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Bougainville Copper—Further Considerations on the Problem of Mining Waste Disposal

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Introduction

The recent paper in Geoforum 18 by Dr. M.J.F. BROWN on waste disposal at Bougainville is a welcome first statement on the problem but further elucidation on the general chemistry and geochemistry of heavy metals in this context is necessary. The discharge of heavy metals from modern mines is an entirely different problem from that of metal processing plants. The latter involve pyrometallurgical and hydrometallurgical techniques requiring chemical reactions that result in fundamental changes in the states of the metals and metal compounds. Pyrometallurgical techniques vapourize metals and hydrometallurgical techniques put them into solution. The flotation process, employed exclusively in all modern sulphide concentrators, is essentially a physio-chemical change on the surface of the metal bearing mineral and is in contrast to metal processing plants. The mineral is rendered hydrophobic which results in air adherence, the effect on the mineral-air composite being to give a lower specific gravity than the crushed rock-water mixture, i.e. the composite will 'float' to the surface to be scraped off as a scum.

Reactions that result in heavy metal solution in the flotation process are those that are the result of the instability of sulphides in normal oxidizing atmospheric conditions. Because any prolonged oxidation inhibits the efficiency of the flotation process, operators minimize its effect by treating ores as soon as possible after mining and immediately after crushing and grinding.

Successful sulphide flotation plants have to give recovery of metals of 90-95%. Frequently this figure is higher. The process is therefore greater than 90% efficient in separating the heavy metal minerals from the rock. Bougainville Copper's sulphide plant is a total sulphide float; all sulphide species present are recovered from the ore and the plant is as efficient as any at present operating (Bougainville Copper: personal communication).

Consideration of metal concentrations alone in the Bougainville case should lead to a re-examination of the charge of chemical pollution by heavy metals due to the mining operation.

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Furthermore, concentrations are only part of the answer when considering heavy metal in anomalous or dangerous values. The full picture can only be seen when the specific behaviour of the metals as ions or complexes in the geological environment is understood. Research in exploration geochemistry since the initial impetus of Russian and Scandinavian workers in the early 1930's has contributed much to the understanding of heavy metals in the environment. Soils, water and plants have long been the subject of intensive analyses and study in the search for ore deposits and the data collected can and should contribute to environmental studies.

Metal Concentrations

Table 1 is a compendium of naturally occurring heavy metal concentrations compared to those reported from Bougainville by the company for operations in 1974 (Bougainville Copper; personal communication). These figures are more up to date than those presented by BROWN (1974), reflecting more sophisticated sampling and analytical techniques developed recently by the mine.

Copper: Copper in the soil phase is enriched in iron oxides, manganese oxides and organic compounds. In the aqueous phase the ions Cu^{+} and Cu^{++} predominate over organic complexes. Copper is sensitive to pH, being mobile below 5.5 but relatively immobile in neutral to alkaline conditions (HAWKES and WEBB, 1962). In common with uranium and to a lesser extent cobalt, copper is sensitive to reducing environments derived from high H_2S activities, precipitating the metal as sulphides. The latter is illustrated by the occurrence of the metal in the copper sandstone deposits (PHILLIPS, 1960; CREELMAN, 1974).

The insoluble nature of the metal in alkaline oxygen rich conditions is attested to by examining the formulae of the secondary minerals (Table 2) where the hydroxyl radical is most evident, indicating that given ions in alkaline solution, deposition is a function of adequate copper concentrations combined with appropriate activities of the sulphate, silicate or carbonate radicals.

The Bougainville situation is on Dr. BROWN's (1974) report markedly alkaline near the tailing discharge point into the Kawerong-Jaba river system, and at various points along the stream no lower than 8.0. Under these conditions it is impossible to obtain significant copper concentrations in the stream waters. The 3 ppm values recorded during the exploration phase of the project are certainly due to the acidic conditions common in tropical streams that are draining the acidic humus piles of the rain forest. It could be alternately argued that the chemical changes in the stream system due to mining operations have effectively reduced copper values. It certainly cannot increase the concentrations under the reported chemical conditions. The filter effluent value for 1973 was taken when some minor plant difficulties were being experienced. It is obvious from the 1974 values that this has now been corrected (Bougainville Copper: personal communication).

Zinc: Zinc is sorbed on hydrated iron oxides and in clay minerals. The form in aqueous solution is variable between organic complexes and ionic Zn^{2+} (WHITE, 1957; HAWKES and WEBB, 1962). The element is the most mobile, and therefore in exploration geochemistry, the most useful of the base metals (BOYLE and CRAGG, 1957; MIESCH and NOLAN, 1958; WEBB, 1958).

