

## Morphology, Mineralogy and Genetic Implication of Placer Gold from the Huongkhe Area, Vietnam

Sang-Hoon Choi\*, Seon-Gyu Choi\*\* and Jin-Kyun Han\*\*\*

**ABSTRACT** : Placer gold in collected heavy minerals from several localities in Huongkhe area, is consistently very fine-grained ( $\leq 100$  to  $400\ \mu\text{m}$ ). The size and size distribution show somewhat differences at Dongdo and Hoahai : at Dongdo, predominant relatively larger and wide distribution; at Hoahai, characteristic relatively finer and narrow distribution range. The morphology of gold grains is divided into the four groups assumed by the dimension ratio : spherical, subprismatic, prismatic, and irregular. The gold grains at Dongdo show wide morphological distribution, whereas, at Hoahai, spherical form is predominant ( $\approx 75\%$ ). Three main types of gold are classified based on their chemical composition and mode of occurrence : type I (electrum; fineness=568-931), type II (amalgam; fineness=671-927), and type III (native gold; fineness=923-999). Type I gold contains, relatively high and variable silver contents ( $\approx 11$  to 58 atomic % Ag), and has been classified into two subtypes based on their silver contents (type IA,  $\approx 11$ -39 atomic % Ag; type IB,  $\approx 40$ -58 atomic % Ag). However, type I gold would have been generally original compositions of electrum which originated at the provenance deposits. Mercury reacts with gold and silver to form amalgam (type II gold) which has variable Hg contents (1.2-30.5 atomic % Hg). The mercury contents in gold grains at Hoahai (10.9-30.5 atomic % Hg) are higher than those at Dongdo (5.8-21.1 atomic % Hg). The gold grains from the area generally exhibit a high-purity gold (type III) rim. The individual rims on the various grains range from  $<1$  to  $80\ \mu\text{m}$  in thickness and have silver contents of  $<10$  atomic percent Ag, even though the core compositions range from  $\approx 11$  to 58 atomic percent Ag. The rim of gold most likely is responsible for the commonly cited cases of gold from placer deposits assaying at higher values of fineness than the gold in the corresponding source lode. The gold-rich rim in the Huongkhe area apparently forms by a combination of self-electrorefining and preferential dissolution of silver under oxidizing nature during the weathering and transport process. All data of gold grains in the Huongkhe area suggest that the transport distances and/or time of placer gold at Hoahai are generally farther than those at Dongdo. The mercurian gold bearing provenance deposits at Dongdo and Hoahai would be suggest nearest epithermal gold-silver vein-type.

### INTRODUCTION

Gold is almost inert component under the physico-chemical conditions prevailing in most weathering environments. Accordingly, it generally behaves an immobile element and secondary dispersion is predominantly by physical mechanisms. This resistance to weathering is largely responsible for the economic concentration of gold as placer deposits in placer systems. The first discovery of the major gold-producing districts was placer gold. Therefore, the search for placer gold remains an important aspect of exploration programs for gold deposits in many

hypogene gold fields. In most streams, the very high specific gravity of the placer gold results in its concentration in areas where obstacles impede normal stream flow. Notable features of placer gold in distal fluvial sediments are its typically fine grain size and narrow size distribution range ( $<1.0\ \text{mm}$ ). However, the ultimate source for placer gold is normally considered to be eroded hypogene deposits in which primary gold may have a wide range of grain size. The morphology and size distribution of placer golds are good qualitative data for exploration of source area.

Vietnam represents a largely unexplored terrain, containing significant mineral resources and new potential for mineral discoveries. The ore mineralization in the Vietnam shows a wide variety in mineral resources, mineralization type and epochs. Gold is one of the main commodities explored in tropical terrains. Extensive base-metals and gold mineralizations have been suspected recently in the

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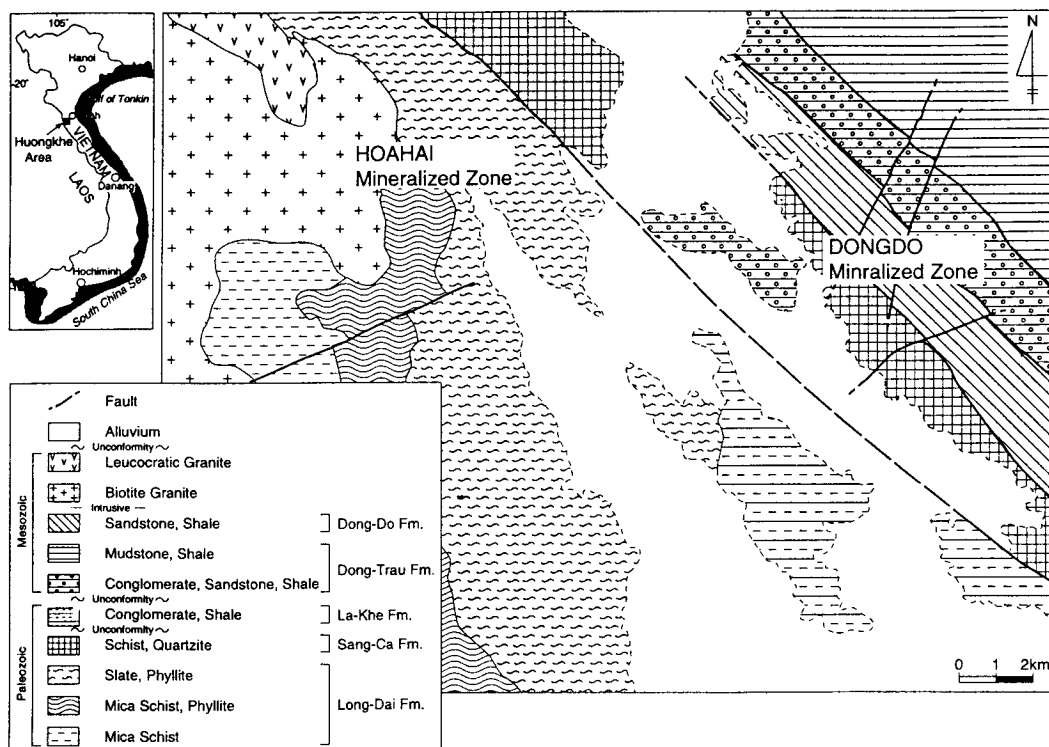


Fig. 1. Geologic map of the Huongkhe area and location of the each mineralized zone.

Huongkhe area, Hatinh province, Vietnam (Fig. 1). The potential zones of the ore mineralization in the area are Dongdo and Hoahai zones with other four zones (Dongkhetai, Traicoi, Manchao, and Phuquan). Geological and geochemical explorations in these zones were carried out by KMPC (Korea Mining Promotion Corporation). Geochemical survey with stream sediments at Dongdo and Hoahai is one of the project.

