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Trace Elements in Human Scalp Hair and Soil in Irian Jaya

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ABSTRACT

Pb, Cd, and Ni contents were determined in the scalp hair of the Asmat of Irian Jaya (Indonesian New Guinea) on 35 adult subjects. These data are presented together with those of Al, Ca, Ti, Fe, Cu, Zn and Sr, which were determined in previous research on the same group. Hair samples were analyzed by EDXRS and ICP. Trace elements were also determined in 12 soil samples from the same area by EDXRS (Al, Si, K, Ca, Fe) and ICP (Cu, Sr, Ti), and by AAS (Cd, Ni, Pb). When hair element levels are compared and discussed with those of other New Guinea populations, acculturated and nonacculturated tropical groups, populations from Western countries and from polluted areas, and "recommended levels" in the literature, they greatly exceed Western levels and generally fit those of other New Guinea populations, stressing the importance of common environment, subsistence, and behavior. The results of soil analyses are consistent with the presence of those elements in hair, and their quantitative distribution follows a common trend. Metal mobility in soil, patterns of absorption, and transfer from soil to plants and to humans are considered here.

Index Entries: Trace elements; human hair; soil; Irian Jaya; New Guinea; EDXRS; ICP; AAS.

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INTRODUCTION

Analysis of trace metal concentrations in human hair is increasingly used in anthropological research as a possible indicator of the nutritional and health status of a population *(1–5)*, population environmental adaptation, and its exposure to pollution *(6–10)*. However, lack of standard procedures and uncertainties about the mechanisms regulating element incorporation still exist *(11)*. In view of the fact that trace metal contents in human hair show high intra- and interpopulation variability, more population data are required. It is not possible to speak about normal levels, but only of normal ranges, for a given population in certain conditions, since the diagnostic value of any analytical technique depends on the validity of its reference ranges. Up to now, a number of studies have focused on population groups of Western industrialized countries *(12–14)*. However, there is little information on populations in tropical areas, living in nonindustrialized environments presumably free from exogenous contamination and still subsisting on local natural resources, with low mobility outside their territory and limited access to imported food *(15)*.

The results of previous research on trace element contents (Al, Ca, Ti, Fe, Cu, Zn, Sr) in the hair of one of these human groups, the Asmat of Irian Jaya *(16–18)*, showed interesting deviations from reference values derived from Western populations, whereas some similarities were noted with element levels obtained for the Gidra, a nearby New Guinea population *(19)*.

Further comparison of our data with those of populations representative of different geographic, socioeconomic, and hygienic conditions should provide a critical approach to the debated topic of the usefulness of hair mineral determinations and the "relative" value of their content ranges. Since trace metal contents in human tissues and organs are expected to be related to local geochemical conditions ("natural concentrations," after Iyengar and Woittiez *[13]*), more data are still required to investigate the relation between trace element presence in soil and water and that in human hair, possibly assimilated through food and cultural habits, such as diving, washing the hair, or smearing it with mud. The interior of New Guinea is a mountainous region rich in minerals (Cu, Pb, Zn, Au, Pt, Ni, Co, and Cr among others) *(20,21)*, which are presumably weathered and brought down to the alluvial plains by the many water courses. The soil of these flood plains is commonly fine-textured, strongly gleyed owing to poor drainage, and subject to inundation during the wet season *(22)*. It contains expanding lattice clays *(23)*, which cause it to crack when it dries out. It also tends to be strongly alkaline near the coast and tidal rivers, and increases in acidity inland *(24)*. Strongly gleyed saturated soil and deep organic peat occur in these permanent swamps. Therefore—despite extension of our research to three more trace elements, Cd, Ni, and Pb—it was considered of some interest

