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THE COPPER DEPOSIT OF BATU MARUPA IN CENTRAL SULAWESI, INDONESIA

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The authors give in this paper the tectonic framework of the island Sulawesi (Celebes) as well as the results of field and laboratory researches into the copper deposit of Batu Marupa (Sang- karopi) in the central part of the island.

Ključne riječi: Oblici bakarnih rudnih tijela, mineralni sastav, mikrofiziografija, postanak ležišta

Autori daju u ovom radu tektonsku građu otoka Sulawesi (Celebes) kao i rezultate terenskih i laboratorijskih istraživanja bakarnog ležišta Batu Marupa (Sangkaropi) u središnjem dijelu otoka.

The tectonic framework of Sulawesi

Plate tectonic models of the Indonesian Archipelago have been constructed by Hamilton (1970, 1973) and Katili (1971, 1973). According to Katili (1973) a double volcanic-plutonic arc with opposing Benioff zones existed during Permian and Cretaceous times in this area. The Tertiary Sunda-Banda east-west trending arc had its origin in a spreading centre situated in the Indian Ocean, while the north-south trending Sulawesi-Mindanao arc-trench system was generated by a spreading centre situated in the Pacific Ocean. The Sulawesi and Halmahera arcs came into existence in the early and late Tertiary period when the Pacific Plate changed its movement to a westnorthwest direction.

Katili (1978) explains the special, bizzare form of the islands Sulawesi and Halmahera (fig. 1.) by the following view: »The continuous northward movement of the Indian Ocean Plate and the westward thrust of the Pacific Plate along the Sorong Transform Fault, accompanied by the counter-clockwise movement of New Guinea, have produced complicated tectonic structures such as the K-shaped form of Sulawesi and Halmahera, bending the Banda arc westward and pushing Sulawesi and Halmahera towards the Asian continent, as well as the opening of the Makassar Strait«. This happened during the Miocene time 19–13 m.y. B. P., on the basis of palaeomagnetic studies.

The Sulawesi-Mindanao volcanic-plutonic arc, striking perpendicularly to the Banda arc extends from western Sulawesi to Mindanao and it is characterized by granites and volcanics that have been radiometrically dated: granites 3,35–31,0 m.y.; volcanites 4,25–17,8 m.y. B. P. The Tertiary Sulawesi subduction zone follows eastern Sulawesi, the Talaud Ridge and the submarine Mayu Ridge. It is characterized by the presence of ophiolites or mèlange in the island (Katili, 1974).

Mineralization

Eastern and south-eastern Sulawesi contains abundant lateritic nickel deposits in the ophiolite complex: Larona, Soroako, and Pomalaa. In ophiolite Acoje, in Latau there are also nickel and platinum sulphides. All these deposits originate from a subduction zone generated by the Pacific Ocean. They are related to collision zones and transform faults.

The western arc of Sulawesi is characterized by copper-silver-gold porphyry doposits occurring in an area where the underlying crust is oceanic in nature and is characterized by a steeply dipping Benioff zone (Katili, 1984).

Porphyry prospects are Tap, Tomb, Malala (with Mo) in the Gorontalo area, northern arm of Sulawesi; Sassak is in the central part of the island.

The copper deposit of Batu Marupa

The mineralized area is situated some 35–40 km north of Makale, which is the administrative centre of the Tana Toradja Province, some 60 km northwest of Polopo port, in the gulf of Bone. Makale is connected with Padang, the capital of the island by a road 350 km in length. The ore deposits are connected by a road to Polopo port.

In North Toradja there are three copper deposists: Batu Marupa (Singkaropi), Mariri and Talimbangan, exploited during World War II by the Japaneses or prepared for exploitation. According to Van Bemmelen (1949) Talimbangan is an iron-ore deposit.