This paper presents the results of our investigations of the morphology and textural associations, and the variations in silver and mercury content of Dongdo and Hoahai placer gold grains in the Huongkhe area. At Dongdo and Hoahai, the term gold grain (and gold) has been used to all placer gold-bearing particles.

### GEOLOGIC SETTING

Three main lithostratigraphic units are recognized in the Huongkhe area: Paleozoic metasedimentary and sedimentary rocks of the Long-Dai and La-Khe Formations, Mesozoic sedimentary rocks of the Dong-Tran and Dong-Do Formations, and Jurassic intrusives (Fig. 1). The Long-Dai Formation is largely composed of schist, phyllite, and slate. The La-Khe Formation,

which overlies unconformably the Long-Dai Formation, consists mostly of conglomerate and shale, and is unconformably overlain by the rocks of Mesozoic Dong-Tran Formation. The Long-Dai Formation, the lowermost unit in the Huongkhe area, is composed of metasedimentary rocks. Three main rock members of the Long-Dai Formation are found in the area. They are, in ascending stratigraphic order, quartz mica schist, mica schist + phyllite, and slate + phyllite, with from Lower Ordovician to Upper Silurian. A number of gold-silver-mercury-bearing hydrothermal vein type mineralizations occupy fractures mainly in the mica schist at Hoahai village. The Formation occurs locally in the eastern portion of the Huongkhe area and is correlated with Upper Silurian slate + phyllite member of the Long-Dai Formation. It mainly consists of mica schist and quartzite. The Lower Carboniferous La-Khe Formation consists mainly of conglomerate and shale within which thin beds of shale and slate with black limestone are locally interbedded.

Mesozoic sedimentary rocks occupies most of the eastern portions in the Huongkhe area, and is divided into the lower Dong-Tran Formation (Middle Triassic) and the upper Dong-Do Formation (Upper Triassic). The Dong-Tran Formation is composed of two main

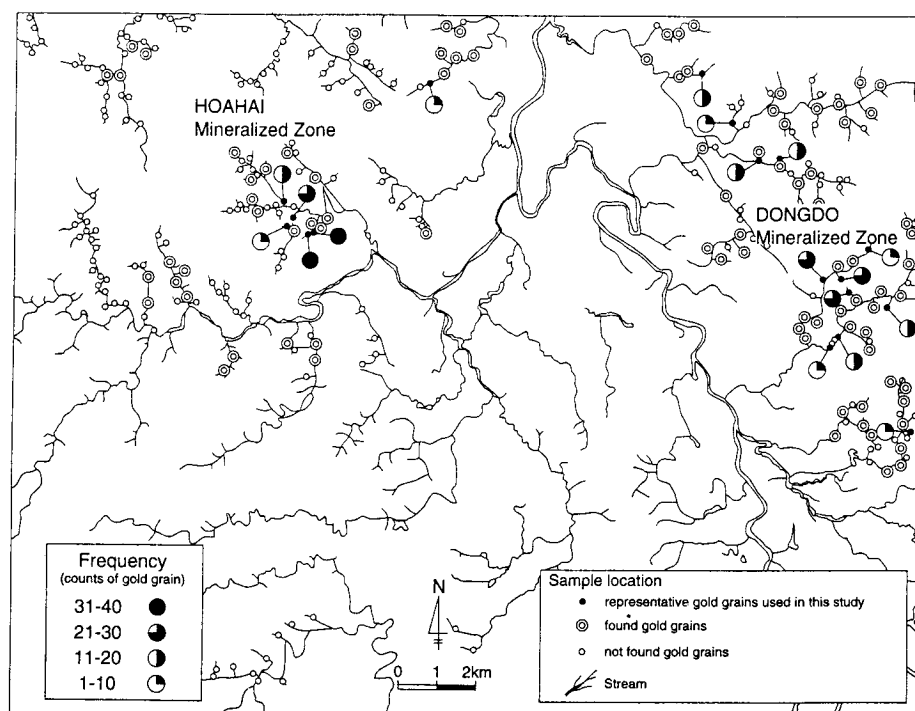


Fig. 2. Sample locations in the Huongkhe area.

rock members : in ascending stratigraphic order, conglomerate + sandstone + shale, and mudstone + shale. The Dong-Do Formation consists mainly of sandstone and shale within which thin beds of coal and shale are locally interbedded.

The metasedimentary and sedimentary sequences are intruded by plutonic rocks of the Mesozoic granites. Middle Jurassic ( $151.0$  to  $191.8 \pm 2.5$  Ma; KMPC, 1995) biotite granite and leucocratic granite occur as batholith and small stock, respectively, in the western portions of the Huongkhe area. The biotite granite was weathered commonly in the area, and shows locally compositional variation as granodiorite and tonalite.

#### SAMPLE LOCALITIES AND SAMPLING METHODS

Sampling for stream sediments and panned concentrates was undertaken at the first, second and third order streams in the Dongdo and Hoahai mineralized zones (Fig. 2). The density of sampling is approximately  $1.4$  samples/ $\text{km}^2$  with about 500 to 800 m as sampling interval on the stream. Concentrated heavy samples by re-panning were mineralogically investigated by binocular. The

identified heavy minerals are mainly ilmenite, tourmaline, garnet, spinel, wolframite, scheelite, monazite, sphene, zircon, rutile, cassiterite and gold. The distribution of gold grain on the streams and the frequency (as counts of gold grain) at representative sample location in the Dongdo and Hoahai mineralized zones are shown in Figure 2.

### OCCURRENCES AND MINERALOGY

#### Occurrences

The morphology of the grains is influenced by numerous factors, including character of the original lode particles, stream energetics, nature of the stream channel material, time spent in the stream, distance of transport, and chemistry of the stream water. Placer gold grains are generally similar in their morphology, such as size and form, in the Dongdo and Hoahai zones. Gold grains are usually of microscopic size, range from  $0.05$  to  $1.5$  mm, and variable shapes.

Gold grains from the Dongdo and Hoahai sediments are consistently very fine-grained (mainly,  $< 1$  mm), with a mode in either the  $\leq 100$  to  $200 \mu\text{m}$  or  $200$  to  $400 \mu\text{m}$  range (Tables 1 and 2, and Fig. 3).

