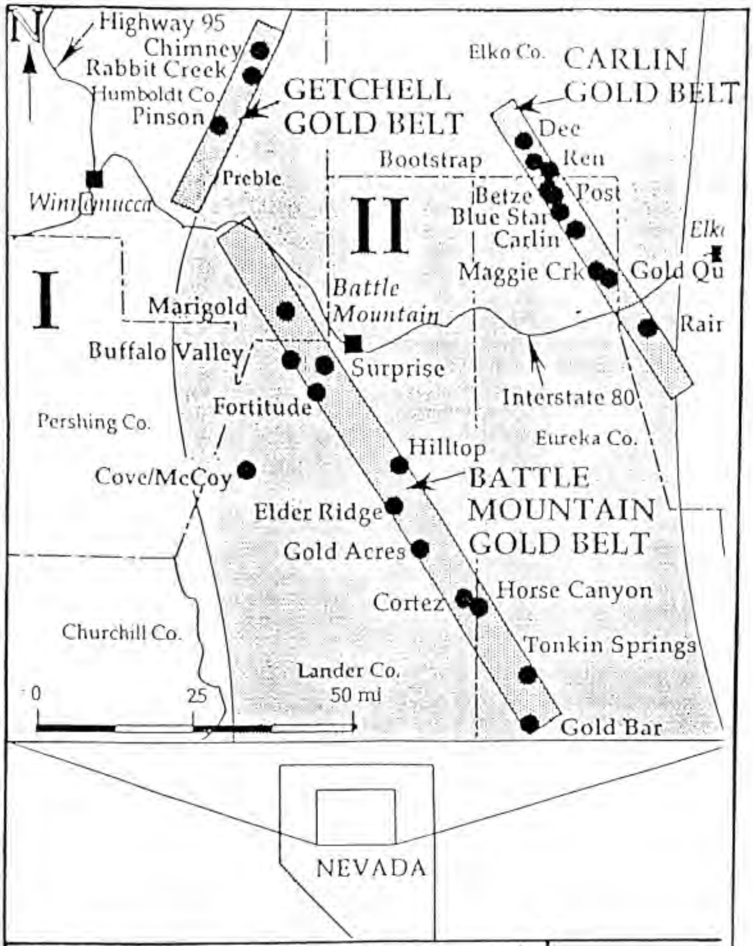

**Figure I.** **Location map of the Carlin, Getchell, and Battle Mt. gold belts of N. Central Nevada.**

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Santa Fe Mining I

ognized the fact that the two major en-echelon vein systems, although locally up to 30 m thick, generally did not crop out above the present-day 960 m a.s.l. elevation. Controls of mineralisation and distributions of pathfinder elements useful to indicate non-outcropping veins at Wild Dog were studied by the author and Adam Wangu of the Geological Survey of Papua New Guinea (GSPNG). We concluded that at the time of mineralisation, the upward extent of fluid-transported minerals was restricted by the presence of a subsurface paleo-watertable, and that within the surrounding area, and possibly district-wide, mineralised vein systems could not be expected to crop out above the present-day elevation of approximately 960 m. Therefore, within the Wild Dog district exploration programmes for epithermal gold veins should rely heavily on the recognition of hydrothermal alteration minerals (clays, alunite, and residual silica) formed by acid steam leaching above a watertable to indicate the location of subsurface hydrothermal conduits. Additionally, fluid-transported elements such as gold cannot be expected to be present in significant quantities above the paleo-watertable, and exploration programmes should be geared to detect gas- and steam-transportable pathfinder elements, such as mercury, arsenic, fluorine, and possibly vanadium.

> **Perhaps one of the most useful and easily recognized exploration characteristics within an epithermal vein district is the vertical range throughout which gold mineralisation is deposited. This knowledge is often directly applicable to surface and underground exploration strategies.**

### Vegetation Anomalies

During district-wide exploration the geologist or prospector should keep an eye out for local vegetation anomalies. There are several common base metal and pathfinder elements which in high concentration can cause stunted or deformed growth in plants. Of the elements associated with epithermal gold systems, arsenic is perhaps the most widely recognized as an agent that stunts or poisons vegetation.

### Case History 7: Mt. Cameron (Tolukuma), Papua New Guinea

The Mt. Cameron or Tolukuma vein system was discovered by Newmont Mining Co. geologists while they were examining a reported occurrence of placer gold. The vein system itself was surmised by a keen-eyed geologist who recognized the presence of a vegetation anomaly on one of the local hilltops. His investigation of this anomaly of stunted and minimal vegetation surrounded by lush jungle growth led to the discovery of gold mineralisation accompanying very high concentrations of arsenic.

As a side note, after Newmont had drilled the vein system and established the presence of significant gold mineralisation, surface samples were collected by geologists of GSPNG which not only revealed the presence of high arsenic and mercury, but also assayed up to 1.68 kilograms (54.5 oz) gold per tonne.

Vegetation anomalies associated with arsenic are also known on various islands in the Tabar – Fenni Island chain, including Lihir Island.

### Choosing Your Target Type

Much of the successful record of discovery of epithermal gold in the western United States has been due to the choice of a trget type which had not been economic in the past. Historically, gold in these districts had been mined from narow high grade vein systems which frequently extended for several hundred metres below low-grade surface sinter deposits. Only when open-pit mining of large tonnage, low grade, gold deposits became economically feasible, could the near-surface portions of high-grade vein systems become realistic targets of exploration programmes.

Because near-surface bulk-minable gold deposits are frequently the upward extension of high-grade mid-level vein systems, knowing the location of either type can lead to the discovery of the other.

### Case History 8: Seven Troughs District, Nevada, United States of America

Gold in the Seven Troughs district was mined sporadically throughout the early to mid-1900s. Mineralisation was generally within tight vein systems in granitic rocks. Ore grades were erratic and frequently miners would dig through large volumes of near-barren quartz vein before encountering a pod of bonanza ore with assays as high as 3 kg gold/tonne. Knowing that those prospectors would not have been interested in low-grade bulk-minable deposits, the author decided to follow these gold-bearing vein systems laterally and vertically throughout the district until they intersected permeable volcanic host rocks. Perhaps the same mineralising solutions, on encountering permeable host rocks would have a good chance to form bulk-minable low-grade gold deopsits. The Wild Cat gold deposit, a small bulk-minable volcanic-hosted gold system was located along-strike of the Seven Troughs gold veins by Emery Roy, a co-worker of the author, using this exploration strategy.

**Sub-economic hot spring type gold occurrences may well be significant pathfinders for high-grade gold veins at depth, and vice versa.**

## NEAR-SURFACE OXIDATION OF EPITHERMAL GOLD SYSTEMS

Any epithermal gold vein system exposed at the earth's surface has been subjected to a series of mechanical, physical, and chemical changes. Even hot spring type gold systems, with surface sinter intact, have undergone at least minor to moderate physical and chemical changes since their time of formation. Some of the changes will have a direct bearing on sampling techniques and the results that can be expected from sampling and assay data.

### Oxidation and Weathering

The oxidation of epithermal gold deposits is a complex subject which is beyond the scope of this paper. As a general reference Blanchard's (1968) Interpretation of Leached Outcrops is highly recommended.

### Case History 9: Sai Mine, Wau District, Papua New Guinea

Mineralisation at the Sai Mine is composed of two distinct economic types, oxidized and reduced. The protore veins are principally composed of manganocalcite, rhodochrosite and quartz with minor amounts of base precious-metal-bearing sulfides and electrum. This pr generally contains 1 to 7 grams of gold per tonne anc to the limited extent of the vein systems, it is curr subeconomic to mine. The present level of oxidati the vein systems is approximately 25 m, and within th metres an abundance of unusually large gold nugget been noted (Figure II). It is believed that gold i protore vein system was put into solution during oxid of manganese carbonate minerals and re-precipitate cally, forming supergene nuggets.

Figure II.

Secondary gold nuggets recovered from the oxidized portion of gold-bearing manganocalcite veins at the Sai Mine, Upper Edie Creek, Wau District of Papua

This phenomenon of supergene high-grade ore in the oxidized portion of low-grade gold-be manganese carbonate veins has been reported in va mining districts throughout the world. Krauskopf ( has addressed the mobility of gold during the oxidati ore deposits and concluded that gold is significantly bile when in the presence of manganese dioxide moderately acid conditions (0.001M HC1).

He also noted that although these conditions been reported to be present in the oxidized portions c deposits, they are so uncommon as to make the app able mobilization of gold a rare and local phenome

**Due to the apparent high mobility of gold in the oxidized portion of manganese carbonate veins, caution must be taken when evaluating these systems not to overestimate their true potential. Frequently near-surface high-grade erratic gold assays associated with manganese dioxide minerals grade downward into protore veins containing low grade to subeconomic gold ore.**

In addition to the local mobilization of gold throu the oxidized portion of manganese carbonate veins, also appears to have been large-scale remobilizati gold in several ophiolite complexes worldwide; it i sible that this remobilization of gold was due t presence of oxides of manganese acting as oxi agents for gold.

### Oxidation of Gold by Vegetation

Another agency for the oxidation of gold i surface environments is the action of plants. One historical methods that prospectors used to employ i search for gold was to shake dirt from the roots of g into their gold dishes for panning. Hence the term "

As it turns out there are dozens of plants throughout the western United States which produce cyanide in their root system. If these plants grow on rocks that contain even trace amounts of gold, the cyanide solutions are capable of oxidizing it along with other elements. Evapotranspiration provides a mechanism for transporting these nutrient-rich solutions (with their gold) towards the plant's root-tips. At the root-tip there is a membrane which filters out particles or elements greater than a certain size. In some plants, gold is drawn in as an impurity within the nutrient-rich solutions. In other plants the gold ion is too large to pass the membrane and is deposited at the root-tip. Over a long period of time gold may thus accumulate as small grains and flakes around the roots of these plants. In the past, prospectors used the presence of such gold as a potential indicator of non-outcropping ore, just as today many exploration geologists take cuttings of plants and have them ashed and assayed for gold.

The role that plants perform in chemically breaking down rock also needs to be fully considered when collecting rock samples. For example, cyanide solutions produced by plants may have already passed through the rock being sampled, and scavenged significant amounts of gold. When collecting rock-chip samples from outcrop it is important to break away the upper rock surface (a zone of possible leaching) and collect the fresh material within.

> **Certain types of plants produce cyanide and probably other chemicals in their root systems capable of oxidizing and transoprting gold from subsurface rock. Panning soil from the roots of plants may be a useful, rapid and inexpensive method of prospecting for non-outcropping gold vein systems, especially in non-carbonate terrains.**

> **When collecting rock chip samples from highly vegetated areas geologists should take into consideration the possibility that cyanide solutions, or other organically produced oxidizing agents, may have already attacked near-surface rock and significantly altered its protore gold content.**

## SAMPLING

With the exception of gold systems which are revealed by evident near-surface native gold, sampling is the mechanism through which nearly all epithermal gold deposits are discovered. An exploration manager commonly allocates a very large percentage of his budget to sample acquisition, analysis, and interpretation. Sampling is possibly the single most important function that a field exploration geologist performs, and regrettably high quality sampling is uncommon. The following is not a discussion of this important subject, but rather a compilation of a few handy hints to aid the prospector and geologist to obtain more meaningful results from their samples.

### High-grading

Sampling techniques should reflect a particular goal. Once an occurrence has been discovered, the goals of a sampling programme are to provide data to define the limits of mineralisation and allow a realistically accurate estimate of potential reserves and resources. During exploration however the first goal of sampling is to locate significant mineralisation.

One approach is to attempt to collect the highest grade samples possible in outcrop. This is frequently easier said than done, but using common sense often increases success. In many epithermal gold systems mineralisation is structurally controlled, i.e., veins, vein-stockworks, and breccia zones are frequently the host of mineralisaiton, and within these epithermal veins gold is commonly hosted by pyrite and other sulphide minerals. Oxidation of these auriferous sulphides generally leaves a residue of limonite (or other iron hydroxides) and native gold grains or micrograins. All too frequently geologists break open these auriferous limonite veins, examine the contents with a handlense, and then casually throw part of the rock into a bag as a sample.

> **The moment that auriferous limonite veins or breccias are broken open there is a great probability that significant amounts of free gold will be lost from the sample. Therefore, when high-grading limonitic vein systems the geologist should include as much intact vein material as possible in the sample.**

### Sample Bags

The three main types of sample bags used by the industry today are cloth, porous synthetic fiber, and plastic. Each type of bag has its advantages and disadvantages, both in cost and performance. However, the choice of the proper bag type can make a great difference in how much gold might be lost from the sample during transport. This is especially true of oxidized rocks that contain free gold, including limonitic veins and breccias. If cloth or porous synthetic fiber bags are used for sample collection of oxidized veins there is a great chance that free gold grains and micrograins will be lost from the sample during transport. This loss can be minimized through the use of heavy gauge nonporous plastic bags and, as noted in the previous section, the collection of large relatively intact samples.

> **For sample collection of epithermal gold vein systems it is recommended that heavy gauge plastic bags be used. Nonporous plastic bags will minimize the loss of native gold grains and micrograins that might be present as a result of oxidation of auriferous sulphide minerals.**

## HYDROTHERMAL ALTERATION OR TROPICAL WEATHERING?

One key aspect to sampling is the recognition of hydrothermal alteration mineral assemblages, and their use in locating potential mineralised vein systems. Although this sounds like an easy task for a competent exploration geologist, the fact is that hydrothermal alteration is frequently misidentified. Either it is present and goes unrecognized, or is absent and is misidentified as being present. Of the alteration mineral assemblages associated with epithermal gold systems, perhaps the most difficult group to identify with confidence are the clays. This is especially true in mountainous equatorial regions where tropical weathering commonly superimposes its alteration of rocks to a great depth.

In a tropical environment the correct answer to the question of whether the clays one sees on the surface are hydrothermal in origin or the result of weathering effects can be crucial to gold exploration programmes. Unfortunately, in many instances this question can not be easily answered, if at all, and may wait upon extensive mapping, geochemical sampling, and even drilling. The problem is rooted in the fact that both hydrothermal alteration and tropical weathering are expressed as a variety of overlapping mineral assemblages, depending on rock type(s) and physical and chemical conditions of alteration or weathering.

### Case History 10: Wild Dog, Papua New Guinea

While studying the epithermal gold vein system at Wild Dog, the author and Adam Wangu (GSPNG) addressed the problem of differentiating tropical weathering effects from hydrothermal alteration. We found that because of the rock types present (generally volcanic flows of basaltic andesite composition and dacitic ash flow tuffs), distinguishing hydrothermally-altered volcanics from tropical weathering effects was relatively simple. Prior to alteration the volcanic flows of intermediate composition contained up to four percent magnetite, and approximately one per cent magnetite was present in the fresh ashflow tuffs.

During hydrothermal alteration, the very generalized sequence of least altered to most altered rocks at Wild Dog is: (1) propylitic alteration where epidote, calcite, albite, zeolites and minor pyrite form at the expense of calcic plagioclase and mafic minerals; (2) argillic and advanced argillic alteration produced kaolinite, various other clays and alunite. Intergrown with kaolinite are abundant finely disseminated pyrite grains as pseudomorphs of altered mafic minerals, and intergrown with alunite are minor amounts of pyrite. Importantly, magnetite is destroyed during the process of hydrothermal argillic alteration; (3) silicification, both as massive pseudomorphic replacement of volcanic rocks and as vein-filling milky quartz.

At Wild Dog tropical weathering produced a mineral assemblage similar to that of hydrothermal propylitic alteration, but with pyrite conspicuously absent. This weathering also produced a high clay content in the volcanics, similar to hydrothermal argillic alteration. Pyrite was absent from the weathered rocks and additionally, magnetite remained present in amounts similar to those in the unaltered volcanics.

Therefore, at Wild Dog the following criteria were used to indicate the presence of hydrothermal alteration in the volcanics:

- The presence of abundant fine-grained pyrite as pseudomorphs of mafic minerals in a matrix of kaolinite and other clays.
- An absence of magnetite from rocks which when fresh contain 1-4 per cent of this mineral.
- The presence of abundant veins and veinlets filled with quartz and other weathering-resistant minerals.

Similarly, the following evidence was used as the indicator of tropical weathering imposed on volcanics which have not undergone hydrothermal alteration:

- The absence of pyrite from rocks which contain abundant clays, or which appear to have undergone propylitic alteration.
- The presence of magnetite in rocks which contain abundant clays.

In addition to the above criteria, mapping of soil types and geochemical analysis of soil samples are very useful in helping to determine the presence of mineralised hydrothermal conduits.

**In volcanics of intermediate composition, the presence of abundant fine-grained pyrite intergrown with clays is generally an indicator of hydrothermal alteration. Conversely, the presence of moderate to abundant magnetite in clays indicates that the volcanics have not undergone hydrothermal argillic alteration, and that the clays most probably formed by intense surficial weathering.**

## CLOSING REMARKS

It is with regret that the above subjects could not have been addressed in more detail, and that additional subjects could not have been added. Perhaps the most important thing to gain from this information is to realize that the author acquired most of it during interaction with other geologists and prospectors. The greatest result that this Epithermal Gold Workshop can produce is to leave all of us with a willingness to listen to others and think, really think, about what they say. Then to modify or adapt that information as necessary and apply it to our own exploration programmes.

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# MERCURY IN SOILS AND SOIL-GAS OVER EPITHERMAL DEPOSITS AND GEOTHERMAL AREAS

by
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## 1. INTRODUCTION

Explorationists are coming to the realization that the days of easy prospecting are over. We find more and more frequently that search leads us to areas covered by barren, exotic overburden. If we are to discover new mineral deposits, we have to develop new geochemical techniques to "see through" this overburden. One such technique is to look for gaseous indicators that emanate from buried ore deposits.

Many different gases are emitted by the earth's crust, and anomalous amounts of such gases may be emitted by various forms of mineralization either as primary exhalations in response to weathering, raising the possibility of using gas-sampling of the atmosphere, soil-gas in pore spaces, or gases adsorbed by solid media such as soils, rocks and stream sediments as a means of geochemical prospecting. Among gas surveying procedures useful in the search for ore deposits, particular attention has centred on the use of mercury in base- and precious-metal prospecting, radon in uranium prospecting, and hydrocarbons in petroleum prospecting.

Recently Hg pathfinder techniques have become one of the routine techniques in geochemical exploration, in particular in the search for young epithermal precious metal deposits and geothermal fields on the Circum-Pacific rim, from Japan, the Philippines, Indonesia, Papua New Guinea, Solomon Islands, Fiji to New Zealand in the western Pacific, and in the western United States of America and Central and South American countries on the eastern Pacific.

The analogy between an epithermal mineralization system and an active geothermal system has been the subject of a number of studies, and it is believed that the epithermal system may be a fossil geothermal system. Active geothermal systems provide the opportunity for studying the deposition of trace metals such as gold and the initial concentrations of ore-forming elements in the deep system. Since active geothermal systems are relatively similar in terms of their distribution of alteration mineral assemblages, they may be used to provide key data on the level of exposure within a fossil system; clay mineral assemblages are quite sensitive indicators of temperature of formation. Similarly the recognition of trace-element enrichments (Au, As, Hg, Tl) provides a clue to structural level in the system. The documentation of high concentrations of the characteristic "ore elements" Au, Ag, Sb, Hg, W and Tl in the surface discharge of active geothermal systems and epithermal systems strengthens the analogy relating both systems (Weissburg et. al., 1979; White, 1981). These elements are presently being deposited in surface sinter above geothermal fields, and often are referred to as "epithermal" elements. Among these elements, mercury has seen use as a pathfinder element in pospecting geothermal fields and base- and precious-metal deposits since the 1960s.

The fact that many mineral deposits do emit mercury which can be detected in soil-gas and soils has been documented by many authors. This paper presents a brief review of the generation and migration of mercury, how mercury in the atmosphere, soil-gas and soils can be sampled and analyzed, some factors affecting Hg anomalies and its use on active geothermal fields and over epithermal precious metal deposits in geochemical exploration. Previous works carried out on various ore deposits are also reviewed.

## 2. GEOCHEMISTRY OF MERCURY

The vapor pressure of Hg at ambient temperatures is significant (13 and 22 ng/mL at 20° and 25°C, respectively) and this factor alone has led to the concept of the vapor-generated anomaly. The solubility of the element in water is also high, where the level exceeds that in the vapor phase by roughly a factor of three. The partition coefficient therefore favours the liquid phase and this has practical consequences. Mercury is significantly soluble in a number of organic solvents which is of possible relevance in organic-rich soils. Within the normal range of soil parameters, Hg can exist in the ionic or associated forms HgCl, $Hg(OH)_2$ and $HgCl_2$, and as elemental Hg in

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soil within various solid phases. The presence of gaseous phase Hg in soil is therefore understandable although it is evident that under conditions of equilibrium the level of free Hg in aerated chloride-containing soil will be low. It can be expected that similar equilibrium conditions apply to the aqueous solutions deriving from sulfide oxidation, since the sulfate ion does not interact strongly with several Hg species. However, much of the Hg contained within soils and weathered rocks is more or less firmly associated with the solid phases, by various bonding mechanisms ranging from simple sorption to structural incorporation within oxidate minerals. The manner of the organic matter-Hg association is clearly important. In general, an important part of the geochemical cycle of mercury is controlled by a disproportional reaction (Jonasson and Boyle, 1972):

$$2Hg^{+1} \rightleftharpoons Hg^{\circ} + Hg^{+2}$$

During the weathering or hydrothermal alteration of small amounts of sulfides and other minerals containing trace amounts of mercury, mercury is released in the $Hg^{+2}$ form. The $Hg^{+2}$ can be reduced by $Fe^{+2}$ or organic matter to either or both $Hg^{+1}$ or $Hg^{\circ}$. Any $Hg^{+1}$ produced in the reduction can be disproportionate to $Hg^{\circ}$ and $Hg^{+2}$. This leads to a net production of $Hg^{\circ}$, which can diffuse upward through the weathered capping soils.

Factors affecting mercury distribution in the surficial environment are shown in Table 1.

**Table 1. Factors affecting mercury distribution in the surficial environment (After Hoffman, 1986)**

| FACTOR | REMARKS |
|---|---|
| Mercuric chloride and other soluble forms of Hg | Can be transported in groundwaters and form hydromorphic Hg anomalies at sites remote from the bedrock source |
| Mineralized float | Cinnabar can be transported as a heavy mineral and accumulated elsewhere under favourable conditions |
| Soil and overburden | |
| Organic content | Hg vapor and ionic Hg can be adsorbed at the base of the organic layer |
| Texture | More porous overburden will promote dispersion of Hg vapor |
| Bedrock structure | Hg emanations will concentrate along brecciated zones within faults giving a greater than normal flux of Hg to the soil |

## 3. SAMPLE MEDIA AND SAMPLING

The use of gaseous species of Hg in geochemical exploration potentially offers a significant advantage over techniques involving solid media. Measurement of Hg in the open air is complicated by wind dispersion. Soil-gas measurements are not as strongly affected by secondary dispersion processes as are atmospheric measurements. Measurements of Hg in a solid media such as soils, rocks and stream-sediments are more quantitative than those in the atmosphere or soil-gas.

Determination methods of Hg in each sample medium are shown in Figure 1. The principle of the methods remains the same, and Hg detectors of various kinds are available commercially.

### 3.1 Mercury in the atmosphere

Klusman and Webster (1981) determined the time variation in mercury and radon emission for one year at a single unmineralized site and attempted to relate these variations to simultaneous measurements of meteorologic and other variables which might influence the gas emission process. A preliminary analysis of a year's data indicated a rather strong seasonal influence on Hg emission rates, but with important shorter-term fluctuations; Hg concentrations in the atmosphere average 9.5 $ng/m^3$ and range from less than 1$ng/m^3$ to 53$ng/m^3$. Important short-term fluctuations of Hg in the atmosphere can be caused by air temperature, soil temperature, barometric pressure, level of water table and the frozen state of the soil.

Recently the use of airborne and vehicle-borne detections for atmospheric Hg has been tried experimentally over known mineralized zones, but so far only very limited technical success has been reported. The utility of Hg in the atmosphere for geochemical exploration is still open to question.

### 3.2 Mercury in soil-gas

Experiments with Hg contained in soil-gas have shown much more promise, mainly because the results are much less affected by short-term meteorological changes. One approach is to insert an inlet tube into a soil auger hole, then pump soil-gas through a portable spectrometer for immediate analysis. Rather than performing a field analysis, a gold foil or wire is inserted in the pumping line to collect Hg by amalgamation from a relatively large volume of soil-gas; the collected Hg is subsequently released from the collector by heating, and measured under laboratory conditions. This approach has been tested under laboratory conditions and recommended by McNerney and Buseck (1973). A third approach is to omit pumping soil-gas by leaving a gold foil or wire collector suspended for several hours or days in an auger hole, or placed in a plastic hemisphere above the soil. The collector methods

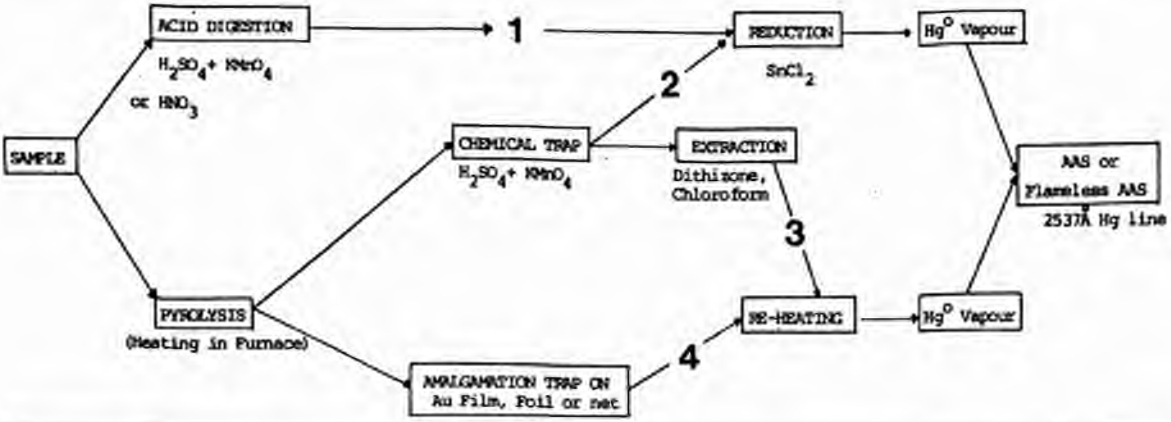

**Figure I. Analytical methods for mercury in soils and rocks.**

*Note 1:* If the sample contains a considerable amount of sulphides or organic matter, buffers such as $K_2CO_3$ or CaO are added.

*Note 2* In some cases, to remove $SO_2$ and $CO_2$, a soda-asbestos tube is set up between the furnace and amalgamation trap.

improve sensitivity and precision but lose the speed of operation offered by field analysis.

Concerning Hg in soil-gas, some comparative studies were published during the 1960s; most of them concluded that Hg had no advantage over the other elements tested in soil surveys (mainly in Canada). With the introduction in the late 1960s of instrumentation of very much higher sensitivity it became possible to analyze Hg in soil-gas and air in a field situation. McCarthy (1972) reviewed publications describing the use of Hg vapor in exploration. McNerney and Buseck (1973) conducted studies of the distribution of Hg in soil-gas above precious- and base-metal deposits in Arizona and Nevada and were able to identify significant anomalies in some cases. However, no other geochemical evidence was provided which would indicate whether the Hg vapor resulted from the presence of blind or buried mineralization, or the near-surface breakdown of Hg-bearing phases. Wu and Jin (1981) compared the distribution of Hg vapor over a deeply buried (more than 150 m alluvium) skarn Cu deposit near Shanghai, China and showed Hg soil-gas anomalies of up to 400 ng/mL over a background of 15 ng/mL.

The Australian CSIRO group, as represented for example by Wilmshurst and Ryall (1980), claim that the approach is regaining popularity and is particularly relevant in exploration in deeply weathered terrain. Many general claims have been made by this group about the distribution of Hg in and around sulfide deposits, but few rigorous investigations have been published. One detailed study in Australia has been described by Ryall (1981a) who investigated the distribution of Hg around several Pb-Zn-Ag lodes to clarify the behaviour of Hg during metamorphism and to evaluate its potential as a pathfinder element for blind deposits. This study concluded that Hg may be liberated from sulfide deposits during moderate to high temperature metamorphism, resulting in a bedrock dispersion halo of Hg useful for exploration of blind metamorphosed deposits, and that metamorphic loss of Hg may be sufficiently great to limit the use of Hg dispersion as an exploration tool in situations where the metamorphosed deposit has been exposed to weathering processes. He found that prograde metamorphism to granulite facies has resulted in recrystallization and remobilization of sulfides but considerable quantities of Hg remain within sphalerite and tetrahedrite structures. Therefore, surficial Hg dispersion haloes could develop during oxidation of analogous metamorphic deposits. In contrast, fresh wall rocks near the lodes do not reveal Hg dispersion haloes.

CSIRO group, Carr, Wilmshurst and Ryall (1986) carried out a comparative study of Hg in soil-gas for twenty-nine base-metal deposits in Australia. The data from these studies have led to the following conclusions regarding the possible role of Hg in exploration for base metals:

(a) Hg is present in sufficient concentration in many styles of mineralization to be a potential pathfinder, and metamorphism does not affect Hg haloes.

(b) Hg tends to give residual anomalies with little observable secondary dispersion. Situations have been defined where the element is a valid pathfinder. However, in general exploration Hg has no special advantage over the target elements, Cu, Pb and Zn.

(c) Hg may, under certain conditions, indicate buried mineralization.

(d) The use of gas-phase sampling is appropriate only in quite specific circumstances; soil is almost always the preferred sample medium.

(e) Hg determinations can be made at or below background levels in a routine manner if certain requirements are observed.

It can be concluded from the above studies that Hg is commonly associated with many ore deposits, but its behaviour is not always predictable. For example, Azzaria and Carrier (1976) found that whilst porphyries associated with porphyry copper mineralization at Murdoch in Quebec contained higher Hg levels than porphyries considered to be unrelated to mineralization, the actual Cu deposits occur within haloes of lower Hg content than surrounding country rock.

Since the middle of the 1970s, the determination of volatile components such as Hg, $CO_2$ and Rn in soil-gas has become one of the most useful and used exploration tools in the delineation of active geothermal fields. This is because these volatile components can migrate from deep geothermal fluids to the surface through fractures such as faults and veins (White et al., 1970; White, 1981). The analogy between an epithermal mineralization system and an active geothermal system has been well-demonstrated by a number of studies, and therefore the use of Hg in soil-gas and soils around the epithermal ore deposits in geochemical exploration has found many recent applications.

### 3.3 Mercury in soils, rocks and ores

Although the volatility of Hg requires that care be taken in preventing contamination or its loss from soil samples, the techniques do not differ from those commonly used in soil sampling. In general, soil sampling is performed at 40 to 100 cm dephs by using a hand auger. After sampling, soils are carefully sealed in plastic bags for storage and transport. Drying of soil samples is achieved by opening the sample bags to the atmosphere at ambient temperature in an environment determined to be free of significant Hg contamination. The dry samples are lightly crushed as necessary and sieved through nylon mesh after removing obvious organic fragments.

Rocks and ore samples are crushed in a percussion mortar and then ground to about 200 mesh in an agate mortar.

Analytical procedures are shown in Figure 1.

## 4. Bibliography

A bibliography relating to the chemistry, geochemistry and determination of mercury in the natural environment is given at the end of this paper. A number of significant case histories are included.

## 5. Conclusions

The results of a broad spectrum of work on mercury as a geochemical indicator element show that mercury in solid material, namely soils and rocks, should be a useful indicator of epithermal gold deposits. Soil gas is also a useful medium, though the interpretation of results is not easy because its behaviour is not always predictable. The use of atmospheric mercury determination has not yet been established as a reliable technology.

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# CHARACTERISTICS OF GOLD IN ALLUVIAL DEPOSITS AS INDICATORS OF EPITHERMAL-MESOTHERMAL, PORPHYRY COPPER-MOLYBDENUM, AND ULTRAMAFIC/OPHIOLITE SOURCES

by
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The first major discovery of gold in Papua New Guinea took place on Sudest Island in 1888. There, approximately 10,000 ounces of gold were produced from alluvial gravels before the deposits were exhausted 4 years later. As production of gold from alluvial gravels diminished, exploration for lode gold deposits increased. Thus began a pattern of gold exploration and exploitation throughout Papua New Guinea by which rich alluvial gold deposits were located and mined first, followed by exploration for lode gold deposits in the uplands of the same alluvial zones.

In fact, the study of alluvial gold frequently discloses much useful information about the type of deposit from which the gold has been shed. Gold in several of the alluvial deposits throughout Papua New Guinea exhibits either genetic or spatial characteristics which tie them to one of three major sources of alluvial gold. These sources are individual epithermal- mesothermal vein systems, large intrusive porphyry copper-molybdenum deposits, and ultramafic–ophiolite complexes. Thus the information gained from the study of alluvial gold deposits can be important to regional exploration programmes for lode gold deposits.

## ALLUVIAL DEPOSITS

Alluvial gold deposits in Papua New Guinea have been an important source of income for both individual miners and companies, having produced some 4,000,000 ounces of gold since the early Sudest Island period. There are 19 major past and presently producing alluvial goldfields throughout Papua New Guinea. Fifteen of these are located on the main island, with the remainder located on Bougainville, Woodlark, Misima, and SudestIslands (Figure I). The principal alluvial deposits on Bougainville are genetically related to porphyry copper mineralization, and the latter three deposits are associated with epithermal-mesothermal vein systems.

By far the greatest alluvial gold production came from the Morobe Goldfield, location of the Wau-Bololo and Edie Creek deposits. Here 3,200,000 ounces of gold have been produced from alluvial gravels since the 1920s. The most important recent gold find was made at Mt. Kare. Discovered in February 1988, between 225,000 and 250,000 ounces of gold have been produced during the first year by Papua New Guinea miners using simple panning techniques.

## CHARACTERISTICS OF GOLD IN LODE AND ALLUVIAL DEPOSITS

The size, morphology, and fineness of gold grains in alluvial deposits is not only a function of distance transported, but of the type of source deposit from which they were eroded. The following information is based on both empirical observations and scientific data regarding the relative differences in several characteristics of gold, based on source deposit type (seeTable 1).

### Gold in Porphyry Copper Deposits

Placer gold from porphyry copper sources is often fine grained and exhibits few, if any, crystal faces. For example, polished section studies of mineralization at the Ok Tedi porphyry copper deposit show that gold grains are invariably anhedral in morphology. Most gold in the gold cap at Ok Tedi is on the order of 50 microns in size (Seegers, pers. comm., 1989). Because of the relatively small grain size, gold grains tend to flatten quickly in an alluvial environment and impurities such as silver and copper are readily leached, increasing the gold's finesess.

Alluvial gold deposits associated with porphyry copper systems are characteristically large in area and often extend into several drainages or drainage systems.

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**Table 1. Characteristics of gold in alluvial deposits and probable source(s). Characteristics that are particularly indicative of a certain source type are shown in bold face.**

| *Probable Source of Alluvial Gold* | *Size of Gold Grains* | *Morphology of Gold Grains* | *Fineness of Gold* | *Inclusions* | *Extent of Alluvial Deposits* |
|---|---|---|---|---|---|
| Epithermal–Mesothermal Vein Systems | Very wide range from dust size grains to ***large nuggets*** weighing 10's of ounces. | Anhedral to a distinctive ***interlocking network of octahedral crystals.*** | Highly variable (550-850) with ***low fineness most distinctive*** of epithermal veins. | ***Numerous.*** Frequently contains soluble and volatile elements (Ag, As, Sb, Cu, Te) as ***sulfosalts and tellurides.*** | Limited extent. Generally within a few drainages. |
| Porphyry Copper-Molybdenum Deposits | Generally small 50 microns to a few mm and up to 10 mm in skarn deposits. | Anhedral. | Medium (700-800). Skarn deposits may contain gold of higher fineness. | Moderate. If gold-bearing skarns are present, inclusions of ***calc-silicate and iron oxide minerals*** are common. | Extensive. Often present in several drainage systems. |
| Ultramafic/Ophiolite Terrains | Small to medium size a few mm to <10 mm. Large supergene nuggets can form during lateritic weathering | Anhedral. | ***High.*** Mostly greater than 900 fine. | Few. ***Inclusions of PGE's are diagnostic.*** Silver minerals are rarely present. | ***Very extensive.*** Throughout several river systems draining a terrain. |

## Gold in Ultramafic/Ophiolite Complexes

Alluvial gold-PGE (platinum group elements) and gold-chromite deposits throughout Papua New Guinea are associated with ultramafic/ophiolite terrains. Magmatic gold commonly occurs in these rock types as small disseminated grains of native gold or more commonly gold-bearing sulfides. Gold in ultramafic cumulates often has a larger grain size and is widely dispersed as a native metal, as gold-bearing sulfides, or as gold-PGE alloy. Serpentinization of these oceanic rocks releases intergrowth gold from the sulfides and native gold from the tightly-held rock matrix. Alluvial gold-PGE and gold-chromite deposits shedding from oceanic terrains in the country are typically very extensive, covering several river systems. The gold in these deposits has a distinctly high fineness, – in the case of gold shedding from the Papuan Ultramafic Belt a fineness of up to 920 has been noted (Davies, 1969). The average fineness of 52,500 ounces of alluvial gold shed from the Prince Alexander Mountains, a mafic and ultramafic terrain in the northwestern part of Papua New Guinea, is 900-940 (Grainger and Grainger, 1974). The presence of platinum group elements or chromite in alluvial gold deposits is also indicative of ultramafic source terrains.

## Gold in Epithermal-Mesothermal Vein Systems

The largest proportion of alluvial gold mined in Papua New Guinea has an epithermal, and to a lesser extent mesothermal, vein source. This includes 3,200,000 ounces of gold won from alluvial gravels in the Wau-Bulolo and Edie Creek areas, which together comprise the Morobe Goldfield. Historically, the presence of alluvial gold deposits in the area has led to the discovery and mining of several lode gold veins. The discovery of the Hidden Valley lode gold deposit in 1986 was a direct result of the follow-up investigation of known alluvial gold workings.

Gold in vein systems throughout the country is marked by wide variations in grain size, morphology, and fineness characteristics which often overlap with the charcteristics of gold from the other two major sources. When used together, however, the combination of characteristics often determines the type of source deposit from which the alluvial gold originated.

### Grain Size

The size of gold grains often varies dramatically within individual epithermal deposits and between different vein systems. In the Lihir Island epithermal-mesothermal deposits, gold is predominantly of micron-size and is tied up in sulfide minerals. In the Wild Dog gold-silver telluride copper-sulfide epithermal vein system gold grains are again characteristically only a few microns in size and are intergrown in sulfide or telluride minerals. Alluvial gold deposits associated with epithermal vein systems that contain micron-size gold are generally low in grade and of limited extent.

Other gold districts, such as the Wau-Bulolo and Edie Creek area, shed a constant supply of unusually large nuggets into the alluvial system. Recently two potato-size nuggets weighing 20 and 32 ounces were washed from gravels of the Bulolo River. Large gold nuggets are also abundant at the newly discovered Mt. Kare deposit. It appears clear that most such gold nuggets coming from Mt. Kare are clasts of gold-quartz veins that were broken apart during a landslide event. Whether these originally massive gold veins were epithermal or mesothermal in nature has yet to be determined, and studies of their genesis are currently in progress.

## Morphology of Gold Grains

In several alluvial gold deposits the morphology of the gold grains is especially useful as an indicator of the presence of epithermal-mesothermal vein systems. Because of the open-flow nature of many of the epithermal systems, gold can be deposited as interlocking crystals that fill veinlets, breccia zones, and other open spaces. Highly crystalline gold is present in veins at the Porgera deposit, where it occurs commonly as arborescent crystal groups, with crystals elongated in the direction of one of the 3-fold symmetry axes. At Mt. Kare a large majority of the gold grains and nuggets exhibit a highly crystalline morphology. There, gold is frequently present as nuggets or sheets of interlocking crystals flattened parallel to an octahedron face. This morphology is most distinctive nearest the source veins, as all gold grains tend to become rounded and flattened as they have travelled in alluvial systems.

Highly crystalline gold is also present in several of the epithermal veins in the Morobe Goldfield. There, gold exhibiting a dendritic or acicular morphology is common in the oxidized portion of epithermal gold-bearing manganocalcite veins. It is likely that this dendritic and acicular shaped gold is supergene, the result of remobilization in the presence of the oxidation of manganese-bearing minerals.

## Gold Fineness

The fineness of gold in epithermal vein systems varies widely and cannot be used by itself as a diagnostic characteristic of deposit type. However, it is very common in Papua New Guinea for epithermal vein systems within individual districts to have a narrow range of gold fineness. For example, the fineness of gold in the Wau-Bulolo alluvial deposits is commonly 550-650. This low gold fineness is also characteristic of the epithermal veins systems that are found in the area. The range of gold fineness at Mt. Kare, based on 600 analyses of more than 70,000 ounces of gold, is generally 800-820, and this narrow range of gold fineness is very distinctive of alluvial gold from that area. At Porgera, gold in alluvial deposits generally has a fineness within the 740-780 range, also reflective of the fineness of lode gold within the epithermal-mesothermal vein systems at Porgera.

## Inclusions

It is much more common for gold grains shed from epithermal vein systems to contain inclusions of other minerals than it is for gold grains shed from porphyry copper-molybdenum deposits, or gold grains shed from ultramafic/ophiolite terrains. This phenomenon is the result of several processes, including:

1. The rapid changes in pH, Eh, temperature, and chemistry of epithermal solutions. These rapid changes often lead to high rates of deposition of minerals in epithermal systems, relative to the slower deposition rates of minerals in porphyry and magmatic systems. High rates of deposition often trap, or include, various minerals with gold as a result of disequilibrium crystallization conditions;
2. The relatively larger size of gold grains and sheets in many epithermal systems allows more inclusions to be incorporated within them, and also for those present to be better preseved from mechanical destruction within the alluvial environment; and
3. The common presence in epithermal systems of an abundance of soluble or volatile trace elements such as silver, arsenic, antimony, mercury, copper, and tellurium, which can form sulfosalt or telluride mineral exsolutions or inclusions within gold grains.

Alluvial gold from Enga Province commonly hosts numerous inclusions of sulfosalt and telluride minerals, characteristic of the epithermal-mesothermal vein systems from which they derived. The Wild Dog epithermal vein system contains a mixture of gold-silver telluride and copper sulfide minerals (Lindley, 1987), and gold shedding from this system can similarly be expected to contain inclusions of silver and copper sulfosalts and tellurides.

Frequently, alluvial gold near an epithermal vein source also hosts inclusions of host rock or gangue minerals such as quartz and (less frequently) mica or carbonate. Analysis of these types of inclusions can be extremely useful in determining the genesis of the gold. Especially useful are studies of fluid inclusions and cross-cutting vein relationships, if such are evident in the small fragments.

Inclusions in (or with) gold may also indicate deposit types other than epithermal vein systems. For instance, alluvial gold deposits were recently examined near the village of Atamo, on Bougainville Island. Some of the gold grains examined were intergrown with magnetite and epidote, indicating that the source could be a gold-bearing skarn deposit. Follow-up work in the area confirmed this speculation.

## SUMMARY

Much information can be gained about gold deposit types within a drainage by examining the characteristics of local alluvial gold deposits. Gold shed from epithermal-mesothermal vein systems is in many respects distinct from gold shed from porphyry copper-molybdenum deposits or ultramafic/ophiolite complexes.

Following is a summary of the characteristics of alluvial gold deposits that, when used in combination, may help to determine the type of deposit from which the gold was shed.

### Epithermal-Mesothermal Vein Systems

1. Numerous inclusions of sulfosalt and telluride minerals.
2. Highly crystalline gold grains forming interlocking networks and plates.
3. Large nuggets.
4. Low gold fineness (500-700) is common.
5. Gold-bearing alluvial deposits limited to one drainage.

### Porphyry Copper-Molybdenum Deposits

1. Gold intergrown with skarn minerals such as magnetite, epidote, and garnets.
2. Fine to medium grain-size of gold.
3. Gold-bearing gravels extending over several drainages.

### Ultramafic/Ophiolite Terrains

1. High gold fineness (>900).
2. An abundance of platinum group elements (PGEs) or chromite within the alluvial deposits, and PGE intergrown or alloyed with gold.
3. Gold-bearing gravels extend over several river systems.

The information in this paper is a combination of empirical observations and scientific evidence. For the most part the characteristics discussed above require only a binocular microscope and simple geochemical tests. The results, however, can be most useful to any regional gold exploration programme in South East Asia.

