Yixunite and Damiaoite—A Twin of New Native Alloys of Indium and Platinum from the Yanshan Mountains

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Abstract Yixunite and damiaoite were found in a cobalt– and copper–bearing platinum ore vein of a contact metasomatic deposit. The chief ore minerals are bornite, chalcopyrite, magnetite and carrollite. The platinum minerals include moncheite, sperrylite, daomanite, cobalt malanite and cooperite. Yixunite and damiaoite occur as immiscible globules, 1.0 to 2.0 mm in diameter. Yixunite is always in the central part of a globule. It is opaque with metallic lustre, bright white colour and black streak. $H_M = 5.8$; $VHN_{50} = 634$ kg / mm^2 (573–681 kg / mm^2); insoluble in HCl, HNO_3, HF or H_3PO_4; no cleavage; no magnetism. Density is hard to measure because of small grain size. Calculated density = 18.21 g / cm^3. Reflective colour is bright white with a yellowish tint. Isotropic. The mean analytical results (ranges) (%) are: Pt 82.8 (81.8–83.6), In 16.4(15.6–17.1) and total 99.2. The empirical formula (based on 4 atoms) is $Pt_{2.993}$ $In_{1.007}$. The five strongest lines of X–ray diffraction (*hkl, d, I*) are 111, 2.30 (100); 200, 1.99 (60); 202, 1.411 (40); 311, 1.203 (80); 222, 1.151(40). Space group: *Pm3m* with a = 0.3988(3) nm and Z = 1. Damiaoite occurs as single globules or was exsolved from yixunite. Opaque with metallic lustre; bright white colour with black streak; $H_M = 5.3$; $VHN_{50} = 485$ kg / mm^2 (434–529 kg / mm^2); insoluble in HCl, HNO_3, HF or H_3PO_4; cleavage: no; magnetism: no. Density: hard to measure because of small grain size. Calculated density = 10.95 g / cm^3. Reflective colour is bright white with a yellowish tint. Isotropic. The mean analytical results (ranges) (%) are Pt 45.6 (45.4–46.0), In 53.5 (52.4–53.9), total 99.1. The empirical formula (based on 3 atoms) is $Pt_{1.002}$ $In_{1.998}$. The six strongest lines of X–ray diffraction (*hkl,d,I*) are 220,2.25 (100); 311,1.92 (60); 400,1.59 (60); 422,1.299 (80); 440,1.125 (60); 620,1.006 (70). Space group: *Fm3m* with a = 0.6364 (3) nm and Z = 4.

Key words: yixunite, damiaoite, new native alloys, cobalt– and copper–bearing platinum ore vein, contact metasomatic deposit

A small number of yixunite globules were found in 1972 and a preliminary study was published in 1974 (Yu, 1974). Supplementary work was done during 1978–1990 after more samples were gathered and then damiaoite was discovered (Yu, 1978). Since some new samples were collected, more data of detailed physical and chemical properties of these two

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minerals were obtained. Yixunite was named after its locality, which is near the Yixun River running across the ore district. Damiaoite is also named after the locality, which is near Damiao Village close to the Yixun River in Hebei Province, about 270 km northeast of Beijing.

Yixunite and damiaoite and their names all have been approved by the Commission on New Mineral and Mineral Names (CNMMN) of the International Mineralogical Association (IMA) in January 1996. The approval numbers are 95–042 and 95–041 respectively. The new mineral materials are deposited at the Geological Museum of China (GMC) in Beijing.

1 Occurrence

Yixunite and damiaoite were found in a cobalt– and copper–bearing platinum ore vein of a contact metasomatic deposit (a contact zone of pyroxenite with plagioclasite), which is a new type of platinum deposit (Platinum Group, Institute of Geology and Mineral Resources, 1976). The chief ore minerals are bornite, chalcopyrite, magnetite and carrollite. They are also associated with PGM such as moncheite, sperrylite, daomanite, cobalt malanite and cooperite. Yixunite and damiaoite were found in ores and also from heavy concentrates of crushed ores. They occur as globules (product of complexes in hydrothermal solution), 1.0–2.0 mm in diameter, which are intimately associated with each other. Yixunite is always situated in the central part of a globule.