**Table 1.** Representative physical and chemical data for placer gold grains from Dongdo mineralized zone.

Specimen and grain no.	Size* (max./min., micro meter)	Shape**	Fineness (Weight percent)			Type***
II-73-1	1720/660	subp.	792	-	801	IA
			980	-	994	III
II-73-2	1820/560	pris.	898	-	902	IA
			989	-	993	III
II-73-3	1040/500	subp.	952	-	994	III
II-73-4	1100/360	pris.	824	-	831	IA
			982	-	996	III
II-73-6-2	1050/780	sphe.		789		IA
			568	-	684	IB
				996		III
II-73-8	2260/1700	sphe.	782	-	787	IA
			973	-	995	III
III-101	2960/860	pris.	741	-	843	IA
			637	-	728	IB
			973	-	994	III
II-70-6	585/365	sphe.	852	-	857	IA
			987	-	989	III
II-70-8	1520/900	sphe.		821		IA
				694		II
II-71-1	2300/2100	sphe.	926	-	996	III
II-71-10	460/290	sphe.	818	-	872	IA
			956	-	987	III
II-75-1	680/250	subp.	891	-	894	IA
II-75-2	2360/760	pris.	897	-	906	IA
			991	-	996	III
IV-89-1	375/190	sphe.	812	-	821	IA
			991	-	998	III
IV-89-2	760/550	sphe.	754	-	910	IA
			983	-	989	III
IV-89-4	1680/640	subp.	926	-	931	IA
			993	-	996	III
IV-89-7	900/300	subp.	897	-	898	IA
III-90-1	500/125	pris.	882	-	884	IA
III-90-3	475/165	subp.	885	-	890	IA
IV-91	138/43	pris.	981	-	986	III
IV-68-3	390/270	sphe.	777	-	781	IA
IV-68-4	560/385	sphe.	741	-	758	IA
II-57-2	275/200	sphe.	845	-	860	IA
IV-72	2440/1440	sphe.	956	-	957	III

\* max.=maximum dimension, min.=minimum dimension

\*\* sphe.=spherical, subp.=subprismatic, pris.=prismatic

\*\*\* IA : original composition; IB : replaced by Ag; II : Hg-bearing electrum; III : weathered composition

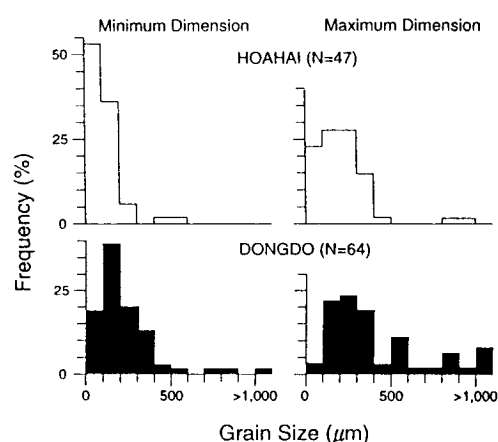
Size distribution is more or less normal about the mode although a very subtle coarse skew is apparent. The size and size distribution show somewhat differences at Dongdo and Hoahai : at Dongdo, predominant relatively larger and wide distribution; at Hoahai, characteristic relatively finer (mostly, < 200  $\mu\text{m}$  in minimum dimension; 90 %) and narrow distribution range ( $\leq 100$  to 400  $\mu\text{m}$  in maximum dimension; 95%) (Fig. 3).

Grain shapes are suggested by sphericity and roundness. Gold grains from the area are characteristic generally subrounded to rounded with rare angular. Therefore, the morphology of gold grains from the area represents sphericity assumed by the maximum to minimum dimension ratio. The grains were divided into the following four general morphological groups: spherical (to semispherical) (maximum-to-minimum ratio, < 2.0); subprismatic

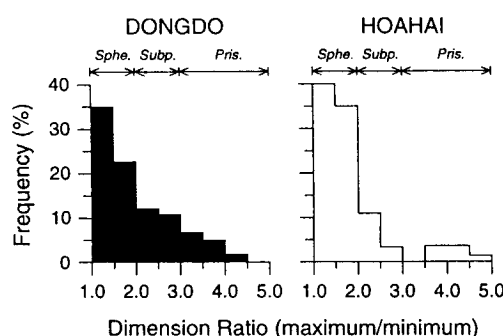
**Table 2.** Representative physical and chemical data for placer gold grains from the Hoahai mineralized zone.

Specimen and grain no.	Size* (max./min, micro meter)	Shape**	Fineness (weight percent)			Type***
III-1-1	340/160	subp.	944	-	951	III
III-1-2	700/330	subp.	944	-	948	III
III-1-5	505/125	pris.	942	-	944	III
III-1-6	500/220	subp.	702	-	770	II
			936	-	940	III
IV-3-1	600/160	pris.	923	-	996	III
IV-3-2	610/135	pris.	901	-	-	IA
			791	-	860	II
IV-30-1	720/200	pris.	636	-	643	IB
			979	-	990	III
IV-20-2	1720/1000	sphe.	981	-	994	III
IV-20-3	650/350	sphe.	991	-	997	III
IV-10-4	240/160	sphe.	671	-	720	II
IV-10-9	120/100	sphe.	666	-	686	II
IV-10-11	340/300	sphe.	926	-	945	III
IV-10-12	340/260	sphe.	945	-	946	III
IV-10-13	500/250	sphe.	946	-	947	III
IV-10-14	730/540	sphe.	681	-	-	II
			942	-	945	III
IV-10-15	670/550	sphe.	681	-	686	II
			943	-	-	III
IV-10-16	140/90	sphe.	941	-	944	III
IV-11-5	285/150	sphe.	948	-	951	III
IV-11-6	450/330	sphe.	943	-	944	III

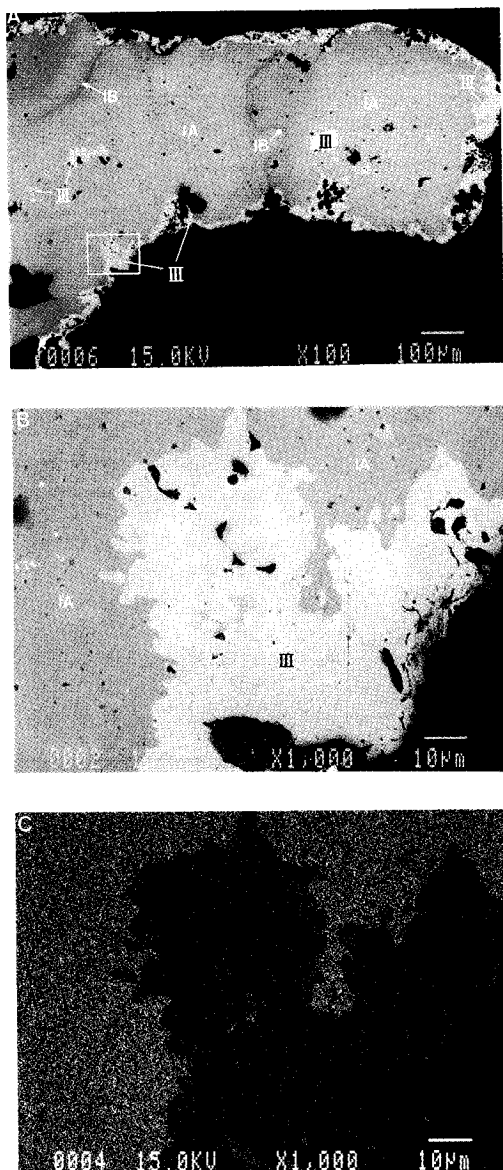
Abbreviations are the same as in Table 1.