The exploitation of copper ore during World War II was most intensive on the ore deposit of Batu Marupa. The Japanese constructed an access road, leading to the mine, and they also erected some primitive smelting plants, but on retreating, they destroyed them again. According to information obtained from the local population, the Japanese used to convey to Polopo port 2–3 trucks of selected ore daily, i.e. 10–15 tons of ore

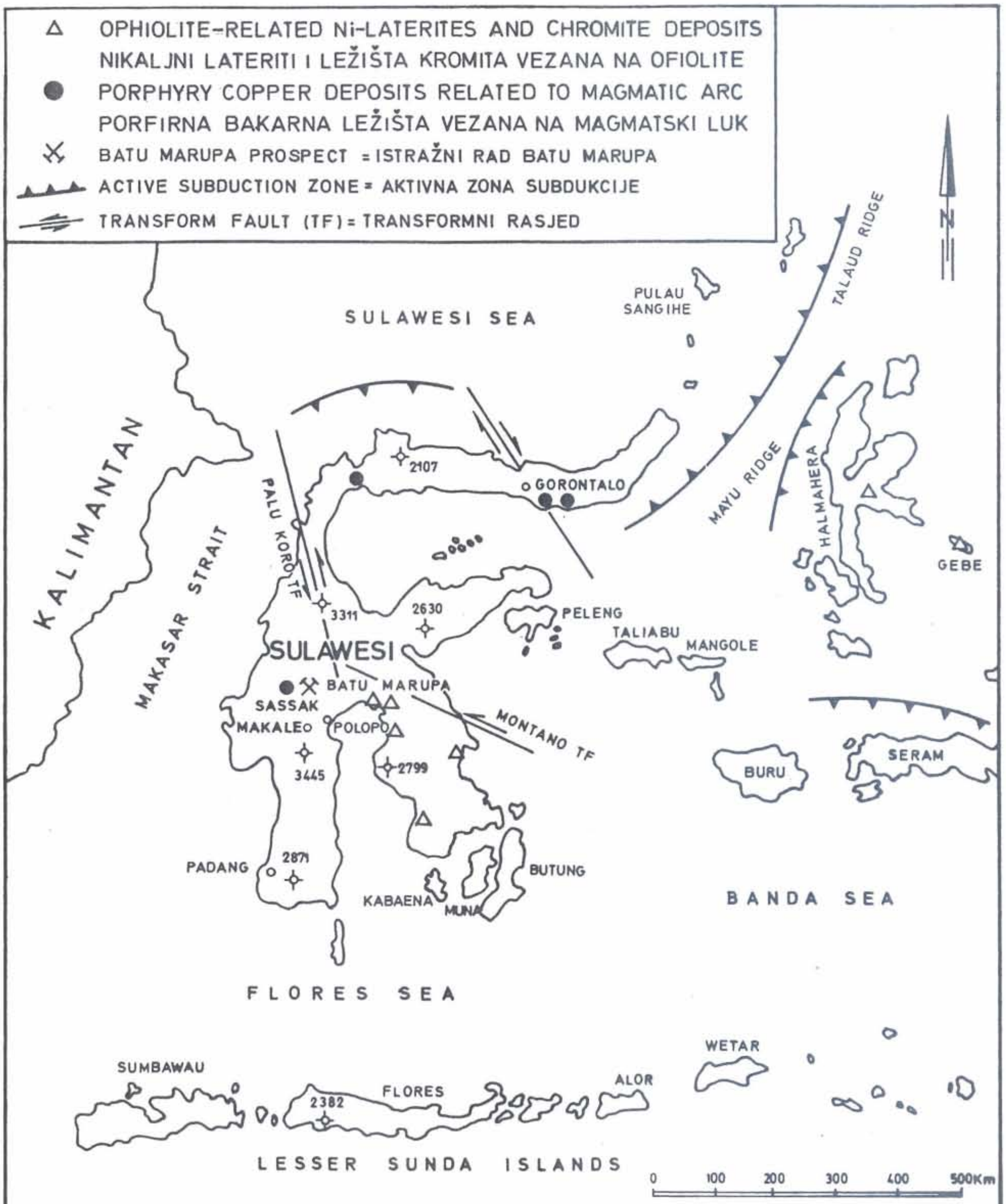

Fig. (Sl.) 1 LOCATION OF BATU MARUPA PROSPECT
POLOŽAJ LEŽIŠTA BATU MARUPA

with 3–5% of Cu. The Mariri deposit, situated about 5 km northwest of Batu Marupa is a somewhat smaller one. The ore of the same type, but on a smaller scale, was extracted and the ore from this deposit was transported in quantity to Singkaropi. The ore deposit of Talimbangan is situated farther from Mariri. According to information obtained from the local population, the Japanese were assuming that the ore deposit of Talimbangan is larger and of greater economic value than that of Batu Marupa, and so they had undertaken the construction of a 40 km long road and started to open and develop the mine, but the interruption of the war had prevented them from realizing their plans further.

The author (B. Zalokar) visited and examined only the Batu Marupa deposit, the other two deposits were inaccessible at the time of his visit.

