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A case history—exploration, evaluation and development of the Mamut porphyry copper deposit

YOSHIO AKIYAMA
OMRD Sabah Bhd, Mamut Mine, Sabah

Abstract: The Mamut deposit in northwestern Sabah is of porphyry copper type, that produces a larger amount of gold and silver as associated constituents than normal porphyry copper deposits.

Exploration activities at Mamut and its vicinity were started in 1965 with detailed geochemical soil surveys by the United Nations Labuk Valley Project team after the completion of a reconnaissance geochemical stream sediments survey in the Ranau-Mt. Kinabalu area. The Mamut deposit was assessed for its grade and lateral extent by diamond drilling by the Geological Survey of Malaysia, followed by further detailed systematic exploration and exploitation programmes by the Overseas Mineral Resources Development Company of Japan.

The success of the exploration programmes and subsequent development of the Mamut deposit has demonstrated the effectiveness of reconnaissance geochemical survey by stream sediment sampling and detailed grid soil sampling in delineated targets for a drilling programme. Grid drilling and subsequent development of the mine revealed the ore deposit to coincide with the most intensely anomalous area of both soil geochemical and IP surveys. The deposit lies approximately within the area of soil copper content greater than 300 ppm and above 10% of frequency effect.

INTRODUCTION

The Mamut porphyry copper deposit is situated in northwestern Sabah, about 68 kilometers east of Kota Kinabalu. The mine and its facilities are located at the southeastern slope of Mt. Kinabalu, at an elevation of 1,300 to 1,500 meters above sea level. The main river systems are the Bambangan River which flows south, the Luhan River which flows southeast to east and the Mamut River which flows east. The area of mining lease granted by the government is 4,800 acres (19.4 Km^2) (Fig. 1). The mine has been in operation for about 8 years and is currently producing 480,000 tonnes of ore averaging 0.57% Cu and 0.65 g/t Au and 630,000 tonnes of waste per month.

The history of exploration of the Mamut porphyry copper prospect can be traced back to 1958 when copper anomalies were discovered in the basalt and ultrabasic rocks in the Labuk Valley (Fitch, 1958). High anomalous copper were found in the stream sediments of part of the Mamut and Bambangan Rivers in mid-1965 by the United Nations Special Fund Labuk Valley Project geochemical surveys which were conducted during the period 1963 to 1965 (Cooper *et al.*, 1965). Follow-up work revealed a large area of disseminated copper mineralization in the headwaters of a south bank tributary M2 of the Mamut River (Woolf *et al.*, 1966). In 1966, the Geological Survey of Malaysia implemented the subsequent prospecting programme at the present ore deposit (Newton-Smith, 1966) and the Bambangan valley (Wong, 1967). This programme involved surface geological mapping, soil and rock geochemistry by means of pitting and shallow diamong drilling so as to make a preliminary assessment of the economic possibilities of the Mamut ore deposit (Kirk, 1967). Following an

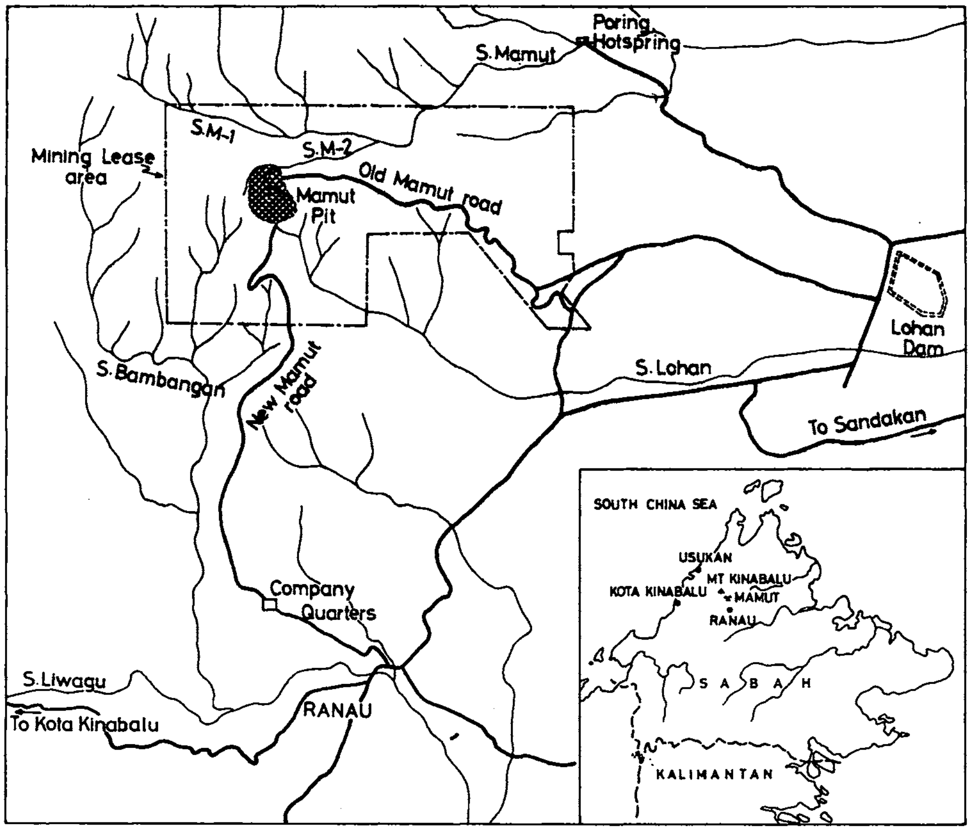


Fig. 1. Location map of the Mamut Mine.

investigation by the Geological Survey of Malaysia, the Overseas Mineral Resources Development Company of Japan (OMRD) conducted an exploration programme in the Mamut area during the period 1968 to 1971. The exploration programme was carried out through the stages of general appraisal by geological mapping, soil and stream sediment geochemistry and airborne and ground geophysics covering the area of prospecting to a detailed investigation by diamond drilling and underground exploratory tunnelling in the mineralized area (Nakamura *et al.*, 1970; OMRD, 1970). The mine was put into operation in May 1975 after the completion of a feasibility study based on the exploration results.

This paper documents the exploration, evaluation, development and some distinctive geological features of the Mamut deposit and provides a synthetic approach to the establishment of optimum methods of exploration and development for a porphyry copper deposit.

OUTLINE OF EXPLORATION PROGRAMME

The OMRD exploration programme was designed with two requirements; first, to narrow down the target area for drilling and then to determine the extent and grade of mineralization by drilling for final evaluation of the ore reserves of the Mamut deposit; second, to locate any other significantly mineralized areas for further detailed investigation over the whole prospecting licence area. Therefore, the exploration works were carried out simultaneously to meet the two purposes. The exploration activities pertaining to the second purpose continued in some other promising areas even after the completion of a feasibility study on the Mamut deposit.

Geochemical surveys consisting of stream sediment and soil geochemistry were concentrated chiefly in the peripheral areas of the Mamut deposit where high geochemical values had already been confirmed by the previous investigation. The density of soil sampling was enhanced in some promising areas such as the M1 tributary, Bambangan River and Nabulau River for detailed investigation. A detailed geochemical investigation had intermittently continued into early 1976 in part of the Mining Lease area.

Geophysical surveys involved a semi-detailed aeromagnetic survey and induced polarization (IP) surveys. An aeromagnetic survey which covered a region of 4,050 square kilometers was conducted in 1970 to assist the search for base metals, particularly for porphyry copper deposits within the region and to further the understanding of geological structures. IP surveys commenced in 1968 at the M2 ore deposit and then extended over the periphery with significant geochemical anomalies such as the areas of M1, Bambangan, Luhan, Nabulau and Nasapang.