**Fig. 3.** Size distribution of gold grains in the Huongkhe area.

(maximum-to-minimum ratio, 2.0 to 3.0); prismatic (maximum-to-minimum ratio, >3.0); and irregular. Some grains of thin subrounded to rounded discoids are observed in the area and included also to spherical group. The irregular form is often produced by tearing of spherical (including discoids) gold grains. The morphological distribution is represented

**Fig. 4.** Sphericity distribution of gold grains in the Huongkhe area. Abbreviations; Sphe.=spherical, Subp.=subprismatic, Pris.=prismatic.

in Figure 4. The gold grains at Dongdo show wide morphological distribution (spherical, 58%; subprismatic, 23%; prismatic, 14%; irregular, 5%). On the other hand, gold grain of spherical form is predominant (75%) at Hoahai (subprismatic, 14%; prismatic, 8%; irregular, 3%). Size and morphological distributions in the area may suggest that the transport distances of placer gold grains at Hoahai are relatively farther than those at Dongdo.



**Fig. 5.** Backscattered-electron and X-ray images of a representative grain of placer gold from Dongdo mineralized zone, Huongkhe area. (A) Backscattered-electron image showing rims (and inclusions) of high-purity gold (type III gold, brighter zones) developed on the lower fineness, lower contrast core (type IA and/or IB golds). Boxed area (in A) enlarged under high magnification (B), and X-ray image for Ag<sub>Mg</sub> (C).

### Mineralogy

Gold is sometimes associated with pyrite, sphalerite, and galena. Gersdorffite, Au-Bi, Ag-Te

(-Au), and Pb-Bi-Cu-bearing sulfosalts rarely occur as tiny inclusions in gold grain. Some covellite and hematite inclusions, and goethite masses occur as products of weathering around gold grain.

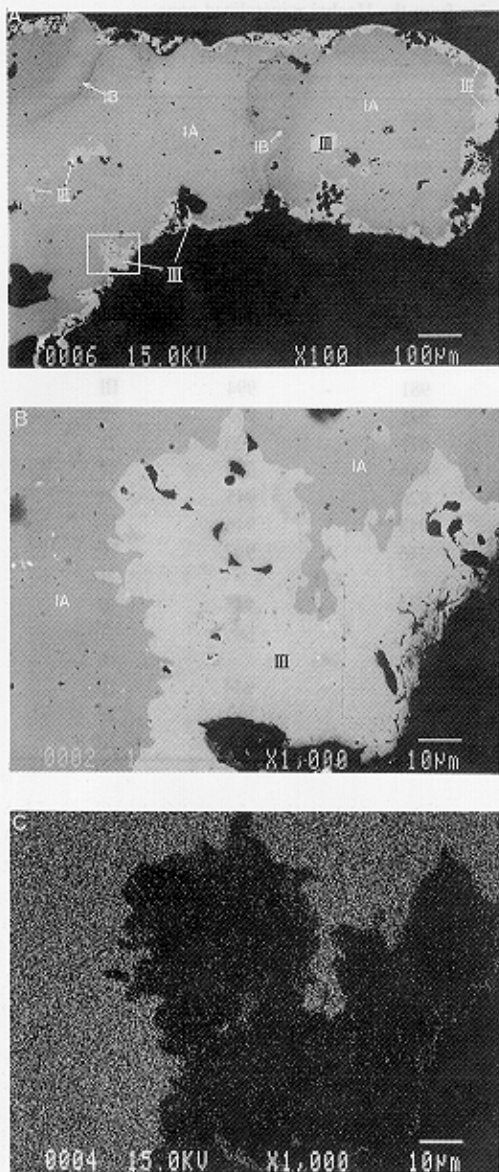
Many of the grains examined in this study are compositionally inhomogeneous, with distinct cores and rims. In the following descriptions the term "rim" is used for all parts of a grain which lie outboard of an optically or analytically discernible core (Fig. 5A and 5B). Rims either completely or partially enclose grain cores and, in most cases, have lower silver contents (Fig. 5C). Cores typically have irregular, ragged boundaries with the grain rims, but some grains with rounded cores occur only. Determination of grain structure was facilitated by element scans (Au, Ag, and/or Hg) and element mapping with the electron microprobe.

Three main types of golds were optically observed, and are classified herein based on their chemistries (Ag and Hg contents in gold), combined with their ore microscopy (i.e., occurrence behavior). They are as follows: type I gold (electrum), type II gold (amalgam), and type III gold (pure gold). Electrum (type I) and pure gold (type III) occur predominantly at Dongdo, whereas amalgam (type II) and pure gold (type III) are observed commonly at Hoahai.

Type I gold contain relatively high and variable silver contents ( $\approx 11$  to 58 atomic % Ag; Table 3), and have been classified into two subtypes (type IA and IB) based on their nature of occurrence and/or silver contents. Type IA electrum grains are often rimmed by a 10  $\mu\text{m}$ -wide (mean value) margin of type III pure gold (having deep gold color) and have lower silver contents ( $\approx 11$ –39 atomic % Ag) than those of type IB ( $\approx 40$ –58 atomic % Ag). Type IB is not common and occurs mainly along fractures and grain margins of type IA. Sometimes, type IA and type IB golds display intergrowth and equigranular mosaic textures. However, type I gold would have been generally original compositions of electrum which originated at the provenance deposits.

Type II gold (amalgam) represents a Au-Ag-Hg mineral having variable Hg contents (1.2–30.5 atomic % Hg). It occurs mainly along fractures and margins of type I and III grains, and shows worm-eaten texture and/or irregular lobate surface (Figs. 6 and 7). Type II occurs often as small ( $\approx 30 \mu\text{m}$ ) isolated grain, and rare droplets in type III grains. The amalgam is relatively abundance at Hoahai zone.