The ore deposit of Batu Marupa is situated on the southern slopes of the volcanic domes of Popomalangi (+ 1242 m) and Bidong Pangpano (+ 1250 m) which are prominently elevated among the surrounding hills and mountains by their morphology. The highest of the mountain peaks is Bidong

Lepong (+ 1580 m) The ore occurrences are encountered at an altitude of 1100–1200 m.

The broader area of the ore deposit is composed of magmatic rocks ranging from acid and intermediary to basic volcanic rocks. The hydrothermal alteration processes, preceding direct mineralization, had affected vast areas and had been very intensive, so that the immediately surrounding rocks have remained almost entirely altered. The three rock specimens analysed by Prof. V. Majer (University of Zagreb) showed as follows: the firs rock specimen shows a completely altered rock with rounded, corroded crystals of quartz, which indicates that the original rock belongs to the group of dacites. The second rock specimen shows an obvious porphyry structure. The predominant phenocrysts are the plagioclases, polysynthetically twinned. They have columnar or lath-like forms. Members ranging from basic andesine to labradorite were dealt with on the basis of their index of refraction. Some of the scarce salic phenocrysts belong to sanidine. The coloured minerals are considerably scarcer, the most frequent among them being pseudomorphoses of uralitized amphibole after pyroxene. The matrix of this rock is holocrystalline, composed of columnar plagioclase and laths and leaves of amphibole, some chlorite, while magnetite and devitrified volcanic glass are subordinate constituents. The third rock specimen represents a rock of indistinct porphyry structure that was promoted by the general reduction of the size of the phenocrysts, so that the amount of them in the matrix has become comparatively small. The main phenocrysts are polysyntheticaly twinned and they belong to andesine by their refraction index, or to more basic members. As phenocrysts, there is augite besides plagioclase (the angle of extinction is about 40°). Magnetite occurs as an accessory mineral. Kaolin substance, some uralite and chlorite are the supergene products. In the druses, there are low-temperature albite and chalcedony. The rocks in the immediate surroundings of the ore deposit, as well as in the sterile portions within the ore bodies, are almost entirely silicified; besides small to fine-grained quartz and chalcedony there is, sporadically, some clayey substance.

Further away from the ore bodies, the rocks are also entirely altered, but there are, besides aggregates of fine and small-grained quartz, rarely coarse-grained quartz, as a product of silicification, two other silicate minerals not precisely identified, developed as products of hydrothermal alteration.

Forms of the ore bodies

The ore bodies are developed in the form of small or large lenses, inside a completely altered intermediary subvolcanic rock. Some ten ore bodies, viz. ore outcrops, were known down to 1962. The largest in size among them is an ore body, some 60–70 m in length, and about 15–18 m wide. The other ore bodies, viz. their outcrops, are considerably smaller in size, but the works formerly carried out by the Japanese during the World War II did not have the character of exploration work, and their activities were concentrated on the exploitation of the largest ore body. There is no access via the old adits, for they are partly caved in and destroyed.

Paragenesis of the ore samples

A great number of the ore specimens were taken from the old ore dump comprisig some 2500–3000 tons of hand-picked ore. Macroscopically, it may be seen that three types of ore are dominant in that area: the yellow type in which chalcopyrite prevails among the copper minerals, the black type with chalcocite and small-grained sphalerite prevailing, and the impregnation type with pyrite in intensively silicified mother rock. Detailed microscopical study carried out by I. Jurković has established the following parageneses:

A. Yellov ore (named »oko ore« by Japanese miners)

Hypogene minerals: pyrrhotite, pyrite, chalcopyrite as main ore minerals, further tetrahedrite, sphalerite, galena, chalcocite, neodigenite, enargite as accessories.

Pyrrhotite and pyrite are the oldest minerals in this paragenesis. Pyrite is strongly resorbed and cataclased, being replaced by younger minerals along cataclases, especially by chalcopyrite. Chalcopyrite replaces pyrite frontally, along the interstices so that only some sporadic »island« structures are noticed, developed by the replacement of pyrite. In some of the specimens pyrite is more abundant than chalcopyrite, while in others the situation is quite the reverse. Pyrrhotite is as old as pyrite, or even older, occurring in scarce irregular masses. The presence of this mineral indicates that the beginning of mineralization was in the katathermal stage.