A phased programme of exploration was adopted for diamond drilling at the Mamut ore deposit. Phase 1 drilling conducted in 1968 was designed on 100 meter spacings along east-west and north-south lines near the centre of the mineralization. In 1969, follow-up phase 2 drilling was carried out at the mid-points between phase 1 drill holes along east-west lines, and was expanded towards the outside of the mineralized area, taking into consideration the results of phase 1 drilling. Furthermore, during the 1969–1970 period, a total of 7 holes with an aggregate depth of 1,728 meters were drilled in part of the Luhan, Nasapang and Bambangan Rivers to test the economic possibilities of mineralization detected by geochemical and IP surveys.

Exploratory tunnelling totalling 1,083 meters, and four raises totalling 71 meters, were made in the mineralized centre of the Mamut deposit to examine the continuity and grade of mineralization and to obtain ore feed for a pilot plant.

GEOCHEMICAL SURVEYS

Drainage Geochemistry

Major anomalies of several times background were found in the Mamut and Bambangan valleys by reconnaissance stream sediment surveys made by the United Nations project team. Afterward the OMRD Co. Ltd. of Japan implemented follow-up stream sediment surveys in the prospecting licence area covering the Mamut and Bambangan valleys and their tributaries (Fig. 2). Samples were collected at 200-meter

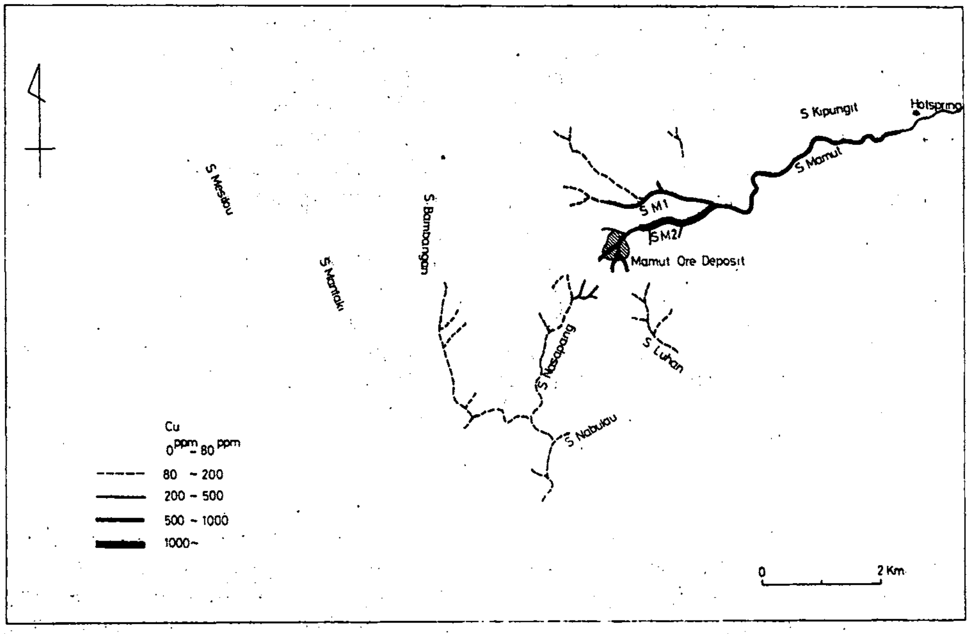


Fig. 2. Stream sediment geochemistry map showing total copper contents in stream sediments under 30 mesh fraction (after OMRD, 1971).

intervals along the main streams, and in addition one sample was taken from each branch stream, totalling 251 samples. Inorganic materials finer than 30 mesh were selected from stream sediments as sample media for assay (OMRD, 1971).

The maximum copper values amount to 1,510 ppm, the arithmetic mean is 158 ppm and the threshold value is approximately 60 ppm. Extremely high anomalies with values over 1,000 ppm occur in the M2 valley just downstream from the ore deposit. Some anomalous copper contents in the range of 80 to 200 ppm were detected upstream in the Nasapang and Luhan valleys. Copper contents in samples from the other streams are of similar order to the regional background value. The overall distribution pattern of copper contents clearly indicates the source area of copper mineralization towards the headwaters of the M2 tributary.

Soil Geochemistry

Soil geochemical surveys were carried out in the areas of M1, M2 and Bambangan valleys and headwaters of Nasapang, Nabulau and Luhan Rivers (Fig.3). Within the area drained by the M2 tributary, which corresponds to the present open pit, soil surveys were made at 15 meter intervals on traverses 25 meters apart by the United Nations project team. Soil copper contents varied widely, reaching 15,000 ppm (1.5%) locally (Woolf *et al.*, 1966). An anomalous area with values exceeding 300 ppm copper approximately coincides with the ore deposit.

In the peripheral areas surrounding the M2 tributary, soil samples were collected at 25 to 50 meter intervals along traverses 100 to 200 meters apart by the Overseas Mineral Resources Development Company. The highest anomalous values, ranging to over 3,000 ppm, were found in soil copper contents of the M1 valley west of the M1–M2 confluence. In the area of Bambangan valley the copper anomalies were detected in a broad zone straddling the Bambangan valley, with copper values ranging up to 1,000 ppm. This anomalous zone extends over into the Quaternary gravels. Probably this is partly because there are some mineralized boulders in the Quaternary deposits and partly because there are anomalous bedrocks exposed within the Quaternary deposits caused by landslip.

A geochemical map of soil copper contents in the Mamut area was produced by linking the survey results of the United Nations prject team in the M2 tributary to those of OMRD in its environs as is shown in Fig.3. The distribution patterns of copper contents obtained from both soil and stream sediment geochemistry well define the location of the ore deposit.

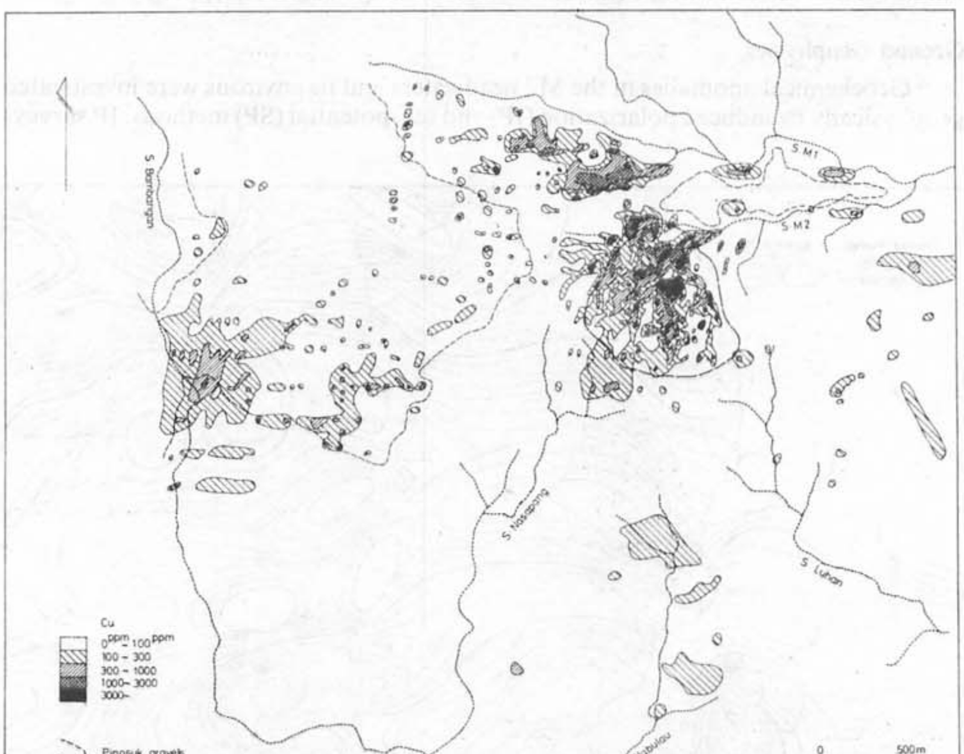


Fig. 3. Soil geochemistry map adapted from Woolf *et al* (1966) and geochemical work made by OMRD Co. Ltd.