Type III gold as a pure gold ( $<10$  atomic % Ag) occurs mainly as about 10  $\mu\text{m}$ -wide rimmed form along margins and fractures (healed fractures) in type I gold grains and rarely contains pyrite, galena or gersdorffite inclusions. It would be resulted from



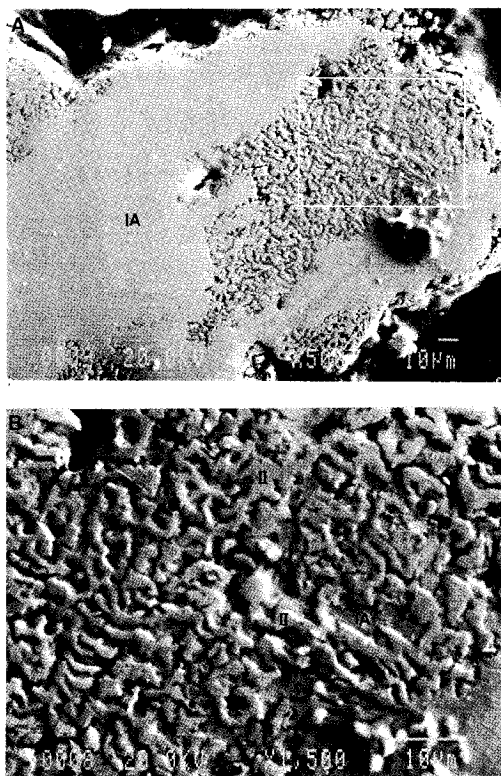
**Fig. 5.** Backscattered-electron and X-ray images of a representative grain of placer gold from Dongdo mineralized zone, Huongkhe area. (A) Backscattered-electron image showing rims (and inclusions) of high-purity gold (type III gold, brighter zones) developed on the lower fineness, lower contrast core (type IA and/or IB golds). Boxed area (in A) enlarged under high magnification (B), and X-ray image for  $\text{Ag}_{K\alpha}$  (C).

**Table 3.** The chemical data (atomic % Au) concerning placer gold grains in the Dongdo and Hoahai mineralized zone.

Zone	Type	Average	S.D.*	Range			N**
Dongdo	Type IA	75.6	7.5	60.8	-	88.0	109
	Type IB	49.3	4.3	41.8	-	59.4	11
	Type II	76.2	9.7	65.4	-	91.8	4
	Type III	96.5	3.3	87.3	-	99.9	89
Hoahai	Type IA	79.0	4.3	74.7	-	83.2	2
	Type IB	49.2	0.4	48.9	-	49.6	2
	Type II	71.1	5.0	65.5	-	84.5	15
	Type III	91.6	3.0	86.8	-	99.4	51

\* Standard deviation

\*\* Number of spot analyses by electron microprobe

**Fig. 6.** SEM photomicrograph of type II gold showing irregular lobate texture.

preferential dissolution of silver and mercury from gold grains during weathering and transport.

## CHEMICAL COMPOSITIONS

### Analytical Techniques

Gold grain chemistry was determined with a JEOL Superprobe JXA-8600 SX with three-channel detecting

system, using 20-KV accelerating voltage and a 2  $\mu$ m beam diameter. Both wavelength dispersion (quantitative) and energy dispersion (qualitative) analysis was used. Pure metal standards were used for gold and silver, and crystalline cinnabar for mercury. Interference between Au and Hg peaks was avoided by setting both background positions for Au and Hg (Youngson and Craw, 1995). Conventional ZAF correction procedures, incorporating the  $\alpha$ -factor (for Au-Ag electron) were used.

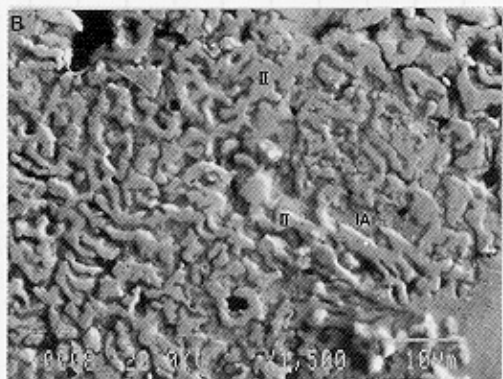
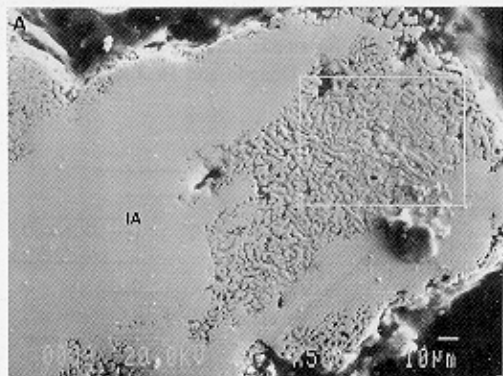
### Fineness

Lindgren (1911) stated, "observations in all parts of the world have shown that placer gold is always compositionally finer than the gold in the quartz veins from which the placers were derived". The purity of gold increases with the time spent in a placer or with the distance from the source (Koshman and Yugay, 1971). They suggested that the increasing fineness resulted from the selective solution and removal of silver from the placer gold.

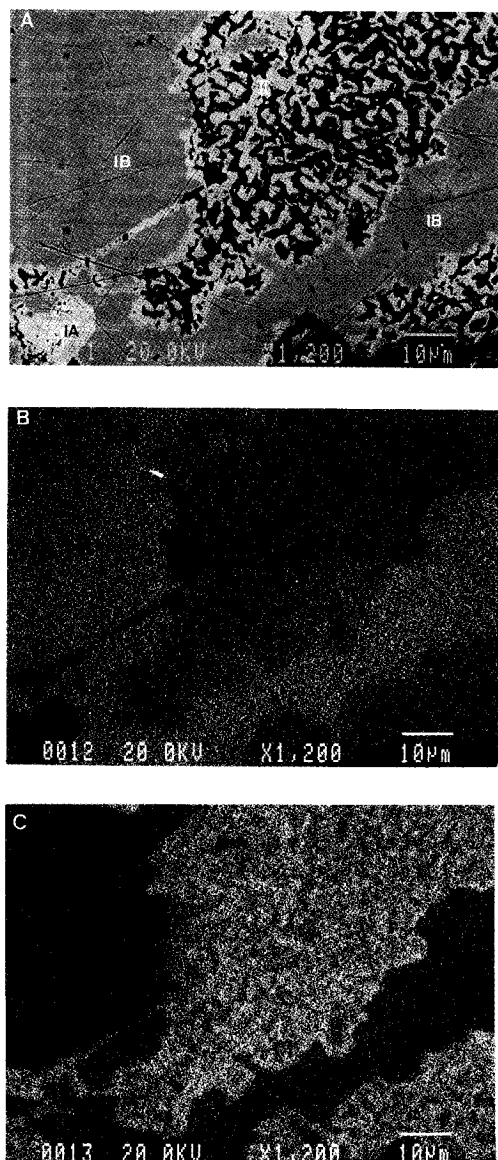
Gold from the Dongdo and Hoahai mineralized zones occurs mainly bound to silver (up to 58.2 atomic % Ag) and mercury (up to 30.5 atomic % Hg) in varying proportions and as native gold (>85 atomic % Au) (Fig. 8). Mercury is a highly mobile element which easily reacts with gold and silver to form amalgam. At Dongdo and Hoahai, the term amalgam has been designated to gold-silver alloys with mercury contents above the detection limit of Hg (1.0 wt. %).