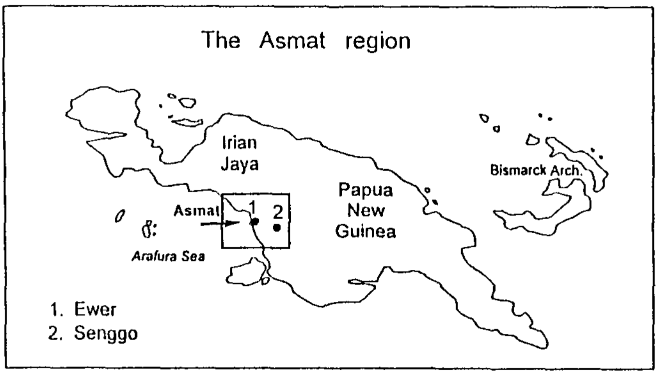

Fig. 1. The Asmat region (Irian Jaya, Indonesia), with local villages involved in this study.

to study mineral trace elements in local soil, in order to investigate any qualitative and quantitative connections between mineral elements in hair and in the environment.

Various studies consider soil metal contents in relation to environment and human biology, such as pollution *(25–27)*, human nutrition *(28–31)*, and pathological conditions (*see* Brown *[32]*), yet much less is known of the association of soil metal contents with trace element levels in human hair *(26,31)*.

The Study Population

The Asmat territory is located in the southwestern part of Irian Jaya, and extends from 140° east to 137° west and from 4–7° below the equator, from the foothills of the Jayawijaya Range to the coast of the Arafura Sea (Fig. 1). It mainly consists of flat alluvial plains, covered with tropical forest, and crossed by a dense network of rivers. Mean temperatures vary between 21 and 35°C, and average rainfall may reach 4600 mm *(33)*.

The Asmat number about 70,000; their language includes several dialects belonging to the Asmat-Sempan-Kamoro group, which is part of the large Trans-New Guinea Phylum *(34,35)*. The Asmat diet is 80% based on sago, the starchy carbohydrate obtained from palms (*Metroxylon rumphii* and *Metroxylon sagu*), which grow spontaneously in the swampy forest soil. Sea and river fishing and hunting (wild boar, cassowary, arboreal marsupials, and small rodents) and gathering (eggs, vegetables, various fruits) integrate their diet, which also includes a number of insects, especially grubs *(36)*. Because of frequent flooding, horticulture is not a traditional practice, and attempts at growing vegetables are only made in a few elevated spots. The consumption of imported food is occasional. Livestock (poultry or pigs) are rare, but dogs are kept for hunting. This population has been in permanent contact with Western officials and missionaries since 1953. In spite of alterations brought about by cultural contacts—such as the permanency of settlements—the Asmat still follow their traditional economy.

MATERIAL AND METHODS

Sample Collection

Hair samples were collected during an anthropological survey in the Asmat region, promoted by the Institute of Anthropology of the University of Padova and the Ligabue Study and Research Centre of Venice. They belong to 35 adult subjects (30 males, 5 females), aged from 17 to 60 yr, living in the coastal village of Ewer *(28)* and the inland riverine village of Senggo *(7)* (Fig. 1).

Hair was collected according to traditional methods. It was cut as near as possible to the scalp with stainless-steel scissors, from various points in the occipital area, and stored in polyethylene bags. The low sample number considered here is owing to the low weight of the samples, which were originally collected from 126 individuals, but were insufficient to fulfill the requirements of the present analyses. Hair collection was also hindered by the difficulty of obtaining even a small lock of hair from people who still strongly believe in witchcraft practices involving human tissues or secretions. Twelve soil samples were collected from different points near the villages and orchards.

Analytical Methods

Hair

Samples were analyzed by EDXRS and ICP methods, in order to determine a large number of element concentrations in about 100 mg of hair. Contents of Fe, Cu, and Zn were measured by EDXRS; ICP was used to measure Al, Ca, Ti, Ni, Sr, Cd, and Pb. This technique proved to be particularly useful to measure low concentrations of these elements. In both cases, suitable samples were obtained by an acid digestion procedure in Teflon vessels using a microwave oven. As digestion solvent, 1 mL of HNO_3 (high-purity nitric acid 65%) containing 200 ppm V solution as internal reference was employed for 100 mg of hair. Targets for EDXRS were prepared by pipeting 300 μL of each solution without dilution on to a Mylar film and drying them in a vacuum drier.