Table 1

• Heavy metal concentrations in natural streams compared to values at the Bougainville operation (all values in parts per million)

	Data on Natural Heavy Metal Concentrations			Bougainville Copper: Heavy Metal Concentrations					
	Solid Phase		Aqueous Phase	Solid Phases		Aqueous Phases			
Metal	Igneous Rocks/Soils	Max. conc. in Nature where found	Range in fresh waters	Average mining grade 1974	Tailing solids 1974	Tailing* effluent 1974	Filter† plant effluent 1974	Tailing effluent 12.9.75	Filter plant effluent 12.9.73
Copper	Range (average) 30-140 (70) 20-100 (20)	300 Black Shales	0.002-0.03	7050	960	0.005-0.015	0.005-0.015	0.003-0.005	0.110
Zinc	50-130 (80) 10-300 (50)	1000 Black Shales	0.001-0.2	180	130	0.005	0.001	0.001-0.002	0.002
Lead	12-48 (16) 2-200 (10)	400 Black Shales	0.0003-0.003	120	70	<0.002	<0.002	<0.002	<0.002
Molybdenum	0.4-1.9 (1.7) 0.2-5 (2)	300 Black Shales	0.00005-0.003	50	20	0.003	0.010	0.003	0.009
Cadmium	0.1-0.9 (0.13) 0.1-0.7 (0.5)	0.3 Black Shales	0.001-0.010	<10	<10	<0.001	<0.001	<0.001	<0.001
Mercury	0.04-0.09(0.06) 0.03-0.3	0.4 Black Shales	0.00001-0.0001	<0.1	<0.1	0.000017	0.000012	<0.001	<0.001

* Tailing effluent is from the sulphide concentrator at Panguna and is delivered into the Kawarong/Jaba river system.

† Filter plant effluent is derived at Loloho on the coast, and is not delivered into the river systems.

< means value found to be less than the lower limit of analytical detection which is the figure following

Sources: Natural Heavy Metal Concentrations: **Hawkes & Webb** (1962), **Bowen** (1966).

Bougainville Data: 1974 figures supplied by Bougainville Copper Pty. Ltd.

Tailings; Filter Effluent 1973 from **Brown** (1974) confirmed by Bougainville Copper

The solubility of zinc is insensitive to pH but limited by aqueous iron concentrations and organic complexing at concentrations above the upper limit of 2 parts per billion (HAWKES and WEBB, 1962; BOWEN, 1966). Zinc is moderately toxic to plants, and only slightly toxic to mammals (BOWEN, 1966).

The zinc content of the ore at Bougainville is insignificant to the point where it was of only limited geochemical usage during exploration (Bougainville Copper: personal communication).

Lead: Lead is the most chemically immobile of the base metals. The aqueous form is Pb^{2+}, the potentially most dangerous form to mammals who accumulate the element to toxic levels (HAWKES and WEBB, 1962; BOWEN, 1966). Lead is present in even lesser concentrations in the Bougainville ore than is zinc, and considering its immobility, it is difficult to visualise why there is even the possibility of lead pollution. Another factor is that galena (PbS), the sulphide mineral of lead, is the most amenable of all sulphides to flotation.

Molybdenum: Molybdenum is a siderophilic element forming on oxidation of the primary molybdenite a series of ferromolybdites all of which are stable and insoluble in the atmosphere. What will dissolve is pH independent, but highly limited if carbonate is present (HAWKES and WEBB, 1962).

Molybdenum is present in lesser amounts than zinc and lead in the Bougainville ore which is in contrast to the 'porphyry copper' deposits of the Americas. The tailing effluent is still within the range found in natural environments.

Cadmium: Cadmium is universally associated with zinc in the ratio of 1 part of cadmium to 500 zinc. The element is not as readily oxidized into solution as zinc, but is just as mobile when it is in the aqueous phase (HAWKES and WEBB, 1962; HEM, 1972). HEM (1972) found a significant number of natural wells and springs in the United States that exceeded the 10 ug/1 upper limit set by the US Public Health Service (1962).

Considering the low zinc content of the ore, cadmium is certainly insignificant. The only environment where there is even the remotest possibility of cadmium pollution is a zinc sulphide ore body, such as Broken Hill, Australia, and then normally only if on site smelting is carried out.

Mercury: CHASE and WEICH (1973) in a review article seriously questioned the mercury pollution 'scare' current among environmentalists and pointed out that the toxicity depended exclusively on the form of the element. Native metal, and the sulphide cinnobar are by far the most common forms and are both harmless to life, as are the very rare chloride, sulphate and oxide. Mercury vapour and mercury bearing organic compounds are, however, extremely toxic, particularly methyl mercury. Mercury is extremely sulphur-seeking, and therefore contamination from vapour, apart from industrial and scientific processes that use the element, is insignificant, considering the amount of sulphur in the natural environment. All cases of mercury poisoning, particularly the Japanese Minamata and Niigata disasters, and those resulting from treatment of seed grain in the U.S. with cyano methyl mercury, were the result of ignorance of the chemistry involved on the part of both the users of the compounds and those who were poisoned. In the case of the Japanese disaster, steps were taken to remove the elemental mercury, but the operators were unaware of the danger of the organic mercury which was found to be the factor responsible for the subsequent deaths.