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Figure I. Location of Alluvial Gold Distr
Papua New Guinea. After A. V
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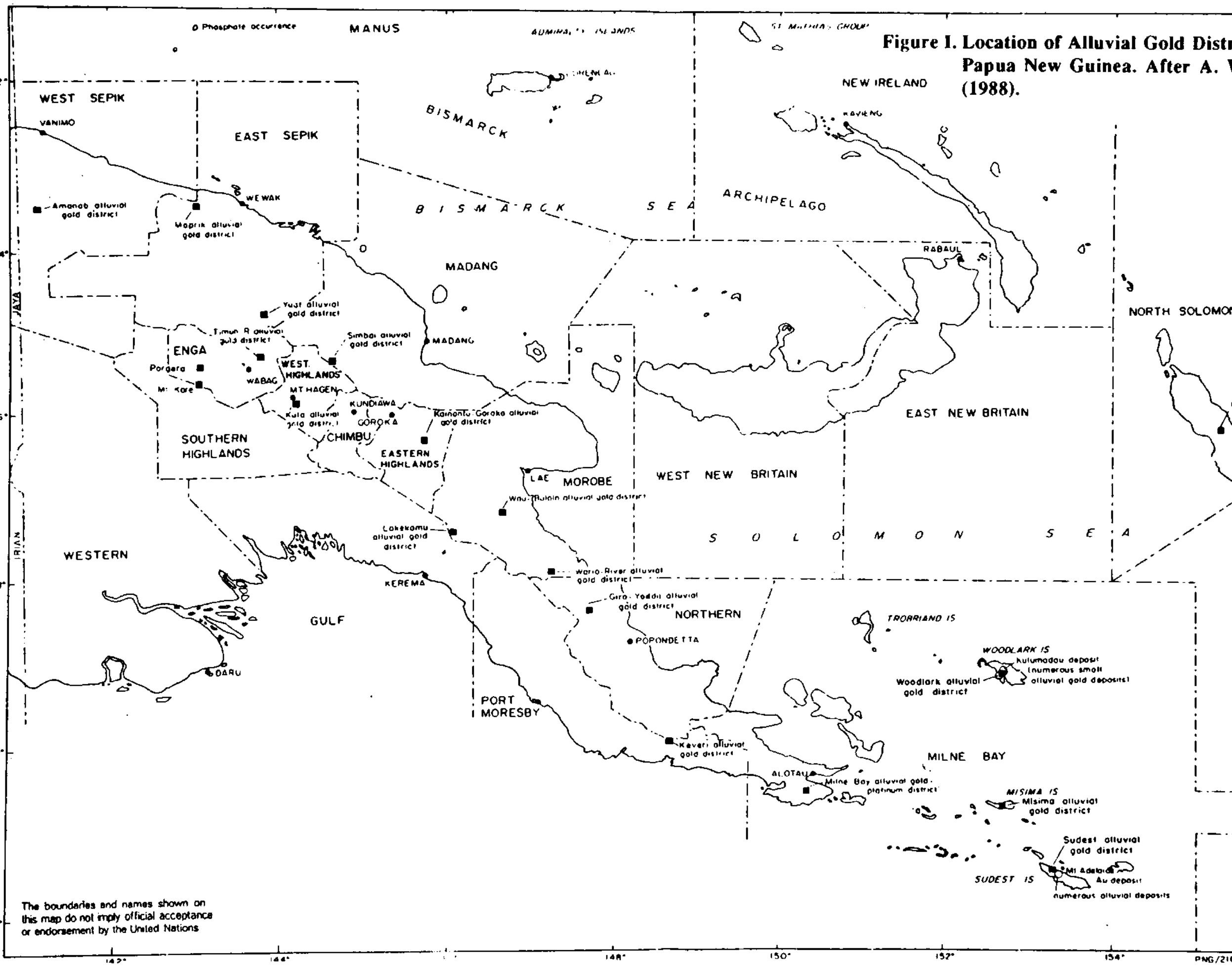

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# THE KELIAN GOLD DEPOSIT, EAST KALIMANTAN, INDONESIA: THE EXPLORATION HISTORY OF A DISSEMINATED GOLD ORE BODY

by
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P.T. Kelian Equatorial Mining, Indonesia[1]

## INTRODUCTION

The Kelian gold deposit occurs in the Indonesian Province of East Kalimantan, on the island of Borneo (Figure I). Kelian is one of a number of Tertiary-age volcanic-hosted gold deposits which occur within a 400-kilometre long by 30-kilometre wide northeast trending volcanic corridor which extends from Central Kalimantan to Central East Kalimantan.

The deposit was discovered in 1976 during follow-up work on alluvial gold deposits in the Kelian River valley. Using the traditional exploration techniques of stream sediment, pan concentrate, rock float and outcrop sampling, the source of the alluvial gold was traced to an area known as Prampus. This initial discovery led to some five years of semicontinuous exploration, utilizing geological mapping, soil, deep-auger, pit, trench and outcrop sampling and several diamond-drilling programmes. These investigations delineated two major ore bodies, West and East Prampus. A major work programme commenced in 1986 after the signing of the Contract of Work (COW) with the Indonesian Government. This programme included further soil and auger sampling, a geophysical IP/resistivity survey, an intensive diamond drilling programme to accurately define both the oxide and primary sulphide ore reserves, and detailed metallurgical and geotechnical studies.

The direction in which the exploration of the Kelian deposit has proceeded at any time has been influenced by the interplay of a number of factors, including the geological understanding of the deposit, the price of gold, metallurgical testwork results and company philosophy. The work to date has outlined a geological reserve of around 77.9 million tonnes grading 1.8 g/t gold in the Prampus area. Although the resource has not yet been fully delineated, the Kelian gold deposit is the largest known gold deposit in Indonesia.

## GEOLOGY

The geology, mineralogy and geological model for the Kelian deposit have been discussed in detail in van Leeuwen et al. (1990) and are shown in Figures II and III. The following is a brief summary.

The geology of the deposit consists of a pile of silicic pyroclastics grading upwards into a series of siltstones, sandstones, minor limestone and carbonaceous lenses of Eocene age. The sequence was folded and faulted along north and northeast trends. A number of alkaline-calcalkaline andesitic bodies intruded the axial region of a regional anticline, probably during the early Miocene. Sometime after the intrusion of the andesites a hydrothermal system was established in the area. This polyphasal event brought about extensive alteration and mineralisation of the country rocks. Ore-grade gold mineralisation is concentrated in the West and East Prampus ore bodies, and several smaller mineralised zones. The mineralisation is closely related to several of the andesite intrusions. The characteristics of the deposit show affinities with both porphyry and epithermal styles of mineralisation. The deposit may represent a transition between the two styles.

## HISTORY OF DISCOVERY, PHILOSOPHY AND RESULTS OF EXPLORATION

### Initial Exploration

As part of investigations into the potential for alluvial gold deposits in the upper Mahakam River area, geologists from Rio Tinto Indonesia (RTI) made the first visit into the Kelian River catchment in April 1975. At this time there were small numbers of miners working the alluvial gravels using panning and pitting methods. Panned concentrate samples were taken of both fixed and active sediments. All stream sediment samples assayed gold. Some pits were also sampled. The gold particles observed occurred as slivers, rods and wires and thick pitted flakes and chips, characteristics which suggested an unreworked derivation from a nearby source. The high gold values in the active alluvium and the very rich gravel deposits along

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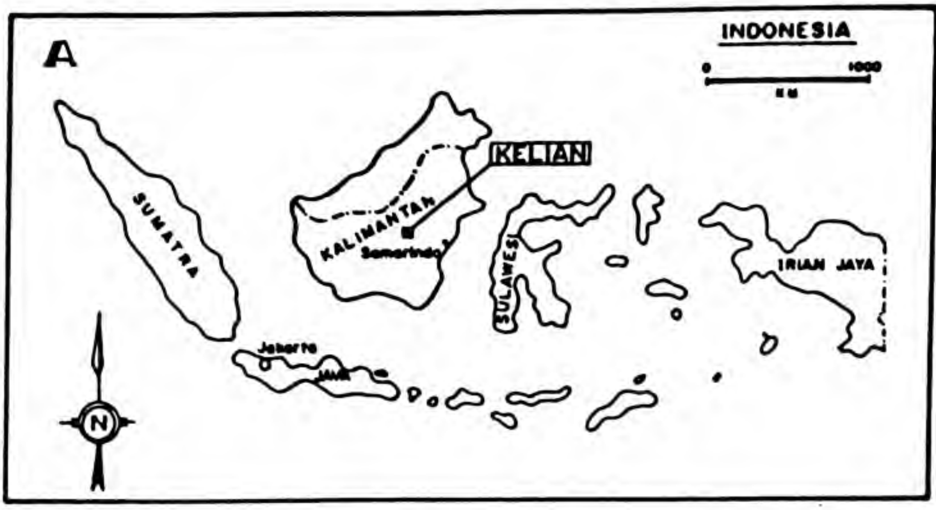

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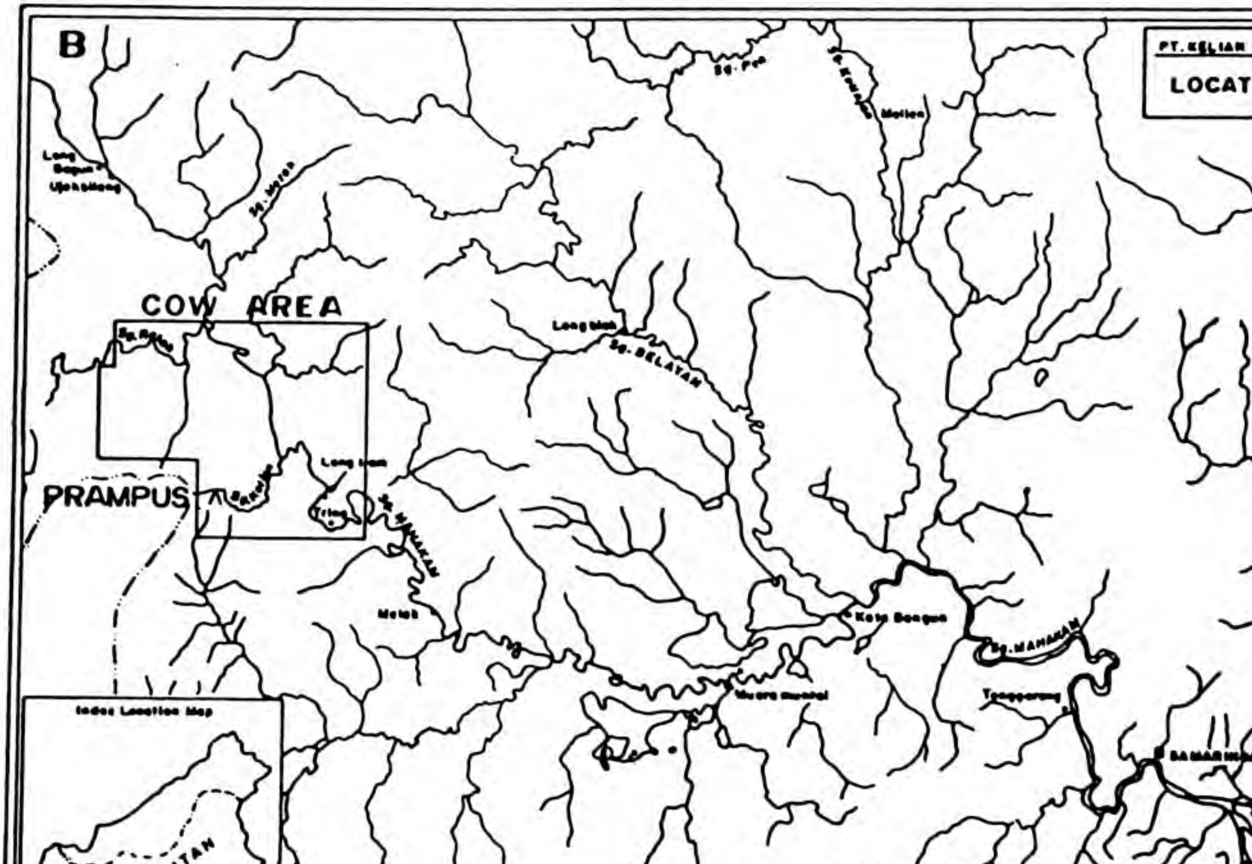

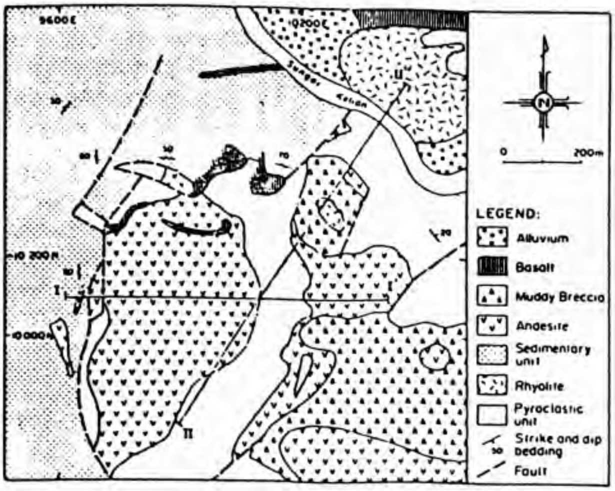

**Figure II. Geology of the Kelian deposit area.**

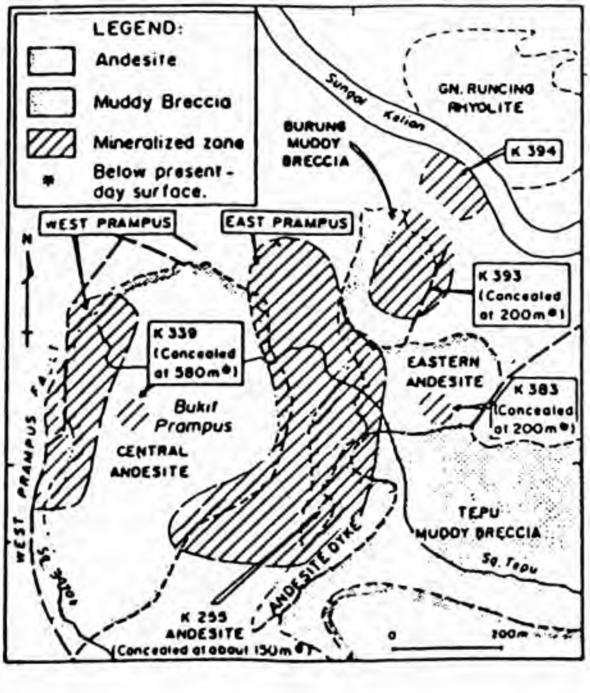

**Figure III. Map of the Kelian deposit area.**

Showing the salient geologic and geographic features. Indonesian names and abbreviations as follows: Gunung (Gn) – Mountain, Bukit – Hill, Sungai (Sg) – River.

the lower Kelian River were considered highly encou
ing for future exploration, but RTI concluded that beca
the alluvial deposits were mainly small and scattered th
was only a low potential for major exploitation by allu
operations.

The occurrence of such high alluvial grades, h
ever, together with the relatively juvenile nature of
gold suggested a high potential for a rich primary sou
upstream. Additional work within the river drain
system to assess the potential for a primary gold sou
and to check on the possibility of larger alluvial depo
further upstream was recommended.

A second trip into the area was made in early 19
The reconnaissance survey involved tape and comp
mapping of the river, stream-sediment sampling for g
silver and base metals, pan-concentrate sampling of ac
and fixed gravels, float and outcrop sampling and gen
geological mapping of the Kelian River and some of
tributaries. A change from sedimentary units to tufface
units was noted upstream of the Muara Nakan. The ini
survey up the Sg. Bayak was not particularly encourag
even though gold was panned. In the Kelian River, i
staining was noted in a cliff face exposed by a la
landslip in the northeast of the area. Closer investiga
of the cliff face, "the discovery outcrop" showed the r
to be highly altered and pyritic. The exposure was thou
to be a dyke and was sampled. No gold was observe
the rocks. The survey teams continued further upriver
recognized and sampled the intrusives and breccias in
area of Sg. Sopan Dua, approximately 6 km upstrean
Gunung Runtuh.

Sampling of the active (gravel bar) and fixed (b
and pit) gravels from the Kelian River between the tri
taries Sg. Bengeh and Sg. Magerang assayed gold gra
of 400-800 mg/m$^3$ with some as high as 2 g/m$^3$. The
luvial potential of the Kelian River drainage area
assessed and considered to have potential only for sm
scale mining methods, and were of no further interes
RTI.

The true significance of the rocks in the Pram
area was not realised until the assay values of the sam
were returned. Stream sediment samples from the
Bayak, assayed 0.84–33.5 ppm Au and two rock samp
one from a boulder and another from a quartz vein,
sayed 8g/t and 100 g/t Au respectively. Tuffs in
Gunung Runtuh area gave values of 1-2 g/t Au. At
time the price of gold averaged $US125/oz and R
target for a hard rock resource was 30 million tonnes o
6 g/t Au.

## Surface Work

The next work programme began in May 1976. Outcrop exposure in the area between the Sg. Bayak and Gunung Runtuh was poor. Therefore, soil sampling was the most effective way to sample the area. Survey stations were initially located on the 8 g/t Au boulder in the Sg. Bayak, and on Gunung Runtuh. A line was surveyed between these two points and a second line was surveyed to the northwest from the survey station C1 (Figure II). The latter line was placed for convenience, without any geological basis. A soil sampling programme was undertaken along these two lines. Fortuitously, the lines crossed all the major gold anomalies in the area.

Assays from the rock samples collected along the Sg. Tepu, where outcrop was good, were generally very disappointing. Some 40 of the 103 samples collected within the Prampus Hill area were anomalous with respect to gold (0.1 – 7.9 ppm). Significantly these samples all came from one area of argillised and pyritised rock.

From July to November 1976, a detailed geological and geochemical sampling programme was undertaken to define an area for detailed exploration. Outcrop sampling and deep auger boring were undertaken and the programme culminated in the sinking of test pits within the anomalous zones indicated by soil geochemistry.

During the period February – May 1977, an additional, more intensive, programme of soil sampling was carried out along contours at 20 m vertical and 50 m horizontal spacings. The distribution of gold in the soils outlined a broad +0.2 ppm anomaly covering an area of approximately one square kilometre within which there is an arcuate series of +2 ppm anomalies (Figure IV). These anomalies generally coincide with the contact zones between the andesitic intrusives and tuffs. The two major anomalies were named West and East Prampus.

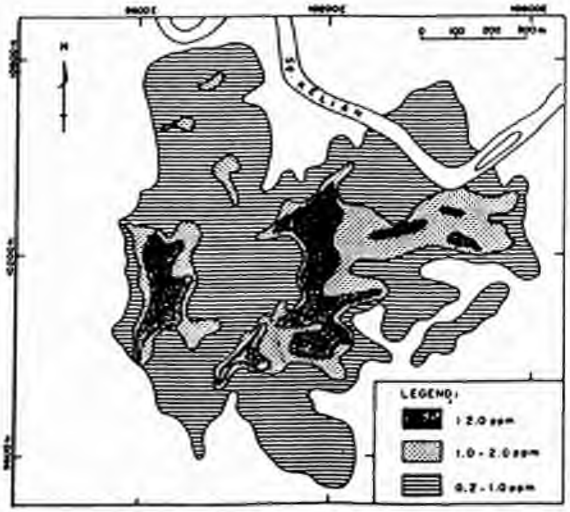

Figure IV. Distribution of gold in soils.

The average of the 77 soil samples within the 2 ppm Au contours was 3.55 ppm. The +3 ppm anomalies were then investigated first by pitting and then by a comprehensive programme of trenching and some Banka boring. The soil geochemistry gave a good, though not infallible, indication of the zones of possible ore-grade rock.

Three Banka bores, with depths up to 21 metres were sunk. Samples collected over one metre intervals assayed up to 105 ppm. One of the Banka bores averaged >20 g/t Au. Assays from these holes suggested that, in some areas, rock grades increased with depth, an effect considered to be more related to structural controls than stratigraphy.

A total of 636 m in 8 trenches were dug, sampled and mapped. Most trenches were dug to give information on grade. Some were sited to elucidate the local geology. A comparison of the assays for the soils and the channel samples from the trenches indicated that, in general, the soils gave a reasonable aproximation of both the position and grade of the mineralised zones.

Assay values from the rock sampling programme generally followed the pattern delineated by the soil geochemistry, although surface sampling could be mis-

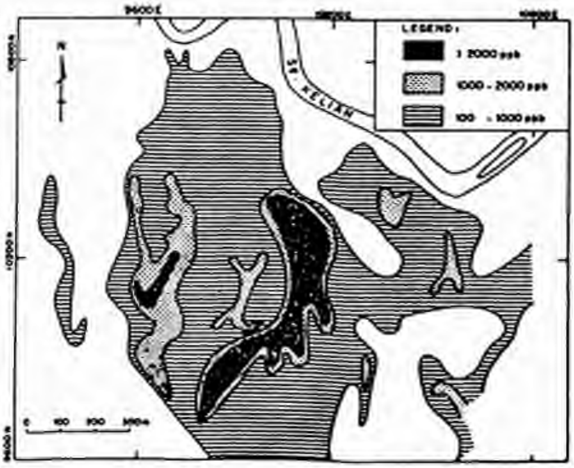

Figure V. Distribution of mercury in soils.

leading. The trenching programme indicated that there are areas outside the 2-3 ppm soil geochemistry contours in which the rock assays are considerably higher than the initial soil assays.

Detailed mapping was undertaken in both the Prampus and Sopan Dua areas. The areas immediately adjacent to Prampus were soil-sampled. A total of approximately 2700 soil samples were taken in the Prampus, Nakan and Sopan Dua areas and the results indicated that there were no extensions to the known Prampus mineralised zones.

In 1977 the results of the various sampling progammes were assessed. It was concluded that the initial target figures of 30 million tonnes at 4 ppm Au could be realised. During the period June – November 1977, an additional 959 metres of trenches were dug, and an additional 11 Banka bores were sunk to better define the surface dimensions of areas of ore grade quality and the most favourable sites for diamond drilling. Results from the Banka holes suggested that the 3 ppm Au soil anomalies were also potential 3 ppm rock grade areas and that within these areas there were zones of 4-6 ppm Au grade.

A re-evaluation of the results of surface exploration in 1977 – 78 indicated that a resource of 30 million tonnes at 4 -6 g/t Au was not economically viable; smaller volumes and higher grades, say 8-10 million tonnes at 8-10 g/t Au might be workable. Two economic models were considered:

8 – 10 million tonnes at 8 – 10 g/t Au, by opencut mining, or

3 – 6 million tonnes at 12 – 25 g/t Au, by underground mining.

By 1978 the Project Geologist stated that "the dominant problem of the Prampus prospect is an insufficient surficial indication of sufficient volume of rock with the required ore grade" and that "it is clear that surface geology investigations have reached their limits and that diamond drilling is the required prospect evaluation tool".

At this stage, the deposit dome, or controlling process of mineralisation, was not clear. A fault-controlled mechanism was favoured. Areas where faulting had been severe, such as at fault intersections, were considered to be the best exploration targets.

### First Drilling Campaign

The first drilling programme, undertaken in late 1978 when the price of gold was $US200-250/oz, was directed towards delineating an ore body of 8 – 10 g/t Au. The initial drilling programme was to be in the West Prampus area only, as the complex faulting and high rock grades obtained in trenches had indicated this area to have the greater grade and volume potential. However, the geology in the first four holes drilled in West Prampus was quite different from that seen at the surface and the mineralisation was not encouraging, and the programme was changed. Two holes were then drilled in the northern East Prampus zone to test beneath the +3 ppm soil anomaly.

The overall results from the drilling were considered disappointing. The drilling failed to solve the problems concerning the geological controls of mineralisation. None of the holes confirmed the high grades that had been obtained in the trenches. The average grades were around 2 g/t Au. Sporadic highs did not occur regularly enough to influence the grade and where intersected could not be tied to any clear geological control.

Concluding the programme, a re-assessment of the resource potential was made. The geologically inferred resource for the whole Prampus area was estimated as 8.7 Mt grading 1.7 g/t Au, tonnages and grade considered insufficient to support an open-cut mining situation. The absence of any clearcut high-grade zone excluded the possibility of underground mining.

Results from the various programmes showed the gold distribution to be sporadic, the geology to be complex and the controls on mineralisation to be difficult to interpret. As a result of the generally uneconomic grades encountered in the drill holes RTI decided that no further monies should be spent on obtaining answers to the above problems, as it seemed unlikely that any of the answers would point the way to a viable gold mine. The programme was terminated and the camp was handed back to the joint venture partner.

In mid-1979 the price of gold began to rise steadily, and lower grade deposits were becoming economically viable. A grade of 2-3 g/t Au was considered a much more realizable goal for Kelian than the pre-drilling goal of 8-10 g/t Au.

### Second Drilling Campaign

In September 1979, a geological model in which the Prampus area represented the surface expression of a sunken caldera-type structure was proposed. The available evidence was taken to indicate that the Central Andesite was not an intrusive andesite but an andesitic tuff. This model meant that mineralisation would not be confined to a contact zone, and it suggested that gold mineralisation may exist beneath the Central Andesite, thus significantly increasing the resource potential of the deposit. A new, staged comprenhensive drilling programme was recommended. The first stage was to test at depth the anomalous gold zones indicated by the geological, soil geochemical, auger and Banka hole data. It was to include a 300 m vertical hole in the domal area between West and East Prampus to test the continuity of mineralisation between West and East Prampus at depth. The aim of the first stage was to outline a resource of 20 million tonnes grading 2-3 g/t Au. The second stage was to follow up any encouraging results obtained in the first stage and would attempt to join bodies of mineralisation of economic grade, if any, located in the first stage, into a body of mineable size.

The hole to test the continuity of mineralisation between West and East Prampus at depth intersected mostly barren green andesite and was terminated before its target depth. Results from the other holes were more encouraging. The holes intersected numerous sections of 2 g/t Au ore with several high grade intersections of 15-450 g/t Au. These drill holes confirmed the complex nature of the geology and the difficulty in predicting the geology likely to be intersected in a drill hole by the simple application of the surface geological knowledge. There was no apparent correlation between gold values, lithology, structure, alteration or mineralisation. The only reliable indicator of gold grade was the assay.

After the first stage was completed, continuation of drilling was recommended but with some changes to overall drilling philosophy. The philosophy of commencing drilling in the peripheries of anomalies with the aim of intersecting ore grade zones at depth had provided needed geological information and outlined relatively large volumes of low-grade ore (0.5 – 2 g/t Au), apparently at the expense of not intersecting what appeared to be shallow subsurface high-grade zones. Projection of such zones below the surface and between drill holes could not be done with any degree of certainty. The result was that probable small, irregular high-grade zones which could push the overall grade into the 2-3 g/t range had not been intersected and measured. In retrospect, holes should have been drilled firstly for grade and secondly for volume.

### Third Drilling Campaign

The results from the two drilling programmes were assessed and additional drilling was proposed. The aim of this programme was to:

- test the possible linkage of individual +2 g/t Au zones in order to confirm the overall resource potential of 15-20 million tonnes grading +2 g/t Au,
- outline any high-grade zones, and
- provide enough information to determine whether the prospect warranted development drilling to define a mine.

The results from the third drilling programme were generally favourable. High-grade zones were encountered in almost all drill holes, and some could clearly be related to shear zones and could be linked from one drill hole to the next, although the geologic controls for others were unclear. Since such zones were considered to be prime factors in the economic viability of any potential mining operation, the next phase of drilling concentrated on a more detailed examination of some of these zones.

By the end of 1981 four drilling programmes totalling over 500 m had been completed, confirming a resource potential of 20-30 million tonnes grading around 2 g/t Au.

### Further Work 1981-1985

The project was put on hold from 1981-1985 awaiting the signing of the COW with the Indonesian Government. A deep auger sampling programme was undertaken in order to obtain data on the surface oxidised zone, to maintain a working presence in the area and prevent illegal miners, who numbered around 6000, from exploiting the oxidised zone. A total of 2124 auger holes were bored manually, which outlined a potential in the oxidised zone of 0.94-0.95 Mt grading 3.2 g/t Au using a 1 g/t Au cut-off.

The COW was signed in January 1985. A major work programme commenced in 1986. A geophysical IP/resistivity survey was undertaken. This survey confirmed the two main areas of mineralisation and outlined additional potential mineralisation in the northern, northeastern and eastern areas (Figure VI ). Drilling results to date have confirmed the mineralisation in the northeastern and eastern areas but not that in the northen area. Possible miner-

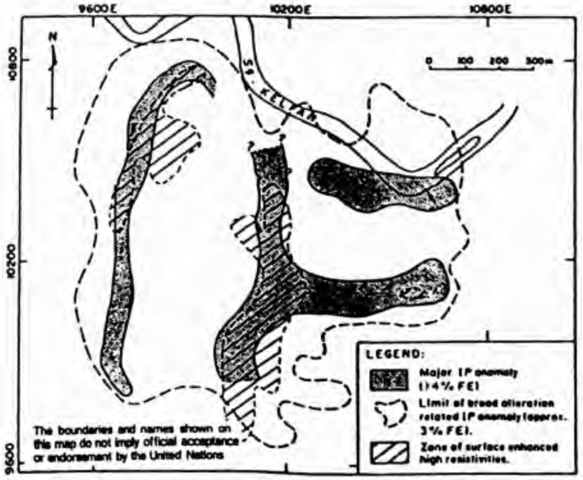

Figure VI. Summary of geophysical interpretation.

alisation in the downfaulted block of the West Prampus zone was not identified.

A mercury soil-sampling programme was undertaken in conjunction with the IP survey. The mercury contour patterns show an intimate relationship with the known altered and mineralised zones but did not outline any significant additional zones (Figure V). The 100 ppb Hg contour line roughly coincides with the 0.2 ppm Au contour. Within this broad anomalous zone a strong (2,000–37,000 ppb) mercury anomaly is associated with the East Prampus ore body, and the 2000 ppb Hg contour line shows a good correlation with the 2 ppm Au contour line. A similar correlation does not exist in West Prampus, where the +2000 ppb Hg anomaly, which has a maximum value of 6600 ppb, is very restricted in size.

### Fifth Drilling Campaign

The drilling programme was designed to firm up the known resources and follow up peripheral areas of mineralisation outlined by soil, auger and trench sampling and the geophysical survey.

As a result of this campaign the resource potential remained about the same, although a significant high-grade zone of 0.3 Mt grading around 8 g/t Au was outlined in West Prampus: one hole (K55) in East Prampus which had been drilled past its target depth of 250 m intersected a zone grading 8.3 g/t Au in the last 23.6 m of the hole. Two holes drilled later also intersected high-grade mineralisation at the same depth, suggesting the possibility of a potential high-grade zone near the base of the East Prampus ore body, as it was then known. Later, in Hole K255, a 14 m interval averaging 30 g/t Au occurred within the same area as the high-grade intersection at the bottom of K55, again supporting the theory of a potential higher-grade zone in the area. Additional drilling was carried out to verify the model, and by year's end a zone of some 2 Mt grading around 5 g/t Au had been outlined. This higher-grade zone was observed to be associated with the upper contact of a subsurface andesite body (K255 Andesite) and with a particular type of carbonate occurrence. In addition, free gold was observed in some samples suggesting that this zone, and possibly others within the main ore bodies might yield high recoveries by simple cyanidation. Thus a re-evaluation of the total resource was deemed necessary.

At the end of 1987 the controls on mineralisation were still poorly understood, although the areas in which grade mineralisation was likely to be intersected were better defined. A comprehensive petrological study of the Prampus deposit commenced, and this contributed significantly to the understanding of the deposit and is continuing in the newly identified mineralised zones.

### Towards Feasibility

By the end of 1987 the deposit was being developed as an open-pit operations, with oxide ores being treated by simple cyanidation and the sulphide ores by a float-roast process. Consideration was also given to the early mining of the 255 Zone by underground methods and processing it with the oxide zone material.

In early 1988, although the main drilling emphasis was shifted to metallurgical sampling, six long exploration holes were drilled in various areas of the deposit to determine whether mineralisation existed beneath the known ore bodies, and this drilling was extremely successful. Several additional areas of ore grade mineralisation were intersected:

. Hole (K339), drilled in the centre of the Central Andesite, was virtually barren to 584 m, but the 584 – 606 m interval averaged 8.3 g/t Au.

. Hole (K383), drilled entirely within the Eastern Andesite intersected 112 m grading 4.25 g/t from 190–302 m, apparently a relatively restricted offshoot of the main East Prampus ore body.

. Hole (K394), in northeastern East Prampus was drilled to test potential mineralisation indicated by geophysics, a mercury soils anomaly and a mineralised intersection in one of the oxide holes. The hole intersected 134 m of 4.09 g/t (including 16 m of 16.91 g/t) from 6–140 m depth. Follow-up drilling has indicated continuity of the mineralisation (394 Zone) as far north as and below the Kelian River.

. Hole (K393) intersected 82 m averaging 5.79 g/t Au. This mineralisation is associated with the contact between the tuffs and a northern subsurface extension of the Eastern Andesite. Follow-up drilling was undertaken and a significant body of higher-grade mineralisation was shown to exist. The zone (393 Zone) extends at least as far north as the Kelian River.

By mid-1988, metallurgical data was still relatively limited, so a laboratory was built on site. Over 5000 sample intervals were tested using simple cyanidation. Some intervals were also tested using CIL methods, and flotation testwork was undertaken on some of the sulphide ore. The metallurgical testing programme indicated that recovery results could vary widely between adjacent sample intervals and that large mineable blocks with consistent recoveries could not be outlined. The aveage recovery from simple cyanidation was around 70 per cent.

The feasibility study was aimed toward answering the question of whether the Kelian deposit could support a viable mining operation based upon bulk mining methods and leach cyanidation extraction. The study, completed in 1989, indicated a positive result, and mine development started soon thereafter. Initial production is scheduled to begin in early 1991.

The ore reserve study of 1989 outlined a geological resource of 77.9 million tonnes grading 1.8 g/t Au, with mineable reserves of 53.3 million tonnes grading 1.97 g/t Au at a recoverable grade of 1.38 g/t Au. The deposit is to be mined at a rate of 6 million tonnes per year, affording a mine life of 9 years. An average of 8.2 tonnes of gold will be recovered each year at this projected production rate.

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# SOME EXPLORATION CRITERIA FOR GOLD MINERALIZATION IN THE BAU AREA, SARAWAK, MALAYSIA

by
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## ABSTRACT

Gold mineralization in the Bau area is genetically related to a north-northeast trending string of small, Miocene felsic stocks of granodioritic composition. The intrusives are aligned at an acute angle to the east-northeast axis of the Bau Anticline. Limestone (Bau Limestone) and shale (Pedawan Formation) of Late Jurassic to Cretaceous age are exposed along the crest and flanks of the anticline respectively. The intersection of the anticline and the alignment of intrusives forms the locus of known Au and Sb mineralization in the area. At the centre of mineralization, major steep north-northeast, northwest to northeast trending fractures, and limstone and clastic sedimentary rock contacts are apparently important in localizing ore deposition. Geochemically, arsenic is the best overall indicator element of gold mineralization; gold itself is also an excellent guide. Among other features useful as exploration criteria for gold, especially at the mine property scale, are: proximity to felsic intrusive rocks, local structural complexity, alteration (clay and silicification), veining, jasperiod, brecciation, colloform banded quartz-calcite/quartz vein, quartz-after-calcite texture, associated ore minerals such as pyrite and arsenopyrite, and ochre-to black-coloured weathered float and soil. Lastly, more than a century of prospecting and mining activity in the area has left behind evidence (old mining records and dumps) which may lead to the finding of new mineable reserves and new deposits if modern technology and concepts of gold mineralization are applied.

## INTRODUCTION

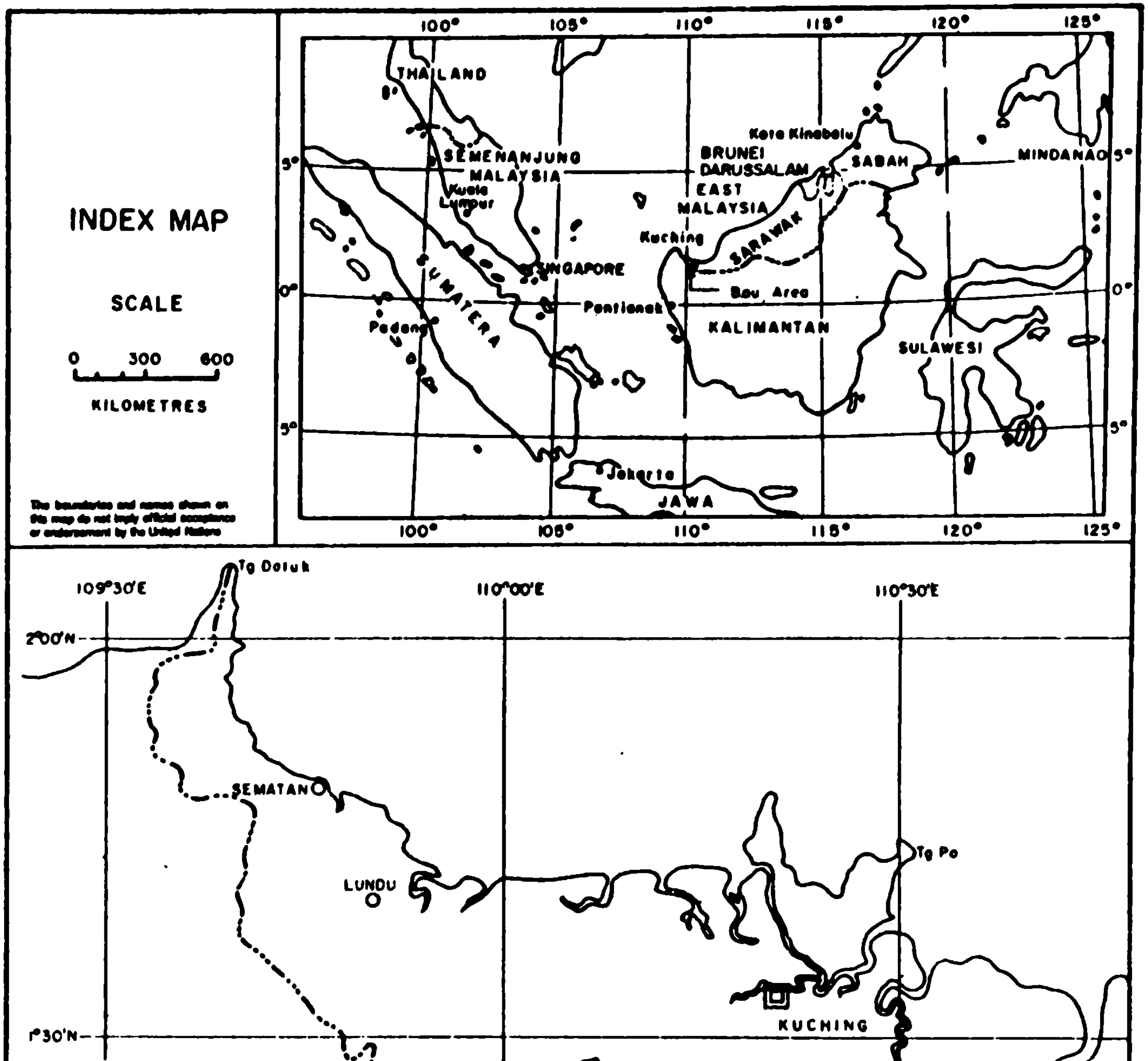
Gold has been mined from the Bau area of Sarawak (Figure I) since the early nineteenth century. According to records, production up to 1988 has totalled about 40,000 kg, of which 15,400 kg came from one mine, the Tai Parit mine operated by the Borneo Company Limited between 1899 and 1921. The area had also produced 91,000t of

some 50 old mine workings in the area most of which were mined for gold on a small-scale basis. At the present time, the area is covered by 26 mining concessions although only three mines are actively working on lode gold deposits. The main company, the Bukit Young Gold Mine accounted for the bulk of the 440 kg of gold produced from the area in 1988; as well as operating an open pit mine in a lode gold deposit, the company obtains much of the feed for its central treatment plant from old mine tailings.

Previous systematic work on geology and mineralization of the area has mainly been done by the Geological Survey of Malaysia. Major accounts include the work of Wilford (1955), Wolfenden (1965), Pimm (1965) and the joint Malaysian-Japanese Mineral Exploration Project (1982-1985). This paper summarizes the geological setting of gold mineralization in the district and attempts to review and categorize some of the geological features useful as criteria in the exploration for gold in the area, particularly at the mining property scale; information has been liberally extracted from past published works and from the writer's own experience in the area.

## GEOLOGICAL SETTING

The Bau area is underlain mainly by rocks of Late Jurassic to Tertiary age (Figure II). The oldest are the andesite and basalt of the Serian Volcanics of Late Triassic age and the Jagoi Granodiorite of pre-Late Jurassic age. The Serian Volcanics are encountered only as small inliers. Recent airborne geophysical data, however, suggested that a large mafic body which is likely to be the hypabyssal equivalent of the Serian Volcanics underlies the central part of the Bau area at depth. This has significant implications in the study of gold ore genesis in the area as the volcanics can be regarded as a highly probable primary source of the gold. The Bau Limestone of Late Jurassic to Cretaceous age, comprising predominantly massive limestone,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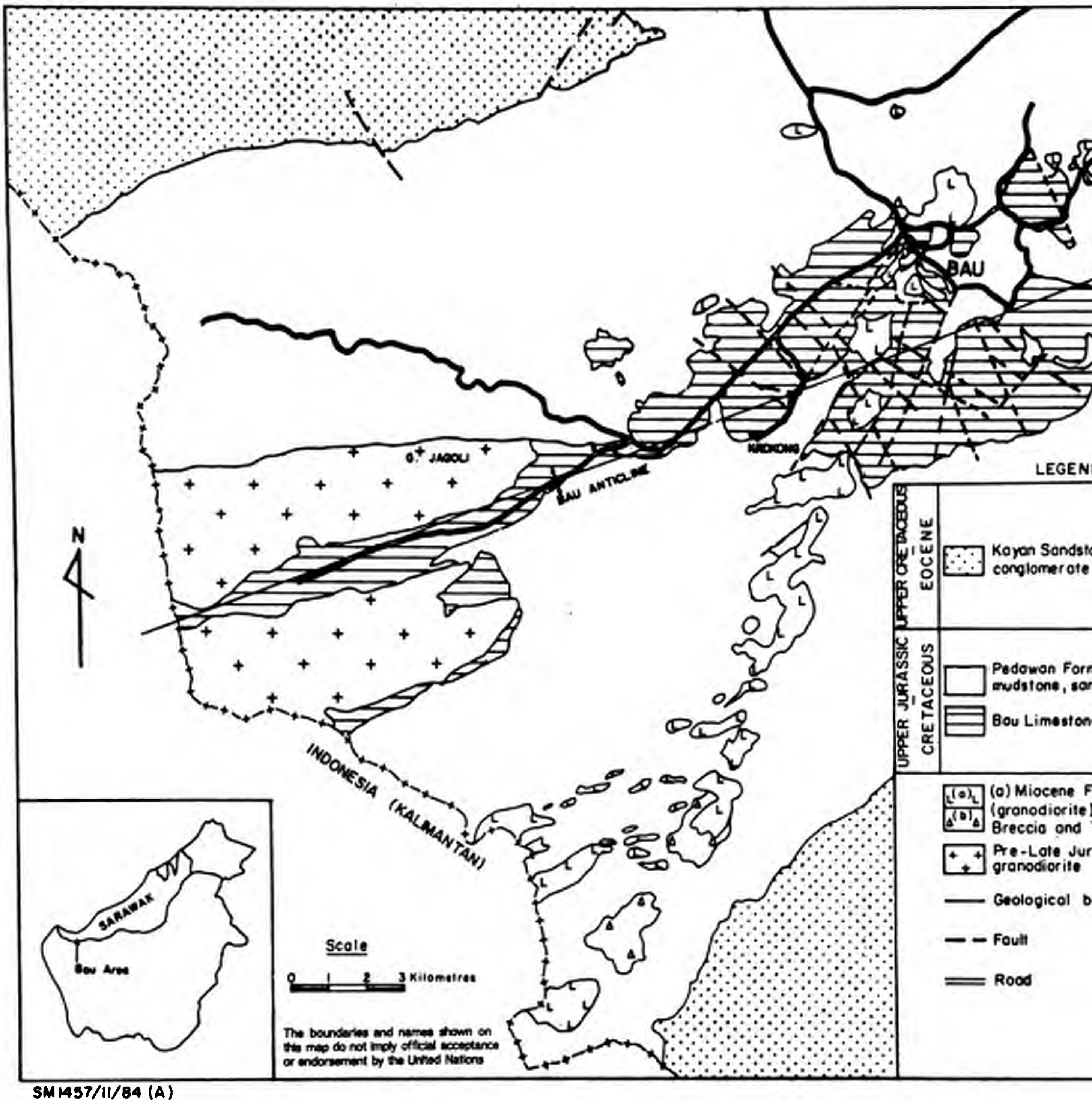


Figure II: General geology of the Bau area.

Formation is unconformably overlain by the Kayan Sandstone of Late Cretaceous to Eocene age.

The Mesozoic rocks suffered strong tectonic deformation during the Late Cretaceous resulting in the development of the east-northeast trending Bau Anticline, north-northeast faults, northwest to northeast fractures and intense folding of the Pedawan Formation. The area experienced another tectonic episode during the Miocene when felsic intrusive stocks were emplaced along a north-northeast trend intersecting obliquely the axis of the Bau Anticline near Bau town. The intrusives are mostly porphyritic in texture and granodioritic in composition. Dikes of a similar composition were also intruded, mostly along northwest – trending fractures. The intrusives, especially those near Bau town, suffered extensive clay alteration, some silicification and minor sericitization. Contact metamorphism is restricted to narrow aureoles around the main intrusive stocks. Skarn minerals have also developed in lens-shaped quartz veins in limestone near the margins of these stocks.