GEOPHYSICAL SURVEYS

Airborne Geophysics

Aeromagnetic surveys were conducted on flight lines spaced one kilometer apart; directed north and south and controlled by east-west tie lines five kilometers apart. The magnetically disturbed zones correlate well with known igneous provinces. The major negative anomalies, in general, could either be correlated with ultrabasic bodies or be within the region of outcrop of chert-spilite. The acidic rocks are associated with lower amplitude anomalies than those which characterize ultrabasic rocks (Metallic Minerals Exploration Agency of Japan, 1970). The anomalies of acidic rocks are in the range of 15 to 50 gammas, whilst the ultrabasic rocks give rise to anomalies of up to 560 gammas. The Mamut porphyry is correlated with a negative anomaly of about 50 gammas (Fig.4).

The principal objective of the survey was to locate target areas for possible hidden acidic intrusions which might contain porphyry copper deposits other than the Mamut. In this respect, the survey failed to attain its objective. The magnetic data, however, have revealed a number of lithological and structural features previously unknown as well as having confirmed much of the geological mapping.

Ground Geophysics

Geochemical anomalies in the M2 headwaters and its environs were investigated geophysically by induced polarization (IP) and self-potential (SP) methods. IP surveys

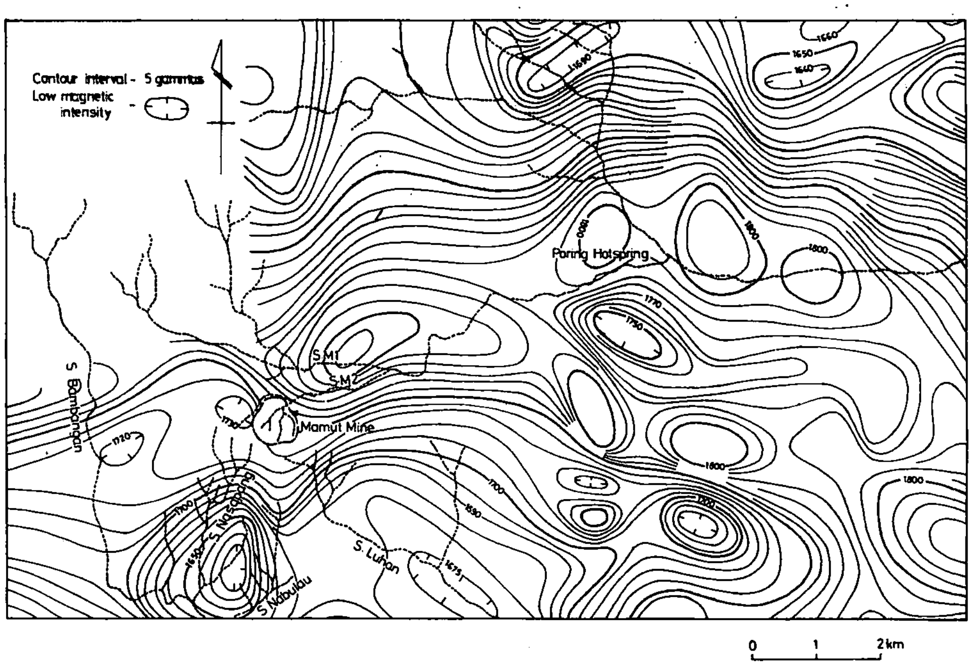


Fig. 4. Aeromagnetic survey map (after Metallic Minerals Exploration Agency of Japan, 1970).

were applied throughout the areas of geochemical anomaly. The measurements were made at an electrode separation of 50 or 100 meters along east-west traverses 100 meters apart in the M2 headwaters and 200 or 300 meters apart in the other areas. North-south traverse lines were partly filled in as occasion arose. The depth measured varied from 100 to 250 meters. SP surveys were made at 25 meter intervals along the same traverses as those of IP surveys. The measurement results were used as supplementary data for the interpretation of IP surveys. Discussions are given below in relation to frequency effect (FE) values of IP surveys as they appear to best respond to underground sulphide mineralizations concealed by overburden (Fig.5).

Strong FE responses were detected in three localities. Among them, the highest FE values were found in the Mamut ore deposit, where they were in the range of 8 to 21 percent at a depth of – 100 meters. The second highest anomalies, ranging from 6 to 16 percent of FE values, were in the Luhan headwaters contiguous to the present open pit.

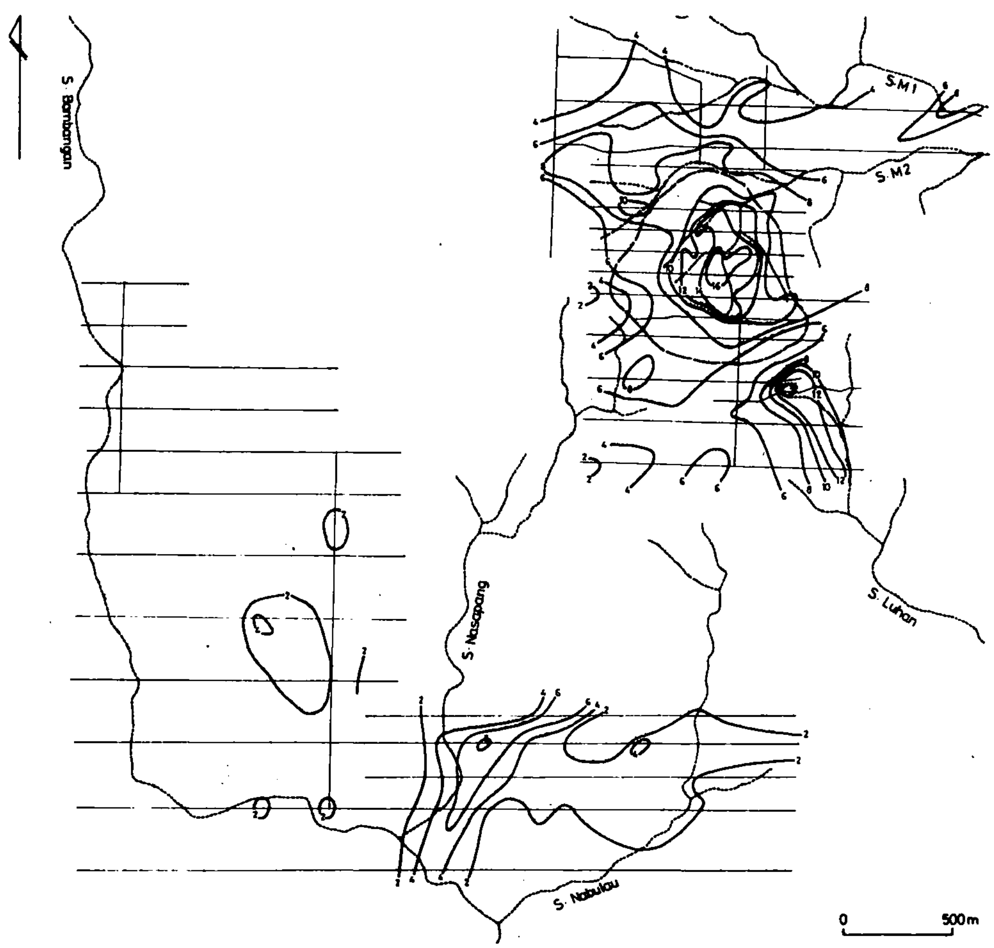


Fig. 5. Frequency effect distribution map compiled from work by OMRD Co Ltd from 1968 to 1971.