Compositions are presented as weight proportions in parts per 1,000 (the fineness  $F = \text{Au}/(\text{Au} + \text{Ag}) \times 1,000$ ) of individual gold grains. Mercury was incorporated into the equation for grains containing Hg (amalgam of type II gold). Fineness variations were studied in three ways, namely: 1) in gold grains of samples collected throughout the Dongdo and Hoahai zones, 2) in gold grains of each type,





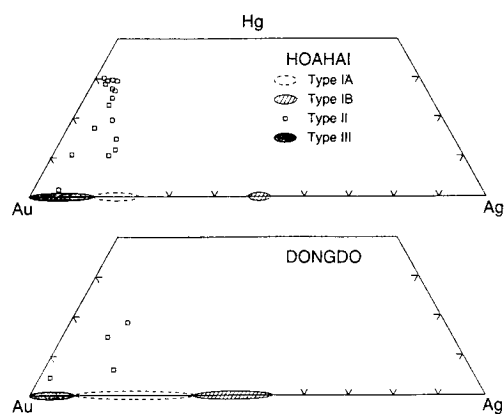
**Fig. 6.** SEM photomicrograph of type II gold showing irregular lobate texture.



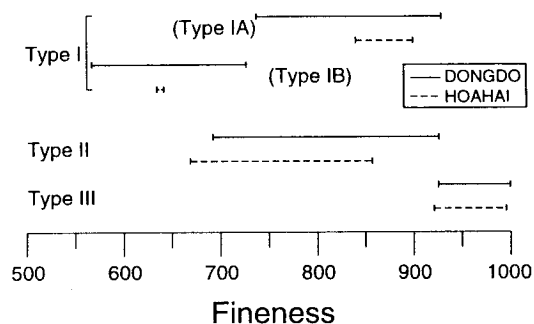
**Fig. 7.** (A) Backscattered-electron image showing development of removal of silver from core of type IB from Hoahai mineralized zone, Huongkhe area. X-ray image for Ag<sub>Mα</sub> (B) and Hg<sub>Lα</sub> (C).

and 3) in individual gold grains. Compositions for the various types of golds from Dongdo and Hoahai zones are represented in Figure 9.

Fineness variations of gold grains were studied in polished sections made from samples collected at Dongdo and Hoahai mineralized zones of the Huongkhe area. In each of the samples up to 120 allogenic gold grains were analyzed and the fineness



**Fig. 8.** Au-Ag-Hg triangular diagrams showing compositional variations (in atomic percent) of type IA, IB, II and III gold grains from Dongdo and Hoahai mineralized zones, Huongkhe area.

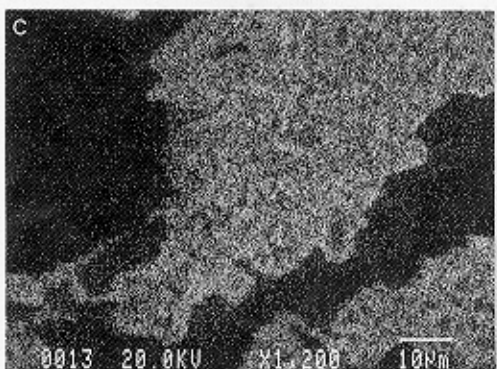
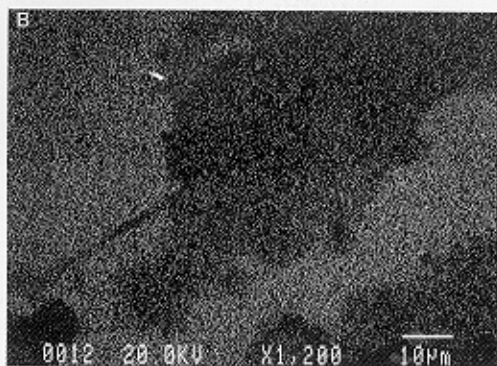
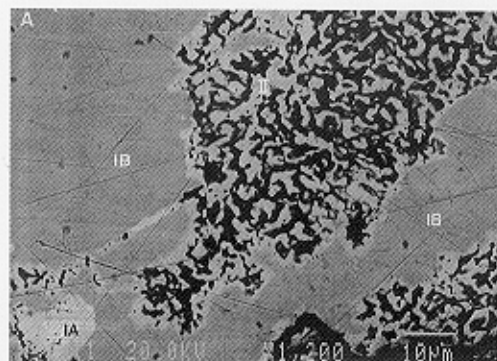


**Fig. 9.** Fineness values of type I, II and III golds from Dongdo and Hoahai mineralized zones, Huongkhe area.

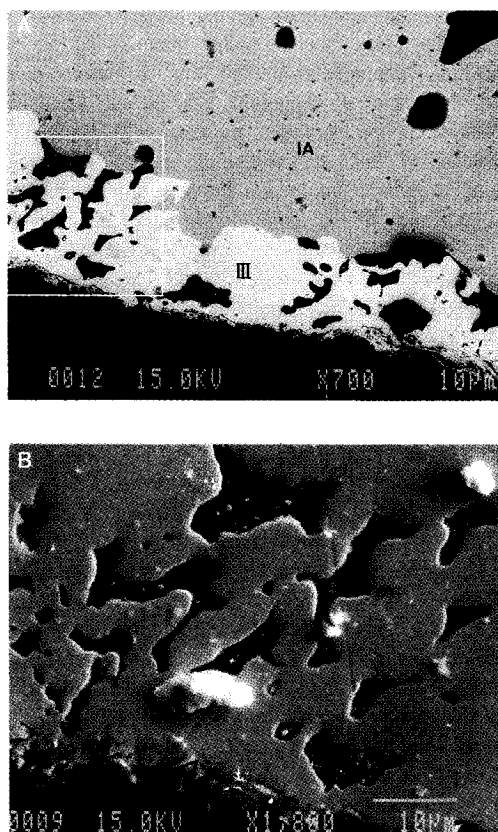
calculated (Tables 1 and 2). The fineness values of gold grains at Dongdo and Hoahai range from 568 to 999 and from 636 to 997, respectively.