## GOLD MINERALIZATION

Mineralization in the Bau area is genetically related to the Miocene intrusive activity. Gold mineralization is mainly epithermal and exhibits most of the physical characteristics attributed to deposits of such an origin. The forms of deposits include veins, replacement bodies and disseminations. Ore textures commonly observed are colloform banding, brecciation, quartz-after-calcite features and vuggy quartz. Clay alteration and silicification are ubiquitous in and near the deposits. The commonly associated ore minerals are pyrite, arsenopyrite, stibnite, realgar, orpiment and native arsenic. Subordinate ore minerals include sphalerite, galena, chalcopyrite and some rare Pb-Sb sulfosalts and bismuthinite. The gangue minerals are quartz and calcite, and in a few deposits in limstone found close to the contacts with intrusive stocks, calc-silicate minerals.

The known primary gold deposits in the area may be classified according to their host rocks into four categories:–

| | |
|---|---|
| Type I: | Limestone-clastic sediment hosted |
| Type II: | Limestone hosted |
| Type III: | Clastic-sediment hosted |
| Type IV: | Intrusive hosted |

Most of the known deposits are of the first two types of which those of Type I are the most productive.

## EXPLORATION CRITERIA

Exploration criteria for gold deposits in the Bau district as discussed in this paper include geological and geochemical features at both the regional (district) scale and at the mining property scale which are considered useful guides in the exploration for new deposits or extensions to known deposits. Emphasis is placed on criteria at the mining property scale as most of the Bau area has already been blocked out into small mining concessions.

### A. DISTRICT SCALE CRITERIA

#### Geological Features

At the district scale, the geological features useful in area selection are the presence of altered small felsic intrusives, limestone and major structures. At the centre of mineralization near Bau town where most known deposits are located, two major structures, the crest of the Bau Anticline and the string of altered, small intrusive stocks of granodioritic composition intesect. Limestone commonly in fault contact with shale and sandstone is exposed there and a pronounced system of north-northeast faults and northwest to northeast fractures has been developed. The anticline and the fracture system were produced during the Late Cretaceous. They constitute the all important ground preparation stage, critical for channeling fluids and localizing ore deposition during the Miocene when the felsic rocks were intruded.

Another probably important large-scale feature detected recently by an airborne magnetic survey is the indicated presence of an extensive mafic body beneath the Bau town area. This body, most likely a hypabyssal parent of the andesitic to basaltic rocks of the Serian Volcanics, would be a suitable source of gold in the light of present day concepts of ore genesis – the heat source being the later Miocene intrusives.

#### Geochemical Features

Stream-sediment geochemical survey at the district scale is effective in delineating general areas with potential for gold mineralization. This has been demonstrated by a survey of the Bau area in which stream sediment and panned heavy mineral samples were collected at sampling densities of 1.2 samples/km$^2$ and 0.84 sample/km$^2$ respectively. The results on the stream sediment samples suggest three broad zones of metal enrichment related to mineralization centred just south of Bau town: a central zone along the intrusive stocks near Bau town of Cu, Pb, Zn and minor Ag and Mo enrichment; an overlapping and surrounding zone of Au, As, Sb and minor W enrichment; and an outer southeast-trending broad zone of Hg enrichment (Figure III). The close association of Au, Sb and As is also clear from cluster analysis and in the correlation matrix of the analytical data. Anomalous threshold values for Au, As and Sb in stream sediments (mean plus two standard deviations) are 0.1 ppm, 40 ppm and 2.6 ppm respectively.

Selection of areas for gold exploration should therefore be directed towards any zone of Au, Sb, As and possibly W enrichment.

## B. MINING PROPERTY SCALE CRITERIA

### Local Structures

Many of the known deposits are located along the already-described fault and fracture axes (Figure IV). The more productive deposits of Type I are found along contacts (commonly faulted) between limstone and clastic sediments. Among these are the Tai Parit deposit which has produced about 15,400 kg of Au from an estimated 2 million tonnes of ore, and the Bukit Young deposit with an estimated original reserve of about 550,000 tonnes at a grade of about 6 g/t Au.

The model propounded by previous workers for this type of deposit was based on an idea of mineralizing solutions rising along steep faults until they met with the overlying impervious shale where hydraulic brecciation took place and ore was deposited. This model is shown in Figure V, and modified to explain the quartz-calcite/ quartz veins (Type II deposits) encountered in limestone, either at higher elevations when over the intrusives or at low elevations but at some lateral distance from the intrusives.

Type II deposits are typically small with reserves of not more than 100,000 tonnes although they can be of very high grade especially when supergene enrichment has taken place. Examples of this type are the Rumoh and Kusa deposits. At Rumoh, reddish brown ore of weathered quartz-calcite may assay more than 100 g/t Au. At Kusa, some arsenic-rich ore samples report more than 70 g/t Au; such arsenical ores are however difficult to treat.

The model of ore deposition proposed gives us a view from afar of a plausible minealization system which has operated in the area. Its main use is to assist the explorationist in postulating his position in the system and therefore guide him in further detailed exploration.

In addition to the local structures discussed above, small-scale structural complexity at the orebody scale of exploration is a strong indication of potential mineralization especially for Type I and IV deposits. Intense fracturing, faulting and folding occur at all the known deposits of these types.

### Soil Geochemical Anomaly

Soil geochemical sampling has been proved to be an important tool in delineating potential targets particularly in mining properties where outcrops are scarce. A study carried out by Hon (1985) shows that in soil, arsenic is the best indicator element of Au mineralization; it was definitive in isolating all known ore deposits (Figure VI). Gold itself is also an excellent guide but it may not be totally reliable because of possible local sampling and analytical problems. Mn and Sb were also good indicator elements of gold mineralization.

### Lithology

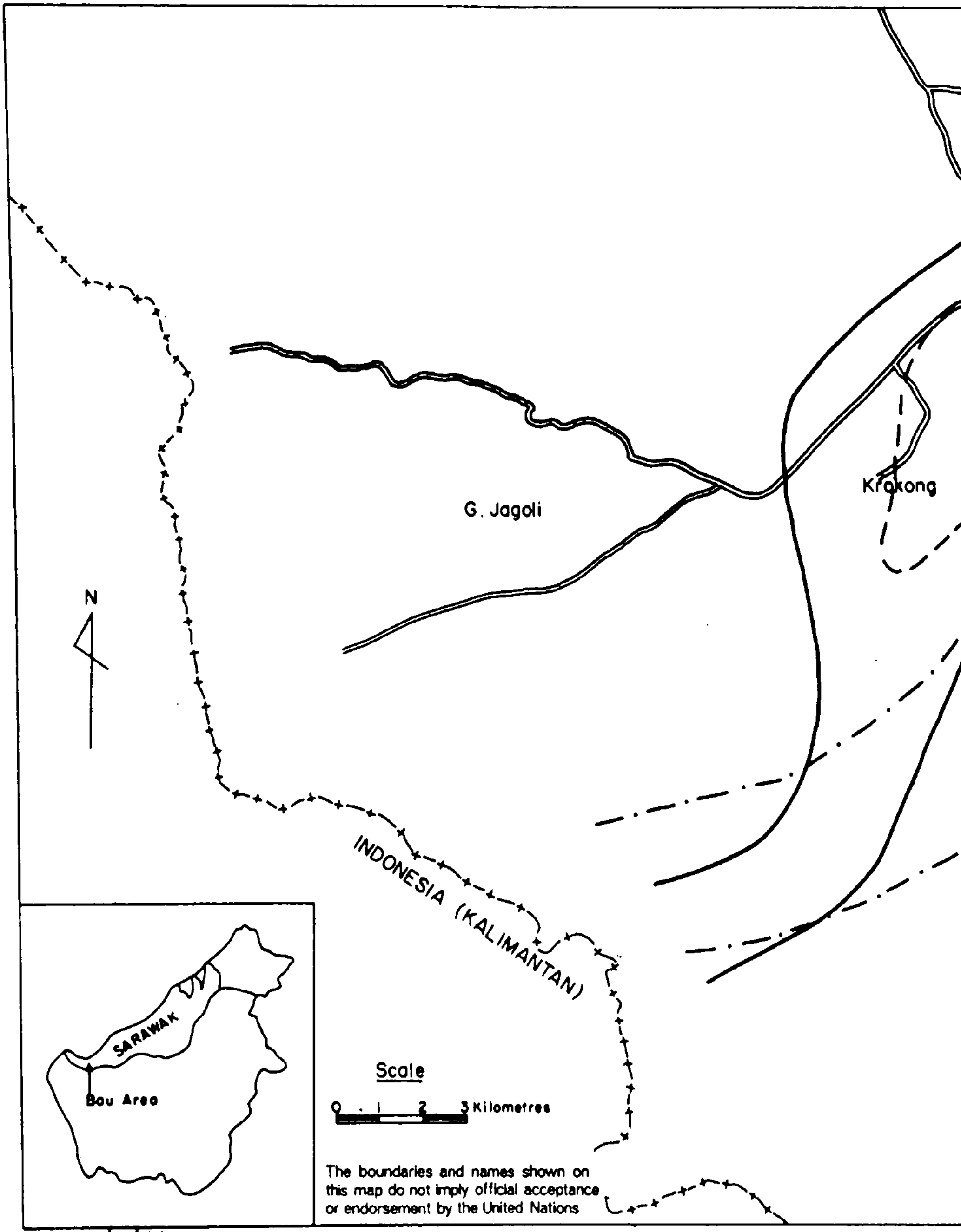
As at the district scale, the dual presence of altered felsic inrusive and limestone are favourable criteria for detailed exploration at the mining property scale. Altered felsic dikes, or nearness to an altered felsic stock are apparently pre-requisites for mineralization. Limestone is thought to be important because it is chemically more reactive and susceptible to the development of a pronounced fracture system. Little work has been done on alteration but empirically it has been observed that all the intrusives associated with mineralization have suffered extensive clay alteration and some minor silicification. Clastic sediments near deposits show some degree of clay alteration and silicification. Limestone shows little or no wallrock alteration except near intrusive stocks where quartz-vein type deposits contain common skarn minerals such as wallastonite and epidote.

### Other Minor Lithological and Mineralogical Criteria

Minor geological features such as veining, clay alteration, silicification (jasperoid), brecciation, ore mineralogy and ore textures are important small-scale features at the detailed scale of exploration.

The intensity of veining (chiefly calcite and quartz veinlets) generally increases near the ore body; in limestones a higher density of cross-cutting calcite veinlets is observed; in clastic sedimentary rocks quartz veinlets, commonly discontinuous and weathered, are more frequent. In deposits at the contacts of limestone and clastic sediments, silicification increases in intensity towards the deposits which occurs commonly as a silicified and brecciated replacement body. Where an intrusive is found near the deposit, silicification in the weathered zone is often distinguishable by patches of vuggy jasperoid within the clay-altered intrusive. Grey-coloured jasperoid is often of ore grade.

The ore textures of deposits and their associated ore minerals, whether observed as float or in outcrop, are



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

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Figure III. Zone of metal enrichment by geochemical stream sed

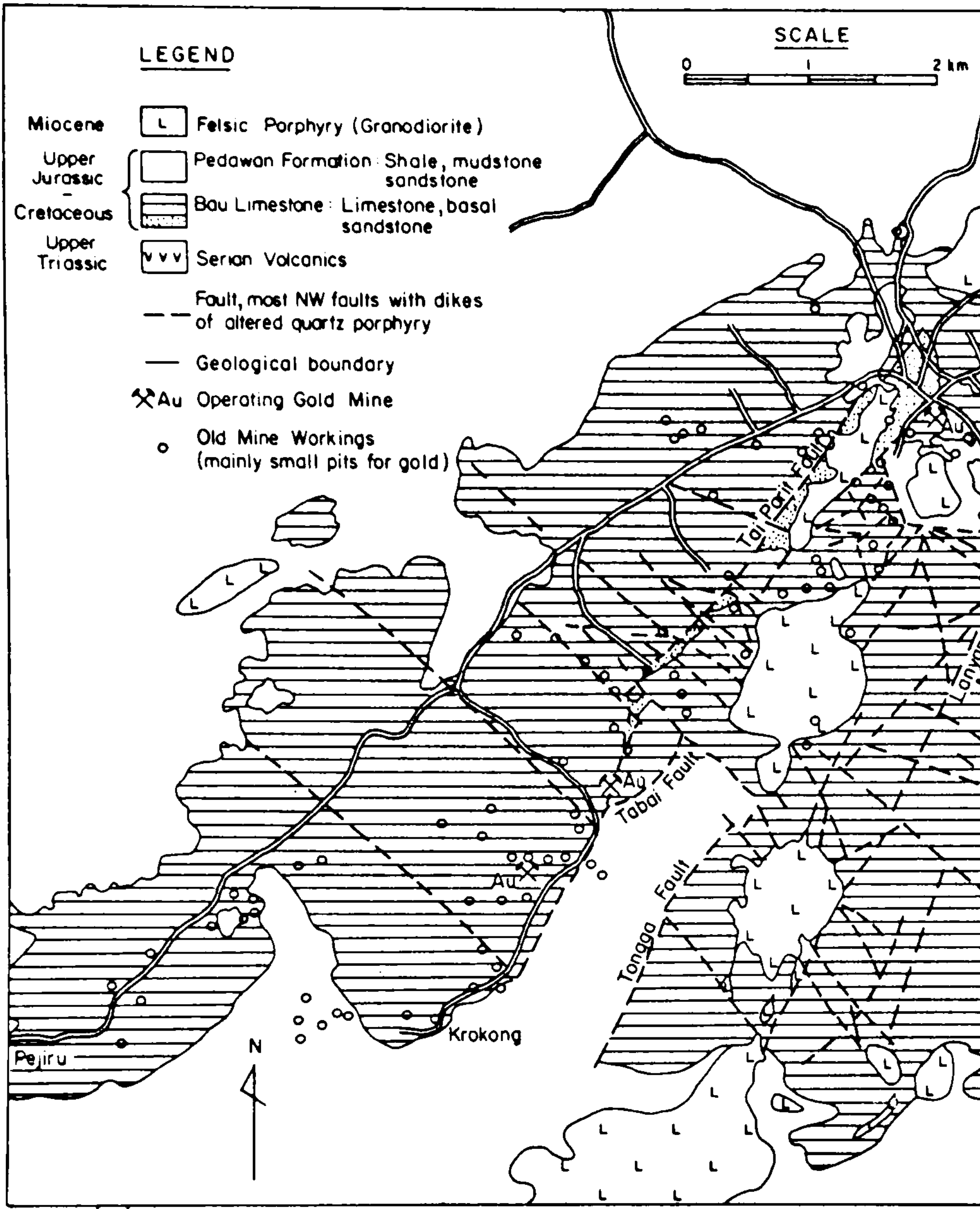

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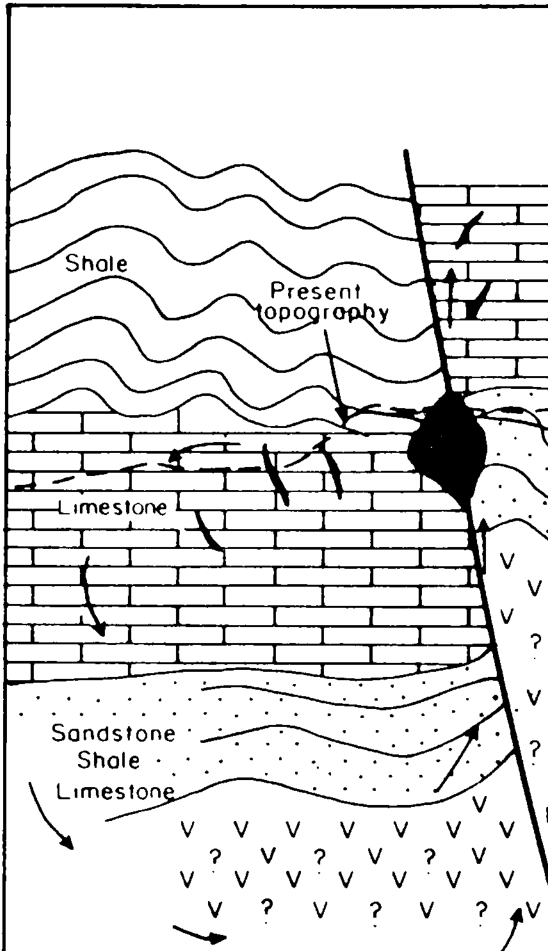
Figure IV. Geology and mine worki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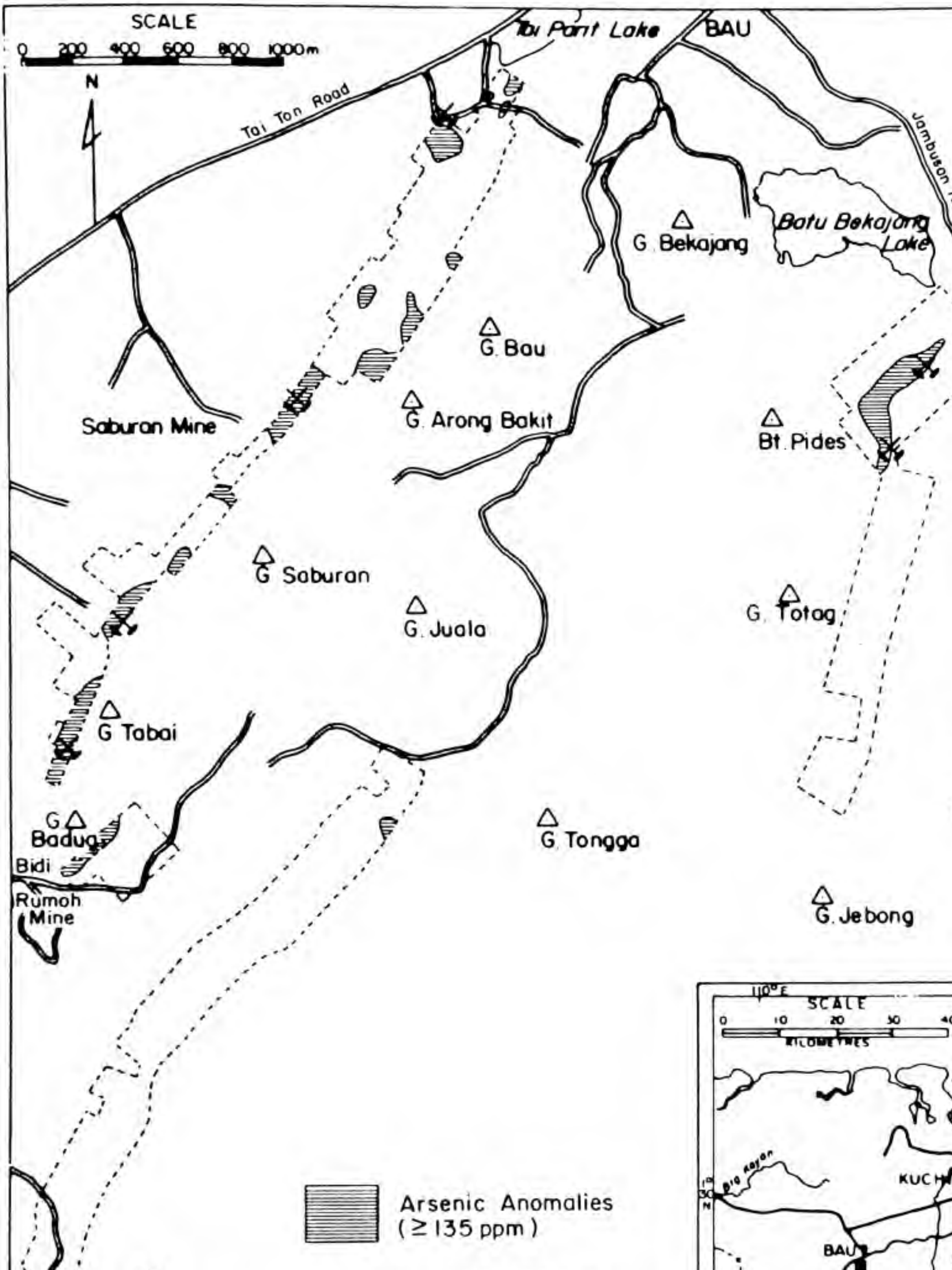
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obviously in themselves useful guides for detailed exploration. Vuggy siliceous rocks with drusy quartz, quartz-after-calcite textures, healed breccia with silicified fragments of host rocks, quartz and/or calcite in a quartz matrix, colloform-banded quartz-calcite/quartz vein, dark coloured calcite (manganiferous) with fine spongy quartz veinlets are among the ore textures to look for. Soil and weathered fragments developed over deposits are commonly ochre to maroon or black coloured.

Noteworthy associated ore minerals, distinguishable with the hand lens, may include pyrite, arsenopyrite, stibnite, native arsenic, realgar and orpiment. Pyrite and aresenopyrite are the most common but may not necessarily always be present.

### Old Mining Signs and Dumps

Finally, more than a century of mining activities in the area has left tell-tale signs of potential gold mineralization. The study of old mining records, maps and documents and detailed scouring of old mine dumps and pits are critical and can be most rewarding. Old mining and exploration activities were undertaken mainly by the traditional prospector often equipped with only a pick and a prospecting pan. He was usually interested only in high grade ore mineable and treatable by simple conventional methods. The application of modern concepts of gold mineralization and technology in such areas therefore has a high probability of leading to the discovery of new mineable reserves and new deposits. In fact, this is the case with the present operating mines in the Bau area which are all working in old mine areas and on old mine tailings. Among the new deposits discovered by exploration near old mine workings are a Type III deosit with a reserve of about 5 million tonnes of refractory ore with a grade of about 2 g/t Au, a Type I deposit with a reserve of about 140,000 tonnes and a grade of 5 g/t Au, and a Type IV deposit with a tonnage of more than 1 million tonnes and a grade of less than 2 g/t Au.

## CONCLUSION

The known primary gold deposits in the Bau area may be classified into four categories:–

| | |
|---|---|
| Type I: | Limestone-clastic sediment hosted, |
| Type II: | Limestone hosted, |
| Type III: | Clastic sediment hosted, |
| Type IV: | Intrusive hosted. |

Features which are useful as exploration criteria at the district and mining property scales of exploration are summarized in Figure VII. At the larger district scale, t presence of altered felsic intrusives, limestone, maj structures and Au-As-Sb enrichment in stream sedimer are exploration criteria for area selection. At the mini property scale, north-northeast trending faults and nort west to northeast fractures, local structural complexit limestone-clastic sediment contacts, altered felsic intrusive As-Au-Sb-Mn soil anomalies, veining, alteration, brecciati and other ore textures and associated ore minerals a features to be noted. Finally, the study of old minin records, mine dumps and pits can often be critical success in finding new mineable reserves and deposits.

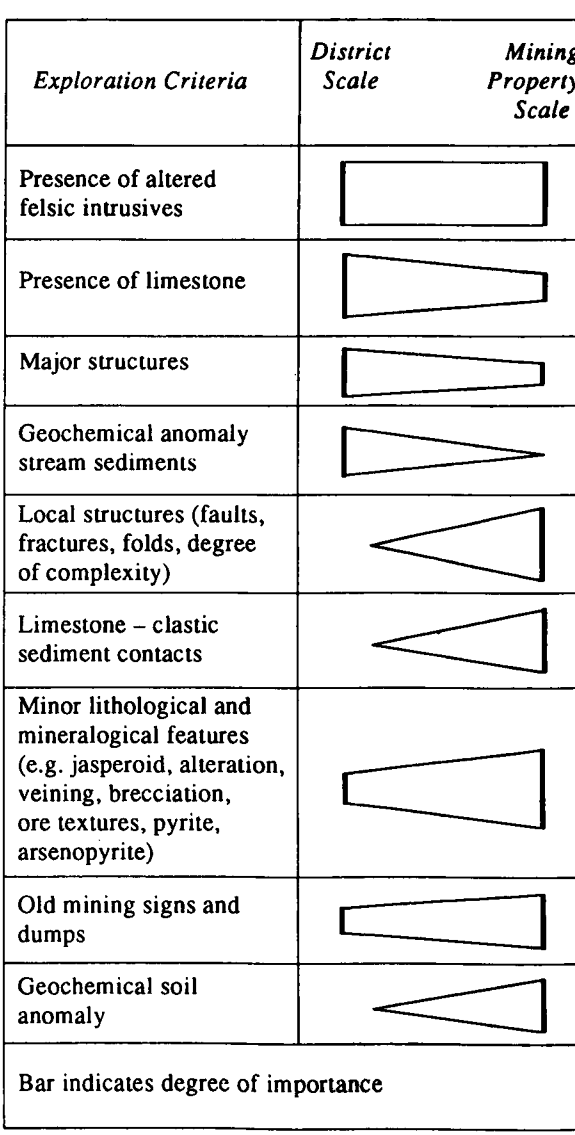

**Figure VII. Exploration criteria for gold deposits, B area.**

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# PART 3

# EXPLORATION REVIEWS AND CASE HISTORIES

# CASE STUDY OF GEOLOGICAL CHARACTERISTICS OF TWO EPITHERMAL GOLD DEPOSITS IN GUANGXI, SOUTH CHINA

by
**Zhao Xun**
**Bureau of Geology and Mineral Resources of Guangxi, China**[1]

## ABSTRACT

Guangxi region lies on the joining parts of the Pacific, Eurasian, and Indian plates. The relative movements of these plates have exerted much influence and control on the evolutionary history of tectonics, magmatic activities, development of sedimentary basins and distribution of mineralization in this region of China.

The epithermal gold deposits developed at the south-west end of the South China fold belt during the Yanshan orogeny (Cretaceous). The left-rotating slide derived from the intensifying relative movements of these plates drove the mantle material to work its way south-eastwards, resulting in the change of Moho depth from 34 to 36 kms in south-east Guangxi to 40 to 46 kms in north-west Guangxi. Meanwhile, new faults and resultant depressions, interior rifts, and shearing belts were developed on the previous tectonic framework. Deep faults were rejuvenated accompanied by intensifying magmatic activities. These came together in an unusually active tectonic-magmatic-mineralizing period, in which epithermal gold deposits were one of the most important mineralization modes.

## TWO REPRESENTATIVE TYPES OF EPITHERMAL GOLD DEPOSITS IN THE GUANGXI DISTRICT OF SOUTH CHINA

### Epithermal gold deposits related to subvolcanoes

The Lungtuoshan gold deposit in Gu-xian is an example of this type. The Lungtuoshan gold deposit occurs at the margin of the Dayaoshan upwarp, which is cut by deep regional faults. The basement consists of slightly metamorphosed Cambrian sandstones and shales covered with Devonian conglomerate, sandstone or mudstone. The Lungtuoshan igneous body is neck-shaped, 600 m x 700 m in area. Its subvolcanic facies are composed of rhyolite porphyry, breccia lava, sub-erupted breccia, porphyric rhyolite and granitic porphyry. Igneous dykes include quartz porphyry, felsic porphyry and dacite-rhyolite. The isotopic ages range from 80 to 116 million years, corresponding to the late Yanshanian orogenic period.

The major mineralized zone (I) was developed in a north-west trending fault-belt which extended along the west side of the igneous body, 1,200 m long, dipping north-eastwards at an angle of 75° to 85°. It includes five irregular lodes, which range from 0.5 to 15 m in thickness. The mineral association comprises native gold, electrum, pyrite, galena, sphalerite, chalcopyrite, antimonite, arsenopyrite, hematite, uranophyllite, quartz, tourmaline, sericite, and barite. The tenors of gold are from 1 g/t to 20 g/t normally, (the highest 70 g/t), and the fineness of the gold is roughly 650 per mil. The fabrics of the ores are crush breccia, metasomatic, disseminated and lumped. The adjacent country rocks are crushed sandstones, volcanic rocks, intrusive rocks and breccia. The alteration is very strong and includes silicification, pyritization, sericitization, chloritization, carbonatization, and tourmalinization. Microscopic or submicroscopic grains of gold occur in sulfides as fissure-fillings or as inclusions. The association of elements is Au-Ag-As-Hg-Pb-Zn-Cu, but the association of elements as determined in the geochemical survey is Ag-Au-Hg-Pb. This type of epithermal gold association is often closely associated with subvolcanoes. The gold is quite abundant in the major country rocks. For instance, in the slightly metamorphosed sandstones and shales it is 9.8 ppb; 3.1 ppb in Devonian siltstones; 4.3 ppb in quartz porphyry; 16.9 ppb in felsite porphyry; in the unmetamorphosed crush breccia, it reaches 63.4 ppb. These gold deposits formed in Yanshanian time, i.e. the period of time when the tectonic activities intensified, as did the deep-faulting. It is surmised that downward-flowing groundwaters were heated and assimilated gold in the magmatic zones in this region. Then the thermal water moved upwards to the crush breccia zones of the subvolcanoes and there formed deposits.

### Hot spring type of gold deposits

The Gaolung gold deposit in Tianlin is an example of this type. The Gaolung gold deposit is distributed around a long-term uplifting dome, which is circled by deep faults, formed of quartzite. The core of the dome consists of Carboniferous-Permian carbonate rocks which are strongly silicified near the faults. The quartzite is very pure ($SiO_2$ content more than 90 per cent), with little argillaceous or ferruginous impurity, shows a thick and lumped structure, caused by brecciation, in which the expanded part is nearly 30

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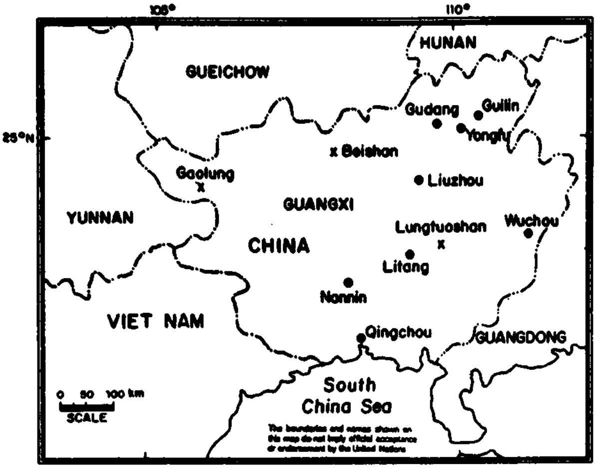

**Figure I.** Location map of Lungtuoshan and Gaolung gold mines in Guangxi, South China.

meters thick; hiatal textures are well developed. Lots of breccia fragments of siltstones and limestones are contained in the swellings in the quartzite, which might have formed during the destruction of country rocks by explosive action as gaseous thermal water was thrust in. Quartz crystals are fine-grained with abundant gas-liquid inclusions. Apart from quartzite, the major country rocks of gold ores, there are also siltstones and silty mudstones of the Banna formation, of middle Triassic age.

The Gaolung gold deposit is subdivided into three sections and eight ore bodies. Numbers 6 and 8 ore bodies have proved to be the largest, with a combined outcrop area of 100 m x 150 m; these are irregular or root-shaped, and better grades and widths are usually found near the surface. For example, Number 6 ore body is 67.16-82.03 m wide on the surface, but only 2 m wide at 56 meters depth, and the tenor declines from 3.94g/t to 1.41 g/t. Microscopic or submicroscopic gold is combined with clay minerals (mostly sericite), limonite and quartz. Sulfide minerals are few, most of which is pyrite with $\delta^{34}S = -1$ to $-7‰$ and S/Se = 1/100,000.

Alteration of the country rocks occurs as kaolinization and silicification, apparently developed at the depths of
200-300 meters. The genetic temperature
measured to be 190°C to 230°C, $\delta^{18}O_{SM}$
+13.37‰, and the $K^+/Na^+$ ratio of the liq
low, =0.12. It can be inferred therefore that mi
ing of groundwaters took place during gold

In sum, this group of epithermal
developed around a dome circled by deep
tectonic movements drove gaseous silica-
waters upwards; this thermal water mix
water which had assimilated gold from Au-
(3-10 ppb of Au), and explosively ente
rocks. This mixed gaseous liquid was
covering mudstone. Gold deposited with co
$(OH)_3$, and Fe $(OH)_3$ under the prevailing
cause of the high pressure of the gaseous w
tion occurred, and the very thick quartzite
dant breccia fragments of siltstones and li
texture, and the gold-bearing limonite deve

## MAJOR CONDITIONS CONTRO GOLD MINERALIZATION

The two types of epithermal gold
ered in this region were controlled by sin
notwithstanding the differences in their ge
teristics;

1. They were both developed at the
of South China fold belt, near the trans
Yangtse paraplatform and South China fol

2. They were both closely related
deep faults cutting along the margins of
domes.

3. Country rocks, such as older se
intrusive or eruptive rocks, are enriched in

4. Mineralization took place ch
period of late Yanshan movement, accom
matic and thermal-water activities. It wa
intensifying tectonic activity going on in th
of the Pacific in the east part of China.

5. In most of these gold deposi
dissolution, transport and concentration
groundwater is not uncommon.

# GOLD EXPLORATION AND MINING IN FIJI

by
J. Lum, S. Niurou and A. Rahiman
Mineral Resources Department, Fiji[1]

## ABSTRACT

There has been a resurgence of gold exploration in Fiji over the last five years following the recognition of epithermal-style gold mineralization associated with Southwest Pacific subduction zones. A large number of companies are active and new mineralized areas have been discovered. The Emperor Gold Mine and the nearby Nasomo zone in the Tavua goldfield are the two producing mines.

## INTRODUCTION

Fiji has a history of mineral exploration that extends back to the latter half of the last century. Early prospectors were mainly interested in gold, and their activities resulted in the discovery of a number of small deposits. A minor gold rush in the late 1920s and early 1930s led to the establishment of mines at Mt Kasi (the earliest producer, 1932), Vatukoula, Vuda and later Momi (Figure I).

After the discovery of the huge copper deposit at Bougainville, Papua New Guinea, and the recognition of the genetic association of such deposits with Circum-Pacific subduction zones, Fiji saw an exploration boom during the early 1970s. This work resulted in the discovery of at least one major porphyry-copper deposit (Namosi) and the identification of numerous small base-metal prospects. Interest in gold was secondary to copper in that period.

With the increase in the price of precious metals in the late 1970s, Fiji saw a revival of interest in gold exploration. Prospecting licences were taken out by companies over many of the old gold mining or prospecting areas and reconnaissance exploration extended to several new areas.

The newest phase in the history of mineral exploration started about 1984 when the interest was stimulated by the discovery of the huge gold deposit at Lihir (Papua New Guinea), and the appreciation by exploration geologists of gold mineralization resulting from epithermal processes related to Circum-Pacific subduction zones.

It came to be recognized that the Emperor Gold Mine in Fiji is of epithermal origin, like the deposits at Lihir and Samberi (Papua New Guinea) and Waihi (New Zealand). Exploration in Fiji based on these new concepts has identified new mineralized areas.

The level of exploration activity accelerated about 1984. Large areas of the country, even the outer small volcanic islands, which had never seen any mineral exploration before, started receiving attention.

Activity of mineral exploration in Fiji since 1982 is shown in Table 1.

**Table1. Mineral exploration statistics**

| *Year* | *Expenditure* | *No Licences* | *Hectares* |
|---|---|---|---|
| 1982 | $2.3 M | 24 | 166,287 |
| 1983 | $1.3 M | 17 | 57,617 |
| 1984 | $2.8 M | 25 | 206,565 |
| 1985 | $2.5 M | 33 | 283,025 |
| 1986 | $5.0 M | 65 | 1,038,288 |
| 1987 | $7.5 M | 70 | 659,929 |
| 1988 | $7.6 M | 83 | 837,071 |

Gold exploration is still very vigorous in Fiji but the situation in early 1989 appears to have stabilized with depressed gold prices and scarcity of risk capital arising from stock-market difficulties.

Most of the results from the recent work remain confidential. However, it can be stated that some encouraging results have been obtained. The interesting feature is the discovery and recognition of mineralization that fits the epithermal model. Figure II summarizes the distribution of epithermal-type gold mineralization and some released data.

Emperor Gold Mine, and the recently opened Nasomo in the Tavua goldfield, are the only producing mines. All the other prospects are at various stages of exploration.

## HISTORY OF GOLD MINING

Gold was first reported in Fiji in 1868 when Charles Gurney found "colours" in gravels of the Navua River. Sporadic exploration by lone prospectors continued till 1929 when gold was found in payable quantities at Yanawai in Vanua Levu. In 1932, gold was first won from the Mount Kasi Mine at Yanawai. During the same year, gold in economical amounts was discovered at Tavua on the north of Viti Levu. In 1933, gold production began on the Tavua

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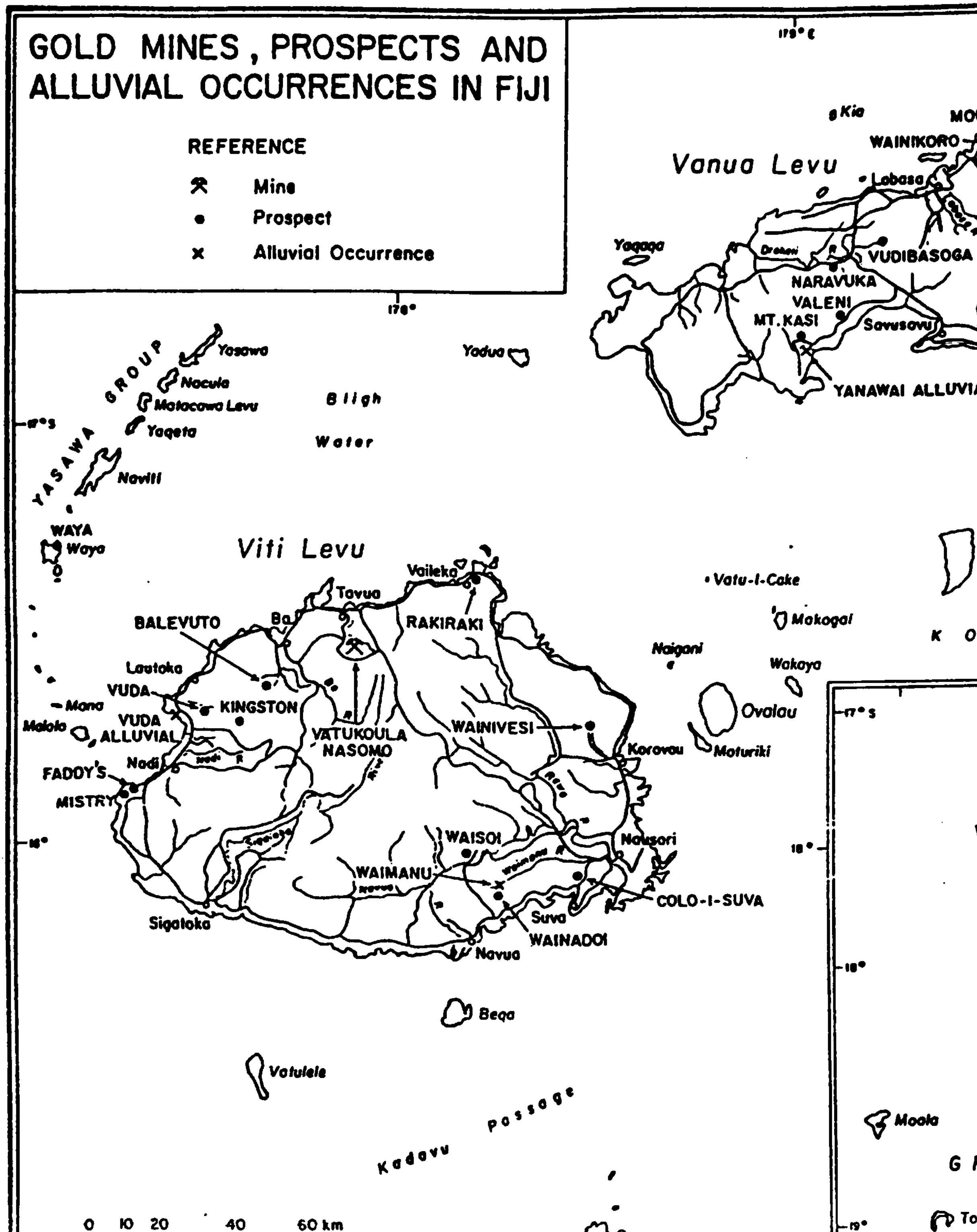
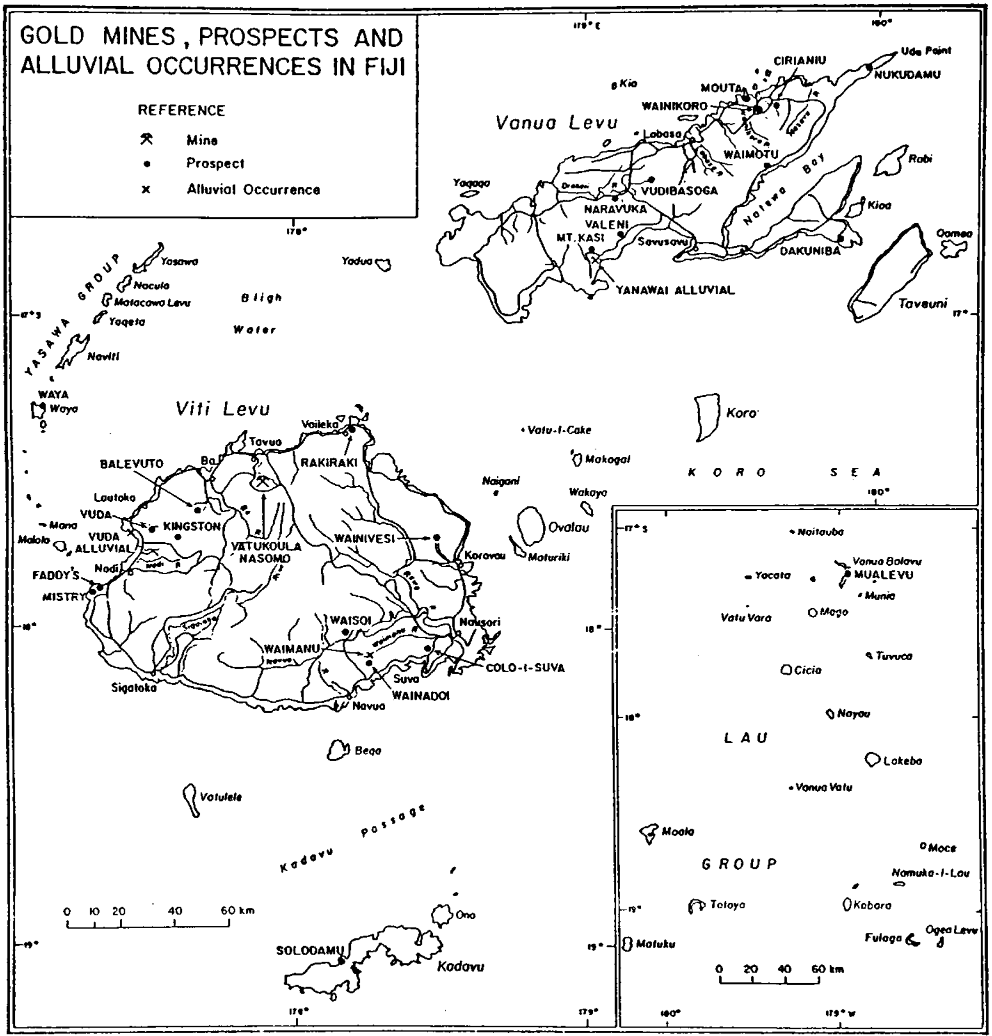
[1] Address: Private Bag, Suva, Fiji.