However, no pronounced geochemical anomalies of copper were discovered there. There is no satisfactory accounting for this inconsistency. Possibly this is partly because of existence of pyrite associated with microdiorite intrusions in the area. The third highest FE values occur in a north-south elongated area between the Nabulau and Nasapang tributaries. They are presumed to have a close relation to a small geochemically anomalous area with copper values exceeding 300 ppm. These geochemical and geophysical anomalies might be interpreted to result from a sulphide mineralization lying far beneath the surface, because there is a post-ore fault existing in the area where the southern block is located stratigraphically lower than in the northern block.

However, no prominent anomalous FE values were detected in the M1 and Bambangan valleys despite their strong geochemical haloes of soil copper values. Copper sulphide mineralization is deemed not to extend to depths as it has gone through weathering processes and been washed away to a considerable extent.

DIAMOND DRILLING

A diamond drilling programme was started at the M2 headwaters, based on the geological interpretation of information obtained from the various kinds of exploration described above, especially from the result of soil geochemistry. Seventy-six drill holes with a total length of 15,620 meters were sunk on a rectangular grid 50 meters apart east-west, and 100 meters apart north-south (Fig.6). Individual holes varied from 61 to 308 meters in depth and showed depths of overburden and weathered surfacial materials of up to 53 meters. Details of the original drill logs for all the holes indicate a variable core recovery with an overall average of 83%. An excellent core recovery, exceeding 90%, was obtained within the hard rock (Kiya & Namiki, 1971).

All the cores were split in half; one half for assay and the other for retention for future use. The samples were taken at every 3 meter interval and assayed for copper. One composite sample of 9 meters was prepared and assayed for gold and silver as well as for check analysis of copper.

A diamond drilling programme at the periphery of the Mamut ore deposit was implemented in parts of the Luhan, Nasapang and Bambangan to examine the geochemical and/or geophysical anomalies. Firstly, a total of 5 holes were sunk proximately to the ore deposit; three holes at the Nasapang headwaters and two holes at the Luhan headwaters to determine the southeastern and southwestern extent of copper mineralization adjacent to the Mamut ore deposit. Copper mineralization of a small amount was found in association with pyrite throughout the sections of all the holes. It was, however, not economically significant enough to warrant further diamond drilling at closer spacing. One drill hole each at Bambangan and Nasapang valleys was drilled to test the geochemical and geophysical anomalies but the results were discouraging.

GEOLOGY

Geological Setting

The regional geological setting of the Mamut area and its vicinity has been

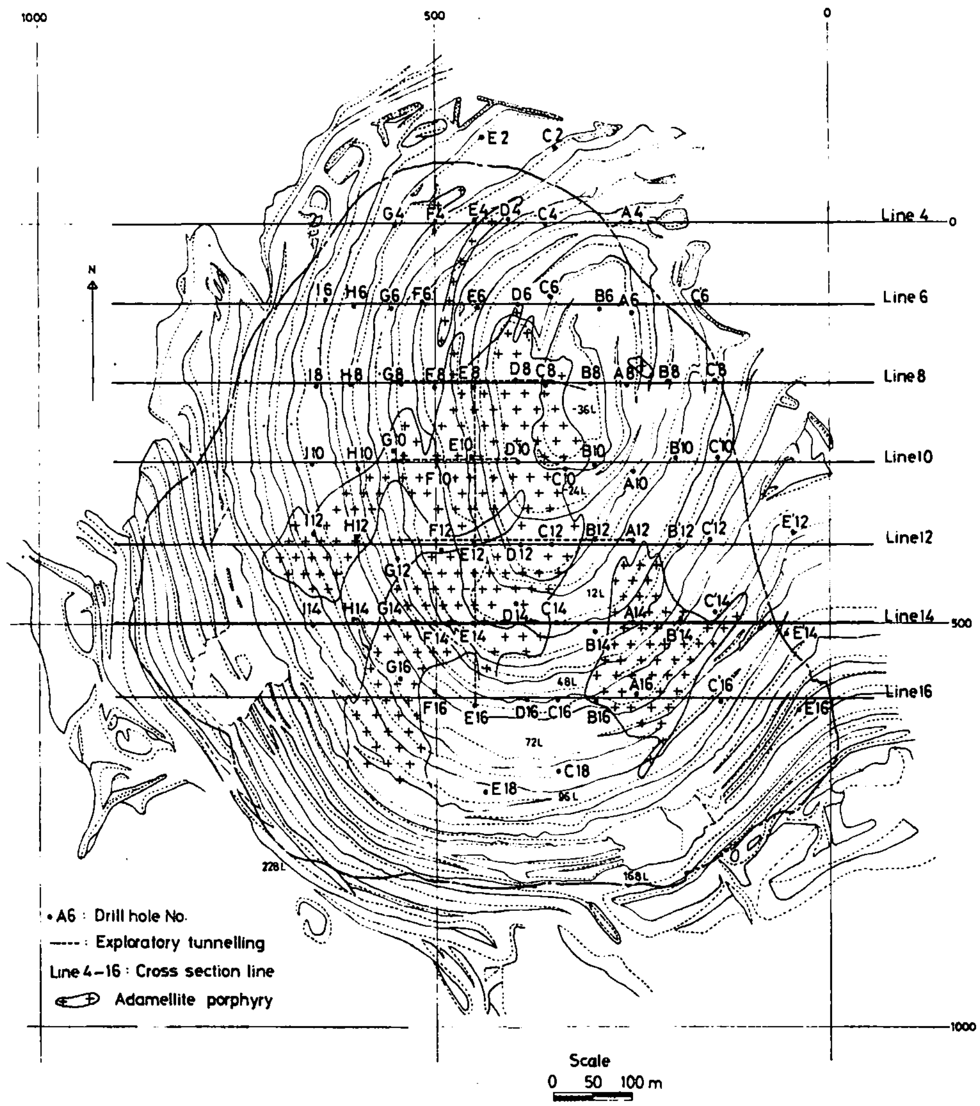


Fig. 6. Location map of diamond drilling at the Mamut deposit.

described by several workers including Collenette (1958, 1965), Hutchison (1968), Kirk (1968), Haile (1969), Kasama *et al.* (1970) and Jacobson (1970).

The geology of the Mamut area is shown in Fig. 7. The main rock sequence consists of sedimentary rocks, igneous intrusions and Quaternary gravels. Sedimentary rocks are separated into two formations. The older units, undifferentiated sedimentary and metamorphic rocks, consist of metasediments and spilitic rocks of possiblMesozoic age. These are distributed in the northern part of the

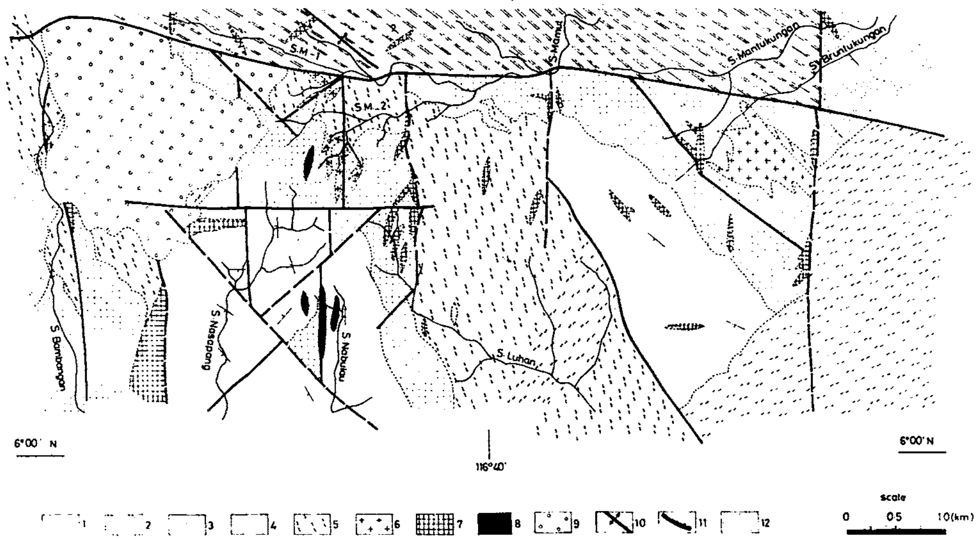


Fig. 7. Geologic map of the Mamut area (after Kosaka and Wakita, 1978).