Calibration was performed with the linear regression method by means of standard solutions. Samples and standards were run under vacuum conditions on a Kevex Delta 770. Instead of covering the samples, to minimize X-ray absorption, the Be detector window was covered with a 4-μm Mylar film in order to avoid nitric acid contamination. Working parameters were as follows: Ge secondary target, 15 kV, 3.3 mA for Cu, Zn, and Fe. The detection limits of EDXRS did not allow quantitative determination of other elements in many spectra. The solutions injected in the ICP spectrometer were obtained by 10-fold dilution with bidistilled water of those contained in the Teflon vessels.

Soil

Samples were analyzed by EDXRS (Al, Si, K, Ca, Fe), ICP (Cu, Sr, Ti), and by AAS (Cd, Ni, Pb). For the EDXRS method, about 10 g of each sample were dried for 24 h at 100°C and ground into a fine powder, and 3 g were then pressed into pellets of 3.1-cm diameter. Quantitative analysis was performed with the fundamental parameter method, and calibration constants were determined from clays previously analyzed by AAS. The accuracy of the method was verified on a certified brick.

Working parameters were: direct excitation, Rh anode, 5 kV, 0.1 mA for Al and Si; secondary excitation, Ge anode, 15 kV, 1 mA for K, Ca, Fe.

For graphite furnace AAS and ICP, 300 mg of each powdered sample were dissolved with 3 mL of HNO_3 in a Teflon vessel using a microwave oven, and the solutions were diluted 10-fold with HNO_3 10%. Calibration of ICP and GFAAS was performed with the linear regression method by means of standard solutions. For statistical analysis, trace element values were converted to logarithms, as suggested by Bencko *(8)*.

RESULTS AND DISCUSSION

Hair Element Levels

The detection limits for EDXRS were found to be 0.11 mg/L for Cu and Zn and 0.14 mg/L for Fe. The accuracy of the method was verified by analyzing three different digestions of Standard Bovine Liver (NBS 1577a) and Orchard Leaves (NBS 1571). Results are reported in Table 1. Agreement between the results and NBS data was evident, apart from Ni values. These differences were probably owing to the low concentration of Ni, which was close to detection limits. If Ni is excluded, the overall mean absolute difference is 8%. The detection limits for ICP and GFAAS are reported in Table 2.

Results of hair analysis are shown in Table 3. Cd, Ni, and Pb values are new, whereas those of Al, Ca, Ti, Fe, Cu, Zn, and Sr were presented in previous works *(16–18)*. For comparison, our results are reported together with data from the literature, differentiated into:

1. Tropical countries, comprehensive of nearby New Guinea populations, such as the Gidra, and other acculturated and nonacculturated groups from various tropical areas (Asia, Africa, and Oceania).
2. Western countries, comprehensive of normal reference values for European and US populations.
3. Polluted areas, comprehensive of populations living in polluted environments (i.e., near mines or Cu smelting works) or exposed by work to pollutants.

Table 1
Comparison of the Certified to the Measured Concentrations in NBS Standards

	1577a (Bovine liver) (mg/L)		1571 (Orchard leaves) (mg/L)	
Element	Certified value	Measured value	Certified value	Measured value
Fe	194±20	210±27	300±20	289±15
Ni	-	-	1.3±0.2	1±0.5
Cu	158±7	149±10	12±1	14±2
Zn	123±8	130±15	25±3	27±6

Table 2
Detection Limits of ICP and GFAAS

ICP mg/L		GFAAS mg/L	
Al	0.05	Cd	0.0002
Ca	0.1	Ni	0.002
Sr	0.009	Pb	0.002
Ti	0.03		

4. Recommended levels, including the normal range (minimum and maximum) and recommended upper limits taken from the literature.