2 Physical and Optical Properties

Both the minerals are opaque with a metallic lustre. Colour: steel black. Streak: black. Yixunite: Hm=5.8; VHN_{50}=634 kg / mm^2 (573–681 kg / mm^2). Damiaoite: Hm=5.3; VHN_{50}=485 kg / mm^2 (434–529 kg / mm^2). No cleavage; no fracture. Density could not be measured because of small grain size. The calculated density is 18.21 g / cm^3 for yixunite and 10.95 g / cm^3 for damiaoite. Malleability: weak. No magnetism. Etching

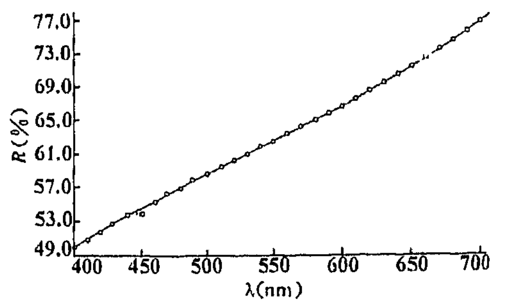

Fig. 1. Dispersion curve of the reflectance for yixunite.

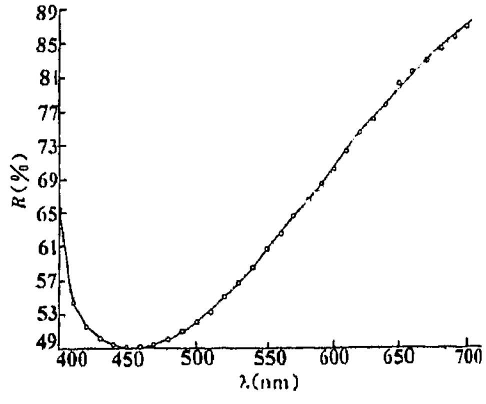

Fig. 2. Dispersion curve of the reflectance for damiaoite.

test: insoluble in HNO_3, HCl or H_3PO_4. Reflective colour: bright white with a yellowis tint. No internal reflection. Isotropic. Anisotropism and pleochroism: no. The reflectanc values were measured with a Zeiss MPM 400 microphotometer using WTiC as th standard, which are shown in Tables 1 and 2. The dispersion curves of the reflectances ar given in Figs. 1 and 2.

Table 1 Reflectance values for yixunite

λ (nm)	R (%)	λ (nm)	R (%)	λ (nm)	R (%)
400	49.9	510	59.3	620	68.4
410	50.8	520	60.1	630	69.4
420	51.7	530	60.9	640	70.3
430	52.7	540	61.7	650	71.3
440	53.8	550	62.5	660	72.4
450	54.5	560	63.3	670	73.4
460	55.3	570	64.1	680	74.5
470	56.1	580	64.9	690	75.5
480	56.9	590	65.7	700	76.6
490	57.5	600	66.5		
500	58.5	610	67.5		

S_E R_{vis} 63.4; x 0.3527; y 0.3476; λd 581.9; Pe 0.102. S_A Rvis 64.3; x 0.4640; y 0.4104; λd 583.8; Pe 0.185. S_C Rvis 63.1; x 0.3285; y 0.3315; λd 580.3; Pe 0.091.

Table 2 Reflectance values for damiaoite

λ (nm)	R (%)	λ (nm)	R (%)	λ (nm)	R (%)
400	65.4	510	53.2	620	74.5
410	54.2	520	55.0	630	76.0
420	51.4	530	56.7	640	77.7
430	50.1	540	58.5	650	80.1
440	49.3	550	60.6	660	81.5
450	49.0	560	62.5	670	82.8
460	49.0	570	64.6	680	84.2
470	49.3	580	66.5	690	85.6
480	49.9	590	68.5	700	86.9
490	50.8	600	70.2		
500	52.0	610	72.2		

S_E Rvis 62.2; x 0.3702; y 0.3513; λd 587.0; Pe 0.165. S_A Rvis 65.0; x 0.4802; y 0.4080; λd 592.6; Pe 0.231. S_C Rvis 62.3; x 0.3456; y 0.3367; λd 585.3; Pe 0.151.