(1) Undifferentiated sedimentary and metamorphic rocks (W)
(2) Undifferentiated sedimentary and metamorphic rocks (E)
(3) Trusmadi Formation (L)
(4) Trusmadi Formation (U)
(5) Serpentinite
(6) Adamellite porphyry
(7) Microdiorite
(8) Granodiorite porphyry
(9) Pinosuk gravels
(10) Anticline
(11) Fault
(12) Mamut Ore deposit

mine area and bounded by the younger Trusmadi Formation by a major east-west trending fault. The Trusmadi Formation of Eocene to Miocene age is subdivided into two members. The lower member comprises mainly massive sandstone with minor spilitic flows and pyroclastics in the lower horizon, and the upper member chiefly comprises massive sandstone and mudstone.

Emplaced into the Trusmadi Formation in the Mamut area are ultrabasic rocks, which were altered to serpentinite towards the mineralized area.

Some small stocks of adamellite porphyry are emplaced into the earlier rocks such as sedimentary rocks and serpentinite. Adamellite porphyry intrusives of late Miocene are thought to be responsible for copper and gold mineralization.

In the western part of the area are distributed the Quaternary boulders of the Pinosuk Gravels, largely derived from granitic rocks of Mt. Kinabalu. These are regarded as tilloid deposits which are poorly consolidated and preserved on the flanks of Mt Kinabalu (Jacobson, 1970).

Mineralization and Alteration

The geology and mineralization of the Mamut deposit has been summarized by Newton-Smith (1977), Lim (1974), Kosaka and Wakita (1975, 1978) and Wakita (1981). The geological data gained during exploration, development and operations enabled them to describe the geological structure, mineralization and alteration of the Mamut area in detail.

The Mamut deposit has a predominantly north-south orientation, aligned with a major fault system. The mineralization is bounded by east-west trending post-ore faults to the north and south, whereas in the east and west direction the mineralization decreases in intensity away from the adamellite porphyry intrusions.

Primary mineralization of the Mamut deposit comprises pyrite, chalcopyrite and pyrrhotite with a minor amount of sphalerite, galena, molybdenite, gold and silver. These minerals occur as disseminations and fracture veinings throughout the host rocks such as adamellite porphyry, serpentinite and siltstone of the Trusmadi Formation. Principal minerals identified from the zones of oxidation and secondary enrichment include limonite, chalcocite, malachite, azurite, covellite, bornite, cuprite and native copper. Although the effect of oxidation is confined to shallow depths (30 to 40 meters from the original surface), its distribution and intensity are controlled by the original topography and the position of the water table. The secondarily enriched zone with a thickness of 10 to 15 meters occurs to a lesser extent below the poorly leached cap. The copper content of the secondarily enriched zone is often upgraded over 1.5 % locally, particularly where sooty chalcocite is abundant as a supergene sulphide.

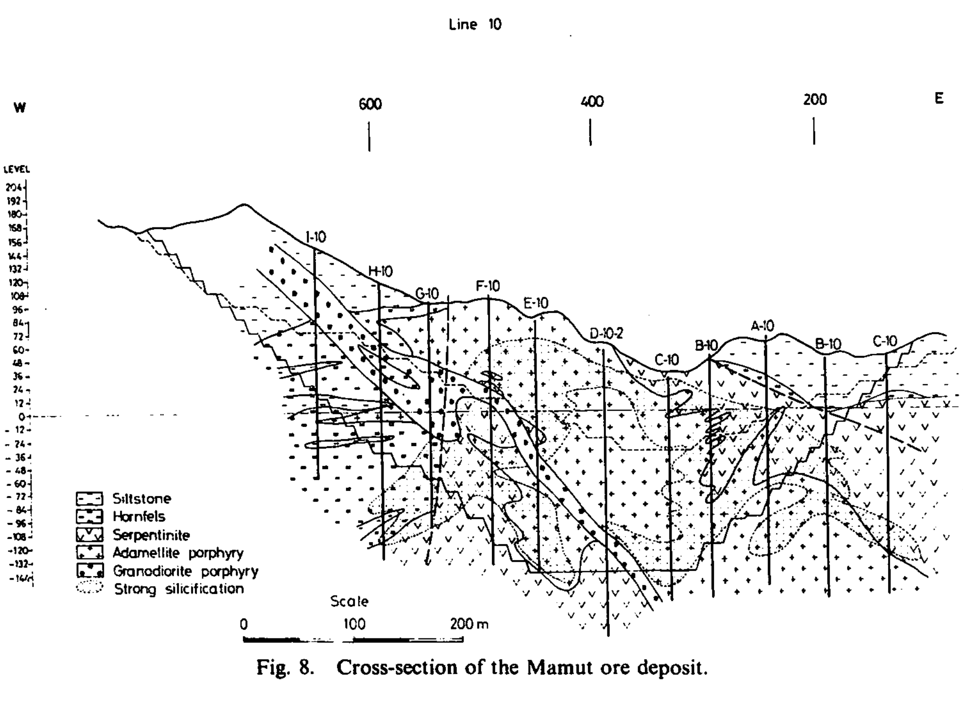


Fig. 8. Cross-section of the Mamut ore deposit.

Diamond drill hole information delineates the zones of intense silicification distributed predominantly close to intrusive contacts between adamellite porphyry and intruded rocks such as serpentinite and siltstone (Fig.8). Silicification gradually decreases in intensity away from the intrusive contacts towards the inside of country rocks and the centre of adamellite porphyry as well, consequently taking the shape of an ore shell around the major adamellite porphyry. Those zones of silicification are thicker in the upper portion of an ore shell than in the bottom. The best copper and gold mineralization is largely conformable with the strongly slilcified zones, where the grades of copper and gold reach approximately 1.0% and 1.5g/t respectively.