Figure 9 reveals that the fineness values of each type gold from Dongdo and Hoahai zones. Each type of gold shows significantly different fineness values (type I, 568~931; type II, 671~927; and type III, 923~999). The fineness values for type III gold are higher than type I gold, and those of type II are variable. These are probably attributable to silver leaching and effect of mercury contents.

Silver homogeneity and heterogeneity in individual gold grains was probed by microprobe spot analyses. Individual gold grain occurs mainly two different fashions, the first, single grain composed almost one type (commonly type I and rarely type II or III) showing silver homogeneity; and the second, has enriched gold rims on nuggets resulted in silver leaching (and/or enriching mercury) and showed



**Fig. 7.** (A) Backscattered-electron image showing development of removal of silver from core of type IB from Hoahai mineralized zone, Huongkhe area. X-ray image for  $\text{Ag}_{\text{Mr}}$  (B) and  $\text{Hg}_{\text{Mr}}$  (C).

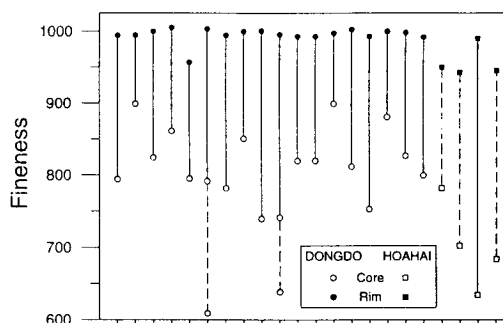


**Fig 10.** Backscattered-electron image (A) and scanning electron image (B) showing finely porous textures with development in embayments and pits on surface (B; boxed area in A).

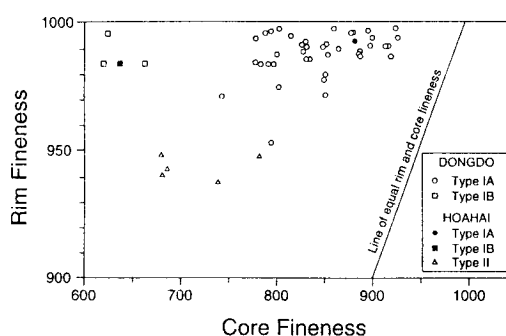
silver heterogeneity (Figs. 5 and 7). A limited number of gold grains displaying intergrowth and equigranular mosaic textures between type IA and type IB golds. These show also somewhat silver heterogeneity (the fineness value range from 739 to 931 for type IA gold and from 568 to 728 for type IB gold).

The present work revealed, furthermore, the comparison of the fineness values of single gold nuggets having enriched gold rims. The clarity and thickness of the rims is highly variable, but a typical example is shown in Figures 5 and 10. The distribution of the Au and Ag in the rim and core of some grains is shown in Figure 11. Almost all of the rims exhibit purities in excess of 950, and are a deep gold color. The sharpness of the boundary between the rim and the core is apparent in the optics (Figs. 5 and 10).

The compositions of coexisting rim-core pairs in



**Fig. 11.** A plot of 22 randomly picked gold grains from the Huongkhe area, showing the range of core fineness and the presence of gold-rich rims developed on grains with a fineness of less than about 900. Dashed line represents fineness range of type II gold.



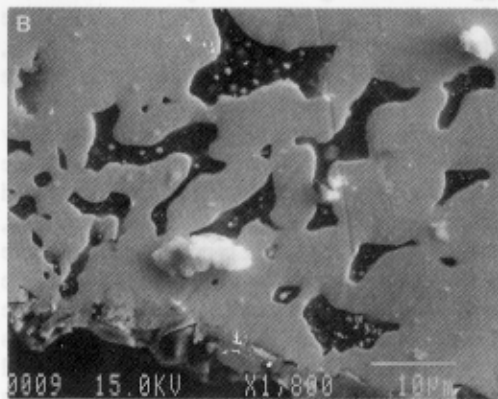
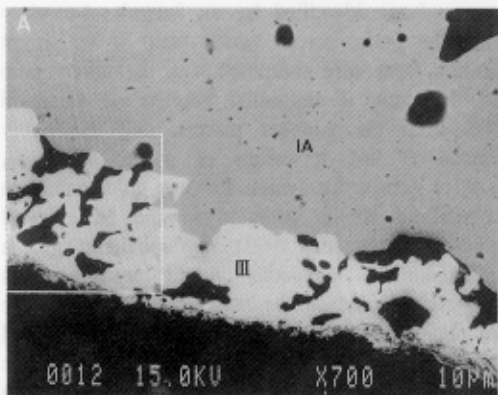
**Fig. 12.** Scatter plot of rim versus core compositions of placer gold grains from the Huongkhe area.

this study are presented in Figure 11. There is no strong relationship between the composition of the core and the potential for rim development. The scatter of rim compositions (Fig. 12) also indicates that there is no real relationship between the purity of the gold-rich rim and the composition of the underlying electrum core.

## DISCUSSION

### Silver Leaching

The origin of gold-rich rims of the type III described and illustrated above on gold grains from placer deposits is not known with certainty, but is probably related to the observations of gold crystals and crusts. Generally, three possible explanations for the origin are: 1) preferential dissolution of silver from the grain surface during the weathering and transport process (Desborough, 1970; Groen *et al.*,



1990; Santosh *et al.*, 1992; Youngson and Craw, 1995), 2) a self-electrorefining process where the electrum at the grain-solution interface dissolves, and the gold immediately precipitates back onto the surface of the placer grain (Groen *et al.*, 1990), 3) new (or young) gold precipitation on the edges of nuggets attributed as crystal growth of gold or as a result of electrochemical leaching (Warren, 1982; Wilson, 1984; Giusti, 1986).

A process of preferential dissolution of silver from the Au-Ag alloy is occurred by the relative solubilities of Au and Ag in low temperature solutions, which is the most commonly invoked mechanism and is not whole mechanism for the development of gold-rich rims. Desborough (1970) suggested that "oxidation of silver from the metal to the ion reduces its size and affords the needed mobility for removal from its site in the alloy, and it is thus placed in solution. The porosity resulting from continued silver removal provides a new interface in the gold-silver alloy for a repetition of the process". Preferential dissolution of silver from the margin of gold grains because there is no means by which the solutions can physically extract the silver from more than the outer few angstroms of the grain and silver diffusion would be far too slow to develop rims of the type observed (Groen *et al.*, 1990). Therefore, self-electrorefining of placer gold grains is also a process that can produce gold rich rims.