3 Chemical Composition

At first an Edax–9900 energy dispersive spectrometer was used for qualitative analysis and then JCMA–733 and EPMA–8705 electron microprobes were used for quantitative analysis with working voltage 20kV. The analyses were performed at a constant electronic current and a beam current of 1.0×10^{-8} amp, using pure metals indium and platinum as the standards. A simultaneous quantitative analysis for two elements was done on two crystals with the spectral line Pet for InKα and LiF for PtMα. Eight chemical analytical data for yixunite, corrected by ZAF, are shown in Table 3. The mean analytical results (ranges) (wt%) are In 16.4 (15.6–17.1), Pt 82.8 (81.8–83.6), total 99.2 (98.7–99.6). The empirical formula (based on 4 atoms) is $In_{1.007}$ and $Pt_{2.993}$. The simplified formula is $InPt_3$ with theoretical compositions being $In_{16.4}$ and $Pt_{83.6}$. Nine chemical analytical data for damiaoite are shown in Table 4. The mean analytical results (ranges) (wt%) are In 53.5 (52.4–53.9), Pt 45.6 (45.4–46.0), total 99.1 (98.8–99.5). The empirical formula (based on 3 atoms) is $Pt_{1.002}$ and $In_{1.998}$. The simplified formula is In_2Pt.

Table 3 Electron probe analyses data (%) for yixunite

No.	1	2	3	4	5	6	7	8	Average
Pt	83.2	83.6	83.1	81.8	83.2	82.0	82.8	83.6	82.9
In	16.3	16.0	16.3	16.9	15.9	17.1	16.2	15.6	16.3
Total	99.5	99.6	99.4	98.7	99.1	99.1	99.0	99.2	99.2

Table 4 Electron probe analyses data (%) for damiaoite

No.	1	2	3	4	5	6	7	8	9	Average
Pt	45.4	46.0	45.5	46.0	45.5	45.6	44.9	45.6	45.7	45.6
In	53.6	52.8	53.6	52.4	53.7	53.7	54.5	53.9	53.4	53.5
Total	99.0	98.8	99.1	98.4	99.2	99.3	99.4	99.5	99.1	99.1

4 X–ray Crystallography

Single–crystal X–ray studies could not be carried out because of small crystal size. X–ray powder diffraction patterns of yixunite and damiaoite were obtained by Mn–filtered Fe radiation with a 57.3 mm Debye camera. The powder diffraction lines of yixunite are listed in Table 5, which resemble artificial In $Pt_3C_{0.5}$ (JCPDS, 1989a). The strongest X–ray powder diffraction lines for yixunite (*hkl,d,I*) are 111, 2.30(100); 200, 1.99(60); 202, 1.411(40); 311, 1.203(80) and 222, 1.151(40). The data were indexed and yixunite was determined to be cubic with space group *Pm3m*. The corrected powder data are a=0.3988(3) nm and Z=1. The powder diffraction lines of damiaoite are also listed in Table 5, which resemble artificial In_2Pt (JCPDS, 1989b). The strongest X–ray diffraction lines for damiaoite (*hkl,d,I*) are 220, 2.25(100); 311,1.92(60); 400,1.59(60); 422,1.299(80); 440,1.125(60); 620,1.006(70). The data were indexed and damiaoite was determined to be cubic with space group *Fm3m*. The corrected powder data are a=0.6364(3) nm and Z=4.

5 Discussion

Yixunite and damiaoite occur in garnet hornblende–pyroxenite (at the contact zone of pyroxenite with plagioclasite) in cobalt– and copper–bearing platinum ore veins. The deposit is a contact metasomatic one, which has not been reported in the world so far. Yixunite and damiaoite consist of two elements, indium and platinum. Indium is actually a dispersed element and platinum a rare element, but the alloys of these two elements were discovered in this deposit. What is the cause for forming the two new alloys in the deposit? The author first of all thinks that indium and platinum are chalcophile elements. This deposit is rich in copper and thus the ore is likely rich in indium and platinum. Besides, the atomic radius of indium is 1.57 Å (1 Å $=10^{-1}$ nm) and that of platinum is 1.38 Å, so they