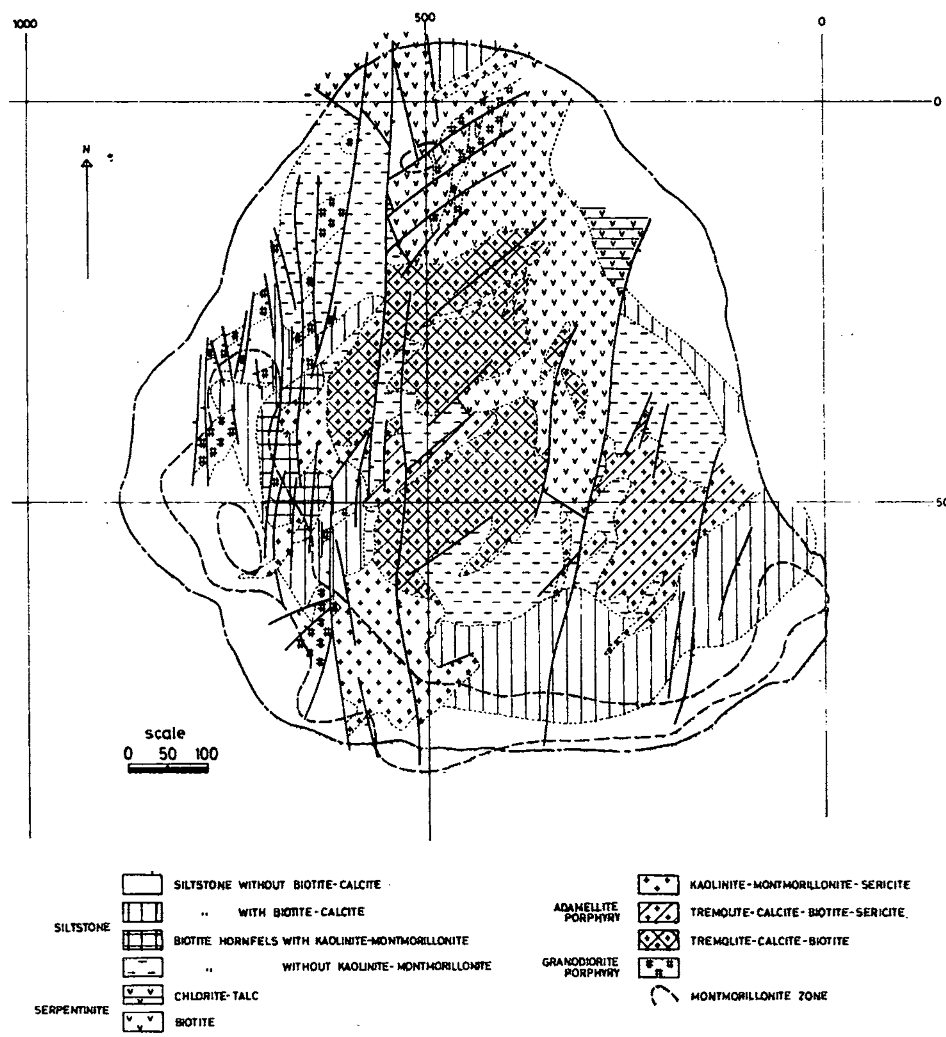


Fig. 9. Geology and alteration map of the Mamut ore deposit.

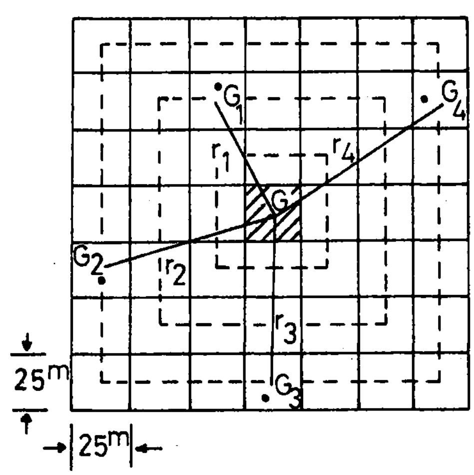
Subsequent development and excavation have revealed the geology and alteration of the Mamut deposit. Several major types of alteration have been recognized by X-ray diffraction analysis and routine geological mapping in each wall-rock type as shown in Fig. 9.

EVALUATION AND DEVELOPMENT OF THE ORE DEPOSIT

Ore Reserve Calculation Method

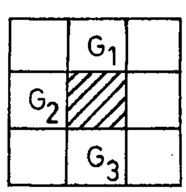
The ore reserves were calculated from the assay values of core samples, using a computer technique. The ore body was divided into three dimensional ore blocks, with a size of 25 meter square and 12 meter depth. From the assay contour of copper grades obtained from the drill hole data, a trend surface of copper mineralization was defined geomorphologically whereby copper grade distribution showed a similar tendency with a strike of N 30 °E and a dip of 35 ° to 45 ° to the southeast (trend adjustment). The objective of this process was to interpolate copper values into ore blocks which did not

PRINCIPAL INTERPOLATION



$$G = \frac{\sum_n G_n \left(\frac{1}{r_n}\right)^4}{\sum_n \left(\frac{1}{r_n}\right)^4}$$

SUBSIDIARY INTERPOLATION



$$G = \frac{G_1 + G_2 + G_3}{3}$$

Fig. 10. Interpolation procedures of ore reserve calculation.

contain drill hole values. The copper grade of each ore block was determined through the following process (Fig.10).

The copper grade in a block which was penetrated by a drill hole was given from the arithmetic mean of the copper values of drill core samples (a basic block). The copper grade in an ore block without drill hole values was interpolated from the grades of at least three drill hole intersections within a distance of a third of the surrounding blocks on the same trend surface described above. The influence of surrounding drill hole values on the block to be interpolated was expressed by an inversely proportional function to the fourth power of the distance from the basic blocks (a principal interpolation block). The copper grade in an ore block, which remained uninterpolated in such a way, was determined by taking the arithmetic average of the adjoining ore blocks containing drill holes and interpolated values (a subsidiary interpolation block). A minimum of three adjoining blocks containing values was required for this subsidiary interpolation.

Ore Reserves and Pit Design

The total ore reserves of the deposit were defined in the above described manner as the total number of blocks with a grade above 0.20 % Cu. The tonnage was calculated as 178,747 thousand tonnes with an average copper grade of 0.476 %, using a specific gravity of 2.7 (Table 1). Within the orebody, as indicated by drill holes, the copper sulphides are associated approximately 47 percent with adamellite porphyry, 29 percent with serpentinite, 21 percent with siltstone or biotite hornfels (altered siltstone) and 3 percent with granodiorite porphyry.

The results of diamond drilling and ore reserve estimation allowed the optimum selection of the pit design for mining operations, using a computer modelling

TABLE 1

ROCK TYPE PERCENTAGE AND ORE RESERVES

	Whole length 75 holes Total length 15,559 m		Within the pit 60holes Total length 5,928 m	
	Length ratio (%)	Cu (%)	Length ratio (%)	Cu (%)
Adamellite porphyry	47	0.49	53	0.63
Serpentinite	29	0.37	23	0.61
Siltstone	21	0.43	10	0.52
Hornfels			14	0.60
Granodiorite porphyry	3	0.13	—	—
Total	100	0.43	100	0.61
Ore reserves	Total ore reserves Cut off Cu : 0.20% Ore : 178,747 th T Cu : 0.476 %		Minable ore reserves Cut off Cu : 0.35% Ore : 83,160 th T Cu : 0.590 %	

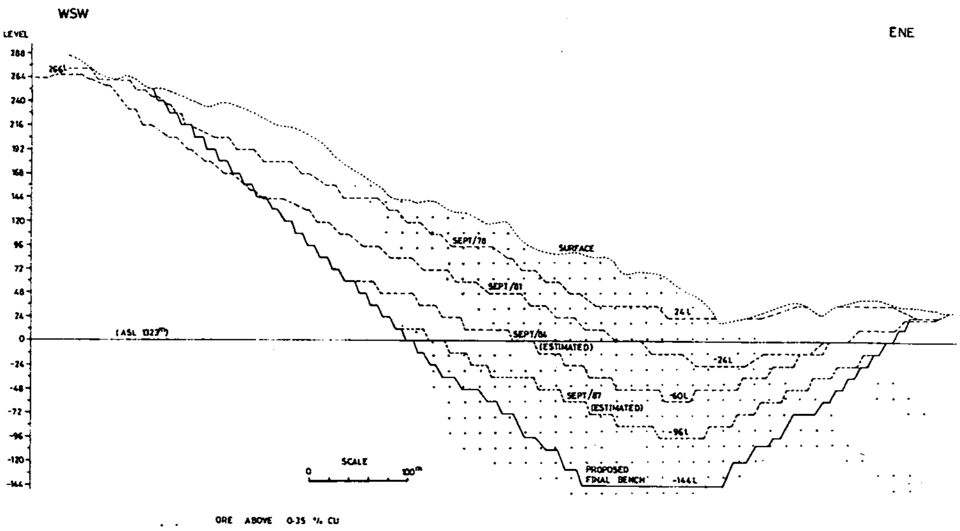


Fig. 11. Cross-section of the proposed final pit design and mineralized area above 0.35 % Cu estimated from drill hole data.

technique. Pit design studies were undertaken to identify the most economic ultimate open pit, taking into account the various fundamental factors, such as copper grades, a ratio of waste to ore and minable ore reserves. The selected pit design has its bottom level at the −144 meter level, which is equivalent to 1,179 meters above sea level, and the topmost level is the 276 meter level, that is 1,599 meters above sea level. The bench height is 12 meters and an angle of 45° was determined as the maximum final slope of the pit wall (Fig.11).