Electrorefining is a hydrometallurgical process in which a multicomponent alloy is electrochemically dissolved, with the subsequent precipitation of a generally pure phase of the most noble dissolved metal (Groen *et al.*, 1990). The driving force for this process is an electrochemical potential as a result of the electromotive force between two dissimilar metals in a solution whose Eh is higher than that in which the starting alloy is stable. Mann's (1984) results with synthetic alloys indicate that placer gold grains can oxidize, releasing dissolved Ag and Au into solution. Once in solution, the less electropositive dissolved Au species accepts the available electrons at the gold-rich areas on the electrum surface, and immediately precipitates. The more easily oxidized silver is washed away. Thus, a combination of self-electrorefining and preferential dissolution of silver can explain the formation of gold-rich rims on the placer gold grains at Dongdo and Hoahai. Using either a preferential dissolution of silver or self-electrorefining mechanism, silver leaching is main process for gold-rich rim development. Leached margins are present on some of the gold grains from the Dongdo and Hoahai

zones and are identified by an irregular boundary within the grain, across which there is an abrupt transition from core composition to essentially pure gold. Leaching is suggested because of the gold grains from the younger placers, and the rarely presence of tiny inclusions of pyrite, sphalerite, galena or gersdorffite within the pure gold. Although authigenic pyrite is common in the host gravel sequences (Youngson, 1995), rare sphalerite, galena or gersdorffite inclusions would argue against authigenic addition of the pure gold. Type III pure gold occurs rarely as inclusion enclosed in type I gold (Fig. 5A) and as replacing form along the healed fractures within type I gold. These also suggest leaching. Leaching has occurred preferentially around the grain margins, along the healed fractures and in the vicinity of small fissures, and often results in a finely porous texture on the grain surface (Fig. 10) (Youngson and Craw, 1995).

The timing of silver leaching cannot be conclusively determined. The occurrences of hematite with covellite and goethite as alteration products in (or around) gold grains suggest that oxidizing nature dominated, at least, during the last mineralization period at the provenance deposits and/or during the transport process in the studied area. Significant oxidizing nature during the last mineralization period at the provenance deposits is not surprising in the relatively shallow hydrothermal system. Many detailed studies of gold in lode deposits have demonstrated that the grains are characteristically homogeneous; Craig (1990) knows of no reports of gold-rich rims developed on gold grains in lodes. Accordingly, it seems that the rims develop after lode gold has weathered from its originally enclosing rock (Groen *et al.*, 1990). Therefore, these may suggest that leaching occurred under relatively reducing stream water conditions during the transport process.

The thickness of the gold-rich rims (as leaching portion) is highly variable, but the rims at Hoahai is thicker (about 10 to 50 % of each grain) than those at Dongdo (about 5~15 % of each grain). Furthermore, gold grains showing fineness homogeneity represented as type III pure gold occur at Hoahai. These phenomena coupled with the process of silver leaching (Groen *et al.*, 1990) suggest that the transport distances (and/or time) of placer gold grains at Hoahai are generally farther than those at Dongdo zone.

### Mercury Content

At Dongdo and Hoahai, mercury reacts with gold and silver to form amalgam (type II gold). The type II gold in the area has variable Hg contents (1.2~30.5 atomic % Hg). The mercury contents in gold grains

at Hoahai (10.9–30.5 atomic % Hg) are higher than those at Dongdo (5.8–21.1 atomic % Hg). Furthermore, type II amalgam occurs commonly at Hoahai but found only four grains at Dongdo. There are a general increasing tendency of mercury contents in detrital gold grains with increasing transport distances or in a direction toward the center of basin (Oberthür and Saager, 1986).

The recent studies of placer gold, especially in the Appalachians, have revealed the common presence of mercury as a contaminant on many gold grains (Craig, 1990). No mercury occurrences are known along the gold-bearing zones in the Appalachians, but mercury commonly was employed during gold recovery. The type II (amalgam) gold (containing relatively high and variable Hg contents; up to 30.1 atomic % Hg, unpublished data) commonly occurs at the provenance vein deposits in the Hoahai zone. So, the mercury may originated from the Hg-bearing minerals as representing primary ore mineralization at the provenance deposits. Therefore, the mercury contents of the gold grains in the studied area are influenced by an abundance of mercury mineralization between the provenance deposits at Dongdo and Hoahai, but can not rule out the small contribution of mercury contamination. There is absence of any correlation between the silver and mercury contents of the type II gold.

Mercurian gold has been reported from several gold deposits (Basu *et al.*, 1981; Nysten, 1986; Shikazono and Shimizu, 1988). The nature of the opaque minerals coexisting with mercurian gold suggests relatively low  $a_2$  conditions. Shikazono and Shimizu (1988) indicate that the gold mineralization including mercurian gold occurred under lower  $a_2$  and slightly higher temperature than the more common epithermal gold-silver vein-type deposits in Japan. Therefore, the provenance deposits at Dongdo and Hoahai would be suggest nearest epithermal gold-silver vein-type.

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## 베트남 홍케 지역 사금의 산상과 생성연구

최상훈 · 최선규 · 한진균

**요 약 :** 베트남 홍케 광화대의 동도 및 호아하이 지역으로 부터 채취된 사금은 일반적으로 세립질로서, 동도 지역 사금은 호아하이 지역에 비하여 상대적으로 큰 입도와 낮은 분급도의 경향성을 보여준다. 이들 사금 입자의 산출 형태는 장경과 단경의 비에 의하여 spherical, subprismoidal, prismoidal 및 irregular로 분류 할 수 있으며, spherical form이  $\approx 75\%$ 인 호아하이 지역에 비하여 동도 지역 사금 입자들의 형태는 다양하게 관찰된다. 이러한 산상에 의하면, 동도지역에 비하여 호아하이지역 사금의 이동거리 (또는 시간)가 길었던 것으로 추정된다. 이들 사금은 그 화학조성에 의하여 electrum (type I, fineness=568~931), amalgam (type II, fineness=671~927), native gold (type III, fineness=923~999) 등으로 분류된다. Type I은 그 산출특성에 따라 상대적으로 낮은 함은량 (11~39 atomic % Ag)을 갖는 type IA와, 상대적으로 높은 함은량 (40~58 atomic % Ag)을 갖는 type IB로 세분되며, 이는 기원광상산 electrum의 화학조성을 보여주는 것으로 사료된다. Type II는 주로 호아하이지역에서 산출되며, 함수은량은 동도지역의 사금이 낮은 경향을 보여준다. Type III는 주로 type I 또는 type II 사금입자의 가장자리에 산출한다. 이들 type III의 gold-rich rim은 이동과 풍화과정중 산화환경에서 야기된 self-electrorefining과 silver의 preferential dissolution에 기인된 것으로 사료된다. 홍케지역 사금중 적어도 일부 높은 함수은량을 보이는 경우는 합금은 천열수 광상과 유사한 환경에서 생성된 기원광상으로부터 유래되었을 것으로 추정된다.