The reference populations are listed in Table 3.

Although Asmat Cd values (0.6 mg/kg) are within normal ranges, Ni (6.4 mg/kg) and Pb (15.7 mg/kg) levels are high and similar to those of subjects exposed to pollution, such as Indian auto workshop workers (Ni 3.76 mg/kg) *(43)* and the Ok Tedi (Pb 23.79 mg/kg) *(44)*, a New Guinea group living near a Cu mine. High Ni and Pb hair concentrations may also be related to smoking—a habit that is widespread among the Asmat—since high levels of these elements have been verified in the hair of smokers *(26,47,48)*.

Comparison of Al, Ca, Ti, Fe, Cu, Zn, and Sr in the Asmat with other populations confirms their high absolute values (with the exclusion of Cu, which is within the norm), well over standard "recommended" levels.

In particular, the high levels of Al (146.6 mg/kg), Sr (12.2 mg/kg), and Fe (242.2 mg/kg) are similar to those of the nearby Gidra *(19)*, suggesting an association between element contents in soil and water and mineral assumption through diet or exogenous exposure, since both populations live in similar environments and share common traditional subsistence economy and behavioral patterns.

Similarly, the Zn (228 mg/kg) level is high and—as is the case with elements, such as Pb and Fe—is comparable with that of the nearby Ok Tedi group *(44)*. Ca (1811.2 mg/kg), and Ti (3.8 mg/kg) are also elevated and, like Zn values, approach those of two South Pacific populations, the Kitava (Trobriand Islands, Papua New Guinea), and the Atafu (Tokelau

Table 3
Trace Element Levels in the Asmat (Present Work) and in Different Populations from Literature

PRESENT WORK					REFERENCE VALUES			
Elem. mg/Kg	N.	G.M.	Min-Max	Median	Tropical countries	Western countries	Polluted areas	Recommended levels (19)
Cd	33	0.6	0.24-1.53	0.6	3 (1), 0.2 (2),	<0.15 (10), 0.14 (11), 0.35-2.43 (12), 0.2 (13)	28.9 (14), 0.75 (15), 3.83 (16)	min 0.1-0.15 max 0.45-0.55 1.6 (20)
Ni	35	6.4	1.2-30	6.1	0.35 (3)	0.39 (10), 0.43 (11), 0.02-1.25 (12), 0.7 (13)	0.74 (15), 3.76 (16)	1.80 (20)
Pb	35	15.7	4.05-39	18.0	5 (1), 0.7 (2), 0.62 (4), 5 (5)	2.43 (10), 8.2 (11), 4.2-52 (12), 8.1 (13)	12.21 (15), 5.6 (16), 23.79 (17)	min 1.7-2.5 max 5-6 15.0 (20)
Al	34	146.5	43.9-491.1	143.5	32.0 (3), 165 (4), 71.6 (6), 22.6 (7a)	3.87 (10), 13.17 (11), 11.59 (13)	45.2 (14), 25.5 (7b)	min 4-6 max 13-18
Ca	34	1811.2	759.9-5189.5	1892.6	895 (3), 843 (4), 2295.1 (6)	799 (10), 360 (11), 416.2 (13)		min 200-350 max 1200-1600
Ti	31	3.8	0.95-17.3	4.0	18.6 (3)	1.17 (11), 1.05 (13)		min 0.2-0.23 max 0.7-0.85
Fe	34	242.0	74-668	233.0	36.0 (3), 282 (4), 176.8 (6), 905 m, 296 f (8)	9.35 (10), 14.14 (11), 13-177 (12), 17.9 (13)	22.3 (15), 25.2 (18), 219.39 (17)	min 13-18 max 40-45
Cu	33	29.0	13-81	26.0	22 (1), 25 (2), 20 (3), 11 (4), 10.5 m, 22 f (5), 22.9 (6), 11 m, 12 f (8), 10.4 f (9)	15.7 (10), 26.6 (11), 6.8-39 (12)	200.4 (14), 18.25 (15), 33.08 (18), 10.29 (17)	min 7-8 max 11-12
Zn	31	228.0	118-353	228.0	192 (1), 306 (2), 211 (3), 120 (4), 250 m, 162 f (5), 129.4 (6), 189 (7a), 276 m, 220 f (8), 155 f (9)	152 (10), 110 (11), 124-320 (12), 144.2 (13)	239.1 (14), 108.54 (15), 169.8 (16), 214 (7b), 167 (18), 113.11 (17)	min 115-160 max 190-210
Sr	34	12.2	5.6-26.4	12.0	7.4 (4)	3.40 (10)		min 0.25-0.6 max 1.3-2.7