After the completion of the final pit design, the total minable ore reserves within the selected pit design were calculated as 83,160 thousand tonnes with an average copper grade of 0.59% and a cut off grade of 0.35%. The ore deposit consists of four major rock types, where the grade, alteration patterns, lithologic features and resultant mineral processing characteristics can differ significantly. Within the proposed ultimate pit design, the total minable ore reserves as estimated from the original drill hole data comprise 53 percent adamellite porphyry, 23 percent serpentinite, 14 percent hornfels and 10 percent siltstone (Table 1).

From the result of ore reserve calculation, an example of ore reserve cross-section is shown in grade ranks assigned to ore blocks along a north-south grid line (Fig.12). Ore is distributed from the 168 level down to the −144 level according to the result of the ore reserve calculation. The minable ore reserve tonnage above 0.35% Cu and the waste tonnage below 0.34% Cu are indicated in Fig. 13, where the cross-hatched area represents the ore tonnage mined and the hatched area represents the waste tonnage mined respectively.

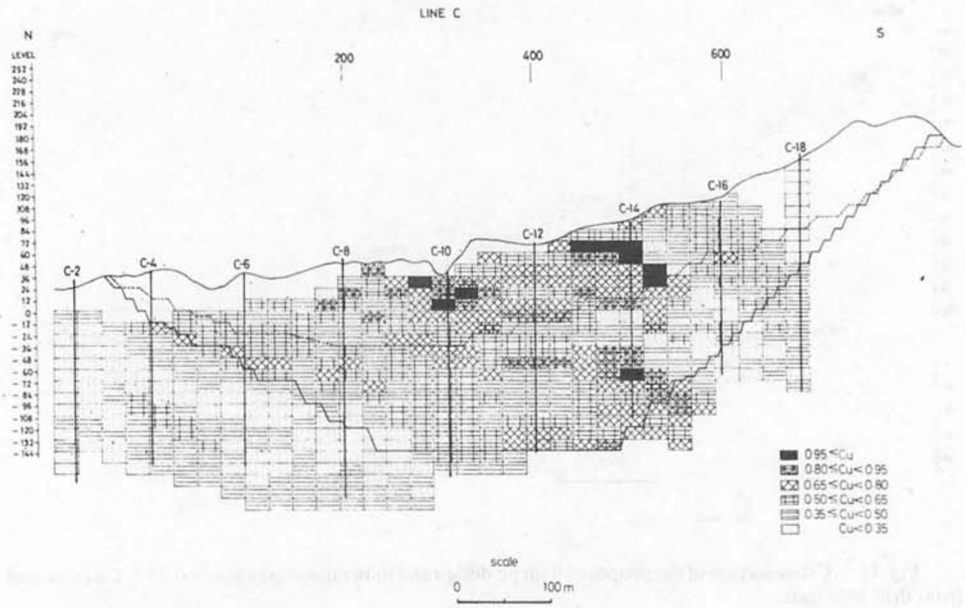


Fig. 12. Cross-section of ore reserve estimation showing copper grade distribution along a north-south grid line of drill holes.

DISCUSSION AND SUMMARY

A history of the Mamut mine, through the stages of prospecting up to evaluation and development, has been fully reviewed here. The copper prospects at Mamut and its vicinity have been discussed from various viewpoints such as geological setting and the results of geochemical and geophysical surveys. The experience obtained through a series of exploration works indicated that a system of detailed grid soil geochemistry and IP geophysics, preceded by reconnaissance stream sediment surveys, were essential to define a target area for evaluation drill holes. It was evidenced by grid drilling and subsequent development of the ore deposit that the best copper mineralization was located by the most intense anomalies of both soil geochemical and IP surveys. The ore deposit lies approximately within the area above 300 ppm of soil copper content and above 10% of frequency effect.

The above-described optimum methods and procedure of exploration and geological data gained through the subsequent exploitation and operations of the Mamut mine have led to the establishment of ore target criteria for use in further exploration of a porphyry copper deposit in this region. The important factors to be taken into consideration in exploration for a mineral deposit of this type include not only the geological and mineralogical characteristics but also the alteration patterns as well as geochemical and geophysical anomalies.

In the environs of the Mamut mine further detailed investigation has to be carried out in a couple of areas, which are known to offer potential for additional ore reserves