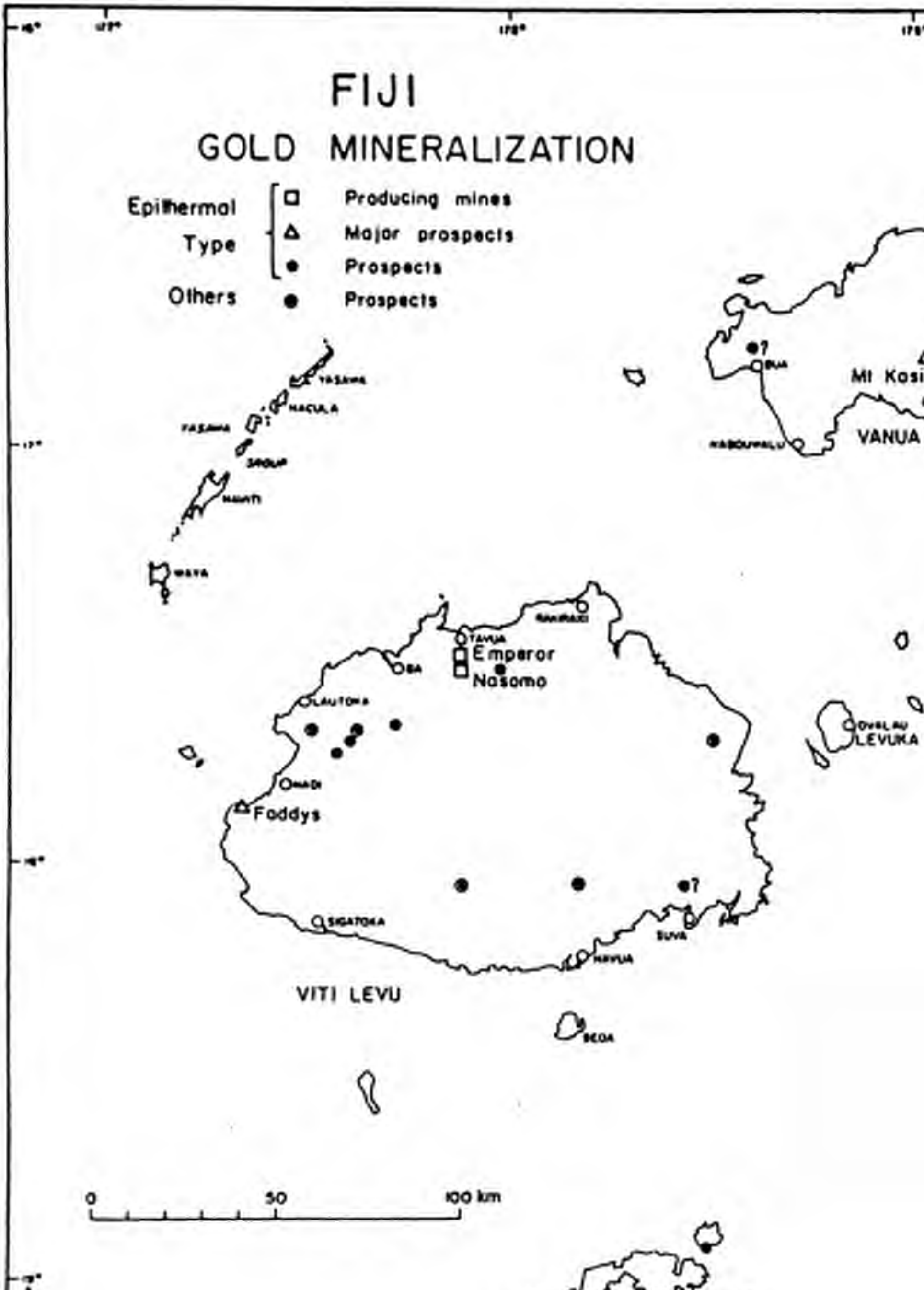

GOLD MINES, PROSPECTS AND ALLUVIAL OCCURRENCES IN FIJI
REFERENCE
⚒ Mine
● Prospect
× Alluvial Occurrence
178°
179° E
17° S
18°
19°
Vanua Levu
Kia
WAINIKORO
Labasa
Yagaga
Drekeni
VUDIBASOGA
NARAVUKA
VALENI
MT. KASI
Savusavu
YANAWAI ALLUVIA
YASAWA GROUP
Yasawa
Nacula
Matacawa Levu
Yaqeta
Naviti
WAYA
Waya
Yadua
Bligh Water
Viti Levu
Vaileka
Tavua
RAKIRAKI
BALEVUTO
Ba
Lautoka
VUDA
KINGSTON
Mana
Malolo
VUDA ALLUVIAL
VATUKOULA
NASOMO
WAINIVESI
Nadi
FADDY'S
MISTRY
Korovou
Vatu-I-Cake
Makogai
Naigani
Wakaya
Ovalau
Moturiki
WAISOI
Nausori
WAIMANU
COLO-I-SUVA
Suva
WAINADOI
Sigatoka
Navua
Beqa
Vatulele
Kadavu passage
Moala
0 10 20 40 60 km



Prepared by Mineral Resources Department, 1990.

Drawn by K.Doss

Figure I. Distribution of gold mines, prospects and alluvial occurrences in Fiji.


FIJI
GOLD MINERALIZATION
Epithermal Type
□ Producing mines
△ Major prospects
• Prospects
Others ● Prospects
16°
17°
18°
19°
177°
178°
YASAWA
NACULA
YASAWA GROUP
NAVITI
WAYA
TAVUA
Emperor
Nasomo
BA
LAUTOKA
NADI
Foddys
SIGATOKA
SUVA
NAVUA
BEQA
VITI LEVU
BUA
Mt Kasi
VANUA
NABOUWALU
OVALAU
LEVUKA
?
0
50
100 km

goldfield and has continued to the present time. At Mount Kasi, gold production continued to 1946. After an "intensive" drilling programme involving 712.2 m of drilling which failed to reveal extensions of the known ore shoot, the mining company closed the mine. During the 1940s, two small-scale gold mines on Viti Levu were developed (Mistry Mine and Natalau Mine) and several gold occurrences were located where small amounts of gold were extracted (Waimanu River and Wainadoi, Waimotu and Dakuniba). During this period all the small-scale mines and workings ceased due to World War II restrictions in obtaining explosives and machinery.

## RECENT DEVELOPMENTS

Today (September 1990), gold mining is being carried out in the Tavua goldfield jointly by Emperor gold Mining Company Ltd. (EGM) and Western Mining Corporation of Australia (WMC) under a joint-venture agreement.*

At the Emperor Mine, WMC is currently the manager of the Vatukoula Joint Venture.* Cumulative historical gold production of the mine to 1987 is 125.5 tonnes of gold. Production in recent years has been in the range of two to three tonnes per year, and exceeded four tonnes in 1988 and 1989. About 30 per cent of production is from open pits, with the balance from the underground mine.

At Nasomo, two kilometres south of the existing mine at Vatukoula, a shaft was sunk in 1985 to a planned depth of 800 m. The mining lease is held by the Tavua Basin Joint Venture, in which EGM and WMC have equal shares.* A total of $18 million has been estimated for the cost of completion of the shaft. Gold production started in late 1987. Some 300,000 t of recoverable ore with 14 g/t gold has been estimated in the Nasomo deposit.

## EMPEROR MINE

### General

Name : Emperor Mine
Location : Vatukoula, Viti Levu
Company : Vatukoula Joint Venture
Ownership : Emperor Gold Mining Company Ltd. (80 per cent)
Western Mining Corporation Fiji Ltd. (20 per cent)

### Reserves

Date : 30 June 1987.
Source : EGM Annual Report, 1987
Proved recoverable ore (tonnes) : 1.2 million (6.4 g/t)
Proved in situ ore (tonnes) : 150,000(7.2 g/t)

### Mine Geology and Mineralization

Generalized geology of Fiji is shown in Figure III.

The Emperor Mine is located on the western rim of the Tavua Caldera in northern Viti Levu. Gold mineralization is epithermal and largely structurally controlled. It occurs in quartz-gold telluride veins within three structural environments – "flatmakes" (faults with dips less than 40°) which are extensive in area, steep shears (dips greater than 40°), and shatter zones (ore formed at intersection of two or more steep shears and a flatmake).

Gold mineralization occurs in discrete veins in Plio-Pleistocene basalts and to a lesser extent in trachybasalts, and is usually surrounded by very narrow zones of intense hydrothermal alteration.

Mineralization varies in width from millimetres to tens of centimetres.

Mineralization has been the result of caldera collapse and resurgent volcanic activity. The age of the caldera is Miocene–Pliocene (5 Ma).

Lode related alteration: silica, pyrite, carbonate, sericite and adularia.

Regional alteration: chlorite, carbonate, sericite and rare epidote.

Ore mineralogy: tellurides, auriferous pyrite and free gold.

Accessory minerals: arsenopyrite, marcasite, sphalerite, native tellurium, chalcopyrite, galena, stibnite and native silver.

Gangue minerals: quartz, adularia, carbonate, sericite and roscoelite. Roscoelite is commonly associated with gold telluride thus is a good indicator of high grade miner-

## NASOMO DEPOSIT

### General

Name : Nasomo
Location : Nasomo, Vatukoula, Viti Levu.
Company : Tavua Basin Mining Joint Venture.*
Ownership : Emperor Gold Mining Company Ltd. (50%)
Western Mining Corporation Fiji Ltd. (50%)*

### Reserves

Date : 30 June 1987
Source : EGM Annual Report, 1987
Possible recoverable ore reserve : 300,000 tonnes
Grade: 14 g/t

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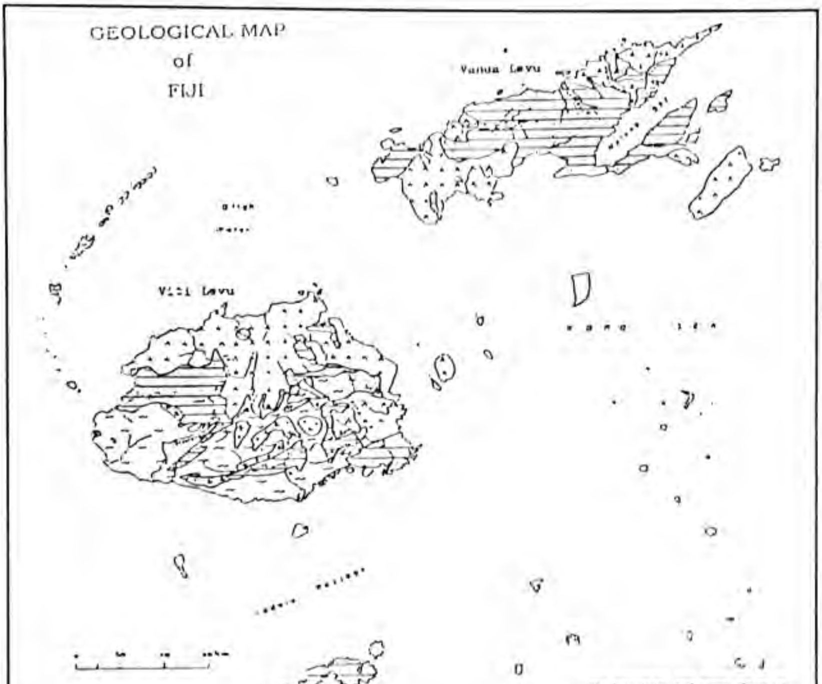
* Editor's Note: In 1991, WMC withdrew from joint ventures in Fiji.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

LEGEND

| | | |
|---|---|---|
| PLIO-PLEI | ▵ | BA Gp. Flows and volcaniclastics of porphyritic basalts grading laterally southwards (VITI LEVU) into greywacke conformably overlying the Suva Gp. Associated andesites. |
| PLIO | ▴ | UDU Gp. Breccia, tuff and flows of rhyolite and dacite overlain by pumiceous strata. |
| MIO-PLIO | ☰ | SUVA Gp. Sandstone and marl grading laterally through coarse epiclastics to andesitic volcanics. |
| EOC-MIO | ~ | WAINIMALA Gp. A deformed volcanic-sedimentary group showing low grade metamorphism related to plutonic intrusions. |
| EOC-MIO | + | COLO PLUTONICS. Stocks and smaller bodies of tonalite to granodiorite, gabbro and diorite. |

Figure III. Geological map of Fiji.

### Mine Geology and Mineralization

The Nasomo mineralization is located two kilometres south of the main workings and is believed to be an extension of the Emperor Mine mineralization. The geology is similar to that of the Emperor Mine. Gold occurs as quartz-telluride veins in a flatmake – the Prince William Flatmake. There has been insufficient surface exploration drilling carried out to understand fully the extent of the flatmake and the ore reserves because of land disputes. However, there were indications from 11 known drill holes, and patterns and styles of flatmakes of the Emperor Mine, to justify the sinking of the shaft.

## MOUNT KASI EPITHERMAL DEPOSIT

The undiluted resource at Mount Kasi, Vanua Levu, in both hardrock and eluvials, is currently assessed at 125,000 ounces of gold.

The mine geology as described by Taylor (1987) comprises a lower sequence of basalts and andesites, overlain by a middle sequence of agglomerates and lapilli tuff and an uppermost layer of scoriaceous lava and tuffs. Epithermal, high sulphur, gold-enargite system occurring within a volcanic caldera of Mid-Upper Miocene age. Mineralization is concentrated in massive quartz-baryte veins developed along steeply dipping northwest trending shears. Breccia pipes have been postulated to have flared upward, opening and forming mushroom shaped breccias parallel to or near the present surface. Various breccia types, intense silicification and multiple quartz veining are identified as good hosts for gold mineralization. Intense argillic alteration with silicification related to brecciation is encountered. Major structures trend northwest, steeply dipping southwestwards, at around 70°. A near-surface supergene enrichment is thought to be represented by an eluvial gold deposit in the hanging wall of the Mt Kasi fault. Between 1932 and 1946, Kasi produced 261,000 tonnes of ore at an average grade of 7.6 g/t.

The Mount Kasi deposit is under development as a joint venture of Newmont Pty. Ltd. and Range Resources.

## OTHER DEPOSIT OCCURRENCES

The locations of other epithermal gold occurrences are shown on Figures I and II.

### Mistry and Faddys Deposits, Viti Levu

Under development by Climax Mining Company, these deposits have a measured geological reserve of 900,000 tonnes grading 4.9 g/t gold.

Other prospects currently receiving attention are the Tuvatu prospect, near Nadi, Viti Levu; the Cirianiu Prospect, Vanua Levu; the Rakiraki prospects, northern Viti Levu; the Vuda prospects in western Viti Levu; the Wainivesi prospect in eastern Viti Levu; and the Dakuniba prospect, eastern Vanua Levu.

## REFERENCE

Taylor, G. (1987). Breccia formation and its relation to gold mineralization at Mount Kasi, Fiji. In Proceedings, Pacific Rim Congress 87, Aust. Inst.Min. Met., 1987, pp. 597-601.

# OVERVIEW OF GOLD EXPLORATION AND EXPLOITATION IN INDONESIA*

by
Yaya Sunarya
Directorate of Mineral Resources, Indonesia[1]

## ABSTRACT

The Indonesian island arc, with its numerous subduction zones of important sub-aerial calc-alkaline volcanics, is a very promising epithermal gold area. Since 1899 to 1989 total gold production was at least 130 tonnes, respectively 80 tonnes, 10 tonnes, 20 tonnes from Bengkulu-Sumatra, Cikotok-West Java, and northern Sulawesi. The remaining production derives from Kalimantan and Irian Jaya. The average gold grade is about 8 grams/tonne. Based on the favourable geological control for gold mineralization, and the increasing world gold price in 1980, many international mining companies came to Indonesia to conduct gold exploration particularly epithermal gold as priority targets. In the years 1985 to 1987, one hundred and three contracts of work (C.O.W.) covering the Indonesian island arc, were signed by the Indonesian government. The gold grade of the new discoveries ranges between 3 to 10 grams/tonne. Consequently, for the low grade ores appropriate mining and gold beneficiation technology have to be applied. The target of gold exploration and exploitation in Indonesia is not only epithermal gold deposits, but also other gold mineralization types.

## INTRODUCTION

The primary gold mining began in Indonesia in 1899. Almost all of the total gold production came from epithermal lode gold deposits hosted by volcanics. Since 1899 to 1989 Indonesia had already produced about 130 tonnes of gold which is less than 0.2 per cent of the recorded epithermal world gold production (Sunarya and Bache, 1987). As the renewed world wide interest in gold mining started around 1975 and the average gold prices in the international markets went up and reached an unprecedented level in 1980, Indonesia became a part of the world wide gold rush (Sigit, 1988). The appropriate geological setting of the Indonesian island arcs which is situated at the convergence of three lithospheric plates and is largely covered by Tertiary volcanics rocks, is one of the most promising areas for epithermal gold deposits. The favourable investment scheme and political stability of Indonesia have drawn foreign mining companies to undertake gold exploration in this country. Recent exploration results show positive indication of widespread occurrences of low grade epithermal gold deposits which may be exploited by the appropriate mining and beneficiation technology.

## TECTONIC FRAMEWORK

The tectonic framework of Indonesia is complicated due to the interaction of the Eurasian, the Indian - Australian, and the Pacific plates. The plate tectonic theory has been largely applied in mineral exploration following the postulations put forward among others by Katili (1974). The convergent plate boundaries along continental margins and island arc are potential for epithermal gold deposition.

Indonesia with many old and present subduction zones and sub-aerial calcalkaline volcanic rocks is a very promising country for epithermal gold mineralization.

## GOLD DEPOSITS AND OCCURRENCES

Gold occurs widely throughout Indonesian island arcs both as lode and alluvial deposits (Figure 1). Sunarya (1987) reported the general characteristics of gold deposits and gold occurrences in Indonesia as follows:

1. *Host Rocks:*

- *Volcanic rocks* (andesite, dacite-rhyolite) is dominant, e.g.: Mangani, Bengkulu (Sumatra), Cikotok, Jampang, Cikondang, Purwakarta (West Java), Paguat - Marisa (North Sulawesi).
- *Sedimentary rocks and metasediment*, e.g.: Muara Sipongi (North Sumatra), Ratatotok (North Sulawesi), Tembagapura (Irian Jaya).
- *Metamorphic rocks*, e.g.: Timor and Nusatenggara Islands, South-East Kalimantan.
- *Ultamafic rocks (serpentine)*, e.g.: South Kalimantan, East Kalimantan.

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* Reprinted from Geologi Indonesia, 12-1, p.345-357, Jakarta 1989.

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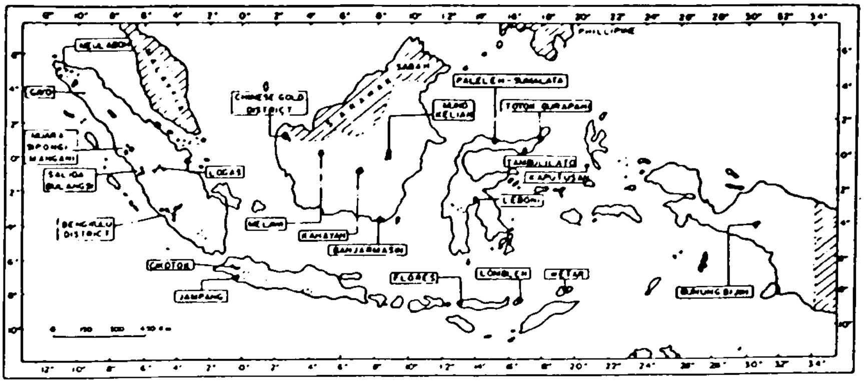


Figure I. Gold prospective locations in Indonesia.

2. *Mineral Association:*

- mostly base metals (Cu, Pb, Zn),
- native gold dominant,
- alluvial gold associated with platinum, e.g.: Meulaboh, Aceh, Bengkalis (Sumatra), Jampang (West Java) and Banjarmasin (Southeast Kalimantan).

3. *Genesis:*

- epithermal lodes dominant,
- volcanogenic ore type deposits,
- replacement ore deposits and/or skarn,
- alluvial and elluvial deposits,
- porphyry,
- metamorphic.

4. *Age:*

Oligo - Miocene, Plio-Pleistocene and possibly Cretaceous.

## GOLD PRODUCTION

Sunarya and Bache (1987), reported the total gold production of Indonesian epithermal lode gold deposits of about 130 tonnes which is less than 0.2 per cent of the recorded gold production in the world. The gold production came from Sumatra, Java, Sulawesi and Kalimantan and was produced from 1899 to 1986 (Table 1). From 1986 to present the gold output of Indonesia was officially listed at 3.3 tonnes a year, excluded gold produced by traditional panners. The annual production mainly comes from Tembagapura (Irian Jaya), Cikotok (West Java), Mangani and Lebong Tandai (Sumatra). Production of alluvial gold deposit is not recorded yet, because the producers are the unregistered miners. It can be assumed that the total production is possibly around 10 to 15 tonnes a year (Subroto in Sounder, 1988) and that in 1986 Indonesia exported a total of 13 tonnes of gold.

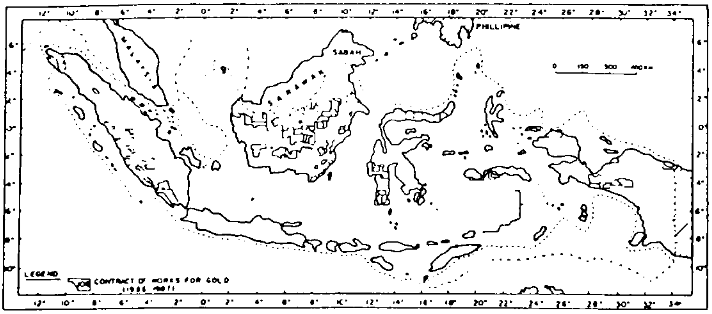
## CURRENT EXPLORATION ACTIVITIES AND RESULTS

Because of the epithermal gold potentials, at present about 20 per cent of the Indonesian land has been covered by 103 COW's (Figure II). Java and Bali islands are closed for foreign investment (COW) (Sigit, 1988). Gold exploration in West Java is undertaken by the Directorate of Mineral Resources in cooperation with PT Aneka Tambang under the assistance of France. Based on the modern epithermal concept, the exploration target areas for foreign mining companies are gold in the unexplored old volcanic terrains and the regions formerly known as the old gold district such as West Sumatra, Bengkulu, the Chinese Gold District in West Kalimantan, Northern Sulawesi and Irian Jaya. The exploration areas could be divided into two categories, namely:

1. Exploration in the areas of the known old gold districts.
2. Exploration in the areas of the unexplored old volcanic regions. The target areas are also supported by the known evidence of gold occurrences and geological environment.

Table 1. Indonesian epithermal lode deposits

| *Island* | *Name of Mine* | *Stock Metal (tonnes)* | | *Years of Production* | | |
|---|---|---|---|---|---|---|
| | | *Au* | *Ag* | | | |
| Sumatra | Lebong Donok | 42 | 230 | 1899 | - | 1941 |
| | Lebong Sulit | 7 | 10 | 1903 | - | 1918 |
| | Simau | 38 | 425 | 1910 | - | 1940 |
| | Tambang Sawah | 2.5 | 182 | 1923 | - | 1931 |
| | Lebong Simpang | 0.6 | 0.3 | 1912-25 | - | 1938-40 |
| | Mangani Aequator | 5.5 | 238 | 1912 | - | 1932 |
| | Mangani Marsman | 0.6 | 10 | 1940 | - | 1941 |
| | Balimbing | 0.5 | 0.4 | 1931 | - | 1934 |
| | Muara Sipongi | 0.6 | 0.3 | 1936 | - | 1939 |
| | Gunung Arum | 0.9 | 6.5 | 1935 | - | 1940 |
| | Salida | 3 | 98 | 1914 | - | 1928 |
| Java | Cibareno | 0.5 | 25 | 1939 | - | 1940 |
| | Cikotok (Dutch Era) | Unknown | Unkonwn | | | |
| | Cikotok | 6.8 | 180 | 1957 | - | 1986 (active) |
| Sulawesi | Totok | 5 | Unknown | 1900 | - | 1921 |
| | Sumalata | 0.2 | Unknown | 1900 | - | 1908 |
| | Bolang Mongondow | 5 | 4 | 1913 | - | 1931 |
| | Paleleh | 8.2 | Unknown | 1896 | - | 1927 |
| Kalimantan | Kahayan | 0.4 | Unknown | 1901 | - | 1918 |
| | Sinturu | 0.4 | Unknown | 1907 | - | 1917 |
| Total about 130 tonnes | | | | | | |



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

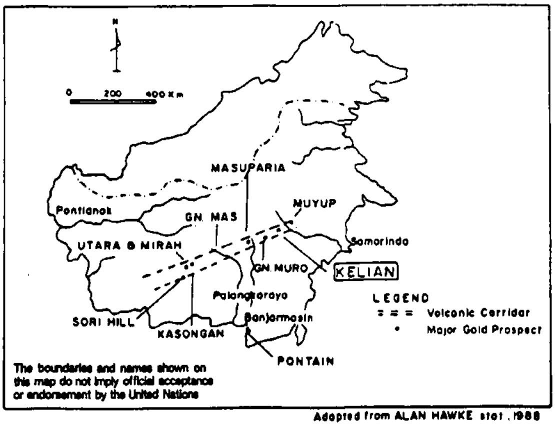
Figure II. Locations of Contract of Work (COW) in Indonesia.

## EPITHERMAL GOLD DEPOSITS

Exploration in the areas of the known old gold districts has produced re-exploitation of the old epithermal gold mines in Sumatra, namely Mangani in West Sumatra and Lebong Tandai in Bengkulu. The Mangani mine of West Sumatra is described by Kavalieris et al. (1987). The epithermal gold of Mangani mine occurs in quartz – rhodochrosite – rhodonite – Ag – Au veins, hosted by Tertiary pyroxene andesite volcanics and quartz phyllite conglomerate. Precious metal vein mineralization is characterised by high Ag/Au ratio (>25), with complex sulphide mineralogy with low total sulphide content of alteration system (<5 per cent). The gold grade 6.62 to 7 g/t, with 279-285 g/t silver.

Alapan (1987) reported the current monthly production of Lebong Tandai mine in Bengkulu Province, Sumatra, managed under PT Lusang Mining with the average of 40 kg of Au and 200 kg of Ag from 4,800 tonnes of ore. The average millfeed was 10.5 g/t of Au and was put through a CCD cyanide plant. The epithermal gold deposits are hosted by andesitic volcaniclastics and tuffaceous sediments of probably Middle to Late Tertiary age. This deposit belongs to the epithermal quartz–lode type which are accompanied by gold, minor sulphides, sulphosalts and tellurides. Electrum occurs as fine particles in almost all sulphides.

In Kalimantan the investors found several new discoveries of epithermal gold deposits hosted by Tertiary volcanics, namely the Kelian deposits which consist of Muyup, Kelian, Mt. Muro, Masuparia and Sori Hill (Figure III). Hawke et al. (1988) stated that these deposits are one of a number of Tertiary volcanic–hosted gold deposits developed within a 200 km long by 30 km wide in a northeast trending volcanic corridor extending from Central Kalimantan to East Kalimantan. The reserves of the Kelian mining area were reported to be 30 to 40 Mt with gold grades ranging from 2 g/t to 3.5 g/t (International Mining, 1988; PT Kelian Equatorial Mining, 1988). Mt. Muro is estimated at 4/10 g/t of Au actual and 20/10 g/t of Au potential (International Mining, February 1988). Mt. Muro mineralization occurs in shear zones ranging in wide from 1 to 15 m and up to 6 km long. Veins may consist of stockworks breccias, branching veinlets, and massive veins of intense silicification associated with argillic alteration and varying halo of propylitization. Pyrite, galena, sphalerite, chalcopyrite and arsenopyrite occur with gold below the oxidized zone and high silver values are common. The PT Kelian Equatorial Mining (1988) also reported that the Kelian gold deposits show mineral assemblages typical of quartz – sericite – adularia epithermal gold deposits.



Adopted from ALAN HAWKE etal, 1988

Figure III. Locations of major gold prospects in Kalimantan.

The Muyup epithermal gold mineralization is hosted by andesitic to trachytic fragmental and porphyritic volcanic rocks. Mineralization occurs in disseminated clusters associated with 1-5 per cent sulphides deposited together with quartz and adularia, illite, chlorite and carbonate gangue (PT Muyup Mas Murni, 1988). Some samples from Muyup prospect areas appear to be silica hot-spring deposits of the epithermal type and contain observable native gold. Masuparia, Central Kalimantan, epithermal gold type mineralization occurs as quartz veins and stockworks hosted by Lower Tertiary volcanic and subvolcanic rocks which have visible gold near the surface level and base metals at deeper levels (BP Mineral, 1987). The Pontain skarn deposit of Southeast Kalimantan was discovered by the Pelsart Resources NL and contains resources of 200,000 t with gold values at 5 g/t calculated. PT Nailaka Marhila Mining (1987) in Banda island, Moluccas has discovered epithermal gold mineralization hosted by silicified argillized andesite.

In Flores, Wetar and Lomblen islands of Nusatenggara several new discoveries of epithermal gold or volcanogenic gold type deposits were reported hosted by submarine volcanic rocks of the Tertiary age. The Wetar ore deposit is said to be a baritic ore gold deposit. Kouda et al. (1988) discovered the new mineralized area in Lomblen Island based on the remotely sensed data that show the ring structure that suggests the cauldron or dome. The ground checks showed the occurrence of lead and zinc mineralization in the northern part of the ring structure. There are two known barite deposits, one of which is associated with silicified volcanic rocks and contains 28 to 86 g/t of gold. The barite ore contains about 1 per cent of strontium/celestite molecule. Kouda et al. (1988) are of the opinion that since the island is covered by Neogene to Quarternary volcanic products, gold mineralizations along the other ring structures in the island are quite likely.

Low grade (1-1.5 ppm) disseminated gold mineralization was discovered in the G. Pani Volcanic Complex of North Sulawesi. It is associated with porphyritic rhyodacites, interpreted to comprise part of endogenic volcanic zone assemblage, within 3.5 km volcanic diameter centre (Kavalieris, 1985). Gold minealization occurs as electrum (20 per cent Ag) with pyrite and in minor base metal sulphides in quartz - adularia lined vuggy fractures and brecciated zones. Silver mineralization also occurs as acanthite in quartz - hematite veins in silicified pyroclastics overlying the rhyodacite dome. The gold and silver mineralization is linked to a phenocryst - rich rhyolitic dome volcanicity spatially, and perhaps genetically.

Based on the Report 4th Quarter 1987 on KP 289, North Sulawesi the LANUT Prospect (Gurapahi) in northern Sulawesi is an epithermal mineralization system of quartz veins and stockwork hosted by Tertiary volcanics. It is estimated that the tonnage reserve is about 5.5 million tonnes with average grade 2.8 g/t. Malik Manurung et al. (1988) issued the reconfirmation of the old known epithermal gold mineralization of Ratatotok area hosted by Miocene limestone and by Early to Middle Miocene volcanic formations.

## PORPHYRY COPPER ASSOCIATED GOLD

The Upper Tertiary porphyry Cu/Au deposit was discovered in Kaputusan area, Bacan Island, North Moluccas, containing about 70 million tonnes ore with average concentration of 0.30 per cent Cu and 0.20 g/t Au (Bering et al., 1985). About 80 per cent of the mineralization is hosted by the intrusive rocks of the younger tonalite porphyrite; the remainder occurs in volcanic rocks near the contact. The author considers that all aspects of the geological configuration on the northern Moluccas island are indicative to the occurrences of epithermal precious metals.

A cluster of porphyry copper - gold deposits, centered in the intrusion of porphyritic quartz diorite of Mid to Late Miocene, occurred in Tombulilato district of North Sulawesi (Carlile et al., 1982). The inferred reserves at Cabang Kiri Sungai Mak and Kayubulan Ridge have been reported as 300 million tonnes at 0.57 per cent Cu and 0.47 g/t Au.

Gunung Bijih (Ertsberg), Irian Jaya is replacement ore body with a polymetallic mineralogical association. Gold is a by-product. The ore was formed in the limestone of the Triassic-Jurassic Kembelangan Formation which was intruded by Pleistocene granodiorite. Annual production is 2.5 tonnes of gold.

Sangihe island in northern Sulawesi is a new discovery of gold potential area which was unknown before. The discovery happended in 1987 when PT Meares Soputan Mining did the first primary gold exploration in the Sangihe-Talaud islands. Network quartz veins containing gold hosted by volcanic rocks were the evidence of the gold mineralization. The discovery was followed by local people mining activities who work at the alluvial and primary gold deposits (Satria et al., 1989).

## ALLUVIAL GOLD DEPOSITS

Previously known alluvial gold deposits which were developed before are Meulaboh, Logas, in Sumatra, the Chinese Gold District, Melawi, Kahayan, Mahakam and Banjarmasin in Kalimantan and Leboni in Sulawesi. The potential reserves range from 1 to more than 45 tonnes of gold (Figure I). These locations are the place for COW's foreign companies for re-exploration and re-exploitation because the deposits are still economically worth.

All those previously known alluvial deposits are also useful and important in guiding the new discoveries of the primary gold deposits. PT Krueng Mesen Mining applying the available data and some more recent information has discovered a new epithermal gold occurrences in the Tertiary volcanics at Woyla area, Meulaboh, northern Sumatra. Several new alluvial gold deposits have also been discovered in Nias Island, West Sumatra and Kasongan in Central Kalimantan. Pelsart Resources NL reported that in Kasongan areas two alluvial gold potential areas were discovered namely:

- Ampalit alluvial gold deposits with the estimated reserves about 28 million m$^3$ at 0.280 g/m$^3$.
- Cempaga Buang alluvial gold deposits with estimated reserves are at least 100 million m$^3$ of 0.300 g/m$^3$.

## IMPROVEMENT OF GOLD EXPLORLATION

The successful exploration of COW's foreign companies resulted in many discoveries of epithermal gold, replacement or contact metasomatic gold type, porphyry Au/Cu type and volcanogenic Au type deposits. The epithermal gold type deposits is mostly hosted by volcanic rocks (Figure IV), while only several are hosted by sedimentary or metasediment, and one in Central Kalimantan is hosted by granodioritic rock. The economic data are partly reported because most of the new discoveries are in the exploration stage. From the available data it might be concluded that more than 50 per cent of the COW's foreign companies achieved positive results. The calculated reserves of epithermal gold are reportedly about 1-40 million tonnes with average grades mostly below 3 g/t and only some about 10 g/t of Au.

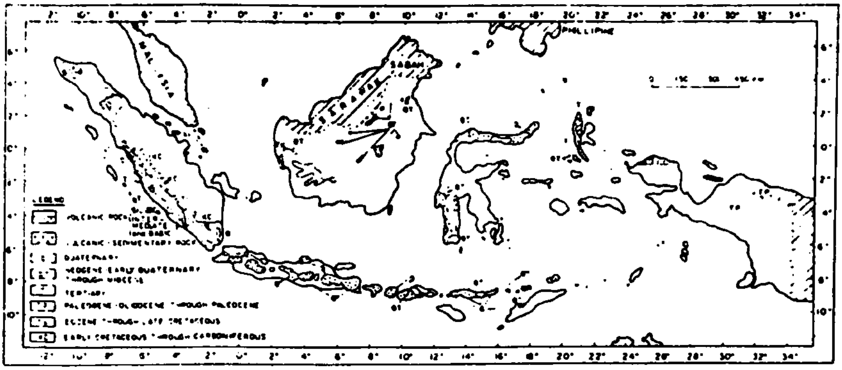


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**Figure IV. Distribution of volcanic rocks in Indonesia.**

The ores previous known as epithermal gold lode deposits of Indonesia have a gold grade of almost above 6 g/t and were processed by cyanidation and flotation (Sunarya and Bache, 1987). Since many new primary gold deposits with low gold grades were discovered, the author recommends the mining companies to improve the beneficiation technology. Takahashi (1988) stated that the new gold beneficiation technology for low grade ores, heap-leaching and carbon-pulp-recovery methods have proven cheap and effective elsewhere and have enabled hitherto uneconomic and extremely low grade disseminated gold deposits to be exploited. This idea is very important for maintaining and expanding current levels of gold production in Indonesia. Indonesia could enjoy a strong growth in gold reserves and production (Wadley, 1988). As an example, today Kidston, an Australian premier mine, operates at 1.8 g/t of Au by carbon-in-pulp technology (International Mining, 1988). It is important to improve the open-pit mining technology, such as that being done in Cikotok gold mines.

## CONCLUDING REMARKS

There are two effective models of exploration in Indonesia:

1. Exploration in the known gold district.

2. Exploration in the unexplored old volcanic regions supported by the new known occurrences and the geological environment.

deposits are dominated by volcanic hosted rock places sedimentary host rocks are also founc Ratatotok prospect, northern Sulawesi. The av reveal that re-exploitation of the old gold r produce high gold grades, whereas the new di general contain low gold grade. The high gol usually treated by conventional technology bu gold grades it is suggested to use the beneficiatio such as carbon-in-pulp or heap-leaching techno open-pit mining system.

## ACKNOWLEDGEMENTS

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# STATUS OF GOLD EXPLORATION IN KOREA, AND THE SETTINGS OF GOLD MINERALIZATION

by
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## ABSTRACT

The production of gold in Korea has decreased from 10.3 tons in 1939 to 1.3 tons in 1988. But demand for gold has rapidly increased from 5.3 tons in 1980 to 18.5 tons in 1988. Imports have also increased 4 tons in 1980 to 7.5 tons in 1988.

The majority of gold deposits in Korea belong to the Jurassic to early Cretaceous epoch. They are embedded in Jurassic granite or in surrounding Precambrian schists and para-gneisses, and usually aligned parallel to the NE-SW Sinian fold-axis and lineament direction.

## STATUS OF GOLD EXPLORATION IN KOREA

There are about 1,200 gold mines which have worked and produced gold at some time in Korea, though most of them are now idle.

Gold production has decreased gradually since 1939 when South Korea produced 10.3 tonnes of gold, and at its lowest ebb, in 1975, production was only 415 kg.

Production has increased from 1,282 kg in 1980 to 11,121 kg in 1988, of which most was produced from imported raw materials (mainly crude copper ores) as a by-product. In fact, real domestic production rose only from 384 kg in 1980 to 1,294 kg in 1988 (Figure I).

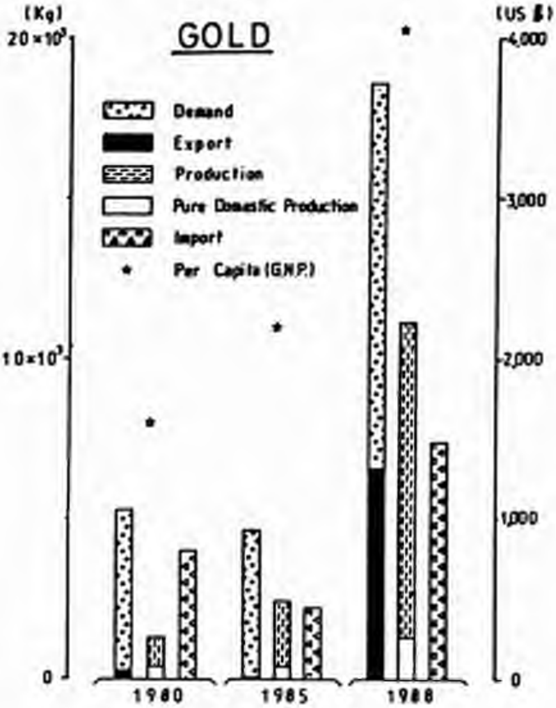

Figure I. Demand, production, export and import of gold.

## METALLOGENIC PROVINCE OF GOLD MINERALIZATION

The metallogenic provinces of gold mineralization in Korea can be divided into four epochs, namely, Permian to Triassic epoch, Jurassic to early Cretaceous epoch, late Cretaceous to early Tertiary epoch and Quaternary epoch. The brief descriptions are as follows (Figure II):

### (a) Permian to Triassic Metallogenic Provinces

These include some gold deposits which are set in Permian to Triassic granite or surrounding Precambrian schists and para-gneisses, and often aligned parallel to the NE-SW Sinian direction. The gold provinces are delineated in three provinces in North Korea, the Gwangjangbong, Hoeryeong and Unsan provinces. These deposits are mostly in mesothermal veins.

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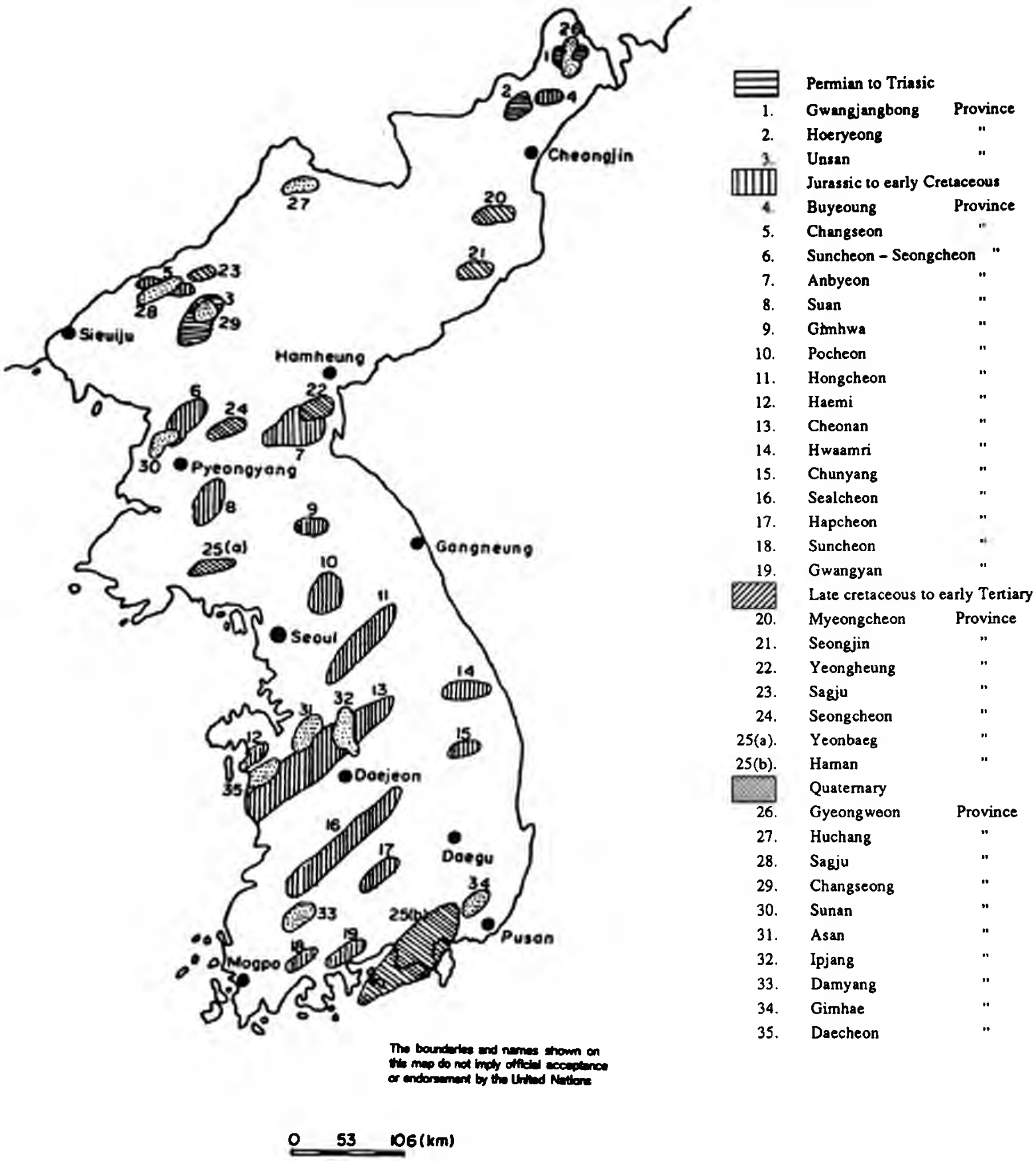

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Figure II. Metallogenic provinces of gold mineralization in Korea.

### (b) Jurassic to Early Cretaceous Metallogenic Provinces

The majority of gold deposits in Korea belong to the Jurassic to early Cretaceous epoch. With few exceptions they are related to Jurassic granite and the surrounding Precambrian schists and para-gneisses, and aligned parallel to the NE-SW Sinian direction. The gold provinces are delineated into 6 provinces in North Korea and 10 provinces in South Korea. These are, in order from north to south, Buyeong, Changseon, Suncheon-Seongcheon, Anbyeon, Susan and Geumhwa provinces in North Korea, and Pocheon, Hongcheon, Haemi, Cheonan, Hwaam, Chunyang, Seolcheon, Hapcheon, Suncheon and Gwangyang provinces in South Korea (Figure II). Among them the Hongcheon, Cheonan and Suncheon are the most prolific producing provinces and trend in Sinian direction. In North Korea the Suncheon-Seongcheon, Susan and Anbyeon provinces are the most prominent provinces.

These deposits are mostly hypothermal to mesothermal veins in granite or Precambrian schists and paragneisses, except in Hwaam province where most of the deposits are emplaced in limestones of Cambro-Ordovician age as vein-type occurrences.

### (c) Late Cretaceous to Early Tertiary Metallogenic Provinces

The gold deposits of this epoch are rather less common and are distributed in only one province in South Korea, and in a few locations in North Korea. The deposits are set in Precambrian gneisses and schists as vein-type lodes trending in a NW direction; the prominent areas are Myeongcheon, Seongjin, Yeongheung, Sagju, Seongcheon and Yeonbaeg provinces in North Korea.

In South Korea the deposits are exclusively fissure-filling veins in andesitic rocks, rhyolitic tuff and hard slated beds of the Upper Hayang group of the H
The Tongyoung gold mine and Mireugdo
tion area are typical epithermal deposits r
this province.

### (d) Quaternary Metallogenic Province

The deposits are exclusively of the
vial type. The prominent areas of placer
North Korea are Gyeongweon, Huchang, Sa
and Sunan provinces, and and Asan, Damy
Gimhae and Ipjang provinces in South Ko

## CONCLUSIONS

(a) The production of gold in Kore
from 10.3 tons in 1939 to 1.3 tons in 1988.
gold was increased from 5.3 tons in 1980
1988.

(b) Export was expanded from 26
6,551 kg in 1988. Import was increased 4 to
tons in 1988.