Chalcopyrite is very abundant, even the most abundant mineral of the ore paragenesis. It replaces pyrite, and contains exolutions of sphalerite, and inclusions of galena and tetrahedrite. In some places it is smallgrained, but mostly coarse-grained and lamellar. It is also affected by cataclasis, similarly to pyrite.

Sphalerite occurs as very small exsolutions in chalcopyrite, and galena as fine inclusions in chalcopyrite.

Tetrahedrite is intimately intergrown with chalcopyrite, occurring in somewhat larger amounts than sphalerite. It occurs sporadically in small masses, almost completely replacing chalcopyrite.

Enargite was noticed in the form of small masses intergrown with chalcopyrite. It is a relatively rare mineral in the paragenesis. Chalcocite and neodigenite are rare minerals in the investigated polished sections.

Goethite, lepidocrocite, malachite, azurite, low-temperature chalcocite, covellite occur as hypergene minerals.

B. Black ore (named »Kuroko ore« by Japanese miners)

Hypogene minerals: pyrite, sphalerite, tetrahedrite as main ore minerals, further chalcopyrite, chalcocite and galena as accessory minerals.

Pyrite is the oldest among the ore minerals. In some places it is very abundant. It occurs usually in the form of regular colloidal spherules or droplets, either aggregated to colonies or to irregular masses of various size. These spherules and droplets of pyrite manifest a concentrically banded structure. If developed in the form of metacrysts, it is to a great extent replaced by tetrahedrite and chalcopyrite, so that only some relicts are left.

Sphalerite is relativery abundant in some of the polished sections, containing extraordinarily dense chalcopyrite exsolutions of microscopic size in the form of lamellae and discs. In addition to chalcopyrite there are large amounts of colloidally formed pyrite. Besides the exsolutions in the sphalerite mass, replacing of chalcopyrite was also observed along the boundaries of grains, i.e. along the fissures or the boundaries between quartz and sphalerite.

Tetrahedrite is the main ore mineral in some of the specimens, mainly replacing pyrite and chalcopyrite. Its basic characteristics are the high degree of fine-porous structure with inclusions of quartz, and also of galena and chalcopyrite. Its structure is zonar, certainly as a result of abrupt cooling. As various tints are noticed microscopically, it may be assumed that it contains isomorphically some other different metals.

Chalcopyrite I occurs as exsolutions in sphalerite, chalcopyrite II replaces sphalerite and pyrite and is itself replaced by tetrahedrite.

Chalcocite and galena are accessory minerals.

Goethite, lepidocrocite, malachite are the most abundant among the hypergene minrals.

C. Impregnation type of mineralization

This type of ore was named by the Japanese miners »keiko ore«. It occurs in the more or less intensively silicified mother rocks, consisting of pyrite impregnations with a very scarce presence of other minerals.

Gangue minerals

The main gangue minerals of these three types of ores are quartz and kaolinite. Silicification is extremely strong and quartz is therefore the dominant gangue mineral.

General paragenetic characteristics

The main ore minerals in the »yellow ore« as well as in the »black ore« are characterized by the fact that they are either full of inclusions and intimately intergrown with the accessory minerals, or they are full of submicroscopic and microscopic exsolutions, expressing typical colloidal textures (which applies especially to the »black ore«). All these phenomena indicate that the mineralization took place in shallow subvolcanic levels with an abrupt fall of temperature and pressure. The occurrence of colloidal textures as well as the intimate intergrown of the main ore minerals with the accessory ore minerals indicates a comparatively great concentrations of metal components in the mineral solutions.

The ore deposit may be genetically determined as a hydrothermal subvolcanic deposit, related to intermediate effusive magmatic activity.

Discussion

Westerveld (1952) stated that the western arc of Sulawesi is characterized by the Middle Miocene Sunda Orogen, while the Eastern Sulawesi contains deposits related to the Late Cretaceous to Middle Miocene Molucass Orogen. According to Stanton (1972) a fundamental connection exists between porphyry copper deposits and volcanic arc structures; deposits of this type are most likely to be formed in the more mature portions of modern volcanic arcs. Katili (1974) interpreted the geology and mineralization by means of the plate tectonic theory. He distinguished mineralization in western Indonesia from that in eastern Indonesia, the first being related to the spreading centre of the Indian Ocean and the latter generated by the spreading of the Pacific Ocean. The Tertiary mineralization in Sulawesi and in other group of islands in eastern Indonesia is more important in comparison to the Sumatra-Lesser Sunda Islands, due to the fact that the crustal elements generated by the Pacific Ocean spreading centre are apparently richer in metals than those of the Indian Ocean. Occurrences of porphyry copper in northern and central Sulawesi demonstrate that this volcanic-plutonic arc of Pacific origin is rich in copper mineralization. Differences in the composition of the mantle beneath the spreading centres of the Indian Ocean and the Pacific Ocean are responsible for differences in mineralization in western and eastern Indonesia. Taylor and Hutchison (1978) emphasized that the group of South-East Asia copper deposits is related spatially and genetically to rocks generated in ocean basins or island arcs. Authors of this paper (1989) gathered from recent literature different opinions concerning the interpretation of this phenomenon.