From 80% to 96% of all mercury in the atmospheric, riverine and biological environment derives from volcanic activity. The 6000 million tons per year from man's activities derives 50% from fossil fuels, 33% from metal smelters, and 4% from cement and ceramic plants. All other industries together contribute the remainder (CHASE and WEICH, 1974).

Mercury values in the Kawerong-Jaba system do not exceed natural ranges (Table 1), which is very much in contrast to other streams in the area considering the proximity of the active volcano Mt. Bagana, and other volcanism on the island. It is unwise to contribute high mercury values to the mining operations unless it can be clearly demonstrated by sampling *all* streams in this region, that the stream carrying the mine waste is in any way different. Bougainville Copper, by illustration, sampled the Sava river which drains part of Mt. Bagana, and report mercury values of 0.115 parts per billion (0.000115 ppm) (Bougainville Copper: personal communication).

Table 2

● Common oxidised copper minerals (FLEISCHER, 1971)

Name	Formula
Malachite	$Cu_2\ (CO_3)\ (OH)_2$
Azurite	$Cu_3\ (CO_3)_2\ (OH)_2$
Chrysocolla	$Cu_2\ H_2\ Si_2\ O_5\ (OH)_4$
Antlerite	$Cu_3\ (SO_4)\ (OH)_4$
Brochantite	$Cu_4\ (SO_4)\ (OH)_6$

Conclusion

There is very little evidence presented by Dr. BROWN in his paper to support his concluding remarks that the rivers and the seas on and around Bougainville are being contaminated with heavy metals by the mining operation. Values quoted are within the natural ranges. The mercury values are considerably below natural background for this area, and the 1973 copper values in the filtration effluent reflect a temporary operations difficulty only.

A positive factor that must be considered with regard to the sediment in the rivers, is that in the long term, after cessation of mining, the sediments will provide fertile flat ground for agriculture. The fertility will be enhanced by the potassium bearing sediments which will be distinctive from the underlying original soils, as potassium alteration, mostly in the form of feldspar, and to a lesser extent sericite, is a distinctive characteristic of the 'porphyry copper' type of deposit that is being mined.

The Bougainville operation contributes greatly to the economic well-being of Papua New Guinea, and since the negotiations concluded by the Government and Bougainville Copper in late 1974, benefits are more equitably distributed than before. It was clearly pointed out by Mr. F.F. ESPIE (1970) that the waste disposal problem was a critical factor in the feasibility study, so important in fact, that if a solution was not found, the project could not proceed. The Company recognised the problems of loss of fishing and on the initial agreement paid $28,000 annually to villages affected by the sediment. This has subsequently been raised to $60,000 on renegotiation of the Bougainville agreement. The Company spends considerable sums on slope stability measures, valuable research has been done (BAUMER *et al.*, 1973) and has sought advice from world experts.

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Land Resources in Indonesia

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Introduction: Land Use in Indonesia

The soil surface of Indonesia is approx. 2 mill. km^2 or 202 mill. ha. Since 1970 an aerial survey is under way which only will be completed in 1976. And then 2 or 3 years will pass before final figures on land use in Indonesia will be available. There are also the statistics of the Directorate General Agraria of the Ministry of Local Government that works on land use maps of the scale 1 : 50,000 or 1 : 100,000 (according to available basic maps without aerial photography). By the end of 1974 the maps were be completed on the 1 : 50,000 scale which will allow to compare with other figures. The following figures partly still are data of the Ministry of Agriculture 1961/1962 agricultural census since the 1971 census figures were published recently.

The Directorate General for Forestry within the Ministry of Agriculture in Jakarta estimates the forest area of Indonesia (1972) with 12o mill. ha. The annually cropped area according to a survey of *Agrar-und Hydrotechnik*, a sub-contractor of the World Bank, in 1971 has been 18.8 mill. ha. This works out at 17.5 mill. ha. cultivated land. The rest or 64.4% are natural grassland, savannahs, mountains without vegetation cover and other areas which are used by mining or carry buildings. The following table gives a breakdown of land use as in 1972.

Land Resources and Possibilities of Improving Agricultural Production

Informed guesses until today are the only basis for the following statements and figures given:

Islands Java/Madura and Bali: Unutilized land at present under natural forests is extremely scarce. Land resources for increased agricultural production have to be sought in the reclamation of highly eroded land as to be found in the Upper Sala Basin with its 50,000 ha. Also production reserves are included under the anticipated 15 years programme of turning land (some 2 mill. ha) with flow irrigation into land with terminal water control, which means individual irrigation plus subsoil drainage. Some US$ 1,500mill. are involved. Besides of some pilot projects this major loan-finance project programme did not start yet. Also the current BIMAS-rice intensification programmes still can be improved considerably. An indirect improvement of agricultural production would be brought about by the current 'greening programme', planting of trees.

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