(c) Metallogenic provinces of gol
can be divided into 4 epochs, namely; Per
epoch, Jurassic to Early Cretaceous epoch,
to Early Tertiary epoch and Quaternary ep

(d) The majority of gold deposits in
Jurassic to Early Cretaceous epoch. They
Jurassic granite or surrounding Precamb
para-gneisses, and aligned parallel to NE-S
tion.

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# GOLD MINERALIZATION IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

by
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## INTRODUCTION

The Lao People's Democratic Republic is a small land-locked country of the South-East Asia nations, surrounded by China to the north, Viet Nam to the east, Thailand and Myarmar to the west and Cambodia to the south. It has an area of about 236,000 sq. km and a population of 3.56 million inhabitants.

In the past, no gold mines nor significant artisanal production of gold have been recorded, although the geographical and geological situation of the Lao People's Democratic Republic vis à vis the neighbouring countries indicate a terranes promising of potential resources of gold. A lack of detailed geological study has hampered systematic search for this mineral commodity.

After the liberation of the country, and especially since 1982, some field work has been conducted with the assistance of the Union of Soviet Socialist Republics and other countries, in systematic geological mapping and in heavy mineral reconnaissance in some areas of the Lao People's Democratic Republic (10 per cent of the country was covered by systematic geological maps at a scale of 1/200,000 or larger, and about 25 per cent of the territory has been covered by regional geochemical exploration). Unfortunately, the concept of gold mineralization and the genetic types of gold deposits were not given any special relevance during the course of these surveys.

According to the literature and other informal information about indicated gold placers, known areas of gold-bearing weathered crust, and recorded areas of the most active panning by local people, it may be assumed at the present time that there are at least six promising prospect areas in the country: (1) Pak Beng - Pak Tha area, (2) Sanakham - Nam Ou area, (3) Xieng Khouang area, (4) Nape - Nam Nhouang area, (5) Tchepone area and (6) Attopeu - Se Kong area (Figure I).

## 1. PAK BENG - PAK THA AREA

This area includes the Ban Houei Sai ancient alluviums where gold is found at lower values in sapphire gravels, and in the Mekong River bed around Ban Houei Sai.

In the area between Pak Tha and Pak Beng ancient alluviums and gold placers are indicated at many places and recently the local people have been actively working for gold in the present alluvium along the Mekong River. The mineralization in this region seems to be related to the sporadic outcropping of the Devonian terrain and/or the older formation comprising crystallophyllian metamorphic rocks of ancient age in which in-situ quartz veins could be observed. It is noted that this area is marked by patches of volcanic rocks such as porphyrites (mostly of pyroxene andesite and andesite tuffs) of indeterminate age.

## 2. SANAKHAM - NAM OU AREA

This area forms a long strip from the south at Ban Sanakham/Mekong River to the upper streams of Nam Ou. Gold mineralization in this area seems to be the continuity of Udon Thani - Nong Khay gold belt in Thailand. Gold occurs in the Sanakham area both in ancient and recent alluviums as well as in the deluviums, e.g. in lower Nam Tone valley, upper Nam Sang valley, Nam Mi valley and around Don Men. All of these areas were recently under concession by the state company and two others by foreign companies. Others indicated gold mineralizations occur in the area just below Pak Lay, upper Nam Met valley, around Tha Deua.

The entire valley of the Nam Ou, up to the level of Phongsaly has been the focus recently of very active gold working by local people at many places, and should be the target area for future reconnaissance. Gold mineralizations throughout the Sanakham - Nam Ou area were observed to group around the Devonian terranes and the older crystallophyllian rocks which are intruded in places by volcanic rocks (porphyrite-andesite, or intrusive rocks such as diorite and granodiorite)

## 3. XIENG KHOUANG AREA

The Plain of Jars, a large plateau surrounded by the the most elevated area of the country is the site of scattered alluvial gold at many places on the piedmont zones.

At its northern peripheral, gold has been found in the Nam Sui, Nam Khap, Nam Sap, Nam Hong valleys. This

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[1] Address: Vientiane, Lao People's Democratic Republic.

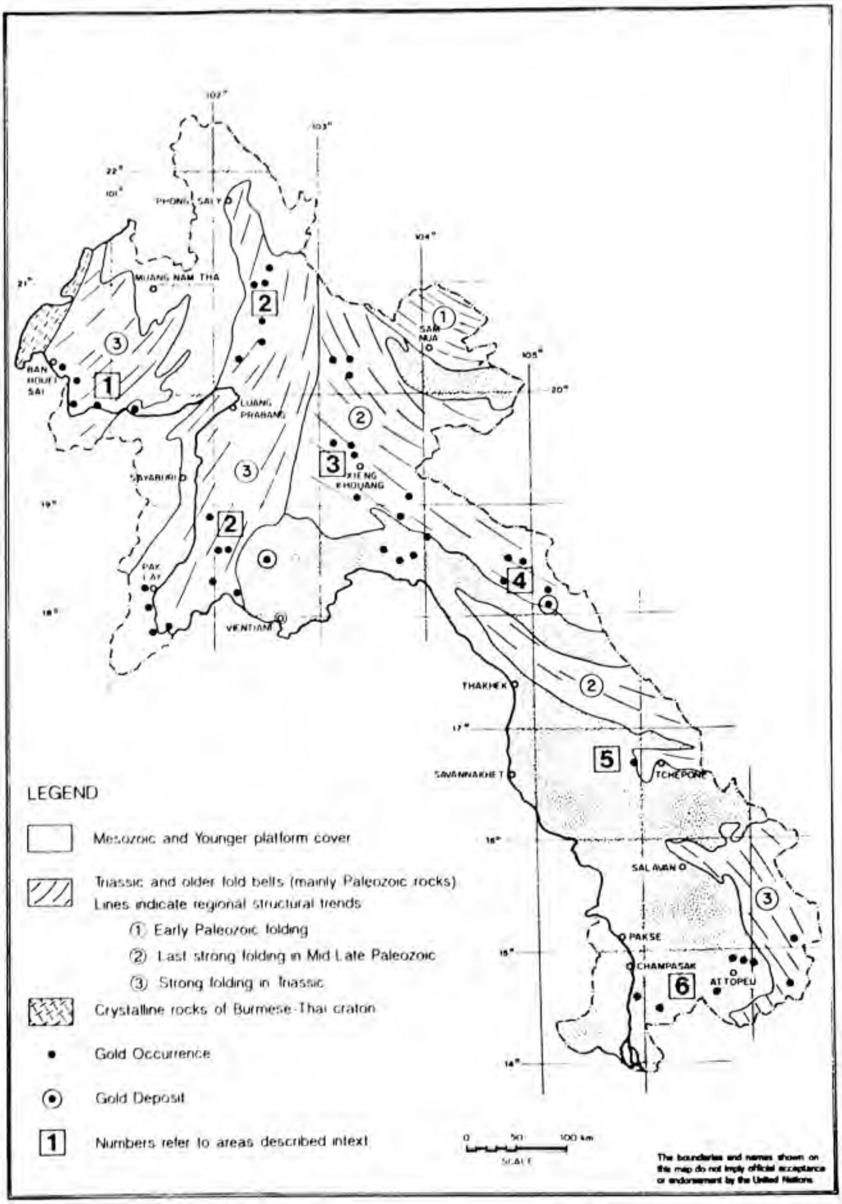

Figure I. Outline of the geological structure of the Lao People's Democratic Republic showing gold occurrences.

gold mineralization seems to be generated from quartz vein lodes in the granitic intrusive of the Phu Loi massif and in the Palaeozoic Hercynian metamorphics.

At its southern peripheral, the geological and tectonostructural situation are complex and poorly known. Whatever the source, gold alluviums in placers (e.g. at Ban Thalat, Ban Hat Kham, and others) are the result of the transport of material by the Nam Ngum, Nam Ngiap, and Nam San from the primary rocks of the southern uplands.

## 4. NAPE – NAM NHOUANG AREA

The area is comprised of an older metamorphic complex of crystallophyllian rocks and less developed orthogneiss and mica schists in the proximity of Nape and Nam Gnala. The granite, of late Carboniferous and of younger Triassic ages, has intruded this area to a great extent. Medium to high-grade metamorphism of the Palaeozoic sedimentary rocks has especially affected the Siluro-Devonian and Devonian terrains. The gold accumulations as alluvial/ deluvial placers are found between the older metamorphic complex and the metamorphosed Devonian and Siluro-Devonian terrains as seen at Nam Pan, Nam Sa Ngoy, Na Kadoc, Khamkeut, and Rao Co.

## 5. TCHEPONE AREA

Placers of alluvial gold are found in Quarternary sediments around Muong Tchepone and about 30 km northwest of this city, and were the subject of the prospecting in this area. The source materials were concentrated by the Nam Sengi and its tributaries from the widely exposed older metamorphic complex of Proterozoic age which is related to the Kontum massif. The crystalline basement is comprised of gneiss, augen-gneiss, mica schist and is intruded by younger granodiorite, diorite and pegmatite dykes. The auriferous materials were also carried by the Nam Kok which has its source in the Devono-Carboniferous terranes (Hercynian bedrock) which occur at the peripheral of this Proterozoic complex and were affected by younger intrusion of probably Triassic in age.

## 6. ATTOPEU AND SOUTHERN CHAMPASSAK AREA

Alluvial gold is reported at many places along the Se Kong valley, and the Se Kaman, Se Xou and other tributaries of the Se Kong. So far the area has been subject of only

## SUMMARY

Alluvial gold indications in the Lao Peopl
cratic Republic are numerous and widely disper
whole country but poorly evaluated and develop
additional indications of deluvial gold and know
gold mineralization give promising signs of po
sources. Special attention should be given to t
sporadic outcroping of Hercynian materials whi
the Siluro-Devonian, Devonian and Devono-Carb
which represent the Indosinian basement. This t
to great extent affected firstly by Hercynian or
later by the Indosinian orogeny of Late Perm
Triassic age. This later orogenic phase was accom
calc-alkaline intrusive and volcanic rocks (mainl
porphyrite andesite, diorite, granodiorite). It is
that the greatest number of gold mineralizations
People's Democratic Republic are related to thi
stratigraphical control.

But, for a better understanding of gold m
tion and gold deposits, the assistance for further s
research programmes will be very necessary.

In order to expand economic, scientific a
logical cooperation with other countries with
exploiting these potential resources, the Lao People's
Republic in the mid-1988 adopted a law on forei
ment, and through this means its is welcoming
investors or companies to participate in gold e
ventures.

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# GOLD EXPLORATION AT PHOU KALAI, VIENTIANE, LAO PEOPLE'S DEMOC REPUBLIC

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## REGIONAL GEOLOGICAL SETTING AND TECTONICS

The Lao People's Democratic Republic forms part of the Indochina Peninsula, a well-defined tectonic unit which also includes Thailand, eastern Myanmar, the Malay Peninsula, the western tip of Kalimantan, the Gulf of Thailand and the Sunda Sea. The Indochina Peninsula is also described by the paleo-geographical name of Indosinia.

The territory of the Lao People's Democratic Republic can be divided into a number of structural-tectonic zones (Figure I), namely:

(1) Vientiane – Muong Phalane Zone

(2) Sekong Zone

(3) Kontum Plateau Zone

(4) Nam Sam – Xieng Khuang Zone (part of the Laos-Vietnam fold system)

(5) Nam Ou Zone

(6) Namtha Zone

(7) Upper Mekong River Zone (part of the Burma Malaya fold system)

The geological framework within the territory of the Lao People's Democratic Republic is formed of continental blocks of Precambrian age: the Indosinian block which is the largest block, located in the central area and southwestern region, and the smaller blocks (massifs) are composed of the Kontum Massif and the Kanshy Domes in the east, and the Upper Mekong zone (comprised of the Burma-Malaya fold system) in the northwest of the country.

The oldest rocks of the Indochina Peninsula are those comprising the Precambrian – Early Paleozoic Orogenic Metamorphic Complex. In the Lao People's Democratic

and Early Mesozoic Eras the Indochina Plate
separate entity southeast of the South China P

## LOCAL GEOLOGY

The Phou Kalai gold prospect area is
50 km northwest of Vientiane, comprising
group of hills of about 200 m relief extendi
Mekong River northward about 8 km. This are
on a gold-bearing granodiorite intrusion belt w
northward from known gold-bearing areas in
the Lao People's Democratic Republic it is k
Sanakham–Vientiane gold belt, and it extends
border northward for over 100 km (Page an
1967).

## LITHOLOGIC UNITS

Lithologies in the Phou Kalai area inc
lowing units:

### A. Volcanics

A thin cover of Late Permian volcanic
La system outcrops over much of the Phou Ka
sequence includes pyroclastic interpolations o
with andesites and rhyodacitic tuffs. These
vary in texture from fine-grained ash tuffs thro
agglomerates. These rocks have been subject
degrees of alteration and quartz-vein mineraliz
units include coarse-grained porphyritic ash-flo
tuffs with varying proportions of ash matrix an
of quartz and feldspar crystals. Some outc
mixture of ash and shard material, and also vo
textures.

Andesites occur as ash-flow pyroclast
sequence and usually as relatively even-grained ro
feldspar crystals occasionally impart a porph

### B. Sub-volcanics

A fine-grained microdioritic rock outcrops as a dark-colored, chlorite-altered porphyritic rock of probable hypabyssal origin. Xenoliths of this material have been noted in granitic stream float. Fine-grained chloritic basaltic andesite (dolerite?) dykes are also observed. This rock is chlorite-altered and hosts a minor amount of feldspar phenocrysts.

### C. Intrusive Rocks

Granodiorite intrusives outcrop in the lower part of the Huei Kalai, and occur as an equigranular mosaic of intergranular biotite and pyroxene minerals. Disseminated pyrite is also observed. These intrusives also possess a porphyritic phase in which coarse quartz and feldspar phenocrysts lie within a fine quartzo-feldspathic matrix. The intrusives become more granitic further up the Huei Kalai valley, where the rock occurs as small apophyses within the volcanics. These areas represent an irregular roof-zone of the underlying plutonic rocks and in places display chlorite-muscovite greisenization.

### D. Sedimentary Rocks

A very minor amount of limestone stream-float was discovered in the Huei Kalai. This suggests that Triassic sedimentary sequences possibly blanketed the Late Permian volcanics in the Phou Kalai area prior to block-faulting, uplift and erosion.

## ALTERATION

All the volcanics have been hydrotherm
by late fluids derived from the granite-granodiori
Four alteration types are discernible in the fiel

- Silicification
- Sericitization
- Propylitic (chloritic) alteration
- Greisenization

Alteration styles and intensities vary
over short distances throughout the volcanics
small localized fluid-flow systems rather than l
tion cells. In general, silicification is spatiall
with quartz-vein foci and fluid-flow zones. Th
haloed by sericitic alterations which in tur
within more widespread propylitic (chloritic)
pristine volcanics are evident in the Phou
although some areas may show only a wea
alteration.

## STRUCTURE

Fracture–joint analysis for the area
dominant trends:

ENE – ESE (80 – 120°)
NNW (170 – 180°)
NE (40 – 50°)

**Table 1. Stratigraphic column of Phou Kalai region, Lao People's Democratic Republic**

| *Period* | *System* | *Lithology* |
|---|---|---|
| Quaternary | – | Alluvial sands, gravels, peat. |
| Cretaceous | Champa | Sandstone, quartzite, arkose, gravel. |
| Jurassic – Cretaceous | Phouphanang | Micaceous sandstone, quartzite. |
| Upper Triassic | Namset | Sandstone, shale, limestone, conglomerate, micaceous, quartzite |
| Middle Triassic | Phou Lekphay | Conglomerate, sandstone, quartzite, limestone, rhyolite, rhyodacite, felsite, porphyry, tuff. |
| Permo – Triasssic | Sakay Complex | Granite, granoporphyry, granodiorite, microdiorite-diorite, porphyry dykes, gabbrodiabase, aplite dykes. |
| Upper Permian | Huei La | Sandstone, quartzite, agglomerate, basalt, andesite, tuff. |

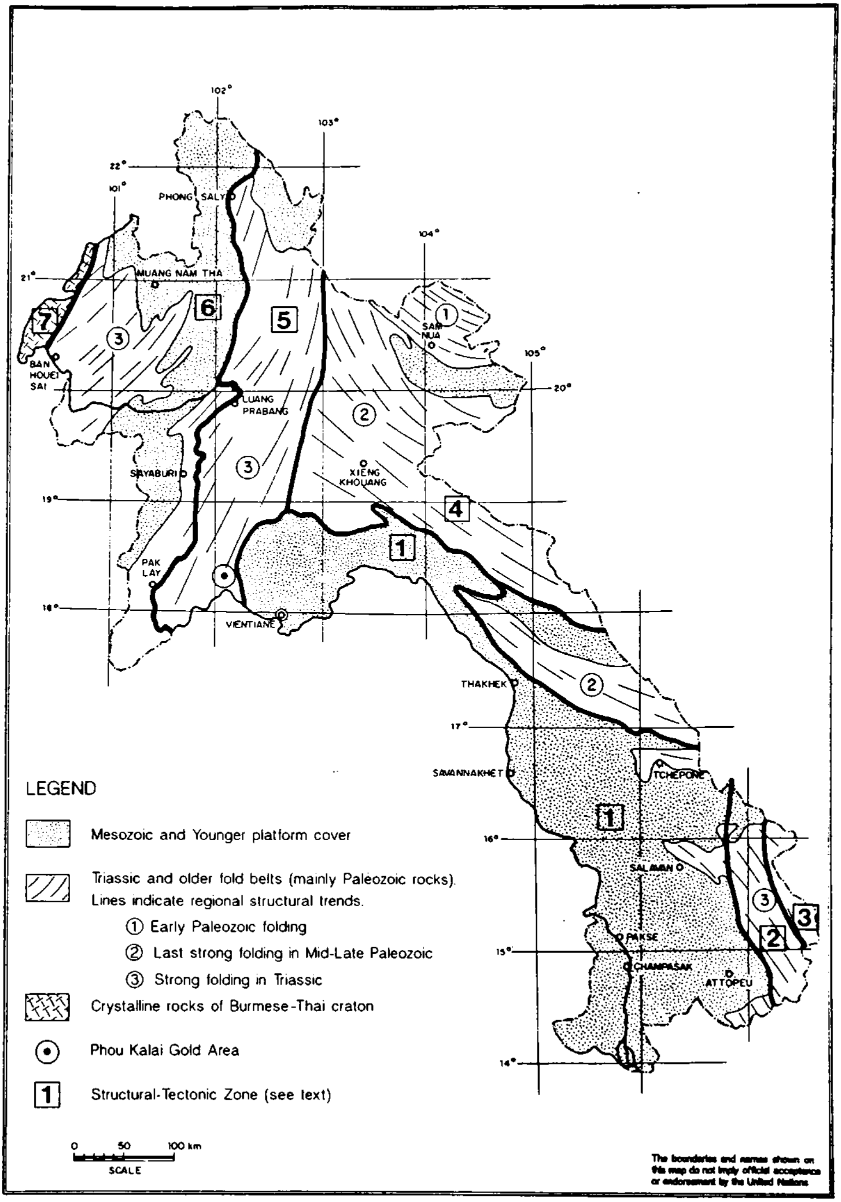

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Figure I. Outline of the geological structure of the Lao People's Democratic Republic.

Shearing orientations display NNW and ENE dominant directions. All quartz-vein occurrences display shear-textures such as boudinage, smearing and brecciation. Shear foliation fabrics are penetrative within the quartz, inferring that the mineralization was pre-syntectonic. Intrusive contacts however are also sheared and brecciated indicating syntectonic granite emplacement. This is further evidenced by the existence of breccias in which angular and subangular volcanic fragments lie within a granitic matrix. The tensional orientation in the Phou Kalai area has no dominant direction and overall, the structural regime is considered to be a tight compressional system. Quartz fibre growths lie at 90 degrees to vein walls, which also infers a lack of lateral displacements. These facts combine to downgrade the potential for large-tonnage resources.

## MINERALIZATION

Gold-silver and base-metal mineralization is hosted within quartz veins of various sizes and orientations within the volcanic successions at Phou Kalai. These are genetically related to the granodioritic intrusions and occur as stringer and veinlet stockworks, quartz breccias within shear zones and as discontinuous en-echelon vein arrays also related to the shear zones.

As stated vein distributions and textures are structurally controlled by shearing and are limited in their lateral and vertical continuity. Typical vein textures demonstrate fine-grained margins with coarse-grained, comb-textured centres. The quartz veins themselves are typically vuggy in outcrop, with iron oxides pseudomorphic after sulfides. Vugs may be lined with fine acicular quartz needles in addition to iron oxides. Quartz breccias are common and invariably carry angular hostrock fragments and strong iron oxide aggregations. Auriferous quartz veins have been noted at two locations within the porphyritic phase of the granodioritic intrusives. They are structurally controlled and possess textures identical to veins hosted in the volcanics.

In general, gold mineralization is quite strictly confined to the quartz veins. Only minor traces of gold occur within the wallrocks.

## SOIL AND ROCK-CHIP GEOCHEMICAL ANALYSES

Detailed orientation sampling in the Huei Kalai drainage system has pinpointed a direct correlation of gold-silver mineralization to the presence of quartz-vein material. All high-value results were derived from vuggy, iron oxide-rich comb-quartz, or from medium-grained quartz carrying finely banded opaques. Other alteration types and lithologies yielded low assays, except where a quartz stringer phase existed. Altered wall-rock samples adjacent to quartz veining reported only minor gold.

After some experience in learning which rock materials were likely to be auriferous, rock-chip sampling became redundant, and the search shifted to rapid regional reconnaissance for areas of quartz-rich materials of sufficient dimension to be of interest. The geochemistry of the Phou Kalai terrane shows that any significant mineralization is related to the granodiorite – granite intrusions, and particularly to their marginal zones. The following relationships were demonstrated:

1. Strong gold – silver and moderate gold – base metal correlations are evident from channel sample, bulk sample and rock-chip sampling results.
2. Silver/gold ratios for rock-chip and channel samples average 13:1 and 39:1 respectively. This indicates a higher mobility for gold than for silver in the mineralization environment.
3. Arsenic is totally unresponsive to fluctuating gold and silver values and remains relatively constant at a background value of about 50 ppm.
4. Several high gold samples were re-assayed for other elements. Results indicated:

| | | |
|---|---|---|
| Low tin, averaging | 1.3 | ppm |
| High boron, | 35-60 | ppm |
| High antimony, up to | 621 | ppm |
| Significant mercury, | 0.9-6 | ppm |

## CONCLUSION

Neither the alluvial deposits nor the hard-rock quartz vein occurrences in the Phou Kalai area present economically viable exploration targets at this time. The potential for significant hard-rock deposits appears to be depressed by the predominantly compressional structural regime, lack of vein-system continuity and the thin host-rock volcanic cover overlying the relatively barren intrusive units. Further work may indicate the location of a structurally more favoured locus of deposition within this demonstrably gold-bearing district, however.

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# EPITHERMAL GOLD POTENTIAL IN MYANMAR

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## INTRODUCTION

Gold has been panned in the streams and on the hillsides very widely in Myanmar, particularly in the Central Lowlands (see Figure I). Most of the gold panned in the Central Lowlands is believed to have come from the epithermal gold mineralizations in the upper levels of the volcanic chain of the Myanmar Arc, whereas the gold in the western margin of the Eastern Highlands, where granitoids and high-grade metamorphic rocks occur, may have come from metamorphic and granite-related sources as well as from epithermal mineralization. Guided by the general concept that epithermal gold mineralization occurs in areas of extensional tectonic settings, associated particularly with volcanic rocks preferably of younger age (usually Tertiary to Quaternary), and bearing in mind that case histories of mineral occurrences often serve as indicators for choosing target areas for mineral exploration, the Central Lowlands and adjacent western margins of the Eastern Highlands of Myanmar have been selected as target areas for epithermal gold deposit exploration. Such mineralization has already been located in the southern part of the Pegu Yoma and in the Kawlin-Wuntho district. Systematic prospecting and exploration remain to be done in this region, particularly in the northern part of the Pegu Yoma around Mount Popa volcano, in the volcano-studded Monywa area of central Myanmar, in the Jade Mines district near Mount Loimye volcano, and along the axis of the Shan Scarp.

## A GEOLOGICAL SKETCH OF MYANMAR

Myanmar can be divided into four tectonic-physiographic belts from west to east, viz. the Arakan Coastal Belt, the Indo-Burman Ranges (or Western Ranges), the Central Lowland Belt, and the Eastern Highlands (Figure I). The Arakan Coastal Belt contains Oligo-Miocene strata of molasse facies which are highly disturbed by recent subduction, but are not penetratively deformed. The Indo-Burman Ranges are underlain by highly disturbed, mostly east-dipping, and penetratively deformed flysch strata younging to the west. Upper Triassic strata occupy a narrow north-south belt along the eastern margin of the Indo-Burman Ranges and Upper Cretaceous strata similarly occupy a relatively broader belt close to the west of the Triassic belt. The large remaining bands of the Indo-Burman Ranges, however, are underlain by both highly disturbed and gently dipping strata of Eocene age. The gently tilted Eocene strata probably represent trench-slope deposits, whereas the highly disturbed and penetratively deformed Upper Triassic, Cretaceous and Eocene strata could have been trench turbidities. The Indo-Burman Ranges represent the emergent, outer arc-ridge of the Myanmar Arc, tectonically comparable to the Andaman-Nicobar ridge to the south. A discontinous line of ophiolitic rock occurrences marks the boundary between the Indo-Burman Ranges and the Central Lowlands to the east.

The Central Lowlands Belt is composed of the Irrawaddy, the Chindwin and the Sittaung River Valleys and the intervening low ranges. The volcanic line (magmatic belt) of the Myanmar Arc runs north-south through the heart of this belt separating it into parallel western and eastern troughs. The western trough contains a thick orderly succession of flyschoid and molasse strata ranging in age from Late Cretaceous to Recent, with local and regional interruptions in the sedimentary record, whereas the eastern trough contains a discontinous and much thinner succession of molasse strata ranging in age from Eocene to Recent. The eastern edge of the Central Lowlands Belt is truncated by a currently active wrench fault system, the Sagaing Fault (Win Swe, 1981) which shows a right-lateral displacement and from which basaltic lavas have been locally discharged. The Eastern Highlands are composed of the mountainous tracts of the northern and eastern Kachin State in the north, the Shan Plateau in the middle, and the mountainous Kayah State and Tennaserim Division in the south. This belt is underlain by Precambrian, Paleozoic and Mesozoic successions which are locally overlain by small areas of Cenozoic lacustrine deposits. Granitoid intrusives occur along a narrow north-south belt on the western margin of the Eastern Highlands and also in irregular bodies to the east in the Kengtung and Tachilaik districts.

## TECTONICS, VOLCANISM AND GOLD OCCURRENCES

Mynmar is situated across the Indonesian-Himalayan Line of plate convergence (Figure II) and the Myanmar sector will be referred to as the Myanmar Arc in this paper.

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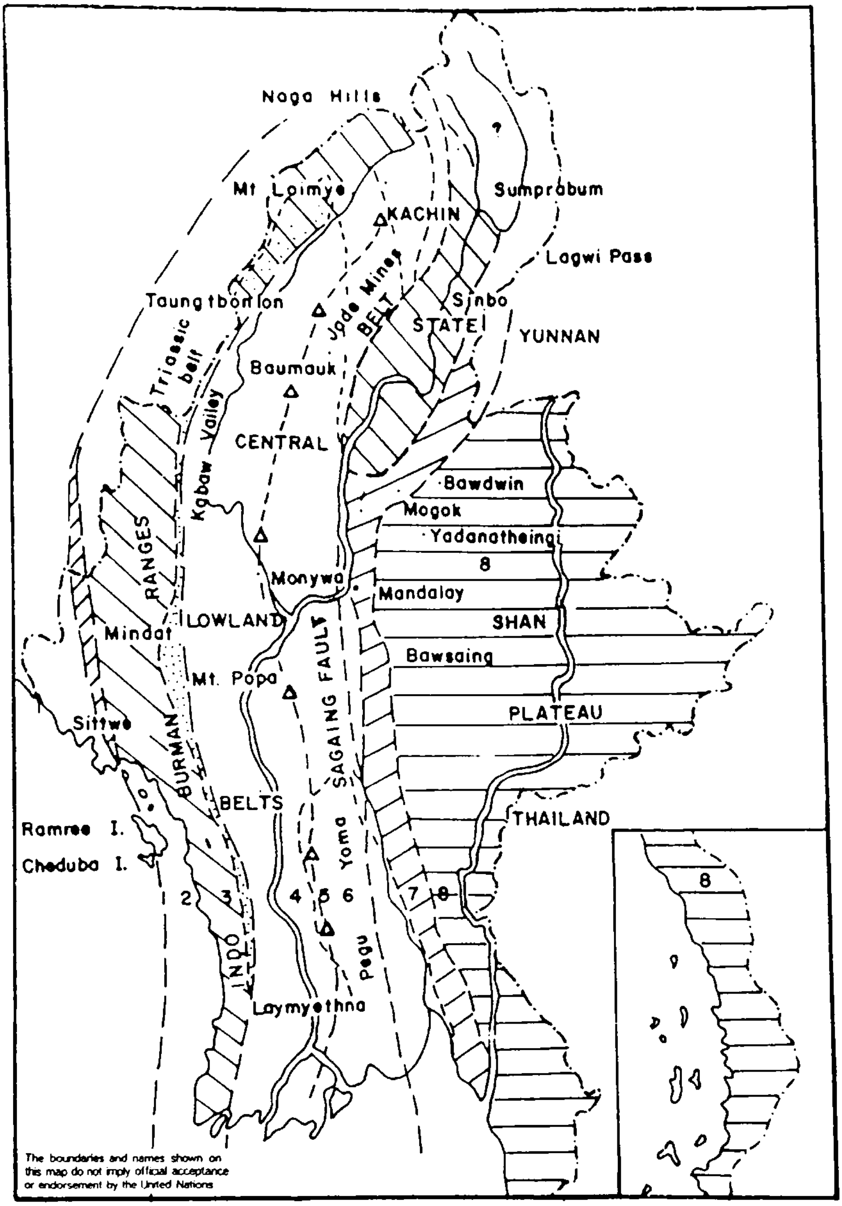

Figure I. Structural elements of Myanmar.

Figure II. Subduction arc zones of the western Circum-Pacific regions.

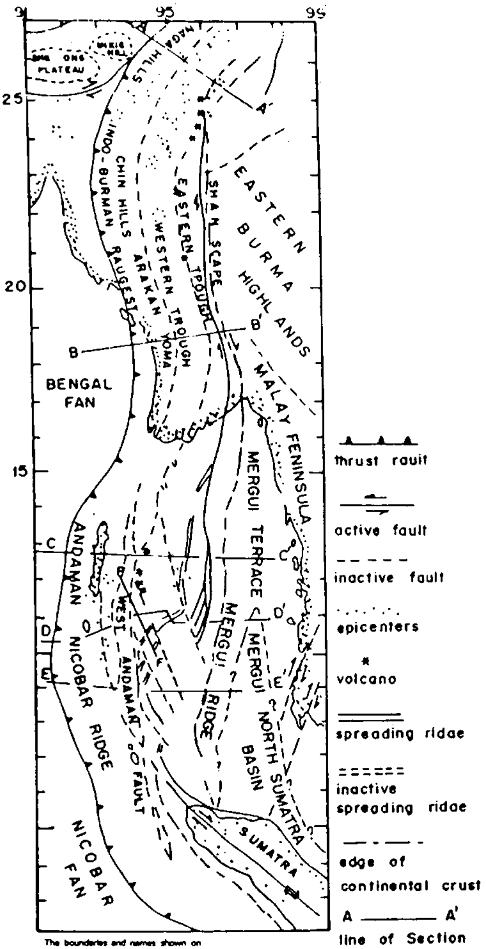

**Figure III. Tectonic elements of the Myanmar Arc – Sunda Arc regions.** (After Currey et al., 1979)

The Myanmar Arc is west-facing, whereas the Indonesian Arc, the Sunda Arc and the Himalayan Arc are entirely different, each constituting a standard style of plate interaction. In the Indonesian region the plate convergence is that of a destructive type, with subduction of oceanic crust along an active trench (the Java trench) under an island arc with a volcanic chain above, whereas the Himalayan Arc is a clear example of a collision zone between two continental plates. The Myanmar Arc occupies the region between these two contrasting types of plate convergence and possesses tectonic features characteristic of both types, but is more closely related by tectonic features to the Sunda Arc. In its southern segments, south of the latitude of Sittwe, plate convergence is of the destructive type with active eastward subduction of oceanic crust partly under a submerged outer-arc ridge (the Andaman – Nicobar Ridge) in the Andaman Sea, and partly under the continental margin consisting of accreted trench turbidites which form the emergent outer arc-ridge (the Indo-Burman Ranges). In its northern segments, plate convergence in the Myanmar Arc is that of two continental crusts, similar to that of the Himalayan region (Win Swe, 1988).

The presence of an east-dipping subduction zone running north-south and lying to the west of the Cocos Islands and Cape Negris, the southwestern tip of the mainland of Myanmar, north through Cheduba and Ramree Islands off the Arakan coast and further northward on land along the Kaladan valley can be inferred from the regional geology and seismic data (Currey et al., 1977; Molnar and Tapponier, 1975). This subduction zone is the northward continuation of the subduction zone along the Java Trench off the coast of Sumatra (i.e. the Sunda Arc) which was traced by Moore et al. (1980) from the Indonesian region where it is well expressed bathymetrically, northward to the southwest part of Myanmar. From the Andaman islands northward the subduction zone gradually loses its bathymetric expression as it is buried under the sediments of the Ganges Estuary at the apex of the Bay of Bengal, which stretch eastward and lap upon the west flanks of the Andaman-Nicobar ridge. Subduction in the Myanmar region is highly oblique, that is north-northeastward, and the lateral component of the movement appears to be taken up entirely by the Sagaing fault system to the east, which transforms the opening of the Andaman Sea northward to the eastern Himalayan System (Currey et al., 1979, Figure IV).

Several mud diapirs occur at the inferred location of the subduction zone on Chedubo and Ramree Islands. Northward and inland, the inferred trace of the subduction lies either within highly tilted but relatively less deformed Miocene molasse sandstones and shales which, at the foot of the Indo-Burman Ranges to the east, are underthrust beneath the more deformed Eocene strata of the ranges.

As the northward continuation of the Sunda Arc, the Myanmar Arc is the locus of a young volcanic chain which is appropriate as a possible sites for epithermal gold mineralization similar to that of the Sunda Arc and other arcs of the Circum-Pacific region. This volcanic chain runs north-

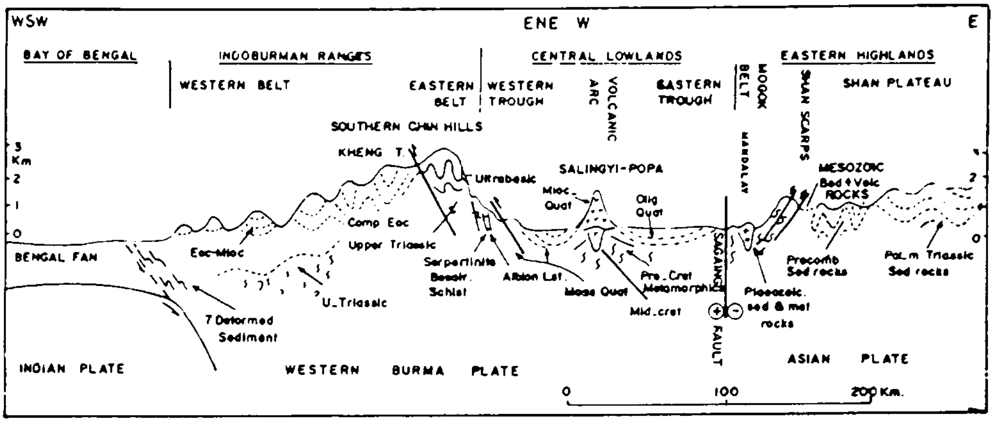

Figure IV. A generalized cross section of Myanmar at the latitude of Mount Pope (Approximately North 21° ).

south through the heart of the Central Lowlands belt. The igneous lithologies in the belt include tuffaceous sediments of Miocene age in the Irrawaddy Delta district, dolerite sills of the Pegu Yoma, the young volcanic cones and craters of the Monywa district, igneous rocks of the Wuntho-Banmauk district, and the igneous activity in the Jade Mines district (Tawmaw) in Kachin State. The belt probably continues northward, though its expression is poorly understood in that remote region.

Tuffaceous sediments of Miocene age occur widely in the Irrawaddy Delta. These occurrences are located slightly to the west off the southward projected trace of the magmatic belt of the Myanmar Arc, which extends southward toward the active volcanoes of the Barren and Narcondam Islands in the Andaman Sea. Northward the magmatic belt passes through the dolerite sills exposed on the Pegu Yoma east of Zigon and Myode. In both areas the occurrences are relatively small but due to their resistant nature they stand out conspicuously across local streams. The country rocks in these areas are poorly indurated sandstones and shales of probable Miocene age. Epithermal gold mineralization has been located in the Myezedaung area on the Pegu Yoma east of Letpadan, where igneous rocks have not previously been known to occur, the nearest such being the previously mentioned sills east of Zigon some sixty kilometres to the north. The hydrothermal alteration zone at Myezedaung is limited but advanced argillic alteration, silicification and quartz-veining on a small scale have been observed. The area awaits a more thorough exploration and evaluation.

In the Mount Popa area, at the north end of the Pegu Yoma, the volcanic occurrences are fairly widespread, covering an area of several square miles. Igneous rocks include bedded tuffs, andesite and basaltic lava flows, and some white ash and rhyolite. The most visible volcanic feature in the area is the cone of Mount Popa itself (1518 m) which dominates the local landscape. Very young volcanic features include lava flows of Quaternary age and a volcanic plug intruding Upper Miocene-Pliocene sedimentary rocks of the Irrawaddy Formation. No plutonic rocks are known in this district. Strangely enough, gold panning has not been attempted by the local people. It is not clear whether this is because the area does not yield any possible gold or whether water is considered too scarce to support systematic panning. The area remains an attractive prospect for epithermal gold occurrences, particularly in view of the young volcanism, favourable lithologies and observed alteration effects. Silicification has been observed nearby at Taungni Hill and in the Kyaukpedaung Hills.

Limited occurrences of volcanic rocks are known in the Shinmadaung area north of Pakokku and igneous rocks are quite widespread in the Monywa area, where they include andesites, dacites and their tuffaceous equivalents. The important features include several volcanic cones such as the Lepadaung Hills, Kyizindaung and Sabedaung Hills (which carry porphyry copper deposits), several craters on both sides of the Chindwin River, and numerous dry craters, partial craters and igneous plugs. Some of the craters in this area are occupied by beautiful lakes which contrast with the dry and poorly vegetated landscape. Granitic rocks of Cretaceous age and greenstones of possible Triassic age are exposed in the basement in this area. One of the youngest and best preserved features in this area is the Taungthanlong volcano of Quaternary age. A deeply eroded porphyry copper deposit is located at Shangalon Village. Gold is panned in this region and primary gold was mined at Kyaukpazat, a few miles north of Wuntho, in the early part of this century. A primary gold deposit has also recently been located at Kyaukpahte on the eastern margin of this region. In fact the gold potential of the whole magmatic belt appears generally favourable in view of the increasing number of small gold discoveries.

Northward in the Jade Mines district of Kachin State, volcanic features are also observed. The most prominent Mount Loimye, forms a cone rising 1590 meters above sea level. Mount Loimye marks the northernmost known expression of the Myanmar Arc magmatic belt.

Late Tertiary or Quaternary volcanism is also known in other parts of the country, off the central axis of the magmatic belt. Loi Han volcano, situated in the Shan Plateau southeast of Lashio, is composed of olivine basalts. Here the volcanic rocks, resting on Late Tertiary lacustrine deposits, form a dome-shaped mass with dykes extending outward in a radiate pattern. The entire mass appears to be a plug, the upper portion of which has been removed by erosion. Fissure-type volcanism is also known on some of the islands of the southern archipelago of Myanmar.

## POTENTIAL TARGET AREAS FOR EPITHERMAL GOLD EXPLORATION

Guided by the general philosophy that epithermal gold mineralization tends to occur in areas of extensional tectonic settings, generally in zones of porous and permeable volcanic rocks particularly of felsic affiliation and of subaerial origin, and preferably of younger (Late Tertiary or Quaternary) ages (since deposits are formed in a near-surface environment and are extremely susceptible to early erosion), and assuming that case histories can serve to offer guiding principles for choosing target areas for mineral exploration, the central volcanic belt running north-south through the Central Lowlands, where epithermal gold mineralization has already been discovered at least in two locations is believed to present the best potential for epithermal gold prospecting in Myanmar.

line and continuing northward along the cou
Irrawaddy River valley. The currently acti
fault system is indicated by the historically
rence of earthquakes in the recorded past w
aged historic landmarks and religious sites a
Pegu, Mon, Pyinmana, Inwa, Sagaing and
are located on or near the fault zone, as
observed lateral offset of streams and drai
fault zone (Win Swe, 1981).

Olivine basalts covering several sq
in the Singu area some 60 km north of Ma
the Sagaing fault zone. Here the lavas appea
up along fissures, rather than through a c
form an almost horizontal sheet resting on t
Pliocene strata of the Irrawaddy Formation.
a very fresh appearance. On their northern li
River makes an abrupt right-angle turn to th
in that direction for about three kilometres b
its normal southward course, thus indicati
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extrusive and pyroclastic rocks are noted
Fault farther north in the vicinity of Htigyai
and structures in these rocks indicate their o
eruption.

Currey et al. (1979) and Moore et
pointed out, as mentioned earlier, that the
system appears to have transformed the op
vectorial direction in the Andaman Sea to
ented movements towards the eastern Hima
since the mid-Miocene, and oceanic crust
ward on land along the Sagaing Fault syste
25° north latitude (the latitude of Banmauk
some 1000 km from the Gulf of Martaban.
of hot springs occur along the east side
section of the fault system, notably along
(Chhibber, 1934). Therefore the region alo
Fault system is believed to have been capab
the hydrothermal activity required for epit
posits since at least Miocene time.

Since the Sagaing Fault system and t
previously discussed are parallel and reaso
proximately 60 km) to each other, the entire
the two, and their related peripheral zones
ered to be fertile prospecting ground, that
Central Lowlands belt, and the adjoining w

## CONCLUSIONS

The Myanmar Arc, being the northward continuation of the Sunda Arc, presents very attractive possibilities for hosting epithermal gold mineralization, in a manner analogous to other subduction-related arcs in the Circum-Pacific regions. Located close to the Himalayas and being their southward continuation, the northern part of the Myanmar Arc forms a collision-type of plate convergence tectonic situation, with similarities to the Himalayan Arc. Most of the tectonic features of the Myanmar Arc, however, are more closely comparable to those of the Sunda Arc to the south, which is formed of an active subduction zone along a trench and an active volcanic belt on the overriding plate. The volcanic belt and the currently active Sagaing Fault system are believed to be capable of generating hydrothermal fluids and perhaps the significant deposition of epithermal gold as well, in a style similar to the epithermal deposits found on the Sunda and other arcs of East Asia and the western Pacific. To these two features should be added the western marginal zone of the Eastern Highlands belt where extensional tectonic settings and felsic intrusives occur. These three tectonic features combine to comprise the prime targets for exploration for epithermal gold deposits in Myanmar.

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# A NOTE ON TWO GOLD PROSPECT AREAS IN MYANMAR

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## A. KWINTHONZE PROJECT

### 1. Introduction

The Kwinthonze Project covers approximately 870 km² and includes a number of gold prospects and a preliminary gold concentration plant at Padaukmyaing. Gold occurrences in the project area were first reported by local people in 1969 and since then placer gold has been worked extensively. An integrated exploration progamme for primary gold deposits was introduced by the Department of Geological Survey and Mineral Exploration (D.G.S.E.) in 1982. At the present time, small-scale production and concentration of primary ore is undertaken from the gossan zone over the main vein at a rate of three tons per day. The plant is producing amalgam gold and flotation concentrations. Within the Kwinthonze Project area about ten gold prospects have been discovered and four of those are currently under exploration investigation.

### 2. Location and accessibility

The project area is located about 100 km north of Mandalay along the Mandalay–Thabeikkyin all-weather road. Prospect areas are accessible by secondary roads and walking tracks at distances of about 2 to 8 km off the main road (Figure I).

### 3. General Geology and Mineralisation

The geology of the region comprises the Precambrian Mogok Belt, which includes dolomitic crystalline marble, calcitic fine-grained marble, calcitic granular marble, calc–silicate rocks and gneiss. Acid igneous rock, the Gabaing Granite, intruded the Mogok Belt in the north of the project area. Possible skarn zones have been identified in the contact region of altered marbles and a syenitic intrusive stock.

Primary gold mineralisation observed in the prospect area occurs as gold-bearing limonitic quartz veins in a sequence of metasediments. At the surface, the veins form a prominent gossan zone. The mineralisation is associated with sulphides including pyrrhotite, pyrite, sphalerite, galena and chalcopyrite. The ten prospects included in the Kwinthonze Project area are as follows:

#### *3.1. Kwinthonze Prospect*

A primary gold deposit, known as the main vein, occurs in marble. The deposit, which trends north-south and dips almost vertically, crops out at surface as an extensive gossan zone which is how being extracted. At about 18 m below the surface, the main vein was intersected by an underground adit and also by diamond and percussion drill holes, which indicate that the width of the vein varies from 3 to 6 m. Possible reserve estimate for the deposit is 0.76 million tons with 2 ppm gold and there is potential for discovering extensions and other parallel zones of mineralisation.