G.M., geometric mean.
References.
Tropical countries
1. Atafu (Tokelau Islands, South Pacific) *(37)*
2. Kitava (Trobriand Islands, New Guinea) *(37)*
3. Indians *(38)*
4. Gidra of New Guinea (estimated mean level in washed hair) *(19)*
5. Southern India vegetarian population *(5)*
6. Nigerians *(39)*
7. a. Indonesians; b. exposed Indonesians *(27)*
8. Bushmen *(40)*
9. Nukunono (Tokelau Islands): m (males), f (females) *(41)*

Western populations
10. Nonoccupationally exposed US adults *(12)*
11. Healthy urban subjects (age < 15) *(7)*
12. Normal reference values *(13)*
13. Urban subjects *(14)*

Polluted areas
14. Workers from Cu-smelter plants *(42)*
15. Metropolitan New Yorkers *(30)*
16. Auto workshop workers in Lahore *(43)*
17. New Guineans living near a Cu mine *(44)*
18. Cu mine workers (Chile) *(45)*

Recommended levels
19. Recommended levels *(46)*
20. Upper limits *(4)*.

Islands, Samoa) *(37)*. The high levels of Fe and Zn are similar to those reported for the bushmen of South Africa *(40,49)*.

This comparison suggests that the high trace element levels in the hair of the Asmat are related to environmental and nutritional conditions, most of which they share with other New Guinea and Melanesian islands groups, rather than to latitude or climate.

The Asmat are a Papuan population, and their skin and hair are strongly pigmented (dark brown). Data on the relationship between hair color and trace element contents are not uniform *(50)*. Higher Al and Zn levels have also been reported for black hair in comparison with other hair colors *(51,52)*. This observation suggests that melanin content may be considered a factor influencing the high concentration of these elements in Asmat hair. Their hair element contents did not vary significantly with age.

Soil Element Levels

The values of the macroconstituents Al_2O_3, SiO_2, CaO, and K_2O (Table 4) lay within normal ranges in soils *(53)*. The Fe soil content (about 5%) was higher than its reference value (45–350 ppm): Fe is insoluble when pH is strongly alkaline *(24)*. As described by Marschener *(54)*, plants can absorb Fe by permeasis after solubilization by exudate extrusion.

It is known that micronutrient cation pools in soils may be divided into:

1. Water-soluble (free plus complexed).
2. Exchangeable.
3. Specifically adsorbed.
4. Organically complexed, but water-insoluble.
5. Insoluble inorganic precipitates.
6. Those held in primary minerals.

The importance of the organically complexed pool arises from findings indicating that organically bound forms of micronutrient cations are more available to plants than the inorganic forms of pools, insoluble inorganic precipitates, and those held in primary minerals *(55)*.

The mechanism of ion uptake into several living systems (bacteria, fungi, algae, plants, and animals, including humans) continues to be of great theoretical and practical interest. Presently, the number of specific carriers involved in the uptake process for a single organism or tissue is uncertain, and single carriers have not been characterized *(56,57)*. Solute uptake may occur by means of various mechanisms involving either one or many carriers for each ion or one carrier for several ions *(58–60)*.