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Bakarno ležište Batu Marupa u središnjem Sulawesi-u, Indonezija

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Kretanjem indijske ploče prema sjeveru i navlačenjem pacifičke ploče uzduž Sorong transformnog rasjeda prema zapadu, uz istodobnu rotaciju otoka Nove Gvineje suprotno kretanju kazaljki na satu, uzrokovali su po Katili-u (1978) kompliciranu tektonsku strukturu i bizaran oblik u vidu slova »K« otoka Sulawesi (Celebes) i Halmahere. Ti procesi su se zbili između miocena i pliocena. U zapadnom kraku Sulawesi-a do otoka Mindanao razvio se vulkansko-plutonski magmatski luk s granitima i vulkanitima za koji su vezana porfirna bakarna ležišta dok je tercijarna zona subdukcije locirana u istočnom kraku Sulawesi-a protežući se duž submarinskog hrpta Mayu i otočnog hrpta Talaud, a karakterizirana je lateritskim nikaljnim ležištima i pojavama kromita (sl. 1.).

Autori su istražili morfologiju i paragenezu bakarnog ležišta Batu Marupa koje se nalazi u središnjem dijelu otoka Sulawesi oko 40 km sjevernije od grada Makale i oko 60 km sjeverozapadno od luke Polopo. Japanci su za vrijeme drugog svjetskog rata eksploatirali bakarnu rudu i talili bakar u primitivnim talionicama. Ruda je sadržavala 3–5 % Cu.

Rudište se nalazi na južnim padinama vulkanskih doma Popomalangi i Bidong Pangpano na visinama od 1100 do 1200 m. Okolina bakarnog ležišta izgrađena je od magmatskih stijena čiji diferencijati variraju od kiselih preko intermedijernih do bazičnijih varijeteta. Sve su stijene vrlo intenzivno hidrotermalno izmijenjene. Najsnažnija je silifikacija, a zatim kaolinizacija. Mikroskopski je istraženo više tipova alteriranih stijena.

Rudna tijela, njih desetak, imaju oblike manjih ili većih leća. Najveće tijelo, koje su Japanci intenzivno eksploatirali, imalo je dimenzije 70mx18m, ostala su bila manja ili nedovoljno istražena.

Brojni uzorci rude s napuštenih starih kupišta detaljno su ispitani u reflektiranoj polariziranoj svjetlosti i utvrđene su parageneze i mikrofiziografske karakteristike identificiranih minerala. Uočena su tri različita tipa rude:

»žuta ruda« s pirotinom, piritom i halkopiritom kao glavnim rudnim mineralima te s tetraedritom, sfaleritom, galenitom, halkozinom, neodigenitom i enargitom kao sporednim sastojcima parageneze;

»crna ruda« s piritom, sfaleritom i tetraedritom kao glavnim rudnim mineralima te halkopiritom, halkozinom i galenitom kao akcesorijama;

»impregnaciona ruda« s piritom i neznatnom količinom ostalih minerala u potpuno silificiranoj stijeni.

Kvarc je dominantan mineral jalovine, u znatnoj količini ima i kaolinita.

Osnovna je karakteristika glavnih minerala u oba prvonavedena tipa rude da su puni inkluzija i da su intimno prorasli s akcesornim mineralima. Puni su izdvajanja submikroskopskih i mikroskopskih dimenzija, a osim toga karakteriziraju ih tipične koloidalne strukture naročito u »crnoj rudi«. Svi navedeni fenomeni indiciraju subvulkanski karakter orudnjenja iz jako koncentriranih mineralnih otopina kojima su se temperatura i tlak naglo smanjivali.

Ležište Batu Marupa je bakarno ležište nastalo unutar magmatskog luka za vrijeme faze subdukcije u subvulkanskom nivou.