Apart from the primary gold mineralisation, widespread occurrences of placer gold, both eluvial and alluvial types, have been worked extensively as small-scale operations by local people.

#### *3.2. Kyetsaungtaung Prospect*

The Kyetsaungtaung Prospect comprises a graphitic calc-silicate band with a strike length of about 300 m and an enriched gossan zone. The gossan near the camp (which grades 4 to 5 ppm gold) was tested by diamond drilling and surface work. The graphitic calc-silicate band was also tested for grade by trenching and both investigations have indicated disappointing results. At Kyaukkhaloke, about 3 km north of the area, there is a surface showing and a discontinuous gossan outcrop covering an area of approximately one-half hectare, presenting two other targets for surface exploration in this area.

#### *3.3. Shweseingone Prospect*

The prospect is located at about 16 km north of Kwinthonze and is marked by a line of gossan outcrop which trends north-south at the contact zone between granular marble and the Gabaing Granite. This has been tested by surface work and trenches, and by geophysical survey (SP and TURAM), at the time of writing.

#### *3.4. Ngweyon Prospect*

The Ngweyon placer gold deposit comprises a 30 to 90 cm thick gravel bed which is located 15 to 20 m below the

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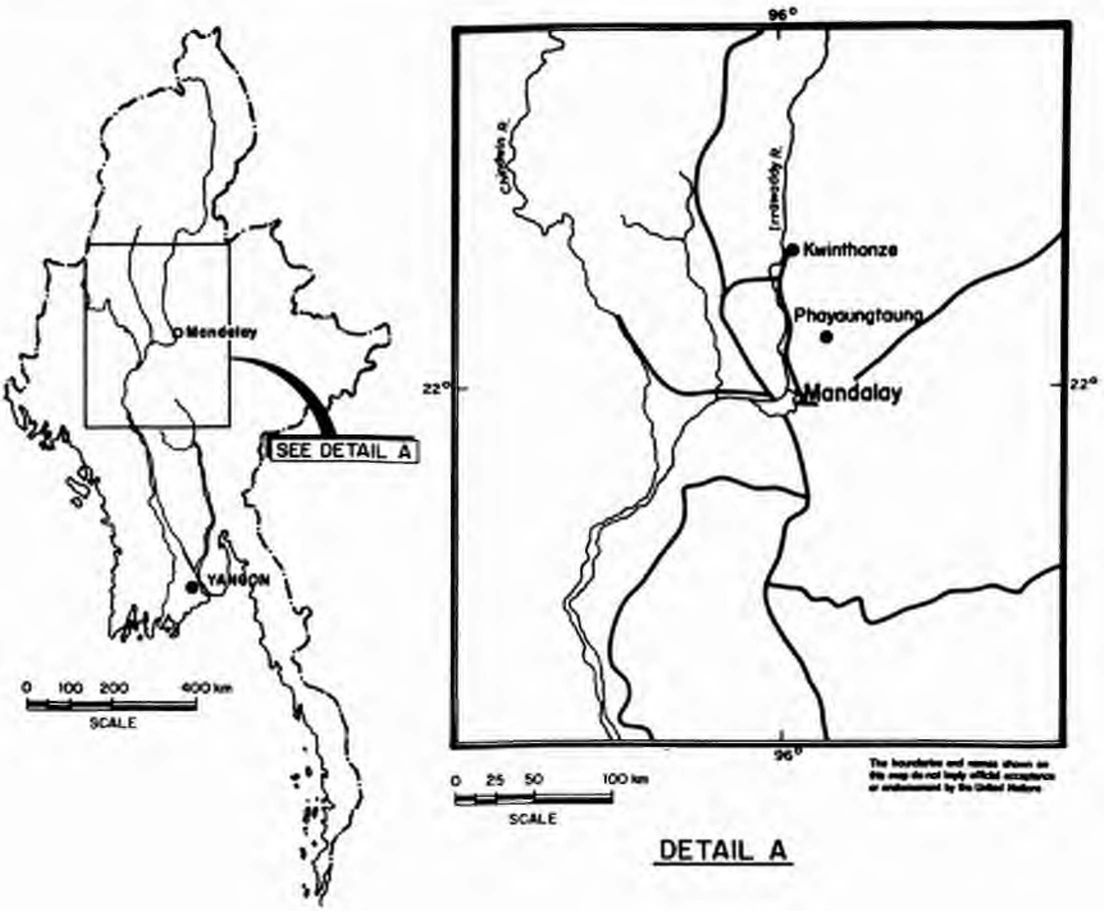

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure I. Location of Kwintonze and Phayaungtaung Projects, Myanmar.

present surface on gneiss bed rock, and appears to be deposited in an old stream channel.

### *3.5. Other Prospects*

Besides the four above-mentioned prospects, there exist others in this district, at Bindang, Zayatkwin, Work-site 2 and 3, Wetthay, Onzon and Wabyutaung west.

### 4. Work done

Exploration work undertaken in the Kwinthonze area includes geological mapping, pan concentrate sampling, test pitting and trenching. In addition, geophysical surveys and sub-surface exploration activities were carried out in the project area including diamond drilling, percussion drilling and, at the Kwinthonze Prospect, about 100 m of underground adits.

## B. PHAYAUNGTAUNG PROJECT

### 1. Introduction

The Phayaungtaung Project covers approximately 250 km$^2$ and includes a number of alluvial and primary gold prospects. Gold was first reported by local people in 1983, when they began working for gold in the Shwemyit Chaung (gold stream). Geologists from the Department of Geological Survey and Mineral Exploration took over gold exploration in 1984, and preliminary production and concentration of primary gold has been carried out since 1986.

### 2. Location and Accessibility

The Phayaungtaung Project is located 19 km north of Mandalay, accessible from Mandalay by 18 km of paved road and 13 km of secondary road (Figure I).

## 3. General Geology and Mineralisation

The gold mineralisation of the Phayaungtaung area is developed in Precambrian rocks of the Chaungmagyi Series comprising quartzites and phyllites. The mineralisation is hosted by two types of quartzite - Quartzite I and Quartzite II - and it is localized in intense quartz-vein stockworks. The mineralisation includes significant visible gold and is associated with iron and copper sulphides.

The possible ore reserve so far is estimated at about 2 million tonnes with 3 to 4 pm gold.

## 4. Work done

Exploration work undertaken at the Phayaungtaung area includes geological mapping, geophysical surveying, pan concentrate sampling, percussion drilling and diamond drilling.

## 5. Future Programme

More detailed diamond-drilling and percussion-drilling to establish potential tonnage and grade of the primary gold mineralisation are necessary. Detailed integrated surface exploration, to find extensions and other parallel mineralised zones is also required.

# PRINCIPAL FEATURES OF EPITHERMAL GOLD DEPOSITS IN PAPUA NEW GUINEA

by
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## 1. INTRODUCTION

Amongst the Pacific Rim countries, Papua New Guinea (PNG) is the leader in new gold discoveries. This leading position is a direct result of the favourable geologic setting along the "Rim of Fire" of Papua New Guinea. Of these new discoveries eight fall into the category of epithermal gold deposits and six of these will be discussed in this paper.

Of the six epithermal deposits to be discussed, four fall into the category of adularia-sericite type deposits (Lihir, Misima, Wau and Wild Dog), and the remaining two (Nena and Wafi) fall into the category of acid-sulfate type deposits.

## 2. REGIONAL GEOLOGY

Papua New Guinea lies on the part of the Circum-Pacific Rim where the Australia-India and Pacific Plates abut (Figure I). It consists of the main island which comprises a series of fold and thrust belts with the Fly Platform to the south-west, and island arcs with their intervening ocean basins (Figure I).

A tectonic interpretation by Rogerson et al. (1987) treats the Fly Platform as the foreland of the Australia-India Plate. This region is bordered on the northeast by fold belts and imbricate thrust sheets formed during foreland thrusting. The fold and thrust belts together with the island arcs are collectively termed the New Guinea Orogen by these authors.

Igneous activity occurred in several centres throughout the fold belt during Miocene and Pliocene times resulting in the formation of several rich gold deposits.

The Melanesian Island Arc contains Eocene-Oligocene basic to intermediate volcanics, intrusives, and minor sediments overlain by Oligocene to Miocene and early Pliocene carbonate-dominated sedimentary sequences (Figure II). The arc has been subjected to calc-alkaline and minor tholeiitic, largely extrusive, igneous activities.

## 3. SUMMARY OF THE CHARACTERISTICS OF VOLCANIC-HOSTED EPITHERMAL GOLD DEPOSITS

Buchanan (1981) published a valuable compilation of selected observations from over 60 gold-silver vein deposits hosted in volcanic to subvolcanic environments. These data, and the intergrated model derived from them, have formed a useful basis for numerous subsequent analyses of the characteristics of epithermal deposits, some of which include Giles and Nelson (1982), Bonham and Giles (1983), Berger and Eimon (1983) and Heald et al. (1987). A detailed investigation of 16 carefully selected, well studied, Tertiary volcanic-hosted epithermal deposits is presented in Heald et al. (1987). They recognize two major classifications of epithermal gold deposits, the adularia-sericite type and the acid-sulfate type. The characteristics used to distinguish these deposit types are principally the presence or absence of major alteration mineral assemblages. The characteristic features of these two deposit types are shown in Table 1 and a brief discussion of the major features is given below.

### 3.1. Principal Features

#### *3.1.1. Mineralogy*

Critical distinction among the epithermal deposits are based on the presence or absence of specific minerals and mineral assemblages. Unique to the acid-sulfate type deposit is the presence of the assemblage enargite + pyrite ± covellite and an advance argillic assemblage including abundant hypogene alunite and kaolinite. Adularia-sericite type deposits are characterised by the presence of adularia and sericite within or near the veins and the absence of enargite + pyrite ± covellite assemblage and of hypogene alunite (Heald et al., 1987). Chlorite is commonly present in most adularia-sericite type deposit but rarely occurs in the acid-sulfate type deposit.

#### *3.1.2. Wall Rock Alteration*

In general, adularia-sericite type deposits are characterised by the predominance of sericite alteration that

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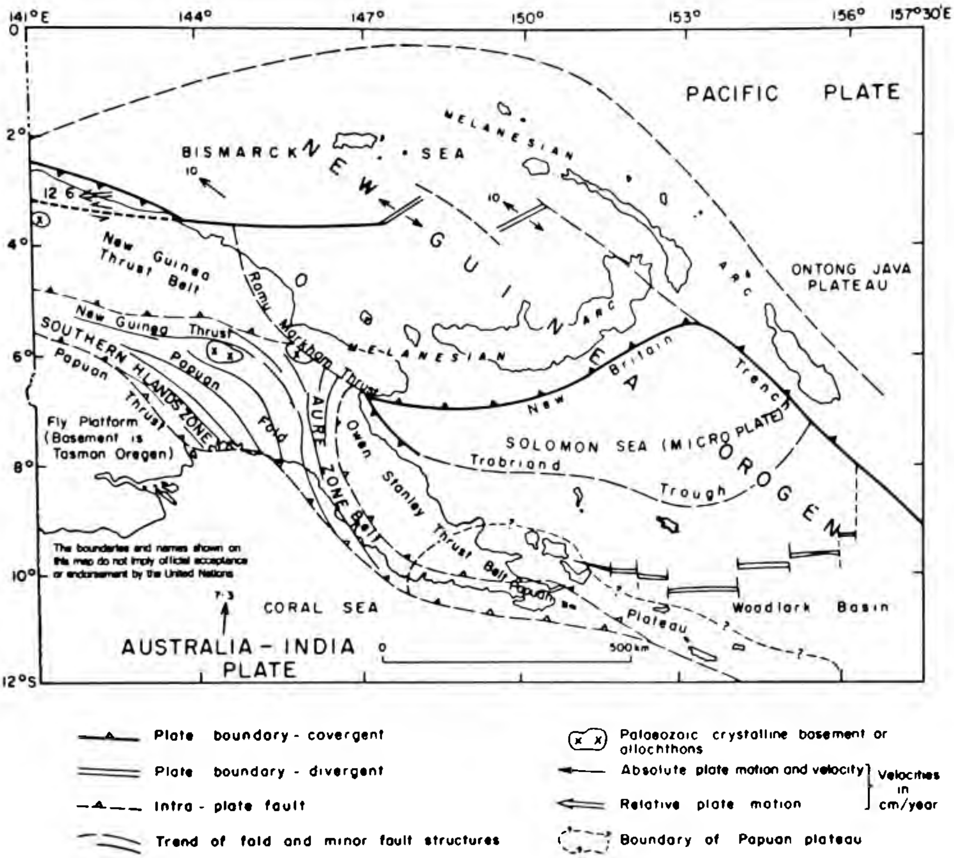

Figure I. Major tectonic subdivisions of Papua New Guinea (after Rogerson et al., 1987).

often borders a silicified zone near veins. Fine-grained potassium feldspar and/or chlorite are often disseminated in the wall rock bordering veins.

In acid-sulfate type deposits, advance argillic alteration is typically associated with mineralization. Alunite, kaolinite and other minerals of the advanced argillic assemblage occur close to the veins and are often coextensive with silicification (Heald et al., 1987).

### *3.1.3 Host Rock Composition*

The composition of the host rocks of adularia-sericite type deposits ranges from rhyolitic to andesitic, and ore is commonly hosted by several different compositional units within a district. The occurrence of ore in several lithologies in adularia-sericite deposits implies that composition of the host rock(s) is not a controlling factor to mineral deposition.

The primary host rock for the acid-sulfate type deposits is almost exclusively rhyodacite, which is commonly porphyritic. The timing of ore deposition relative to the emplacement of the host rock is of particular importance. Studies by Heald et al. (1987) showed that one deposition very closely (within 0.5 m.y.) followed emplacement of the host rock, indicating a possible genetic relationship.

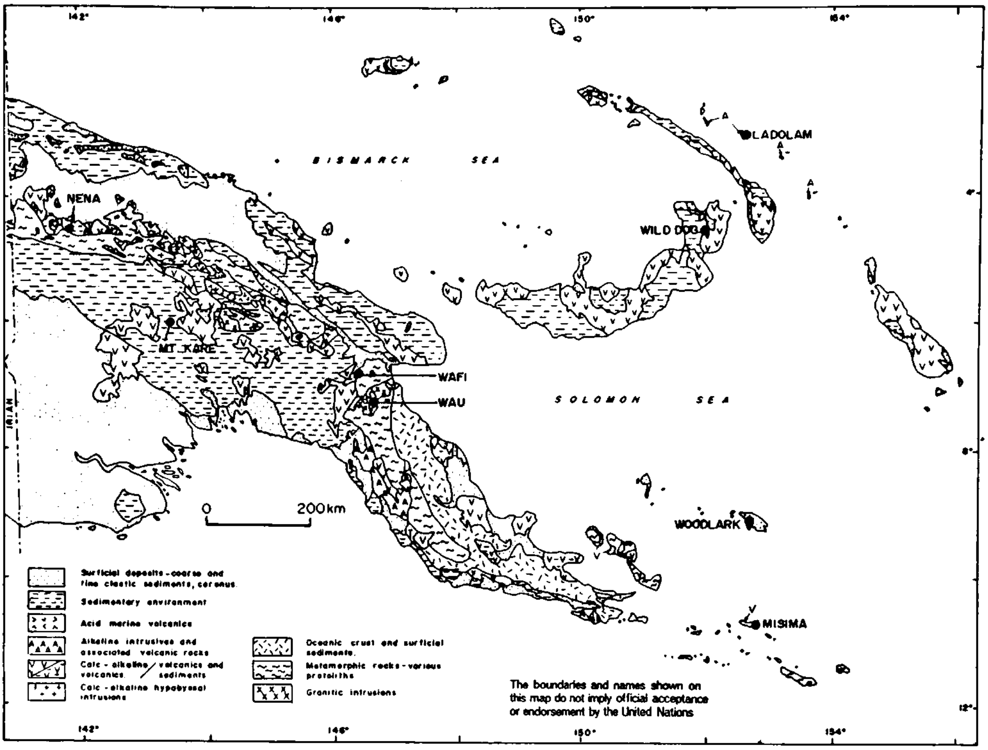

**Figure II.** **Simplified geology of Papua New Guinea (after Rogerson et al., 1987) with the location of six epithermal deposits.**

## 4. DESCRIPTION OF EPITHERMAL DEPOSITS IN PAPUA NEW GUINEA

Both acid-sulfate type and adularia-sericite type epithermal deposits occur in tectonic settings associated with subduction zones at plate boundaries. The ores occur in structurally complex environments, typically with several episodes of faulting developed in two or more directions.

In Papua New Guinea adularia-sericite type epithermal deposits are most commonly associated with calderas. Two of these, the Ladolam and the Wild Dog deposits are within calderas, and the third, the Wau deposit, is within a field of volcanic domes that may be caldera-related (Figure II). The fourth adularia-sericite type deposit, Misima, is related to a major fault zone.

The two acid-sulfate type deposits to be discussed (Nena and Wafi) occur in structurally complex areas effected by faulting, and to a lesser extent folding. Nena occurs along the Frieda Fault, a major fault zone. Wafi is situated between two sets of northeast-trending faults, namely the Wampit Fault to the east and other northeast-trending faults to the west.

### 4.1. Adularia-Sericite Type Deposits

### *4.1.1. Ladolam (Lihir Island)*

*Structural Setting* – The Ladolam gold deposits occurs within the Luise Caldera, a steep walled Quaternary volcanic caldera on the eastern side of Lihir island. Lihir island is part of a 250 kilometer long chain of Miocene to Recent volcanic islands. These islands are all characterised by shoshonitic volcanism and presumably have a common origin.

*Host Rock* – Gold mineralization is hosted within clast-supported hydrothermal breccia composed of high K-basalt and subvolcanic syenite and monzonite (Davies and Ballantyne, 1987).

*Mineralogy* – The ore is sulphide rich containing abundant pyrite, with subordinate marcasite, and minor arsenopyrite, chalcopyrite, bornite, tetrahedrite, tennantite, galena, sphalerite, and molybdenite. Trace amounts of several species of telluride minerals have also been identified.

*Alteration* – Surface alteration includes locally abundant opal, clays, alunite, illite, and chlorite. A large volume of the near-surface volcanics have been altered to an assemblage of alunite, opal, and kaolinite. This advanced argillic alteration grades downwards into an argillic alteration characterised by an assemblage of kaolinite, smectite, and illite (Cox and Rytuba, 1987). Below the argillic alteration is a zone of porous clast-supported breccia referred to as the "boiling zone" by Davies and Ballantyne (1987). Within the boiling zone, cavities between clasts are coated by any of a host of minerals including sulphides, calcite, adularia and anhydrite. The clasts exhibit argillic or advanced argillic alteration near the top of the boiling zone and intense potassic alteration, including biotite, near the base of the boiling zone (Davies and Ballantyne, 1987). Alteration extends downwards into the monzonite porphyry intrusions, where strong potassic alteration and anhydrite vein stockworks (± calcite and quartz) are well developed.

*Other Characteristics* Niugini Mining Limited (1987) reported mineable reserves of approximately 497.6 tonnes (16 million oz) of gold at 3.38 g/t Au. Gold is the principal commodity with accompanying variable amounts of silver and base metal sulphides. Oxygen and hydrogen isotope data for quartz, carbonate, alunite, kaolinite, and sulphates indicate that meteoric water was the dominant fluid for the

*Mineralogy* – Primary mineralization consists of varying amounts of medium- to coarse-grained, often anhedral pyrite, galena, sphalerite, chalcopyrite, together with tetrahedrite and gold. Pyrite is the most abundant sulphide mineral followed by galena and sphalerite, and with minor chalcopyrite (Williamson and Rogerson, 1983).

*Alteration* – Alteration assemblages vary with different wallrock lithologies and mineralization events. Intensely fractured greenschists of the Sisa Association are highly permeable to hydrothermal fluids and therefore were more susceptible to alteration than other local igneous rocks. The dominant alteration products are chlorite, epidote, clinozoisite and white mica, which form envelopes adjacent to veins. The veins consist of assemblages of quartz, chlorite, calcite, and sulphides.

*Other Features* – As of December 1987, mineable reserves for the project are stated as 77.2 tonnes (2.48 million oz) of gold and 1,175 tonnes (37.78 million oz) of silver in 55.95 million tonnes of ore, at a grade of 1.38 g/t Au and 21.0 g/t Ag. Fluid inclusion and isotope studies by Williamson and Rogerson (1983) indicate that the hydrothermal fluids responsible for the mineralization were predominantly of meteoric origin, with a salinity of between 4.17-7.85 weight per cent NaCl equivalent. Homogenization temperatures obtained from quartz indicate temperatures of mineralization between 275°–301°C (Williamson and Rogerson, 1983).

### *4.1.3. Wild Dog (Rabaul)*

*Structural Setting* – The Wild Dog gold-silver-copper deposit is hosted within Nengmutka caldera of Teriary age. The caldera ranges in composition from andesitic to dacitic and is probably of Mio-Pliocene age (Lindley, 1987).

*Host Rock* The major vein systems of Wild Dog are

Additionally, argillic and advanced argillic alteration zones are locally well developed. Alteration assemblage mineralogy is as follows:

| | |
|---|---|
| Silicic | (replacement of host rock by quartz) |
| phyllic | (quartz – sericite – pyrite) |
| propylitic | (carbonate – chlorite – pyrite – epidote and zeolites) |
| argillic | (kaolinite – illite (sericite) – quartz – pyrite) |
| advanced argillic | (kaolinite – quartz – alunite – pyrite) |

*Other Features* – The Wild Dog deposit consists of three major veins. The East Vein has a length of 350 m and a width of 20 m. The Central Vein has a length of 135 m and width of 30 m, and the West Vein has a length of 450 m and a width of 20 m. The deposit is a gold-silver rich copper sulphide system with significant concentrations of lead, zinc, molybdenum, antimony, vanadium, selenium and tellurium. Fluid inclusion studies by KRTA (1985) indicate a temperature range of formation for the mineralized sulphidic quartz of 235°–250°C, with the hydrothermal fluids dominantly of meteoric origin. No salinity determinations were made.

### *4.1.4. Wau*

*Structural Setting* – Gold mineralization at Wau is hosted within a maar-diatreme system that is localized along an east-west trending fault.

*Host Rock* – Most of the gold mineralization in the Wau district is in structurally controlled vein systems and breccia zones. These have generally formed near the contact of Plio-Pleistocene dacite porphyry intrusions and the basement complex, a locally carbonaceous low-grade metamorphic unit of Cretaceous to Paleogene(?) age. Both the igneous and metamorphic rocks host mineralization.

*Mineralogy* – Primary mineralogy at Wau consists of calcite, manganocalcite, quartz, adularia, pyrite, galena, sphalerite, rhodochrosite, chalcopyrite, tetrahedrite and sulfosalts.

*Alteration* – Two broad varieties of hydrothermal alteration are recognized in association with the maar: a zone of silicification (indicated by opal) with accompanying pyrite and marcasite, and above this, a zone of alteration characterised by cristobalite, kaolinite, alunite, and small amounts of iron sulfides (Silitoe et al., 1984). A second phase of alteration occurs in the intramaar sequence and is characterized by the presence of quartz, calcite, kaolinite, and smectite. Both of these alteration types are feldspar-destructive and are devoid of gold mineralization. Gold mineralization is present within veins composed of manganocalcite, quartz, adularia and minor sulphides.

*Other Features* – Precious metal mineralization is thought to have resulted from hydrothermal fluids containing up to 3.0 weight per cent NaCl equivalent. Deposition of the gold-silver minerals is thought to have taken place at minimum temperatures of 190°–270°C as a consequence of $H_2S$ loss and meteoric fluid dilution (Syka, 1985).

## 4.2. Acid–Sulfate Type Deposits

### *4.2.1. Nena Deposit*

*Structural Setting* – The Nena deposit, part of the Frieda River Prospect, is located between the Frieda and Lagaip Fault zones, two major structural features of the New Guinea Fold Belt. The deposit is associated with an andesitic volcanic complex interstratified in the mid-Miocene Wagamush Formation sediments. It is proximal to a large presently subeconomic porphyry copper deposit, the Frieda deposit. The Nena deposit is a typical gold-enargite-bearing acid-sulfate system and is probably the upper portion of a porphyry copper deposit.

*Host Rock* – Nena mineralization is hosted by the Middle Miocene Neva Volcanics and consists of volcanic breccia, tuff breccia, lapilli tuff, tuff and tuffaceous mudstone.

*Mineralogy* – The sulphide mineral assemblage consists primarily of gold-bearing pyrite, enargite-luzonite and chalcocite. Sooty chalcocite, replacing and coating pyrite is a common supergene copper mineral, accompanied by minor covellite, digenite and djurleite.

*Alteration* – Pervasive silicification characterizes hypogene alteration with varying degrees of replacement by alunite, pyrite and native sulphur. The volcanics have been altered to an assemblage of quartz, alunite, pyrite, sericite or pyrophyllite, and kaolinite (Asami and Britten, 1980).

### *4.2.2. Wafi Prospect*

*Structural Setting* – The Wafi prospect is situated between the Wampit Fault to the east and major northeast-trending faults to the west.

*Host Rock* – Gold mineralization is hosted within late intrusive breccias consisting of siltstone and sandstone fragments with angular quartz vein fragments.

*Mineralogy* – The mineralization is dominated by pyrite with lesser quartz, alunite and minor base metal sulphides and sulphosalts (Kirk et al., 1987). Other minerals include covellite, digenite, bornite, tetrahedrite and enargite-luzonite.

*Alteration* – Six distinct alteration assemblages can be recognized in association with mineralization at Wafi (Kirk et al., 1987). These are:

| | | |
|---|---|---|
| a. | advanced argillic | (quartz and alunite ± kaolinite pyrophyllite ± diaspore) |
| b. | acid argillic | (quartz ± diaspore) |
| c. | argillic | (illite-smectite or chlorite-smectite ± carbonate ± chlorite) |
| d. | phyllic | (sericite or illite ± chlorite) |
| e. | potassic | (biotite) |
| f. | propylitic | (chlorite ± actinolite ± carbonate ± epidote) |

*Other Features* – Fluid inclusions from two quartz samples indicated the mineralization temperatures to be in the range of 250°–300°C (Kirk et al., 1987).

**Table 1. Characteristics of the adularia-sericite type and acid-sulfate type deposits (Simplified from Heald et al., 1987)**

| | *Acid-Sulfate Type* | *Adularia-Sericite Type* |
|---|---|---|
| Structural environment | Intrusive centers, 4 out of the 5 studied related to the margins of calderas | Structurally complex volcanic environments;<br>Commonly in calderas |
| Size<br>length: width ratio | Relatively small;<br>Equidimensional | Variable; some very large;<br>Usually 3:1 or greater |
| Host rocks | Rhyodacite typical | Silicic to intermediate volcanics |
| Timing of ore and host | Similar ages of host and ore (<0.5 m.y.) | Ages of host and ore distinct (>1 m.y.) |
| Mineralogy | Enargite, pyrite, native gold, electrum, and base-metal sulphides;<br>Chlorite rare, no selenides, Mn-minerals rare, sometimes bismuthinite | Argentite, tetrahedrite, tenantite, silver, and gold, and base-metal sulfides;<br>Chlorite common, selenides present, Mn gangue present, no bismuthinite |
| Production data | Both gold- and silver-rich deposits with noteworthy Cu production | Both gold- and silver-rich deposits with variable base-metals |
| Alteration | Advanced argillic to argillic (± sericitic);<br>Extensive hypogene alunite;<br>Major hypogene kaolinite;<br>No adularia | Sericitic to argillic;<br>Supergene alunite;<br>Occasional kaolinite;<br>Abundant adularia |
| Temperature | 200° to 300°C* | 200° to 300°C |
| Salinity | 1 to 24 wt% NaCl eq.** | 0 to 13 wt% NaCl eq.** |
| Source of fluids | Dominantly meteoric, possibly with significant magmatic component | Dominantly meteoric |

* Limited data, possibly unrelated to ore.

** Salinities of 5 to 24 wt% NaCl eq. are probably related to the intense acid-sulfate alteration which preceded ore deposition.

## 5. DISCUSSION

From observations based on the four adularia-sericite type deposits discussed the following points can be made:

1. All four deposits at one time or another were associated with hydrothermal systems similar to those of the Taupo volcanic zone in New Zealand (as described by Henley, 1985).

2. Gold mineralization in all four deposits took place after the main volcanic event.

3. Though not all four deposits are associated with caldera systems, they are all related to structures that acted as excellent plumbing systems for the hydrothermal fluids.

4. Meteoric water seems to be the dominant source of mineralizing fluid for all four deposits, with mineralization temperatures ranging between 200°–300°C and salinities of 3-7 weight per cent NaCl equivalent.

Due to the limited data from the two acid-sulfate deposits little can be said of them except that they occur in structurally complex areas, and are characterised by the presence of enargite-luzonite-pyrite assemblage. Of importance genetically is their close spatial relationship to large instrusive bodies and porphyry copper type mineralization.

## 6. CONCLUSION

Data presented in this paper are necessarily incomplete because the systematic study of these deposits is seriously hampered by lack of exposures, dense jungle and logistical difficulties. These data however support and generally coincide with the characteristics outlined by Heald et al. (1987) for the adularia-sericite and acid-sulfate type deposits.

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# GEOLOGY OF THE LADOLAM GOLD DEPOSIT, LIHIR ISLAND, PAPUA NEW GUINEA

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## ABSTRACT

The Ladolam gold deposit on Lihir Island, in Papua New Guinea, is a large disseminated gold deposit hosted by hydrothermal breccias. The deposit occurs in the cupola zone of a 350,000 year old monzonite stock which is emplaced in the collapsed caldera of a shoshonitic stratovolcano.

## INTRODUCTION

The Ladolam gold deposit occurs on Lihir Island, a 15 km by 20 km volcanic island, located at latitude 3° south, longitude 152° 30' east, in New Ireland Province, Papua New Guinea. The deposit occurs within Luise Caldera, a spectacular, steep walled Quaternary volcanic caldera on the eastern side of the island. The caldera is partially breached by the Pacific Ocean to form Luise Harbour, a natural deep water harbour. A Prospecting Authority over Lihir Island is held by a Joint Venture comprised of Kennecott and Niugini Mining Limited.

## DISCOVERY AND ORE RESERVES

Gold mineralisation was first discovered in coastal bluffs along the shore of Luise Harbour in August 1982. Diamond drilling commenced immediately inland from the coastal bluffs in September 1983 and in on going. Through June 30, 1987, 120 diamond drill holes for a total of 39,643m and 420 reverse circulation drill holes for a total of 14,425m have been completed. These holes lie within a two square kilometre portion of the floor of Luise Caldera.

Exploration of the Ladolam deposit has progressed through a sequence of exciting new ore discoveries. The economic significance of the mineralisation in the Coastal area was confirmed when the first diamond drill hole, collared in September 1983, intersected 29 m of oxide ore averaging 7.69 g/t, and several good sulphide ore intersections, the best of which is 21 m averaging 7.09 g/t from 91 m to 112 m.

The second significant discovery came in June 1984 when DDH L13 collared in the Lienetz area, 1000 m inland, intersected 54 m of oxide ore grading 2.41 g/t and 70 m of sulphide ore grading 5.10 g/t starting at 173 m below surface. This proved to be the first of numerous holes which intersected a horizon of deep plus 5 g/t sulphide ore in the Lienetz area.

The third, most recent, and perhaps most significant, discovery was made in November 1986 when hole L88, collared in the Minifie area, 1500 m inland and 500 m south of the Lienetz area, intersected 180 m of sulphide ore grading 5.81 g/t from 18 m to the bottom of the hole.

Preliminary mineable reserves for the Ladolam deposit were recently announced as follows:

| | *Million Tonnes* | *Gold Grade (g/t)* | *Strip Ratio* |
|---|---|---|---|
| Lienetz & Coastal | | | |
| Oxide * | 8.1 | 2.18 | 0.8:1 |
| Sulphide * | 88.9 | 2.82 | 2.6:1 |
| Minifie | | | |
| Sulphide ** | 22.5 | 4.90 | - - |

* Includes drilling through L66 and portions of L67-L71; cutoff grade is 1.0 g/t.

** Includes drilling through the first 11 holes; cutoff grade is 1.1 g/t.

## GEOLOGIC SETTING

The geology of Lihir Island and its geologic setting have been described in detail by Wallace et al. (1982). Lihir and the other smaller islands of the Lihir Group are part of a 250 km long chain of Miocene to Recent volcanic islands, which extends from the Tabar Islands to the Feni Islands, parellel to the coast of New Ireland and to the West Melanesian Trench. The islands of this chain presumably have a common origin since they are all characterised by shoshonitic volcanism. However, as discussed by Johnson (1979), the origin of the volcanism has not been satisfactorily explained.

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The islands of the Lihir Group, Lihir, Mali, Masahet and Mahur, crest a 2000 m high submarine ridge which trends NNE, normal to the coast of New Ireland. This ridge is tectonically active as evidenced by five shallow (less than 70 km) earthquake foci recorded along the ridge in the period 1964 to 1977 and a shallow, magnitude 7.5 event recorded at the north end of the ridge in 1944.

Lihir Island is dominated by three Pleistocene volcanos built on top of the eroded and faulted remnants of two or more earlier volcanos of probable Pliocene age. The island has undergone recent uplift and tilting and is fringed by a plateau of raised coralline limestone which is elevated to 50 m above sea level around the northern end of the island.

The Ladolam deposit occurs within the caldera of Luise Volcano, the youngest and best preserved volcano on Lihir. Luise is a stratovolcano made up of alternating lava flows, volcanic breccias and tuff horizons. Analyses of lavas collected from the walls of the caldera indicate that most are trachybasalts (Wallace et al., 1982).

Luise Volcano has a remarkable ellipitical caldera six kilometres long by four kilometres wide with steep walls rising to 700 m above sea level. Prior to collapse the volcano must have reached an elevation of approximately 1200 m. The northeastern end of the caldera is breached by the Pacific Ocean to form Luise Harbour. The raised coral reef, present around the rest of the island, is absent from Luise Caldera indicating that breaching of the caldera has postdated formation and uplift of the reef.

## GEOLOGY OF THE LADOLAM DEPOSIT

The Ladolam deposit underlies low hills and valley bottoms ranging from 30 m to 130 m above sea level in the floor of Luise Caldera. The surface rocks overlying and adjacent to the deposit are very strongly altered. Most appear to be volcanic flows, tuffs and breccias which prior to alteration may have been similar to the rocks in the caldera walls. Minor areas of alluvium extend up two major drainage systems in the floor of the caldera, while thick colluvium, overlain by brown forest soils, mantles the lower slopes of the caldera walls and partially covers the mineralised and altered rocks in the caldera floor (Figure I).

appear to postdate the other intrusive r
shown on Figure IIa, a monzonite stock ur
the Lienetz area below the -100 m elevati
monzonite have been intersected in holes c
of the Minifie area.

Dark grey-brown hornfelsed volca
adjacent to monzonite intersections in hole
in the poorly mineralised portion of the d
the Lienetz and Minifie areas (Figure IIa)
of intrusive breccia, in which the mon
volcanic rocks and finer-grained phases of
are common in Lienetz area drill holes.

A plagioclase hornblende porphy
tains flow-oriented plagioclase phenocry
pseudomorphs after hornblende phenocry
in length, has been intersected in several d
rock type has been variously interpreted a
a hypabyssal intrusion.

Various types of hydrothermal br
common both in surface exposures and in
the Ladolam deposit. These include crack
which unrotated angular fragments are sep
of pyrite, quartz, opal, alunite, calcite or a
ised breccias, in which milled fragments
rock types occur in a matrix of sulphides,
secondary minerals; and larger scale expl
similar in apparance to the fluidised bre
angular clasts. Distinction between hydrot
and volcanic breccias is often tenuous and s
of hydrothermal breccia types upon one an
volcanic breccias is common.

## SURFACE ALTERATION

Bedrock exposures on the floor of
exhibit weak to intense hydrothermal altera
on Figure I, four surface alteration types

*Silica Cap:* Massive outcrops of opaline s
alunite and sulphides occur in the coasta
isolated small exposures in the Lienetz
indicates that these siliceous zones are ro

*White Rock:* This is a local name for a po
consisting entirely of opal, alunite and kao
with the white rock on Figure I are ar

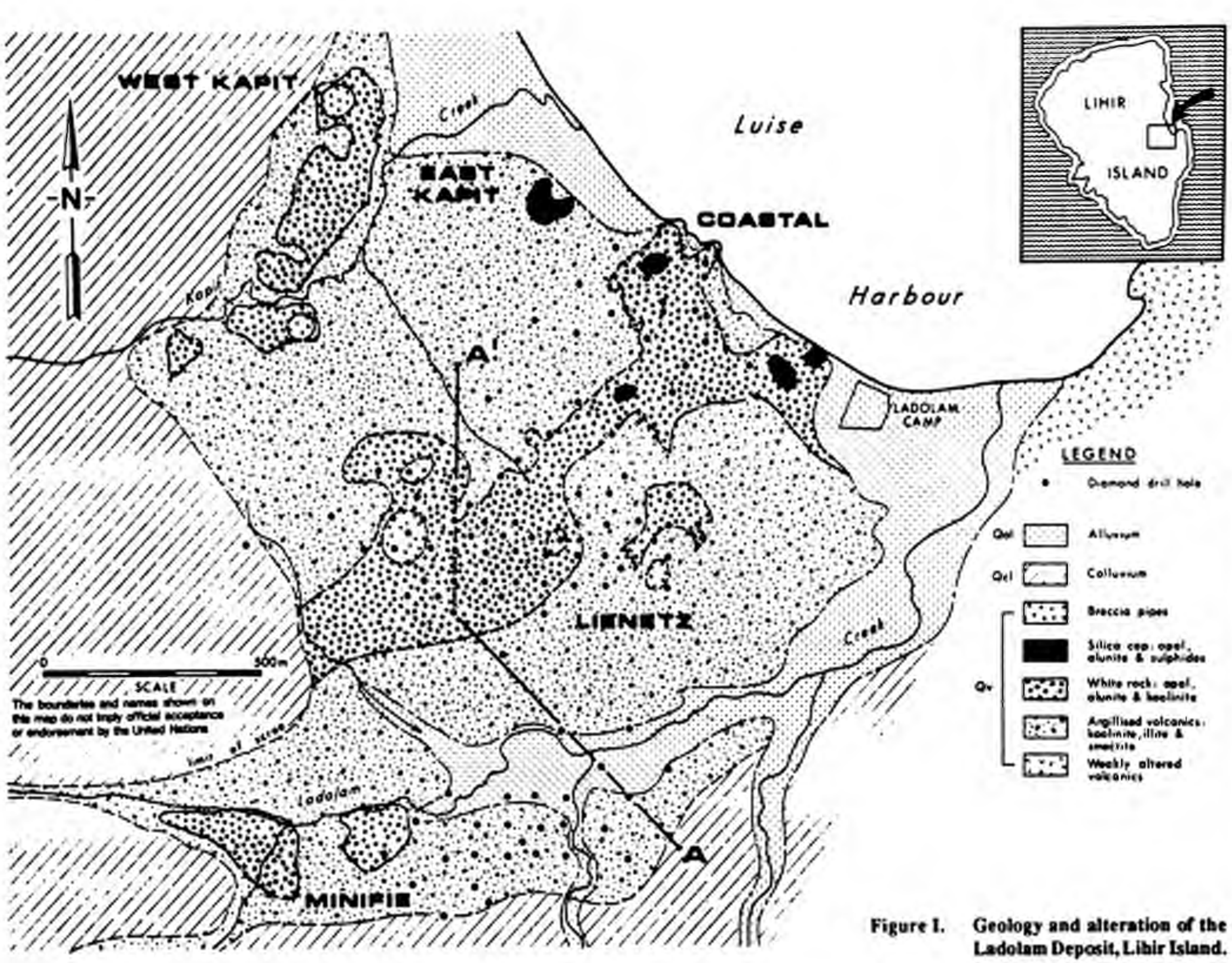


Figure I. Geology and alteration of the Ladolam Deposit, Lihir Island.

# LADOLAM DEPOSIT - LIHIR ISLAND
## SECTION A - A (See Figure I)

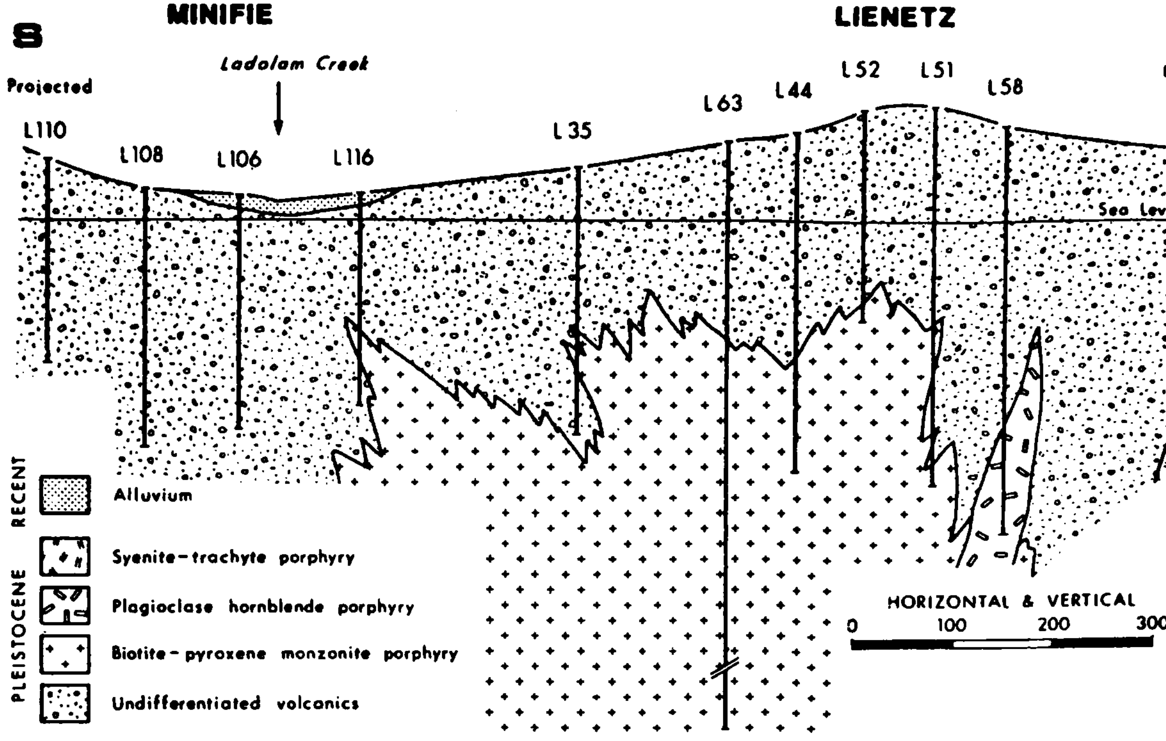
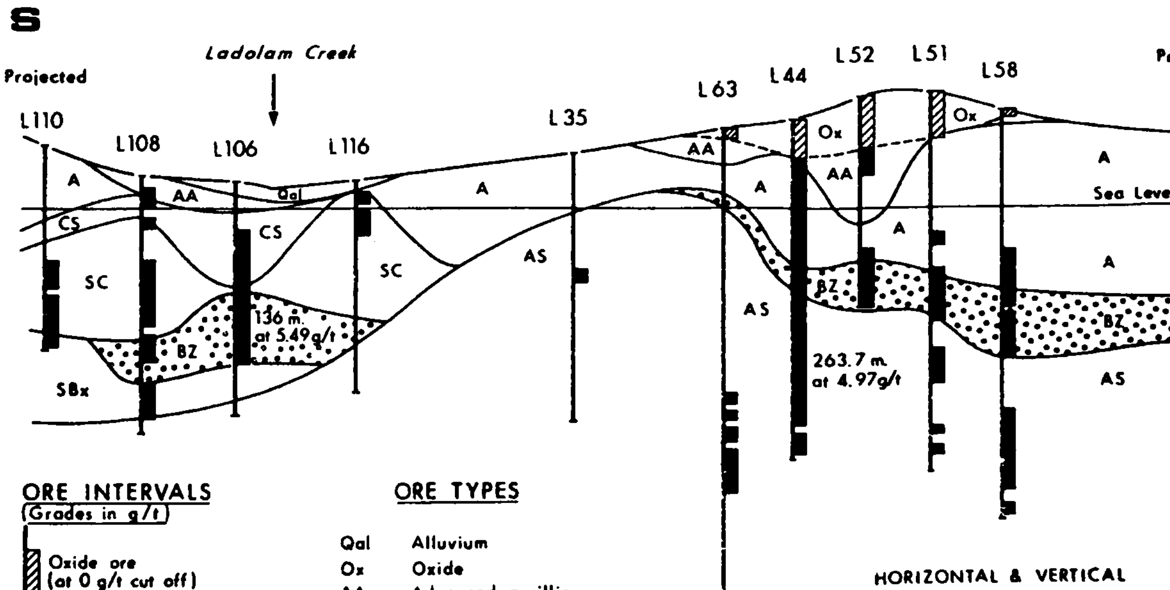


Figure IIa. Geology.