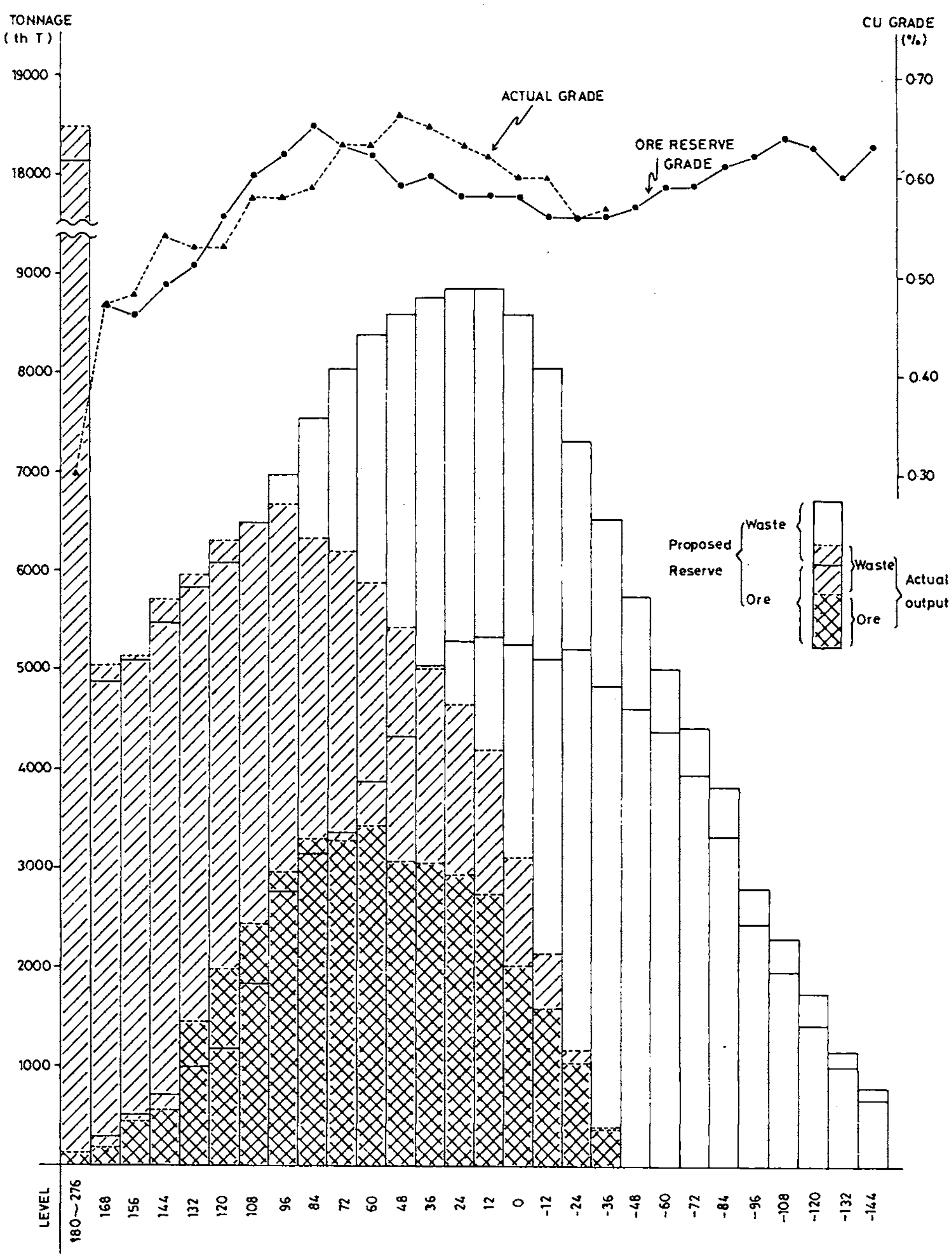


Fig. 13. Variation histogram showing ore reserve tonnage and grade with a cut-off grade of 0.35 % Cu and waste tonnage at each level. The cross-hatched area represents the ore tonnage mined and the hatched area represents the waste tonnage mined as of the end of November 1982.

or to indicate some mineral showings. Particularly the M1 area, which is considered to be a northern continuation of the Mamut deposit, has the most promising potential for economical viability. Although no intense IP responses were obtained from the M1 area, a significant soil geochemical halo accompanied by an advanced alteration of serpentinite exists over the area (Bishimetal Exploration Co., 1981). This strongly suggests the existence of supergene-enriched copper mineralization. Copper sulphide mineralization in the M1 area, however, is considered not to extend to depths because it is located stratigraphically in a horizon higher than its original position due to the post-ore uplift along the major fault trending east-west.

At the area between the Nabulau and Nasapang valleys where the third highest FE values and weak geochemical anomalies were found near the poorly mineralized granodiorite porphyry dykes, sulphide mineralization could possibly be displaced to a deeper position than that of the Mamut deposit.

The Bambangan area, which has a similar geological setting to the Mamut deposit, contains geochemical anomalies and some outcrops of weakly mineralized adamellite porphyry associated with serpentinite and siltstone. But results of IP surveys undertaken in the area were not encouraging, although IP surveys have not covered the whole Bambangan valley. In particular the area concealed by the thick blanket of the Quaternary Pinosuk gravels could not be surveyed.

In the areas of Nabulau and Bambangan valleys, there remain some unknown factors yet to be further investigated with regard to geological structure and wall-rock alteration. The M1 area could be developed and put into production by expanding the existing pit limit towards the north and incorporating the area into present operations if economically minable ore reserves could be discovered there.

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REFERENCES

BISHIMETAL EXPLORATION CO., LTD., 1981. *Report on a geological study of the S Mamut-1 area.* 1–19 (unpublished).

COLLENETTE, P., 1958. The geology and mineral resources of the Jesselton-Kinabalu area, North Borneo. Brit. Borneo Geol. Survey Mem. 6, 1–194.

COLLENETTE, P., 1965. The geology and mineral resources of the Pensiangan and upper Kinabatangan area, Sabah, Malaysia. Borneo Reg. Malaysia Geol. Survey Mem. 12, 1–150.

COOPER, R.A., WOOLF, D.L., and TOOMS, J.S., 1965. A geochemical reconnaissance survey of part of the Labuk Valley, Sabah. Borneo Reg. Malaysia Geol. Survey Ann. Rept. for 1964, 176–185.

FITCH, F.H., 1958. The geology and mineral resources of the Sandakan area, North Borneo. Brit. Borneo Geol. Survey Mem. 9, 1–202.

HAILE, N.S., 1969. Geosynclinal theory and the organizational pattern of the northwest Borneo geosyncline. *Geol. Soc. London Quart. Jour.*, v.124, 171–194.

HUTCHISON, C.S. 1968. Tectogene hypothesis applied to the pre-Tertiary of Sabah and the Philippines. *Geol. Soc. Malaysia Bull.*, no.1. 65–79.

JACOBSON, G., 1970. Gunong Kinabalu area, Sabah, Malaysia. Geol. Survey Malaysia Rept. 8, 1–111.

KASAMA, T., AKIMOTO, H, HADA, S., and JACOBSON, G., 1970. Geology of the Mount Kinabalu area, Sabah, Malaysia. *Jour. Geoscience Osaka City Univ.*, V.13, no. 16, 113–148.

KIRK, H.J.C., 1967. The Mamut copper prospect, Kinabalu, Sabah. Borneo Reg. Malaysia Geol. Survey Bull. 8, 68–80.

KIRK, H.J.C., 1968. The igneous rocks of Sarawak and Sabah. Borneo Reg. Malaysia Geol. Survey Bull. 5, 1–210.

KIYA, Y., and NAMIKI, K., 1971. Diamond drilling in the Mamut mine. *Mining Geol.*, v.21, 179–185 (in Japanese with English abstract).

KOSAKA, H., and WAKITA, K., 1975. Geology and mineralization of the Mamut mine, Sabah, Malaysia. *Mining Geol.*, v.25, 303–320 (in Japanese with English abstract).

KOSAKA, H., and WAKITA, K., 1978. Some geologic features of the Mamut porphyry copper deposit, Sabah, Malaysia. *Econ. Geol.*, v.73, 618–627.

LIM, P.S., 1974. *Geology and copper mineralization of the Mamut area, Sabah, East Malaysia.* B. Sc. (Hons) thesis, Univ. Malaya, 1–117.

METALLIC MINERALS EXPLORATION AGENCY OF JAPAN, 1970. *Aeromagnetic survey of the Kinabalu-Tambuyukon area, Sabah, Malaysia.* Part one, 1–28 (unpublished).

NAKAMURA T., MIYAKE T., KANAO N., and TOMIZAWA N., 1970. Exploration and prospecting in the Mamut mine, Sabah, Malaysia. *Mining Geol.*, v.20; 106–133 (in Japanese with English abstract).

NEWTON-SMITH, J., 1966. Geology and copper mineralization in the Mamut River area, Kinabalu. Borneo Reg. Malaysia Geol. Survey Ann. Rept. for 1965, 88–96.

NEWTON-SMITH., J., 1977. Geology and mineralization at the Mamut Copper Prospect, Sabah. Malaysia Geol. Survey, Geol. Papers Vol. 2, 55–65.

OMRD CO., LTD., 1970. *Report on prospecting survey in Mamut prospecting Licence area. 1–11 (unpublished).*

OMRD CO., LTD., 1971. *Surveyed report in prospecting licence qrea around Mamut, Sabah. 1–11 (unpublished).*

WAKITA, K., 1981. The alteration and mineralisation of serpentinite of the Mamut porphyry copper deposit. *Mining Geol.*, v.31, 351–365.

WONG, N.P.Y., 1967. Geology and copper mineralization of the Bambangan Valley, Kinabalu, Sabah. Borneo Reg. Malaysia Geol. Survey Bull. 8, 81–88.

WOOLF, D.L., TOOMS, J.S, and KIRK, H.J.C, 1966. Geochemical survey in the Labuk Valley, Sabah. Borneo Reg. Malaysia Geol. Survey Ann. Rept. for 1965, 212–226.

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