Soil trace element levels (Cd, Ni, Pb, Cu, Sr, Ti) are presented in Table 5. Cd is more mobile in soil, both in soil solution and organically bound to soil, and more easily absorbed by plants than other heavy metals, notably Pb and Cu. Accordingly, the potential for moving from soil to plants and to humans is greater *(61)*, but in our soil samples, Cd lev-

Table 4
Soil Monoconstituents (wt%) Determined by EDXRS (no. 12).

Element	mean	s.d.
Al_2O_3	21.8	0.3
SiO_2	65.9	0.4
K_2O	2.8	0.1
CaO	0.3	0.0
F_e2O_3	7.2	0.1

Table 5
Soil Trace Elements (mg/kg) Determined by GFAAS* and ICP (no. 12).

Element	mean	s.d.	ref.value (56)
Cd*	0.06	0.03	0.06
Ni*	12.1	8.0	40.0
Pb*	19.3	3.0	10.0
Cu	16.9	2.8	20.0
Sr	< 5.0	0.0	-
Ti	2125.0	333.4	-

els were very low (0.06 mg/kg), in that the normal Cd soil level ranges below 1–2 mg/kg *(62)*.

Although there are many uncertainties regarding Ni uptake and transfer, it seems that this element is absorbed via the same mechanism as Cu and Zn *(53)*. Ni soil content was 12.1 ppm, and this value falls within the 5–500 ppm range *(53)*, suggesting that Ni is absorbed by exchange sites in roots and transferred to the upper part of the plant, probably bound to the lowest-mol-wt humic fraction *(63)*.

Pb soil content was 19.3 mg/kg (normal level: 10–150 mg/kg) *(62)*; also Pb may be linked to the organic matrix of soil and absorbed by the plant root system *(54)*.

Water

Another source for the high element levels in the Asmat, living as they do in a coastal environment, may be sea water, which is particularly rich in trace elements. The subsistence behavior of populations depending on seafood sources may therefore be partly responsible for the high mineral contents verified in their tissues *(64)*. Exogenous element deposition in hair may also take place through habitual immersion in muddy river waters, or the occasional rubbing of mud or sago flour into the hair for ceremonial purposes.

Further indication for the impact of water on trace element concentrations in human hair comes from studies of the Gidra *(19)*, demonstrating that water is related to the absorption and deposition of several elements *(9)*. When Gidra hair element concentrations were analyzed in

Table 6
Nutritional Content of Sago
(*M. rumphii* and *M. Sagu*) Flour
and Sago Grubs (*Rhynchophorus sp.*)

Sago content (100g):

Water	27 g
Carbohydrates	71g
Proteins	0,2 g
Fibres	0,3 g
Calcium	30 mg
Phosphorus	12,5 mg
Iron	0,7 mg
Traces of: fat, carotene, thiamine, ascorbic acid and potassium.	

(65,66)

Sago grubs content (100 g):

Proteins	6.1%
Fat	13.1%
Carbohydrates	9%
Iron	4.3 mg
Thiamine	0.08 mg
Riboflavin	0.43 mg
Niacin	2.4 mg
Calcium	461 mg
Nutritional value: 760.2 kj	

(67)

relation to well-water element concentrations, the profiles of Ca, Cu, and Sr matched.

Nutrition

All the above trace elements are mainly absorbed and transferred through the alimentary cycle, so that the importance of meal composition and the different involvement of metals in centers of physiological activity must be taken into account. Since sago is the main staple for the Asmat, its Fe content (0.7 mg/100g) and the presence of carotene, thiamine, and ascorbic acid in sago *(65,66)* may favor the absorption and transfer of Fe and Fe-related elements, such as Pb and Ni. The high levels of Ca in hair may also be related to the high content of this element in sago grubs (*Rhynchophorus* sp.) *(67)*, a local delicacy consumed in large quantities on ceremonial occasions *(36,68,69)* (Table 6).

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