*Clay-Chlorite Alteration:* Weak illite-smectite alteration with or without chlorite is present in areas peripheral to the mineralised zones.

## MINERALISATION

Approximately 7% of the Ladolam ore reserves consist of oxide ore. The base of oxidation, which always lies above sea level, reaches a maximum depth of 70 m in the Lienetz area and 50 m in the Coastal area. There is no significant oxide ore in the Minifie area.

Approximately 60% of the oxide ore is white rock ore and 40% is oxide-clay ore. Both ore types are amenable to conventional cyanide leaching and give gold recoveries in the order of 90%

The sulphide ore types all contain abundant pyrite with subordinate marcasite and minor arsenopyrite, chalcopyrite, bornite, tetrahedrite, tennantite, galena, sphalerite and molybdenite. The abundance of base metal sulphides appears to increase downwards and this observation is supported by assay data which show copper contents to 3.6% and molybdenum contents to 400 ppm in the bottom of some holes. Trace amounts of several species of telluride mineral have been identified by scanning electron microscopy.

The majority of the sulphide mineralisation is disseminated although sulpides also occur in veins and as vug fillings. Pyrite and marcasite are typically fine-grained, occuring as porous anhedral grains from 1 mm down to less than 20 microns. Sulphide sulphur contents range from greater than 10% in the upper ore zones of the Minifie area, and approximately 8% in the argillic zone in the upper part of the Lienetz area, to approximately 5% in the boiling and anhydrite-sealed zones in both areas.

All Ladolam sulphide ore types are refractory and yield gold recoveries of less than 40% when subjected to conventional cyanide leaching. Study of flotation concentrates indicates that the gold is contained chiefly in pyrite and to a lesser extent in chalcopyrite and arsenopyrite. Electron microscopy indicates that much of the gold occurs in particles finer than 0.01 microns. Pressure oxidation, bio-oxidation and roasting are all effective in varying degrees in improving the amenability of the ores to cyanide leaching.

The distribution of gold ore at a 1.0 g/t cutoff is indicated on Figure IIb. Ore grade gold mineralisation is hosted principally by the boiling zone and the anhydrite-sealed zone in the Lienetz area and by the silica clay zone and the boiling zone in the Minifie area.

## K-Ar DATING

The K-Ar ages suggest that gold deposition in the Ladolam deposit probably occurred in the interval from 350,000 years to about 100,000 years before present.

## GEOTHERMAL ACTIVITY

Geothermal conditions exist beneath much or all of the floor of Luise Caldera. Areas of hot spring and fumarole activity occur in the Kapit and Ladolam drainages and at the foot of the Coastal bluffs and hot water is encountered in most diamond drill holes. Diamond hole L63 was drilled to 750 m in 1985 to test the geothermal system and produced a water and steam discharge at a maximum temperature of 231°C. Descriptions and analyses of the hot spring waters were published by Wallace et al. (1982) and Willamson (1983), while KRTA (1984, 1985) and Geothermex (1987) have reported analyses of surface springs and water samples from dill holes.

Chemical and isotopic analyses indicate that thermal waters from the hot springs in the Ladolam drainage and from most of the hot springs in the Kapit area, are highly acidic, sulphate rich, steam heated waters of meteoric origin.

Deeper thermal waters collected from hole L63 and from one of the Kapit springs have neutral pH's and chloride compositions close to that of seawater. However, other characteristics of these fluids are atypical of seawater. Levels of sulphate are unusually high and oxygen and hydrogen isotope values indicate that the thermal fluids are derived from local meteoric water. Chemical and isotopic data therefore suggest that the Ladolam geothermal system is now isolated from the sea.

Temperatures of water-rock equilibration, calculated from concentrations of Na, K and $SiO_2$ in the thermal fluids, range up to 230°C and correlate well with the maximum temperature measured in hole L63.

Extensive drilling within Luise Caldera has not encountered any trapped steam zones. The geothermal system appears to be water-dominated and open to the surface. Boiling is apparently only a very local phenomenon.

## DISCUSSION

The sequence of subhorizontal alteration/ore type zones present in the Ladolam deposit is consistent with a boiling water table model for gold deposition, such as that proposed by Cunningham (1985). According to this model, the boiling zone breccia may in the past have hosted an actively boiling water table, the level of which fluctuated over approximately 50 to 100 m. During boiling, $H_2S$ would have partitioned into the vapor phase, oxidised near the surface, and dissolved in surface meteoric waters to form highly acidic, sulphate-rich fluids. These acidic fluids would have caused argillic and advanced argillic alteration of the rocks overlying the boiling zone.

Gold deposition, according to the model, would have occurred primarily in the boiling zone due to loss of $H_2S$ to the steam phase and destabilization of the gold bisulphide complex. Additional gold deposition would have occurred at greater depths during downward migration of the boiling level during periods of explosive brecciation. A second zone of gold deposition appears to have occurred at or near surface in the advanced argillic zone. This may postdate the period of intense boiling and result from mixing of neutral chloride fluids with acidic superficial fluids.

The vuggy, boiling zone breccia probably results from dissolution of anhydrite which formerly occupied the matrix of the breccia (as in the underlying anhydrite sealed breccias). This interpretation is supported by the presence of anhydrite inclusions encapsulated in quartz crystals within boiling zone vugs.

The unusual intensity and extent of gold mineralisation in Luise Caldera may be due in part to unusually good ground preparation in the form of very extensive brecciation. Dissolution of the anhydrite breccia matrix on a progressive basis, during the period of boiling and gold deposition may have played an important role in maintaining a permeable aquifer for the mineralizing fluid.

## ACKNOWLEDGEMENTS

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# AN OVERVIEW OF MINERAL EXPLORATION IN SOLOMON ISLANDS

by
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## ABSTRACT

Solomon Islands, a group of islands to the east of Papua New Guinea with a total land mass of 28,900 km$^2$, is also part of the Circum-Pacific metallogenic belt. The geology of Solomon Islands is about 50 to 90 million years old and is described as a 'Primary Fractured Arc' composed mainly of oceanic basalt basements, calc-alkaline volcanics and sedimentary cover. Economic minerals have been known since the islands were discovered in 1568 but it was not until the 1930s that any form of mineral prospecting began. A number of mineral occurrnce discoveries have been made to date, although none has so far proven to be economically exploitable except the recently proved Gold Ridge gold deposit. As much detailed work is yet to be done in the country, there is still much to be known about the mineral resources of Solomon Islands.

## 1. INTRODUCTION

Solomon Islands form a double chain of islands to the east of Papua New Guinea extending in a northwest to southeast direction for some 1,500 km in length. They lie between latitudes 6 and 11 degrees south and longitudes 156 and 165 degrees east (Figure 1). The island group consists of six main islands of areas up to 5,000 km$^2$, plus numerous small ones, with a total land mass of 28,900 km$^2$.

The main exports are mainly copra, palm oil, cocoa, tuna and timber. Mineral exports play a low key at this point in time. The population of Solomon Islands was about 280,000 in 1986 with an annual growth rate of 3.5%.

The islands are geotectonically located in the Circum-Pacific Belt, which passes in a southeasterly direction from Bougainville Island in Papua New Guinea through Solomon Islands, Vanuatu, Fiji and New Zealand.

## 2. GENERAL GEOLOGY

Solomon Islands has been described as a "Primary Fractured Arc" which extends from Bougainville in the northwest to San Cristobal in the southeast and consists of seven major island groups forming a double en echelon chain (Figure II). A discontinuous trench lies on the Coral Sea (southwest) side of the arc and another poorly defined series of trenches lies on the northeast side of the arc towards the Pacific. The Santa Cruz Island group in the east belongs structurally to the New Hebrides Arc. Most of the area is seismically active. The geology can be described in terms of three structural/stratigraphic elements: the oceanic basement, the calc-alkaline volcanics and the Sediment Cover (Table 1).

The basement is formed of oceanic basalts and cognate intrusions of dolerite and gabbro of the alkali basalt lineage which is generally considered as upraised ocean-floor. On Guadalcanal, Florida, San Cristobal, Santa Isabel and Choiseul, the basalts are fractured and variably metamorphosed up to amphibolite facies. In the axial regions they are transformed into basic schists which show evidence of at least three phases of deformation. Also in the axial regions there are Alpine-type ultramafic bodies, some of which are emplaced as thrust sheets. In contrast, Malaita has a basement of oceanic basalts which are practially undeformed and metamorphosed.

The sedimentary cover comprises up to 5,000 m of varied sediments which lie unconformably on the basement. The earliest sediments are assigned to the Upper Cretaceous. Greywackes and associated lithologies form the greater part of the successions, although there are extensive developments of Miocene and Pleistocene reefal limestones. From the Pliocene onwards volcaniclastic sediments become an increasingly important component.

The calc-alkaline volcanics form andesitic cones and volcaniclastic lithosomes, the earliest dated as Oligocene (Suta Volcanics) and latest in the Plio-Pliestocene (New Georgia). Large intrusive bodies are also present (Koloula and Poha-Lungga diorite complexes, Guadalcanal) which show porphyry-style copper mineralisation. The andesitic

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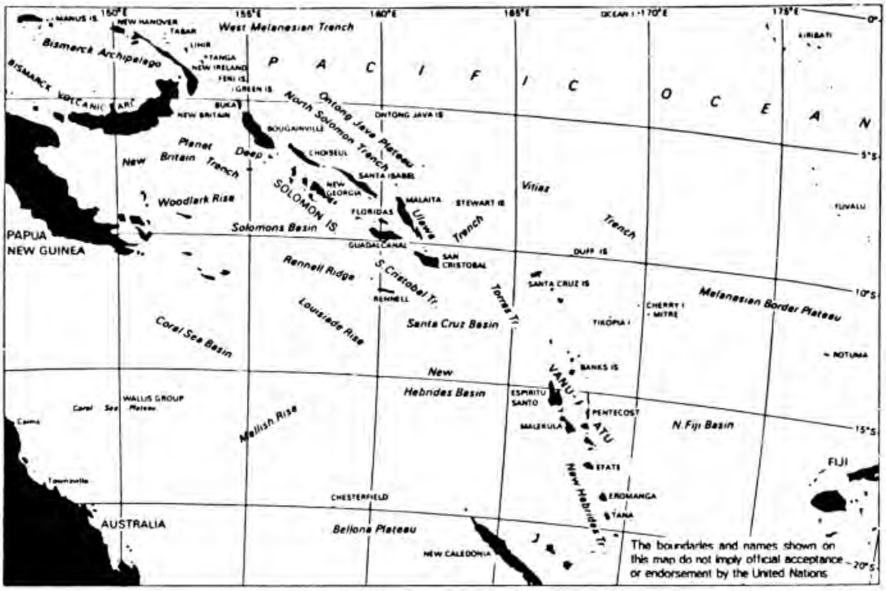

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure I. Regional setting of the Solomon Island arc (modified from Hackman, 1980).

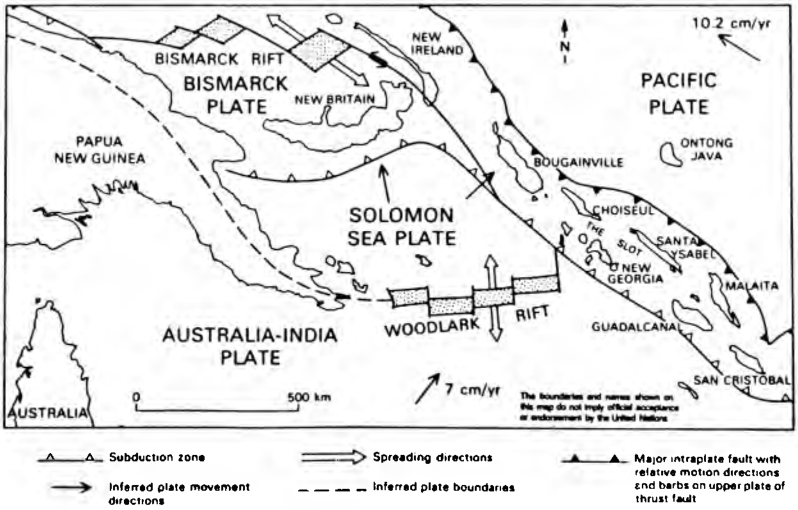

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Figure II. Present geological setting of the Solomon Islands; taken from the plate-tectonic map of the Circum-Pacific region.

Table 1. Generalised stratigr

| | BOUGAINVILLE | SHORTLANDS | CHOISEUL | S.YSABEL | FI |
|---|---|---|---|---|---|
| PLEISTOCENE | Limestone | Limestone | Limestone<br>Shelf sediments | | |
| PLIOCENE | Calc-alkaline Volcanics | | ?<br>Calc-alkaline Volcanics | | |
| MIOCENE Late | | | | Tuffaceous sediments | |
| MIOCENE Middle | | ? | Clastic Sediments | + Pelagic Limestone | Ca<br>S |
| MIOCENE Early | Limestone<br>Calc-alkaline Volcanics | Calc-alkaline Volcanics | Limestone | ? | |
| OLIGOCENE | ? | ?<br>~?~? ~ | ?early Island Arc Tholeiites<br>? | | Bas<br>A |
| EOCENE | | altered Basaltic Lavas | Unmetamorphosed & Metamorphosed Basaltic Lavas + Schists | Unmetamorphosed & Metamorphosed Basaltic Lavas + Schists | Me<br>I<br>C |
| PALEOCENE | | | | | |
| CRETACEOUS | | | | | |

volcaniclastics (Gold Ridge) carry hydrothermal gold veins.

In 1974, Coleman and Hackman (Hackman, 1980) divided the region into four geological provinces each with a distinctive assemblage of rocks (Figure III). The provinces are:-

— Central Province,

— Pacific Province,

— Volcanic Province, and

— Atoll Province.

These geological provinces form parallel zones cutting the main trend of the arc at a slight angle.

The Central Province is characterized by fractured metamorphosed basement and complex geology, in general showing more signs of crustal mobility than elsewhere.

The Pacific Province has more stable unmetamorphosed (but folded) basement and pelagic sedimentation; it may have formed as part of a more stable oceanic block subsequently translated into the main island arc.

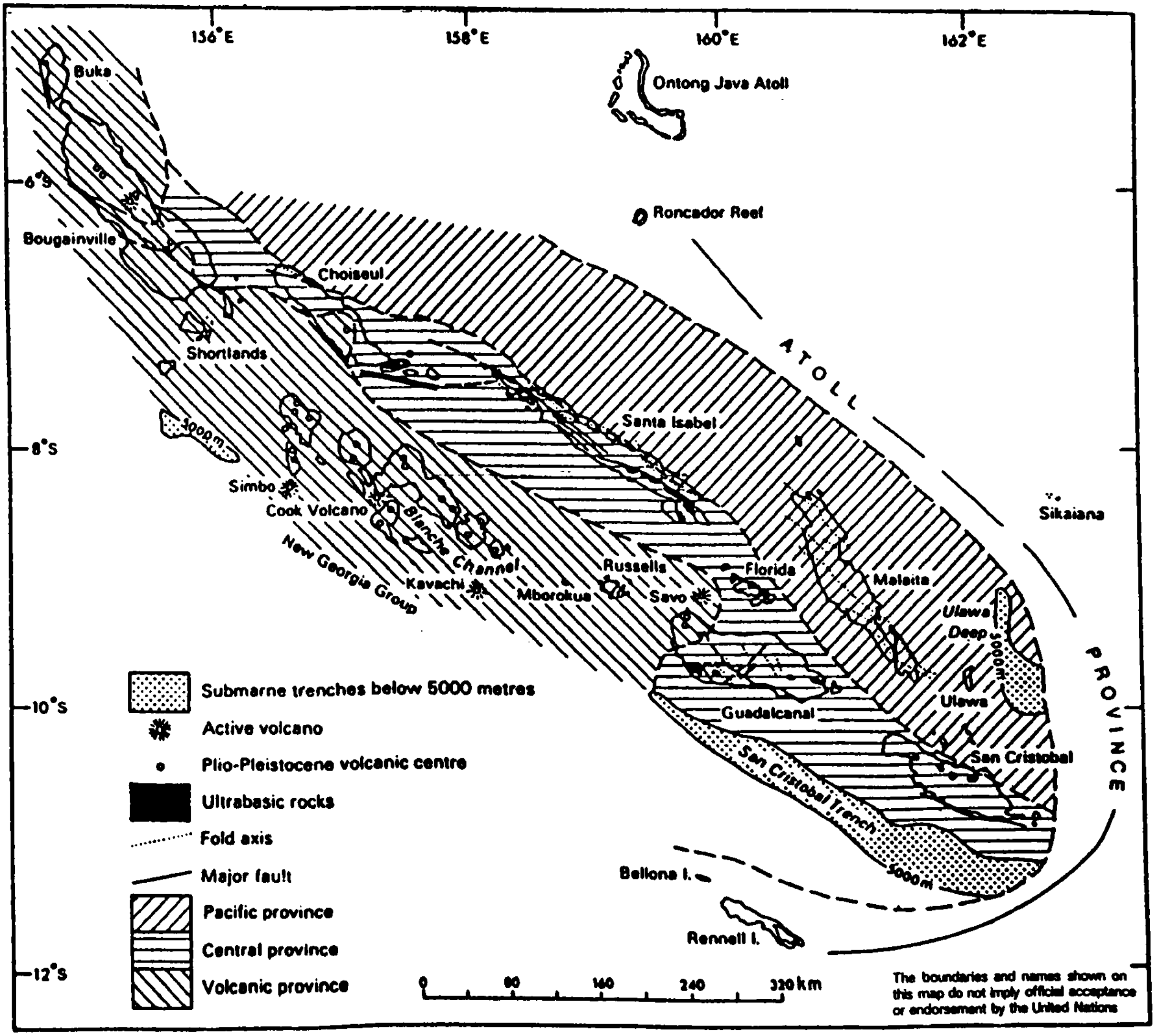

Figure III. Geological provinces of the Solomon Islands.

The Volcanic Province is the latest addition to the arc, being a series of coalesced volcanic cones with peripheral (and ongoing) fumarolic activity.

The Atoll Province, consisting of upraised coral atolls, does not form part of the main Solomon Islands arc.

## 3. MINERAL EXPLORATION

Mineral occurrences are known to have been present in the islands since their discovery in 1568 by a Spanish explorer, Alvro De Mendane, who found a gold nugget upon landing at a river mouth on Guadalcanal Island. Having found the existence of gold, the islands were then named after King Solomon of the Bible, for the gold which was mistakenly assumed to be abundant in the islands.

It was not until the early 1930s that any form of mineral prospecting began to flourish, after the discovery of gold in the Gold Ridge area of Guadalcanal. A syndicate was formed and began prospecting and mining in the area. All activity abruptly ceased when fighting reached the islands in 1942 during World War II.

It was in 1953 that systematic prospecting and geological investigations resumed when the first Government Geologist (J C. Grover) was appointed to the local administration. Previous to his time there was a total lack of systematic knowledge about the geology of Solomon Islands in particular and the island arcs in general. While only meager resources were allocated to the study of this apparently unpromising area, many scientific advances were made however as reconnaissance traverse began on New Georgia, Santa Isabel, and Guadalcanal. Systematic mapping, not begun until 1963, led to the discovery of nickel-bearing laterites capping ultramafic rocks at several localities throughout Solomon Islands; the Bellona phosphate and the Hanesavo manganese also attracted reconnaissance prospecting by mining companies. The first geological map of Solomon Islands was published nine years after the arrival of the first geologist, in 1962.

In 1965 the United Nations Development Programme (UNDP) sponsored an aerial geophysical survey project in the islands which was carried out by A.B. Electrik Malmletning (ABEM) using radiometric, magnetic and electro-magnetic methods, completed in 1966. A regional gravity survey had been done a few years earlier and routine seismological observations were made by the Geological Survey, and a regional photogeological study was carried out. Many of the geophysical anomalies were checked in the field with stream sediment geochemical follow-up by UNDP and the Solomon Islands Geological Survey staff. Among other achievements, the UNDP survey was responsible for the discovery of the West Rennel bauxite deposit (25.2 million tonnes of 48% alumina) and the Koloula copper mineralisation. During the later years of the 1960s and into early 1970s the islands experienced a mineral exploration rush, which led to most of the country being covered by Reconnaissance Permits and a few areas receiving more detailed prospecting. Discouraging results led to dwindling activity by the mid-1970s, and prospecting activity remained at a low level until the early 1980s.

In 1982, the Solomon Islands government called for tenders from international companies for the detailed evaluation of the Gold Ridge primary gold deposit which ranks as the most attractive undeveloped gold prospect in the region. Amoco Minerals Australia Company won the tender and commenced work under a three-year prospecting licence in mid-1983.

This re-opening of work in the country, along with the availability of results of geological and geochemical surveys by the Institute of Geological Sciences (IGS) of the United Kingdom and the Solomon Islands Geological Survey in the mid-1970s has prompted interest in other gold prospects in the country resulting in an increase of exploration activities in country by exploration groups. Important gold discoveries in the neighouring Papua New Guinea also contributed to the peak level of exploration activity reached in 1986 when almost all of the country was under prospecting application and licences. Unfortunately this peak did not last and in 1987, signs of waning were noticed partly in response to the international stock market difficulties and partly due to internal problems relating to land access. The downward trend continues to date; there are only nine current prospecting licences still valid of which only three are active.

## 4. MINERAL OCCURRENCES

The mineral occurences of the Solomon Islands can be grouped into three broad categories by age and association, namely the oceanic basement association, the calc-alkaline association and the residual deposits.

Numerous indications of mineral occurrences have been noted in almost all islands of the country as a result of geological and mineral exploration work. A mineral occurrence map was produced in 1978 and an update of the map is now underway.

### 4.1 The Oceanic Basement Association

This include all mineral occurrences found in basalts, gabbros, metamorphics and ultramafics of the pre-Oligocene basements.

Mineralisation occurs as sulphides in small veins, disseminations and stockworks in the basement basalts and metamorphics, as exhalative products (managanese oxides), and as silicates in ultramafic bodies.

### 4.2 The Calc-alkaline Association

This includes mineral occurrences associated with andesitic volcanics and their parent dioritic stocks (New Georgia and western Guadalcanal) of the Oligocene.

Mineralisation occurs as sulphide stockworks of porphyry-copper style (e.g. Koloula, Guadalcanal), as sulphides in the andesites and volcanic porphyries (e.g. Galego and Umasani volcanics), and as hydrothermal mineralisation in altered, reworked andesitic pyroclastics (Gold Ridge).

### 4.3 Residual Deposits

Residual deposits formed either by mechanical accumulation or chemical weathering during the Quaternary.

The mineral occurrences are as bauxitic clays on upraised reef limestones (e.g. Rennel and Vaghena), as lateritisation products from calc-alkaline volcanics and ultramafic rocks, as oceanic phosphates on raised atolls (e.g. Bellona), and as volcanic sublimates, chiefly sulphur occurring in fumarolic areas (e.g. Savo).

### 4.4 Other Minerals

Industrial minerals are known to exist principally as limestones for possible cement manufacture, volcanic ash with pozzolanic properties and sand and river gravels used for construction purposes. There is still need for more exploration into this category.

No hydrocarbons are known to exist in Solomon Islands as yet but recent work in Fiji and Tonga suggests some possibilities. Four large offshore basins occur in Solomon Islands. The recent re-interpretation of past collected geophysical data of one of the basins has revealed the existence of reefal structures within the sediment successions which are favourable reservoirs for hydrocarbons. Exploration drilling has been proposed already.

## 5. MINING POTENTIAL

Metallic mineralisation has been confirmed to have occurred in Solomon Islands, although to date none of the known occurrences warrants exploitation except the long-known epithermal style gold deposit of Gold Ridge on Guadalcanal where mining is expected to begin early next year (1991). Calculated ore reserves stand at 5 million tonnes with an average grade of 2.5 grams per tonne of gold. Until this production begins, the only mining operation in the country is individual gold panning by local people downstream from the Gold Ridge gold deposit, an activity which has been going on for some decades now and which produces some 40 to 80 kg of gold per year.

The Chovohio valley downstream from Gold Ridge is an extensive alluvial valley with an apparent potential for a feasible alluvial mining operation. The estimated reserve stands at 13 million cubic metres at 0.3g/m$^3$ Au.

Some mineral prospects in the country have been well prospected and their reserves calculated. Table 2 summerizes some of these calculated deposits.

## 6. CONCLUSIONS

The generally limited results of the exploration work carried out to date in Solomon Islands should not be taken to rule out the possibilities of future exploitable mineral resources in Solomon Islands. The islands remain largely undeveloped and unexplored by modern methods.

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**TABLE 2. Summary of calculated tonnage of mineral deposits in Solomon Is**

| LOCATION | MINERAL | OCCURRENCE | NOTES |
|---|---|---|---|
| West Nendo,<br>Santa Cruz Island | Gibbsite, *Bauxite* | Laterite capping on Pleistocene reef limestones | 8,300,000 tons<br>at 50% $Al_2O_3$<br>8% $SiO_2$ |
| West Rennel,<br>Rennel Island | Gibbsite, *Bauxite*<br>Geothite | Bauxitic soil in small pockets overlying reef limestones | 25,200,000 tons<br>at 48% $Al_2O_3$<br>18.4% $Fe_2O_3$<br>1.7% $P_2O_5$<br>2.1% $TiO_2$ |
| Tirua Hill,<br>South New Georgia | Gibbsite, *Bauxite*<br>Kaolinite, Geothite<br>Isohemite | Laterite cappings on calc-alkaline volcanics | 15,000,000 tons<br>at 43% $Al_2O_3$<br>3% $SiO_2$ |
| Hiriro,<br>South Central<br>Rendova | *Bauxite* | Laterite cappings on calc-alkaline Tertiary volcanics | 2,000,000 tons<br>at 45% $Al_2O_3$<br>2% $SiO_2$<br>2.5% $P_2O_5$ |
| Vaghena,<br>Choiseul Group,<br>Central Vaghena<br>Island | *Bauxite*<br>Gibbsite<br>Geothite<br>Cranadallite<br>Millisite | Lateritic capping on Pleistocene reef limestones | 30,000,000 tons<br>at 47% $Al_2O_3$<br>16.6% $Fe_2O_3$<br>1.7% $TiO_2$<br>3.3% $P_2O_5$<br>3% $SiO_2$<br>High moisture and organic carbon content |
| Gold Ridge,<br>Central<br>Guadalcanal | *Gold*, Arsenopyrite,<br>Pyrite, Mn-Oxides,<br>Fe-oxides | Dissemination and veins in altered andesitic volcaniclastics | 1,300,000 tons<br>3.68 g/t Au |
| Chovohio, Central<br>Guadalcanal | *Alluvial Gold* | Alluvial and colluvial gravels at Gold Ridge | 10,700,000 $m^3$<br>at average<br>0.11 g/$m^3$ Au |
| Ghome River Estuary,<br>South Choiseul Coast | Magnetite<br>Ilmenite | Beach sand deposit | 270,000 tons at 24.6% heavy minerals |

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# GOLD MINERALIZATION IN THAILAND

by
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## ABSTRACT

Currently available evidence indicates that there are at least three zones of significant potential for gold mineralization in Thailand. Two of these are closely related to the volcanic rocks of Permo-Triassic volcanisms, mainly rhyolite, andesite, tuff and agglomerate with abundant small porphyries and subvolcanic intrustives of acid to intermediate compositions. The ages of the volcanics are not well established and it is possible that the younger deposits also occur. Mineralization associated with the volcanics is dominantly porhyry-related, with the style of deposits depending on the intruded host rock and the level of exposure. The abundance of limestones, particularly of Permian age, in the host stratigraphy has resulted in the formation of numerous skarn-style deposits. Other styles observed within the porphyry systems include mesothermal to sub-epithermal veins, porphyry-hosted stockworks and breccias. The third zone is closely related to the acid intrusive rocks which have intruded into the Silurian-Devonian metasedimentary sequence. This gold mineralization is closely associated with the tin-bearing granite belt and has formed deposits of the hydrothermal vein type, metamorphic vein type and breccia type. The deposits are frequently controlled by major structures such as faults and shear zones.

The patterns of gold mineralization and the zonal distributions of the known occurrences are likely to determine the major targets for future exploration projects. Recent exploratory work by the Department of Mineral Resources, Thailand, has indicated that the known deposits represent only a small fraction of the mineralization present within these high potential zones and therefore the potential for new economic discoveries remains high.

## INTRODUCTION

Thailand, with an area of about 518,000 square kilometers, is bounded on the west and north by Myanmar, by the Lao People's Democratic Republic to the north and the east, by Cambodia to the east and by Malaysia to the south.

In Thailand gold has been known since ancient times. Evidence for gold mining can be traced back to the 13th century A.D. Many golden Buddha images, and the practice of decorating palaces and monastic places with gold attest to this history. It can be suggested that large amounts of this gold were mined at many localities where ancient gold pits have been observed. Since the Department of Mineral Resources (DMR) was established in 1891, at least five gold mines have been operated and developed by French and Thai groups. Unfortunately, those mines were abandoned at the beginning of World War II, and none has since resumed operations.

In 1984 a project on gold exploration was launched by DMR. The results reveal that at least three zones of high potential can be delineated. Many gold occurrences coincide with these high potential zones, some of which have been considered to be interesting and to have potential commercial interest.

## REGIONAL GEOLOGIC SETTING

Geologically, in brief, Thailand can be divided into two main areas: the western Paleozoic fold belt intruded by numerous Carboniferous to Cretaceous acid intrusives, and the eastern Mesozonic continental area underlain by sediments resting unconformably on the older rocks (Figure I).

The rocks within the western belt include Cambro-Ordovician quartzites, followed by a succession of deep-water sediments ranging from Ordovician to Carboniferous in age. These rocks are pebbly mudstones, graywackes, shales and limestone. Sedimentation on its eastern margin changed to the shallow-water carbonate rocks of the Upper Carboniferous through Permian units. Volcanic activities took place during late Permian to early Triassic periods, which formed two arc-shaped belts of acid to intermediate volcanic rocks. Many acid to intermediate subvolcanic intrusions also occur in both areas (Figure II).

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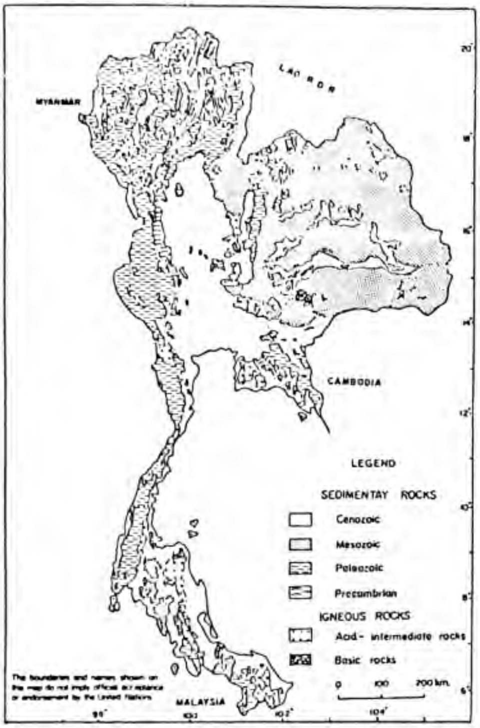

**Figure I.** Simplified geological map of Thailand (from the Geological Survey Division, DMR, Thailand).

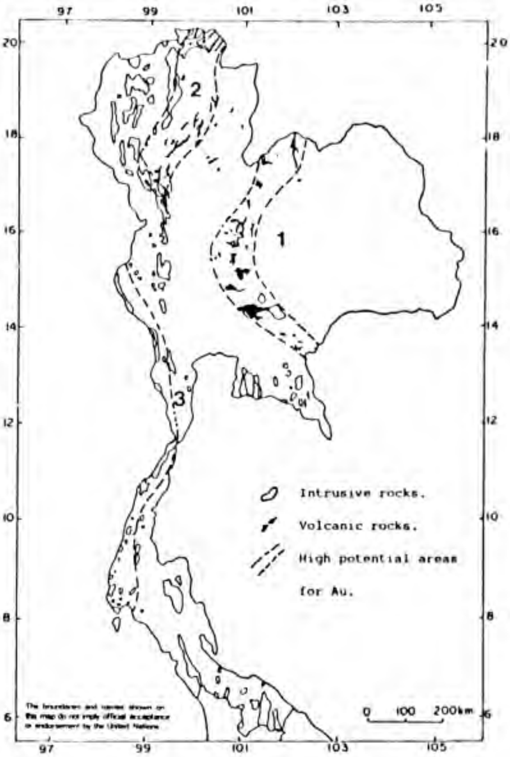

**Figure II.** Map showing three high potential areas which are closely related to the distribution of acid to intermediate volcanic and intrusive rocks.

On the eastern block, the Mesozoic sediments are continental deposits of conglomerate, sandstone, siltstone and shale which were deposited in large basins. This whole sequence is called the Khorat Group.

At least three periods of granitic intrusions took place in the western fold belt. The first event occurred during the Late Carboniferous and Early Permian; the second event occurred during the Middle to Late Triassic. The last event occurred during the Late Cretaceous and Early Tertiary.

The area between the western fold belt and the Khorat Plateau is occupied by a large tectonic basin which is filled with Tertiary and Quaternary sediments forming the great plain, the Chao Phraya Basin, of central Thailand.

## GOLD MINERALIZATION

Three zones of high potential for gold can be delineated (Figure II):

The first zone, arc shaped, lies along the western margin of the Khorat Plateau. The volcanic rocks of acid to intermediate composition, which include rhyolite, andesite, volcanic tuff and agglomerate, are distributed along this zone. Shallow subvolcanic intrusives of equivalent compositions occur as porphyries and stocks and can be located at several localities.

The known gold occurrences (Figure III) in this zone are hosted entirely within the Upper Paleozoic-Lower Mesozoic sequences. They show several styles of mineralization which can be grouped as follows:

### 1. Skarn Type

These may vary in size from small to large, as irregular bodies controlled by carbonate host formation and contact morphology. This type is closely related to subvolcanic intrusive porphyries of quartz monzonite to diorite composition.

Native gold and electrum has been found disseminated in the cracks, fractures and pore spaces of epidote-garnet skarn. Quartz veins and veinlets, which contained various amounts of gold, also occur as stockworks and swarms. Associated minerals many vary from place to place, and the gold is closely related to copper, lead, zinc and arsenic with rather high total sulfides (Figure III; Localities 1-4) in the northern part of the zone. These gold-copper-lead-zinc metasomatic deposits are located at Phu Lon, Ban Samjian (Locality 2), and in the Phu Hin Lek Fai and Phu Khum areas (Localities 3 and 4).

The base metal and sulfide abundances decrease southerward along this zone, though the skarn and contact metasomatic deposits are still noted at Ban Tha Tako, Ban Bo Thong, Ban Na Lom (Localities 5-7).

Assays from these deposits, done by DMR, show gold content in hard rock samples ranging from 0.8 to 16.0 g/t, with the maximum of 90 g/t.

### 2. Hydrothermal Vein Type

The mineralization styles of gold-quartz lodes are commonly found in this zone. The host rock can be any rock, although it is found that they have a significant relation with volcanic terranes of rhyolite, andesite, volcanic tuff and agglomerate. The quartz lodes vary both in size and style; they occur as veins to veinlets, in places forming stockworks or large individual veins (Figure III, Localities 8-10). Total sulfide in these deposits is usually low. The gold content ranges from 0.6 to 43.0 g/t.

From these primary deposits, the secondary gold has often been found and mined by local people from the

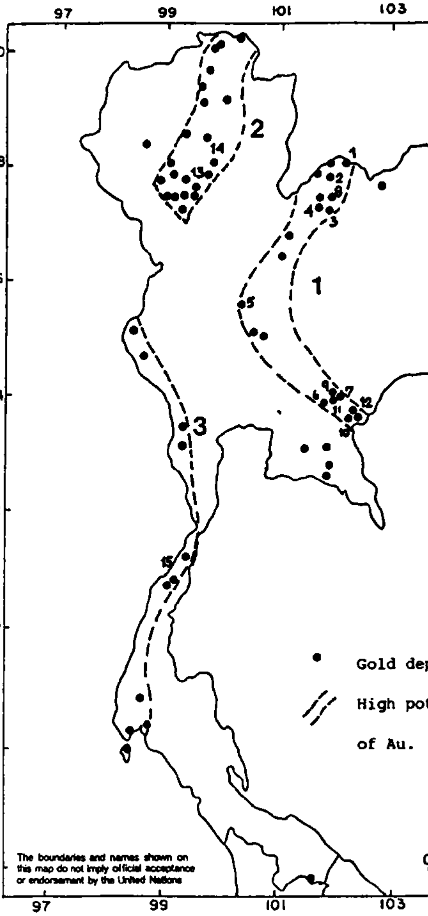

**Figure III. Map showing the distribution c and the limits of high potenti**

Lower Triassic volcanics which include an andesitic tuff, rhyolitic tuff and agglomera porphyries, equivalent to these volcanic this zone. Gold mineralization occur hydrothermal quartz veins and veinlets. veinlets are irregular and are commonly quartz stockworks and breccia-fillings ho canic terrane.

Structurally, the major faults in th active and are indicated by several hot spri

In Huai Kam On (Locality 13, Figure III) gold values range from 0.03 to 76.0 g/t with a maximum of 600 g/t. The gold-bearing quartz lodes, hosted in the volcanic terrane, are highly fractured and friable.

Mon Khum Kam (Locality 14, Figure III) is located northwest of the Huai Kam On deposit. The mineralization is fault/fracture controlled with alteration zones of silicification and chloritization. Gold grade ranges form 0.03 to 6.6 g/t.

Other deposits in this zone show an almost identical style of mineralization. The grades of these deposits have not been worked out but a high potential for gold can be expected.

The last, third zone is aligned close to the western boundary of Thailand. The gold mineralization style in this zone is not clear, but it shows clear relations with the vein systems of the tin-bearing granitic belt in which granites intruded into Siluro-Devonian metasedimentary sequences. It has also been noted that local structures, faults and fractures are closely related with gold occurrences.

### 3. Placer Type

Several tin placers in this area produce a significant amount of gold dust nuggets as by product. The best known gold deposit in this zone is the Bang Saphan gold-tin deposit (Locality 15, Figure III).

The gold mineralization in this zone is probably incidental to the emplacement of the tin-gold bearing quartz lodes and metamorphic veins of the granitic belt.

## SUMMARY

Since the project on gold exploration was launched by the Department of Mineral Resources of Thailand in 1984, detailed studies have been done and the results show that there are at least three zones of high potential interest for gold. Two of these are closely related to volcanic rocks of acid to intermediate composition and their subvolcanic intrusive equivalents. Metasomatism on contacts between carbonate rocks and porphyries also are expected to be of high interested as well as the gold-bearing quartz lode occurrences.

Another potentially favorable situation is in the tin-bearing granitic belt, in which gold may be produced as a by-product.

More detailed study must be carried out in these areas of high potential to delineate and evaluate their gold occurrences. Several occurrences are of current commercial interest and it can be predicted that gold will be an important mineral commodity in Thailand in the near future.

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# GOLD DEPOSITS OF VIET NAM

by
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## ABSTRACT

In Viet Nam, gold deposits and occurrences are mainly distributed in four gold metallogenic regions, namely: North Indochinese, Central Indochinese, South Indochinese and West Indochinese.

Almost all gold deposits in Viet Nam are distributed in folded zones of a platform subjected to tectonic activation in the Mesozoic, usually along deep-seated faults, on the margins of tectonic depression and on uplifted domes. Gold deposits characteristically are of quartz-gold, quartz-gold-sulphide, gold-silver, gold-sulphide and placer gold types.

Among the above-cited occurrence types, the principal gold deposits are mainly concentrated in three types: quartz-gold (Cam Ton and Lang Mo deposits), gold-silver (Na Pai, Tan Mai and Buu Long), and quartz-gold-sulphide (Pac Lang, Bong Mieu, Tra Nang and Kim Boi mines).

### 1) Quartz-gold mineralization

This gold mineralization occurs in Cam Thuy district, which is so far the most important gold-bearing area. The gold-bearing veins in Cam Tan and Lang Mo deposits were discovered in 1986. The deposits are mainly hosted in the Late Permian-Early Triassic grey-greenish basic volcanics. Two main ore bodies are seen in Cam Tan and three in Lang Mo. The main mineral components are free gold, arsenopyrite and pyrite. Free gold is distributed independently in cracked quartz veins or in the marginal part of quartz veins in strongly altered spilite; gold grains to 1-3 mm can be observed in oxidized pyrite. Gold content in samples from Cam Tan and Lang Mo varies from 8 to 15 ppm, in some places to 45 ppm.

their surface parts (Pac Lang, Bong Mieu, Boi and Bo Cu deposits). The Pac Lang mi in 1908, is among the oldest.

At Pac Lang, 50 gold-bearing vein coaly-shale and sandstones of the Triass continental rift zone. Quartz-sulphide- commonly 0.2-1.0 m thick, in some places are developed along the strikes to length The sulphide minerals present in the ve (68%), sphalerite (2-5%), galena (3%), c 3%) and arsenopyrite (2-3%). The free 0.01-0.25 mm, and can be frequently visibl eye. Possible reserves are estimated as 137 Assays range from 5 to 185 ppm.

The Bong Mieu mine was continu from 1895 to 1940 during which period 3, and 2,500 kg of silver were produced by a Fr This mine is entirely situated within an a ture. Within the mine area, there are main metamorphic rocks including gneissose silimanite gnesisses and quartz schists of Lo age. The ore bodies are in the form of ve and are distributed in three main minera namely the Nui Kem, Ho Gan and Ho Nuoc the ore minerals are free gold, pyrite an Less frequently seen are galena, hemat chalcopyrite, pyrrhotite and sphalerite. Th the gold is usually 0.05 to 1 mm and assay adits gave results of 5 to 7 ppm, with reaching very high values (311 to 677 p reserves are estimated as 192.5 tonnes of

### 3) Gold-silver mineralization

sion and deformation. Mineralization at the Na Pai deposit is likely related to post-volcanic hydrothermal alteration. The ore bodies and mineralization zones are 3 to 40 m in length and 0.3 to 3.5 m in width.

The gold-bearing ore bodies are developed along the shear zones cutting through rhyolite-dacite which has been subjected to propylitization, or through rhyolite tuffs affected by intensive alteration. In gold-bearing zones, the main ore minerals are free gold and pyrite. Less common are arsenopyrite, marcasite, native copper, calaverite, electrum and chalcopyrite. The free gold grains are 0.02 to 2 mm in size. Assays in several zones gave results in the range of 5 to 25 ppm of gold, and selected samples reached values of 975 to 11,800 ppm gold. The gold fineness in Na Pai varies from 637 to 867. Possible reserves are estimated as 50 tonnes over an area of 5 km².

### 4) Gold-sulphide mineralization

The deposits and ore occurrences classified in this type include Deo Gio, Cho Dien, Tu Le, Dong Mo and Na Tum.

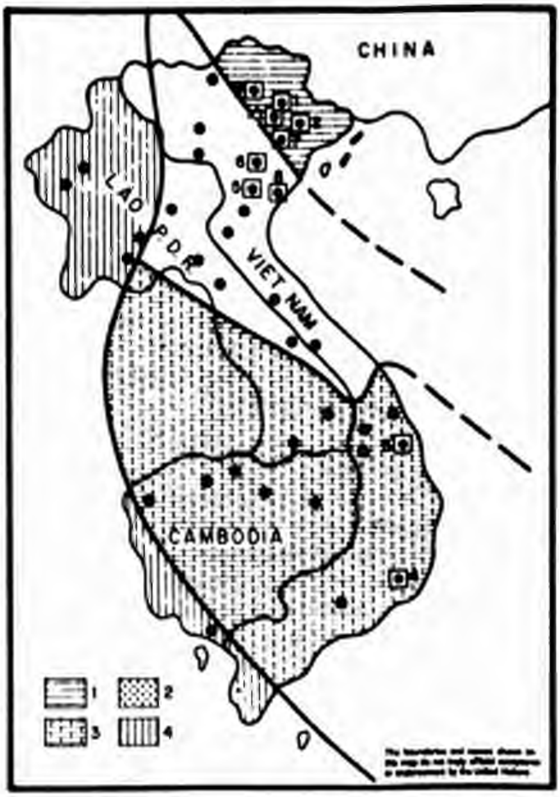
Gold-sulphide deposits are mainly distributed along the margin of the Chiem Hoa-Phu Hoat uplifted domes or are developed along the volcanic depression of the Da and Hiem Rivers. In general, the mineral composition in those deposits is quite diverse; the main ore minerals are galena, sphalerite, and free gold plus lesser pyrite and chalcopyrite. In some deposits (Deo Gio, Mo Ba), the gold grade reaches 30 ppm, while silver reaches 57 ppm.

According to the latest field results, some iron caps developed on these gold-sulphide deposits also bear significant gold. The most promising deposits are Na Tum, Cho Dien, Dong Mo and Tu Le. In Na Tum iron cap, there is a possible reserve of 4 million tonnes of gold ores.