Table 5 X–ray powder diffraction data for yixunite and damiaoite

Yixunite I	Pt_3In $d_{(meas.)}$	$Pm3m$ $d_{(calc.)}$	a 0.3988 nm hkl	*Damiaoite* I	$PtIn_2$ $d_{meas.}$	$Fm3m$ $d_{(calc.)}$	a 0.6364 nm hkl
5	3.99	3.988	100	50	3.67	3.68	111
4	2.82	2.812	110	10	3.18	3.18	200
100	2.30	2.302	111	5	2.30②		
5	2.25①			100	2.25	2.25	220
60	1.99	1.994	200	3	2.00②		
3	1.92①			60	1.92	1.92	311
8	1.78	1.783	210	10	1.84	1.837	222
5	1.62	1.628	211	60	1.59	1.591	400
40	1.41	1.410	220	40	1.46	1.460	331
10	1.33	1.329	221;300	20	1.421	1.423	420
3	1.300①			80	1.299	1.2990	422
10	1.262	1.261	310	40	1.225	1.2248	511;333
80	1.203	1.202	311	5	1.203②		
40	1.151	1.151	222	60	1.125	1.1250	440
3	1.130①			50	1.076	1.0757	531
6	1.105	1.106	320	70	1.006	1.0062	620
10	1.067	1.066	321				
20	0.997	0.997	400				

① Mixed with lines of damiaoite; ② mixed with lines of yixunite.

tend to form native alloys provided chemical and physical conditions are appropriate. For further discussions on the genetic mechanism, we must understand that yixunite, damiaoite and platinum minerals such as sperrylite, moncheite and cooperite in the deposit all have the appearance of liquid drops but yixunite and damiaoite are especially typical. The author considers that this is a phenomenon of immiscibity, which often occurs in magmatic deposits rather than hydrothermal deposits. The author thus puts forward a view: the occurrence of drop–like minerals in hydrothermal deposits is due to the presence of PGE complexes in mineralizing solutions. (Common platinum complexes are $[PtCl_2 \cdot (NH_3)_2]$ and $[Pt(NH_3)_4]Cl_2 \cdot H_2O$ and common indium complexes are $[InCl_3 \cdot NH_3]$ and $[InCl_3 \cdot (3NH_3]$.) Platinum and indium complexes will form complexes of yixunite or damiaoite in ore solutions and be separated out from the solutions when temperature becomes lower, but their crystallization occurs after the crystallization of rock–forming or ore–forming minerals such as cupric sulphide. During cooling of the drop–like complexes, platinum is concentrated in the central part of a globule while indium in its periphery. Therefore yixunite appears in the centre of a globule and damiaoite in the periphery. Moreover, a significant number of worm–like damiaoite crystals were found in yixunite.

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References

Joint Committee on Powder Diffraction Standards, 1989a. Powder Diffraction File (28–472). ICDD. USA.

———, 1989b. Powder Diffraction File (3–0949). ICDD. USA.

Platinum Group Institute of Geology and Mineral Resources, 1976. Platinum–bearing Basic–Ultrabasic Rocks and features of Platinum Deposits and Minerogenesis. *Dizhi Kuangchan Yanjiu* (1): 15–43 (in Chinese).

Robert, C. (ed.), 1970–1971. Handbook of Chemistry and Physics, 51st. Ohio: The Chemical Rubber Co., p.165.

Yu Tsu–Hsiang, Lin Shu–Jen, Chao Pao, Fang Ching–Sung and Huang Chi–Shun, 1974. Some New Minerals of the Platinum Group and Another Associated New One. In: Platinum–bearing Intrusions in a Region of China. *Acta Geological Sinica*, (2): 202–214 (in Chinese with English abstract).

Yu Zuxiang, 1978. Supplement for Yixunite. *Acta Geological Sinica*, (4):320 footnote (in Chinese with English abstract).

Explanation of Plates

Photographs 1–8 of Plate I are all back–scattered electron image photos.

1. Globule yixunite is surrounded by damiaoite. ×500.
2. Characteristic PtLα X–ray picture of Photo 1. ×500.
3. Characteristic InLα X–ray picture of Photo 1. ×500.
4. Globule yixunite is surrounded by damiaoite.
5. Characteristic InLα X–ray picture of Photo 4
6. Banded damiaoite (greyish black) separated out from a yixunite globule (grey).
7. Worm–like damiaoite (grey black) in a yixunite globule (white)

Photographs 1–9 of PlateII (except 4 and 5) are all back–scattered electron image photos.

1. Globule damiaoite
2. Globule damiaoite (grey) and yixunite (white).
3. Globule yixunite is surrounded by damiaoite.
4. Characteristic InLα X–ray picture of Photo 3.
5. Characteristic PtMα X–ray picture of Photo 3.
6. Grain and plate damiaoite (grey black) separated from yixunite (grey).
7. X–ray powder diffraction pattern of yixunite.
8. X–ray powder diffraction pattern of damiaoite.

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