## INTRODUCTION

In Viet Nam, gold deposits and occurrences are distributed in four gold metallogenic regions, viz., the North Indochinese, Central Indochinese, South Indochinese and West Indochinese regions.

Figure I shows the areal distribution of these geological regions, the locations of the more prominent gold mines or districts of Indochina, and the location and names of districts in Viet Nam which are described in this paper.



LEGEND

▭ GOLD METALLOGENIC REGIONS OF INDOCHINA

1 North Indochina
2 Central Indochina
3 South Indochina
4 West Indochina

● GOLD MINE OR DISTRICT

⊡ GOLD DISTRICTS DESCRIBED IN TEXT

1. Pac Lang
2. Na Pai
3. Bong Mieu
4. Tra Nang
5. Lang Neo
6. Kim Boi
7. Bo Cu
8. Cam Tan - Lang Mo
9. Lang Vai
10. Na Tum

Figure I. Location of gold mines in the Indochinese region.

On a regional scale, almost all the gold deposits are distributed in folded zones of a platform subjected during the Mesozoic tectonic activities along deep-seated faults, on the margins of depressions, and on uplifted domes caused by soda-rich intrusive bodies. The gold deposits are mainly of hydrothermal origin.

In the northern metallogenic region, the deposits are concentrated along the margin of the Song Hiem terrigeno-volcanic depression (Pac Lang and Na Pai mines).

In the central metallogenic region, the gold deposits are mainly distributed along deep-seated faults of the Hong, Da, Ma and Ca Rivers. Gold mineralization in this region is related to acidic and mafic intrusions and to basic volcanic rocks of the Song Ma Anticline (covering the Cam Tam, Lang Mo and Lang Neo mines). It is also found in the eastern margin of the Hoa Binh uplifted block in the Kim Boi area.

Most of the gold deposits in the southern metallogenic region were developed along the northern and eastern margins of the uplifted Kontum block (covering the Bong Mieu mine). Several newly-discovered gold deposits (Tra Nang and Suoi Ty) have also been found south of the Kontum block in Mesozoic terrigeno-volcanic formations.

In the western metallogenic region, the deposits appear to be more scantily distributed.

The depositional types of gold deposits are mainly quartz-gold, quartz-gold-sulphide, gold-silver, gold-sulphide and placer gold (Do Hai Dzung, 1986). The principal gold deposits are mainly of the quartz-gold-sulphide (Pac Lang, Bong Mieu, Tra Nang mines) and gold-silver (Na Pai mine) types.

## GOLD VEIN DEPOSITS

### 1. *Pac Lang mine*

The Pac Lang gold mine is located some 10 km south-east of Ngan Son township (Figure II), and 330 km from Hanoi by road. Alternative access is by rail from Hanoi to Thai Nguyen town and then 130 km by lateritic road to the Pac Lang deposit which is located along the Pac Lang valley at an elevation of 400-450 m. The relief northward of the mine gradually becomes higher, reaching 800-1,200 m in mountain ridges with a north-east/south-west direction.

The Pac Lang deposit was discovered by Manu, an Italian soldier who served in the French army in 1908. For many years prior to this date, placer gold in the Pac Lang area had been exploited by local people. Consequently, Duclos (1912) Moulinet (1923) and other Frenchmen investigated the primary mineralization and exploited it by adits totalling 662.8 m in length.

Gold exploitation in Pac Lang at that time was by traditional methods of grinding and jigging, and focused mainly on some veins of high gold content which could be detected with the unaided eye. From 1943 onwards this exploitation was abandoned.

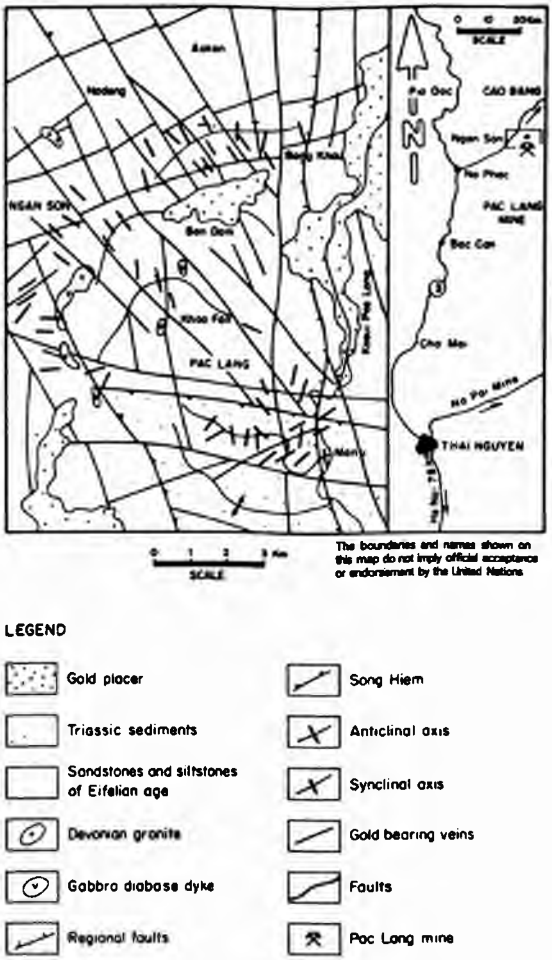


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**Figure II. Distribution of gold-bearing veins in the Pac Lang mine**

According to Masse (1923), it was possible to recover 97.50 kg of gold from the Paul Haut, Madeleine and Manu veins. Then, in 1972-1975, a preliminary study of the Pac Lang deposit was made through the compilation of a 1:50,000 scale geological map of Ngan Son area. According to Gia Tan Dzinh (1975), and Do Hai Dzung (1982, 1984, 1986), the Pac Lang mine is of medium size and could be prospected for further exploitation.

The deposit occurs at the margin of the Song Hiem continental rift zone where Middle Triassic terrigeno-volcanic formations overlie the Paleozoic terrigeno-carbonaceous sequence.

The area is crossed by fault systems with a north-west/south-east trend which played a role in the formation of the main gold mineralization zones, especially where the zones are intersected by faults of meridional and submeridional direction.

In the central part of the Pac Lang deposit, in the Manu area, gold-bearing quartz veins are hosted by shale, coaly shale and sandstone of the Song Hiem Suite of Middle Triassic age. Quartz veins extend 50 to 200 m in length and 15 to 30 m in width. The quartz-sulphide-gold veins are commonly 0.2-1 m thick, sometimes up to 2-3 m, and are developed along the strata of 30°, 70° and 120°.

Among the nearly 50 gold ore veins found so far in Pac Lang, up to 20 have been manually exploited on the surface. In the centre of the mine, along the Pac Lang stream, there are seven veins; the sites of the principal veins of economic value are listed in Table 1.

In the Manu terrace, 18 kg of gold was mined (Masse, 1923), while 8 kg of gold was recovered from the Leroy Haut vein (Moulenet, 1929). In the north and south-west of Pac Lang, there are 25 gold ore veins with a content of less than 5 ppm.

According to Gia Tan Dzinh (1975), the gold-bearing quartz veins are smoky-coloured, cracked and porous. The sulphide minerals present in the veins are: pyrite-68 per cent; sphalerite-2 to 5 per cent; galena-3 per cent; chalcopyrite-1 to 3 per cent; and arsenopyrite-2 to 3 per cent. Among the vein minerals the common ores are quartz, calcite and barite. The native gold of grain size between 0.01 and 0.25 mm can be observed by the unaided eye.

Silver occurs in Pac Lang either in native form or argentite and galena. Gold of 0.3 to 32.6 ppm is also frequently found in gersdorffite and galena. Gold-bearing veins and veinlets are usually developed in secondary alteration zones. However, gold fineness is not high, ranging from 530 to 797. The forming temperature of the Pac Lang gold ore varies from 140° to 196°C. The research results reached by Do Hai Dzung (1986) show the presence of gaseous $CO_2$ and solid NaCl in three-phase inclusions of the Pac Lang gold ore veins, indicating that the ore was crystallized from solution containing 30 per cent NaCl under a pressure of 70 atmospheres.

Pb-isotopic age determination gives an age of 149 million years for the Pac Lang and Ngan Son gold-bearing veins.

**Table 1. Gold content in some major veins of the Pac Lang mine**

| *Gold-bearing* | *Thickness of* | *Content of* | *Length of* |
|---|---|---|---|

Apart from the primary ore, there
placers in the Pac Lang and Ban Dam
contain 0.3 to 0.95 g/m³ of gold. Gold is oft
form of roughly rounded grains of 0.05 to
The gold placers are 250-1,500 m in length
width and 0.3 to 1.95 m in thickness.

Further mineral exploration should
with the objective of developing the Pac L
possible reserves have been estimated at
metal gold.

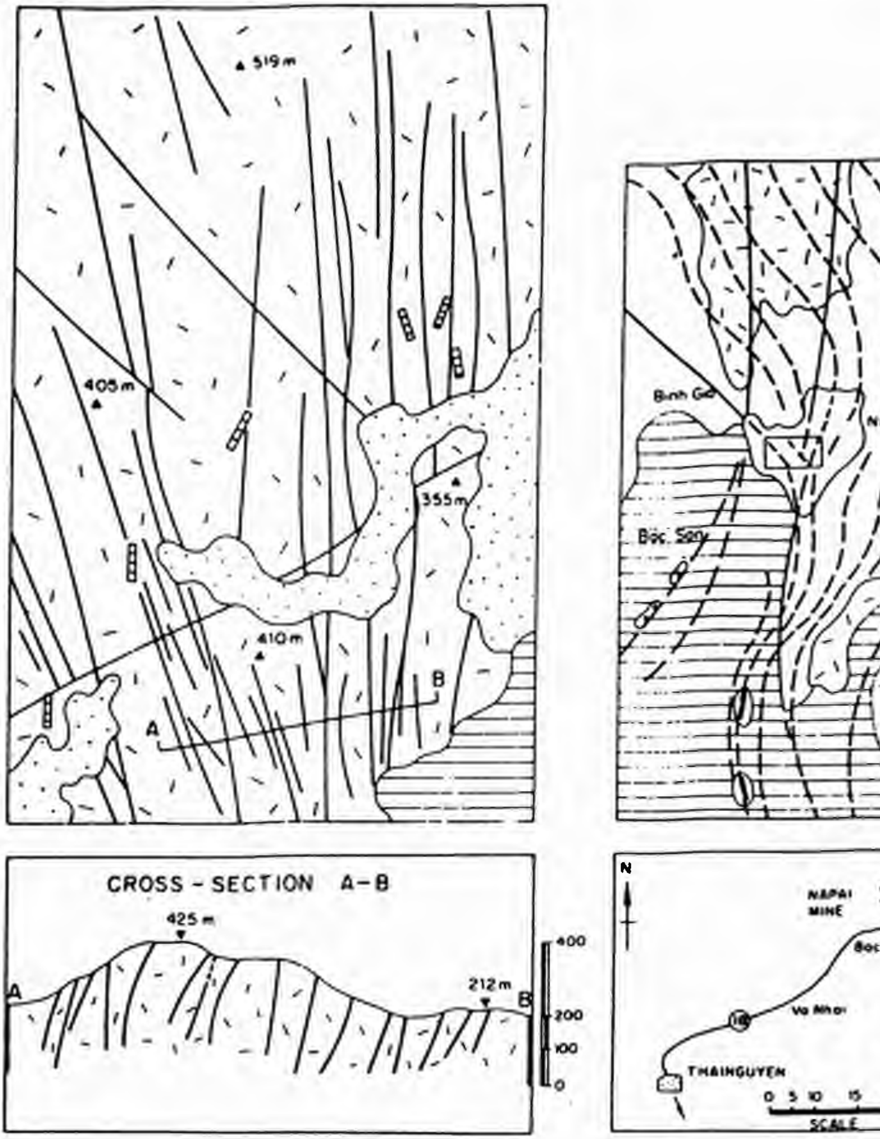
## 2. *Na Pai mine*

This gold mine was discovered in
the Binh Gia area, close to the Binh Gia
passes through Thai Nguyen and Bac Son
III). Access is also possible by rail from
Mo (120 km) and then from Dong Mo to Na
km). The Na Pai mine is located at an elev
400 m. North of the mine mountain ridges
to a height of 800 m. Owing to the high
this deposit, intensive small-scale mining
explorations have been carried out recentl

The Na Pai deposit is situated on
margin to the Song Hiem Triassic depressi
The deposit covers an area of some 1.5 km
occupied by a narrow area of shale, siltsto
the Song Hiem Suite, surrounded by acid
rhyolite, rhyolitic tuff and rhyolitic dacite
volcanic rock at Na Pai was subjected to st
in which propylitization and quartzitiza
important role in the formation of gold
South of the mine, the Carboniferrous-Per
is separated from the Triassic terrigeno-vo
faults.

Tectonically, the deposit is located
gent plate boundary affected by various
pression and deformation. So far, ten or
developed along meridional and north-west/so
faults have been discovered.

Adjacent to the ore bodies, there are
porphyry granite and felsite, the formatio
most probably associated with differentiat
the Bac Son granitic massif.



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LEGEND

▤ Paleozoic sediments

Deep – seated

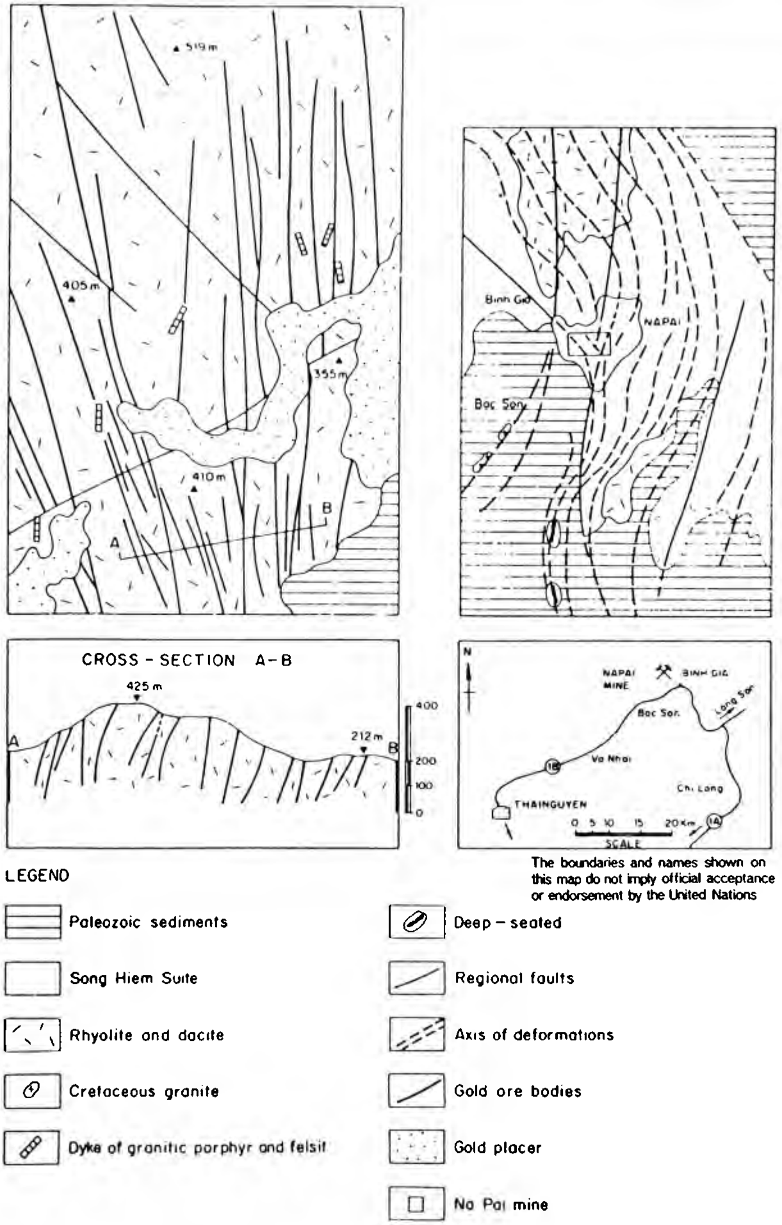

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Figure III. Geological map of the Na Pai mine.

The Na Pai deposit is a typical gold-silver type, formed not more than 200 m below the surface in low-temperature conditions. Gold ore bodies develop along shear zones in rhyolite-dacite which is subjected to propylitization, or through rhyolitic tuff subjected to intensive alteration. The product of the propylitization process is characterized by the formation of melanocratic rocks containing albite, chlorite, epidote, calcite, chalcedony, sericite and pyrite. In addition, quartzitization and argillization processes also play an important role in the formation of gold-bearing zones.

The main ore minerals in the gold-bearing veins and bodies are free gold and pyrite. Arsenopyrite, marcasite, chalcopyrite, galena, sphalerite, native copper, calaverite,electrum and cassiterite are less common.

Free gold is distributed mainly in crevices or disseminated in host rocks and arsenopyrite. In micro-crevices which cut through arsenopyrite free gold occurs in grain sizes between 0.02 to 2 mm. Analysis of this type of ore usually shows 975-11, 798 ppm of gold. In some samples free gold can be detected around nests of arsenopyrite with the unaided eye. The gold in the Na Pai deposit varies in fineness from 419 through 637 and 782 to 876. The elements present in free gold are Ag, Cu, Fe, As and S (Table 2).

**Table 2. Chemical element content in free gold at the Na Pai mine**

(%)

| *Sample analysis* | *Au* | *Ag* | *Cu* | *Fe* | *As* | *Total* |
|---|---|---|---|---|---|---|
| 3001/1 | 81.31 | 15.77 | 1.09 | 0.87 | 0.92 | 99.96 |
| 3001/2 | 82.16 | 15.79 | 1.18 | 0.25 | 0.73 | 99.51 |
| 3008 | 85.62 | 13.86 | - | - | - | 99.48 |

*Source:* Nguyen Van Ngoan, 1988.

The gold content in the Na Pai ore bodies is very uneven. Since 1986, 45-50 kgs of gold have been mined from ore bodies I and II of the deposit.

**Table 3. Gold and silver content in Ore bodies I and II of the Na Pai deposit**

| *Content (ppm)* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
|---|---|---|---|---|---|---|---|---|---|---|
| Au | 0.12 | 23.6 | 30.0 | 69.0 | 25.0 | 1.8 | 355.7 | 8.8 | 5.6 | 1.1 |

**Table 4. Some chemical elements fou bodies I and II of the Na Pai**

| *Sample analysis* | *Content (ppm)* | | | |
|---|---|---|---|---|
| | *Au* | *Ag* | *Cu* | |
| NP/1 | 0.60 | - | 14.51 | 1 |
| NP/2 | 53.46 | 6.60 | 13.70 | 2 |
| NP/3 | 33.73 | 5.50 | 16.93 | 1 |
| NP/4 | 75.60 | 92.18 | 16.93 | 1 |
| NP/5 | 0.34 | - | 24.19 | 3 |
| NP/6 | 0.20 | - | 16.98 | 2 |
| NP/7 | 273.30 | 20.30 | 14.51 | 1 |
| NP/8 | 14.00 | 5.50 | 12.90 | 2 |
| NP/9 | 13.20 | - | 14.51 | 1 |
| NP/10 | 0.20 | - | 20.00 | 6 |

*Source:* Do Hai Dzung, 1987.

Apart from ore veins and bodies, th ous alluvial eluvial-deluvial gold placers value in the central part of the Na Pai depos In some samples, the gold content reaches 0 Free gold in the placer deposits is rod-like, 0.1 mm, dendritic sized from 0.2 x 0.3 mm t or grained at 0.5 to 0.8 mm.

The above indications suggest that f exploration should be carried out at the N prior to further development of mining a possible reserves have been estimated at 17 in an area of 0.3 km$^2$, and 50 tonnes of gol 5 km$^2$.

### 3. *Bong Mieu mine*

The Bong Mieu gold mine is situat district, 90 km from Da Nang city (Figure I is located at an elevation of 200 to 493 m a Vang River, a tributary of the Thu Bon distance from Hanoi to Tam Ky is 864 km an Minh City to Tam Ky, 999 km. The mine ously exploited from 1895 to 1942, when 3, 2,500 kg of silver and140 tonnes of lead we a French company.

Since 1976 the mine has been under but due to lack of funds, geological explor concentrated on the primary ore. Small-sc mining is being conducted by a provincial

The Bong Mieu gold deposit belong Indochinese gold metallogenic region (Figu

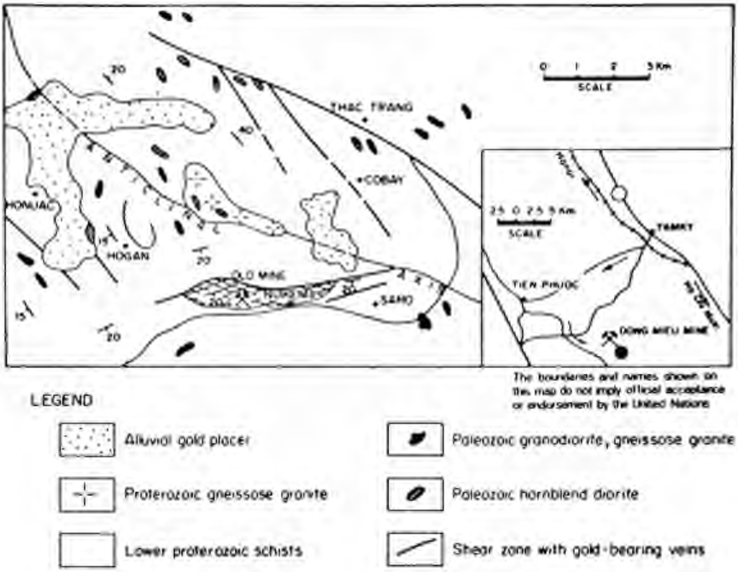

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**Figure IV. Geological map of the Bong Mieu mine.**

The mine area is mainly composed of Precambrian metamorphic rocks such as gneissose granite, biotite-sillimanite, sillimanite-biotite-quartz, biotite gneisses and quartzite of Lower Proterozoic age.

Intrusive rocks are represented by granodiorite, granitogneiss of Proterozoic age and hornblende diorite of Paleozoic age. Most of the intrusive bodies crop out in small hills or lenses along the main faults. Pb-isotopic dating indicates an age of 200 million years for Bong Mieu ore. Among six major fault systems, the most important one shows a south/south-west trend, dipping 10°-20° and running through Ho Gan, Nui Kem and Sa Ro. The north-west/south-east oriented fault system dips 60°-80° and runs through Ho Nuoc and Thac Nuoc, which is another favourable direction for gold accumulation. However, mineralization here is more scanty.

The Bong Mieu gold deposit belongs to the quartz-gold-sulphide type. The composition of the ore minerals comprises free gold, pyrite, arsenopyrite, quartz (86-90 per cent), calcite, hydromica and graphite. Galena, hematite, magnetite, chalcopyrite, pyrrhotite, sphalerite, molybdenite and cassiterite are less common.

Free gold in Bong Mieu is grained, allomorphic or dendritic. The grain size is usually 0.05 to 1 mm, and the share of fine gold is high. Gold mineralization is of the hydrothermal type related to the hydrothermal alteration process such as chloritization and sericitization.

The ore bodies, in the form of veins and lenses, are distributed in three main zones as described below.

*(i) Nui Kem zone*

Nui Kem (Zinc Mountain) is an old mining area at Bong Mieu. During 40 years of mining activities by French companies, from 1903-1942, 3.5 tonnes of gold were extracted with an average of 10 gm/tonne of ore. Over 18,000 m of adits were excavated in 15 stages at an elevation of between 200 and 400 m above mean sea level. The ore body in the Nui Kem mining area is in the form of a reef situated in a shear zone, impregnated with gold-sulphide (mainly pyrite) quartz veins of 0.4 to 4 m thickness dipping 20° conformably with surrounding Proterozoic metasediments of the southern wing of the Nui Kem Anticline. The ore body which has an east/west trend, shows outcrops for more than 3,000 m along the mountain slope.

Samples taken between 1976-1977 in the old adits tested at 1 to 37 gm/tonne of gold. Several samples even reached 311 to 677 gm/tonne.

The extension of the ore body at Nui Kem, which dips southward below the old mining elevation of 200 m above sea level, needs to be prospected by drilling. Geological exploration should also be extended to assess the gold potential of the Bong Mieu area

### *(ii) Ho Gan zone*

This zone, located north-west of the Nui Kem area, was developed in a shear zone hosted by quartz-sillimanite schists. The average gold content is 8.3 ppm. In the centre of the zone several ore veins extend discontinuously from 250 m to 1,000 m in a north-west/south-east direction. The average thickness of the veins is around 0.9 m.

### *(iii) Ho Nuoc (waterfall) zone*

This zone is sited along tectonic breccia zones which are 0.5 to 0.8 thick and some 350 m deep, striking 200°-210° and 70°. The gold content in the veins is as high as 5 ppm.

Geological investigation shows that the above three ore zones are the main source of placer gold, among which the most important are in the Co Bay, Phuoc Long and Bong Mieu valleys with a length of 700 to 2,300 m and a width of 100 to 400 m. The thickness of the gold-bearing bed varies from 0.60 to 6.00 m. In the alluvial pebble stratum, the gold content varies from 0.14 to 0.36 gm/m$^3$.

Up to now, the Bong Mieu gold mine has not been systematically studied. Further geological exploration for primary gold ore should be undertaken to meet the demand of the mining sector in the near future . The possible gold reserves are estimated at 192.5 tonnes.

### *4. Tra Nang deposit*

The southern Viet Nam gold metallogenic region comprises a series of gold deposits and occurrences which developed in the Late Mesozoic terrigeno volcanic formations. The most prospective is the Tra Nang area (Figure V), where gold was discovered in February 1986. Placer gold deposits along the Tra Nang valley, 60 km south of Da Lat, are being intensively mined by the local population. However, geological exploration of primary ore remains very limited.

The Tra Nang deposit extends along a north west/south-east oriented fault, which stretches from 10 to 15 km long, from Da Lat to Suoi Ty.

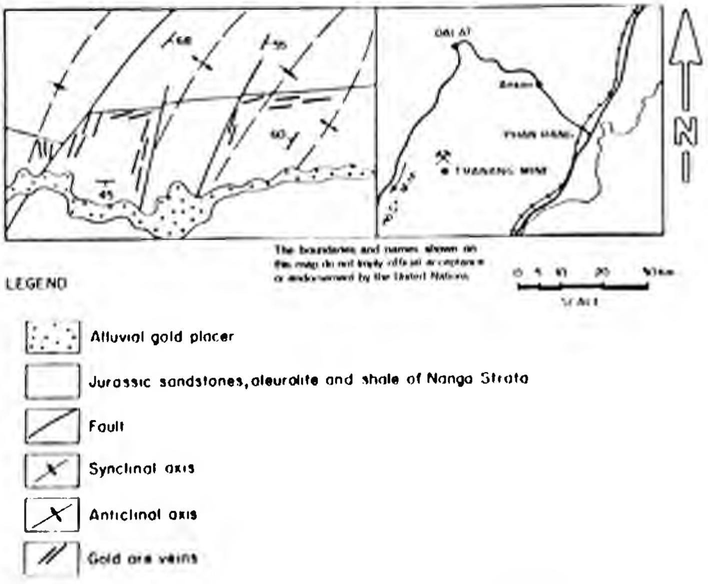

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Figure V. Distribution of gold-bearing veins in the Tra Nang mine.

The extension of the ore body at Nui Kem, which dips southward below the old mining elevation of 200 m above sea level, needs to be prospected by drilling. Geological exploration should also be extended to assess the gold potential of the Bong Mieu area.

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This zone, located north-west of the Nui Kem area, was developed in a shear zone hosted by quartz-sillimanite schists. The average gold content is 8.3 ppm. In the centre of the zone several ore veins extend discontinuously from 250 m to 1,000 m in a north-west/south-east direction. The average thickness of the veins is around 0.9 m.

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The Tra Nang deposit extends along a north-west/south-east oriented fault, which stretches from 10 to 15 km long, from Da Lat to Suoi Ty.

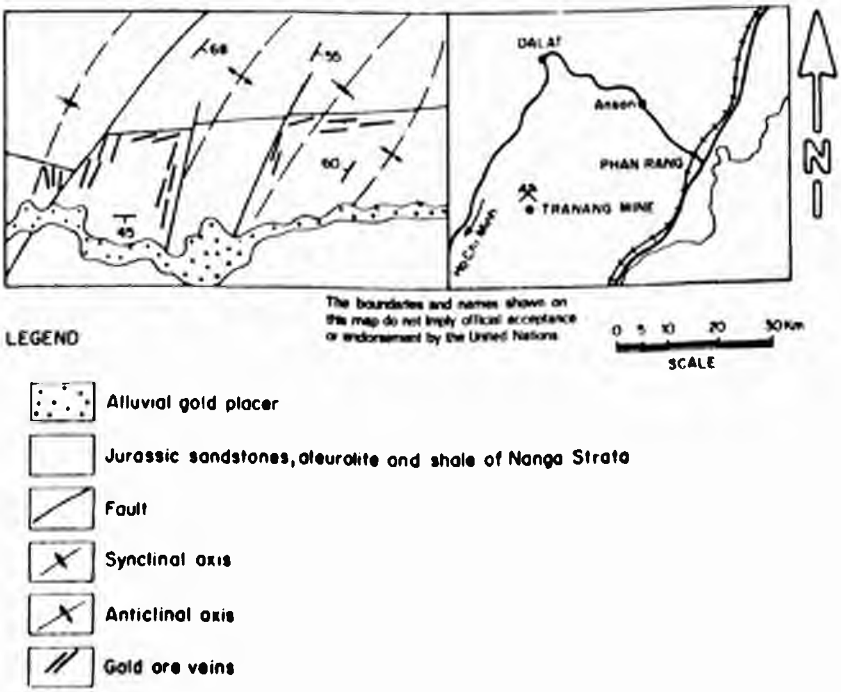

**Figure V. Distribution of gold-bearing veins in the Tra Nang mine.**

Gold ore bodies in Tra Nang occur in the form of veins hosted by terrigenous sediments which are composed of sandstones, siltstones and shale. The largest gold ore zone in Tra Nang is 20 to 80 m wide and extends discontinuously for 4 km; it comprises numerous gold-bearing quartz sulphide veins.

The Tra Nang gold deposit belongs to the quartz-gold-sulphide type. The main ore vein extends in a north-east/south-west direction and dips 70°-80° (Figure V). The main ore body, located on the east of the Tra Nang valley, is 50 m wide and 4 km long. It consists of crushed quartz containing 2.5 to 10 gm/tonne of gold in some trenches; the gold-bearing quartz veins, which show a north-east/south-west trend, are 0.3 to 0.9 m thick and 35 to 200 m long.

The sulphide content in the ore veins is 5 to 18 per cent. They contain mostly arsenopyrite, pyrite, chalcopyrite, sphalerite and galena, while quartz, muscovite, sericite and feldspar are also common. The gold-bearing quartz is white, gray and smoky, and often cracked; the pores are filled with sulphides. Arsenopyrite (up to 10 per cent) is often altered into scorodite. Pyrite (less than 6 per cent) occurs in grain sizes of 0.2 to 2 mm.

Analysis of some ore veins has indicated 104 ppm of gold; the gold mineralization is closely associated with sericitization, quartzitization and pyritization. Compared with free gold in other deposits of Viet Nam, the Tra Nang deposit has the highest fineness, ranging from 772 to 896 (Nguyen Minh Loan, 1986). Gold mineralization inTra Nang is genetically related to the Cretaceous granodiorite, granite and alaskite magmatic series (Nguyen Van De, 1986, 1988).

In Tra Nang and its adjacent areas there are many rich gold placers, where the free gold is in a grained, tabular or dendirtic form with grain sizes ranging from 0.1 x 0.5 mm to 1.2 x 0.5 mm. The gold placers are located near primary ore and are developed perpendicularly to the primary ore zones.

In general, Tra Nang is considered to be a very promising area with regard to primary gold mineralization, which is related to volcano-plutonic activity of the continental margin during Late Mesozoic. The possible gold reserves have been estimated at 100 tonnes.

### 5. *Lang Neo deposit*

The gold deposit in Lang Neo was discovered in 1983 (Figure VI). Located in Cam Thuy district of Thanh Hoa province, on the Dien Lu-Ba Thuoc Anticline, it belongs to the Central Indochinese gold metallogenic region (Figure I). Access to the Lang Neo deposit is by a 110 km-long road from Thanh Hoa provincial town via Vinh Loc and Cam Thuy district towns.

Preliminary exploration of the deposit by trenching was carried out in 1983. At present, the local population is exploiting the surface portion of the ore body. So far, some 15 kg of gold has been extracted.

The Lang Neo deposit occurs in Cambrian gray and dark-gray limestone penetrated by veinlets of quartz and calcite. Gold mineralization is mainly concentrated along the tectonic shear zones with either an east-west or north-east /south-west trend.

Three principal fault systems have been discovered. The Lang Neo fault plays a mineralization-controlling role, while the other systems cross the Lang Neo fault and are defined as 'depositional'. The centre of the Lang Neo deposit is represented by a dyke of granitoid composed of quartz–36.2 per cent, oligoclase–16.8 per cent, orthoclase–14.3 per cent, biotite and a small amount of muscovite, zircon and sulphide.

Several gold mineralization zones have been found within the deposit. The northern zone, situated upstream of the Can River, shows an east-west trend 180 m long and 20 m wide. Sample analysis shows 1 ppm of gold and 1.3 ppm of silver. The central mineralization zone is 750 m long and 35 m wide. Breccias of limestone contain gold from 21.3 to 173.3 ppm, and silver at around 3.9 to 8.9 ppm. Gold occurs in the form of grains sized up to 2 mm. The possible gold reserves have been estimated at 19 tonnes.

### 6. *Kim Boi area*

Kim Boi means "Gold Cup", a name that obviously comes from gold mining activities which have been carried out in the area for centuries. Located 45 km south-west of Hanoi, the Kim Boi area occupies a mountainous region of about 5,000 km$^2$ at an elevation of 150 to 500 m above sea level (Figure VII). Access to the area is by highway No. 6 from Hanoi to Hoa Binh and then by lateritic road to the various deposits.

Placer gold deposits in the area have long been exploited by the local population. From 1937 to 1945, gold was extracted from the Da Bac, Xuan Mai, Thung Quay, Lang Mi and Dong Thanh placer deposits by a French miner.

In 1960-1963 Geological Team No.23 explored the Cho Ben placer, which has calculated gold reserves of 165 kg. The total reserves of gold placer deposits in the area have been estimated at 2,076 kg. The reserves of primary gold are probably much higher, but geological exploration needs to be increased in order to assess the actual reserves.

The Kim Boi dome occupies the southernmost part of the Fansipan Anticlinorium over an are of 400 km$^2$; it

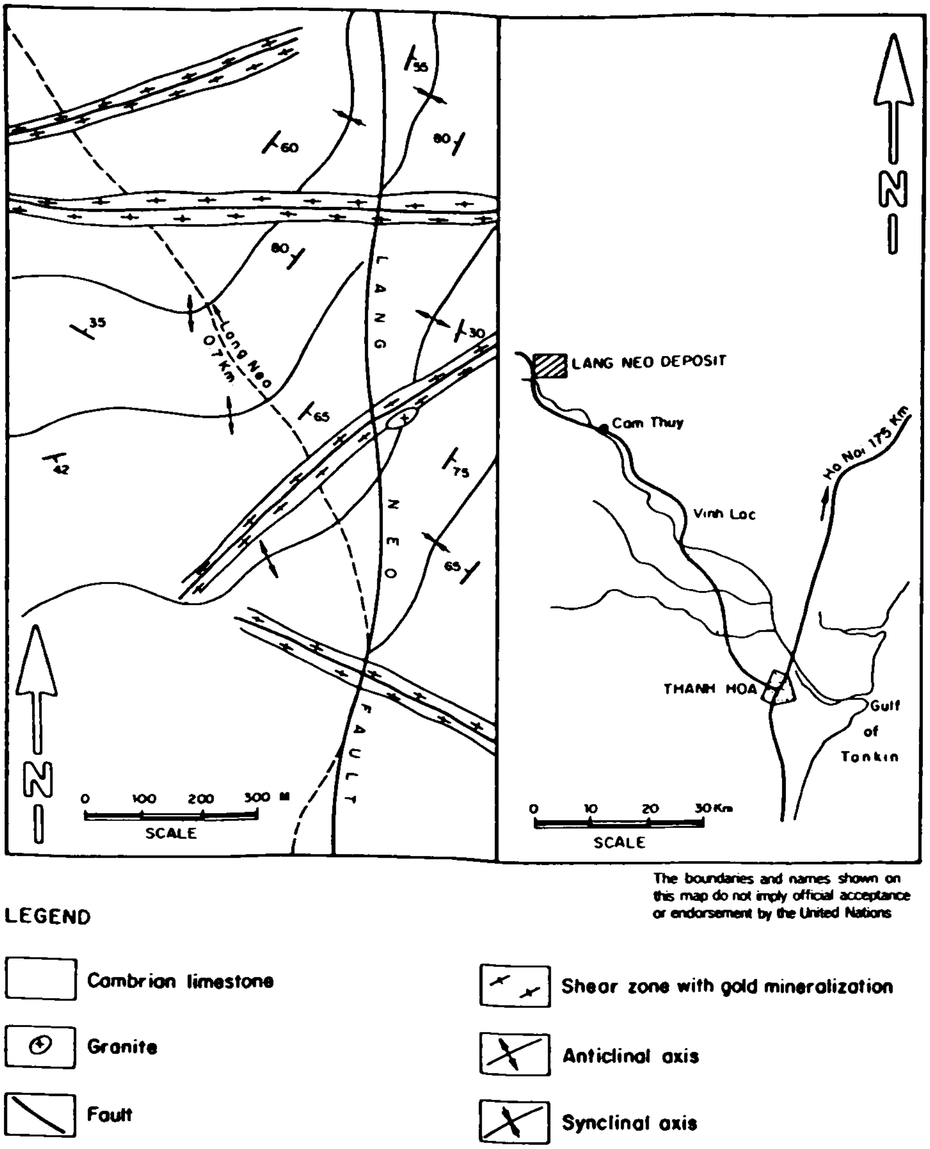

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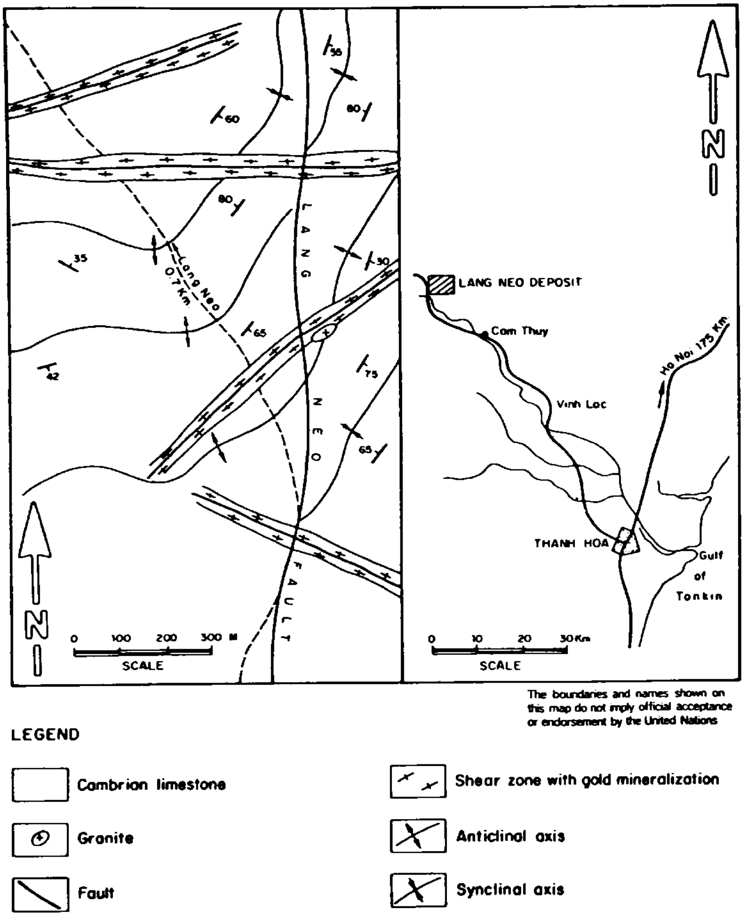
Figure VI. Geological map of the Lang Neo gold deposit.

occurs in basic volcanics of the Late Permian which are intruded by Late Triassic granites. The dome is hosted by volcano-sedimentary and sedimentary formations of the Lower-Middle and Upper Triassic. The area was uplifted and intersected by various faults during the Late Mesozoic and Paleogene.

Two gold ore zones have been identified on the western and eastern sides of the Kim Boi dome. The eastern zone is 80 km long, and between 5 and 10 km wide with a north-west/south-east trend which extends discontinuously to Luong Son, then from Xuan Mai down to Kim Son and Lac Thuy. The western Kim Boi gold zone is 30 km long, and between 2 and 3 km wide, extending from Hoa Binh through Kun Pass and Da Bac, to the east of Tan Lac district.

The gold zones are controlled by faults with north-west/south-east and north/south trends. The host rocks of gold ore are mafic volcanics, siltstone and shale, with interbeds of mafic volcanic rocks.

Among the known primary gold ore occurrences, the most promising are those in the Lang Nhanh, Doi Nau and Lang Lot areas of the eastern Kim Boi zone. Gold



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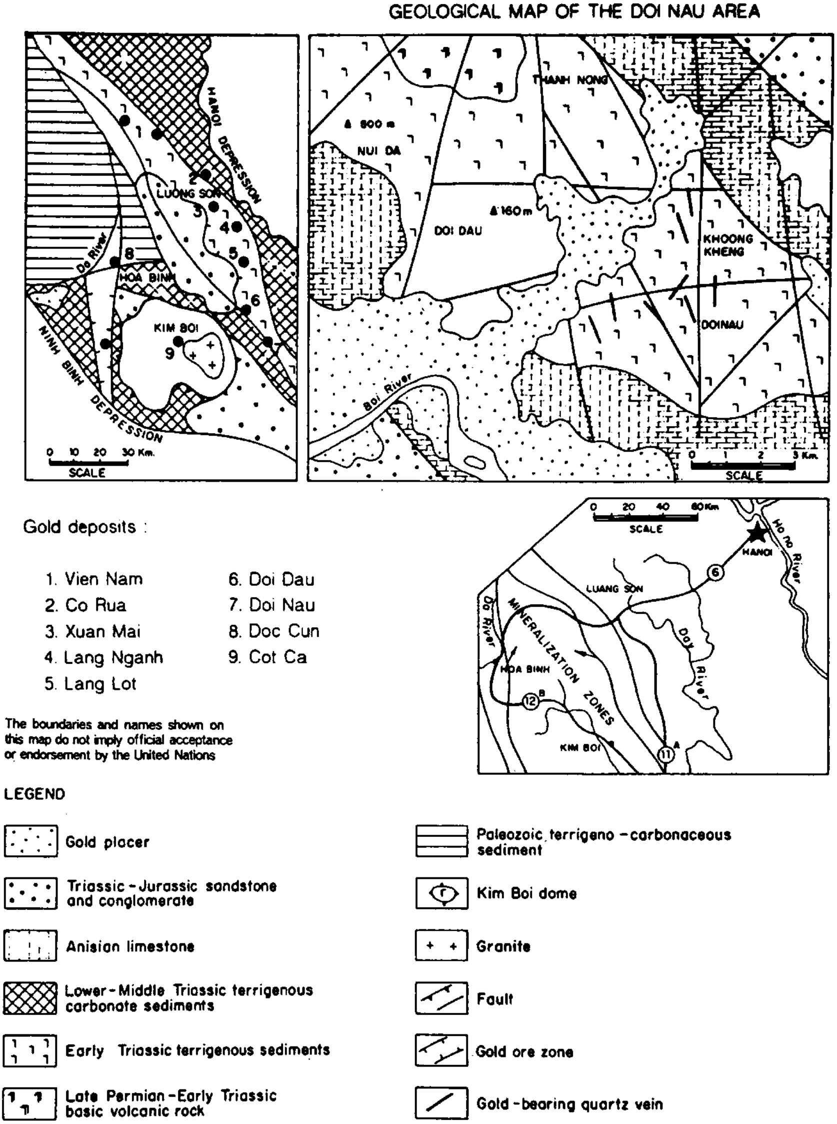

Gold deposits :

1. Vien Nam
2. Co Rua
3. Xuan Mai
4. Lang Nganh
5. Lang Lot
6. Doi Dau
7. Doi Nau
8. Doc Cun
9. Cot Ca

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LEGEND

- ⁘ Gold placer
- ⁘ Triassic - Jurassic sandstone and conglomerate
- ▥ Anisian limestone
- ▩ Lower - Middle Triassic terrigenous carbonate sediments
- ˥ Early Triassic terrigenous sediments
- ˥ Late Permian - Early Triassic basic volcanic rock
- ▤ Paleozoic terrigeno - carbonaceous sediment
- Kim Boi dome
- + Granite
- Fault
- Gold ore zone
- / Gold - bearing quartz vein

Figure VII. Geological map of the Kim Boi gold area.