



Article Mineralogy and Geochemistry of JingFenCui (Rhodonite Jade) Deposit from Beijing, China

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Abstract: JingFenCui is a type of rhodonite jade from the Changping district of Beijing, China, which is a manganese skarn deposit formed through the metasomatism of the granite aplite and Cambrian limestone. The pink color of JingFenCui is richer and brighter than that of rhodonite jade from other deposits. The surface of JingFenCui exhibits dendritic iron and manganese oxides, which is the outstanding advantage of rhodonite jade for carving works. The zoning pattern of mineralogy between the contact zone with the wallrock is obvious. The main skarn minerals consist mainly of spessartine, diopside, augite, manganotremolite, clino-suenoite, rhodonite, galena, etc. Compared with rhodonite jade from the Makeng in Fujian and the Luziyuan in western Yunnan, vittinkiite (MnSiO₃) is more concentrated in the rhodonite of the JingFenCui Deposit as a Mn-Ag-Pb-Zn-Fe polymetallic deposit. There is a good agreement among the rhodonite, amphibole, and galena in the spider diagrams of the trace elements. The results of trace elements and REE analysis show that the metallogenic fluids of the JingFenCui deposit is a manganese skarn deposit formed through the metasomatism of the manganese-bearing limestone and fine-grained granite of the Heixiongshan.

Keywords: JingFenCui; rhodonite; manganese skarn; trace elements

1. Introduction

JingFenCui is the commercial name for rhodonite jade from the Changping district of Beijing, China [1]. It has an attractive pink color and high hardness. In addition to Beijing, rhodonite jade is also found in Qinghai, Shannxi, Sichuang, Taiwan, Fujian, and Yunnan, etc. [2]. The color of JingFenCui is rose-red, pink, or fuchsia, with some white, gray, yellow, or brown lumps, or dendritic Fe-Mn oxides locally distributed. Due to its medium transparency, JingFenCui is often processed into ornaments such as cabochon, bracelets, or larger pieces, which have been very popular in worldwide jewelry markets since the 1960s [1]. In this research, we first conducted systematic mineralogical examinations on JingFenCui to determine its gemological characteristics, mineral compositions, and geochemical characteristics, using a polarized light microscope, electron microprobe analysis (EMPA), and inductively coupled plasma mass spectrometer (ICP-MS).

2. Geological Setting

The JingFenCui deposit is located in Changping district, Beijing. With a paragenetic Mn-rich garnet, it is a typical manganese skarn deposit found in the contact zone between



Citation: Kang, Z.-J.; Shi, G.-H.; Lei, W.-Y.; An, C.-X.; Liu, L.; Liu, S.-H.; Lu, F.; Xu, L. Mineralogy and Geochemistry of JingFenCui (Rhodonite Jade) Deposit from Beijing, China. *Crystals* **2022**, *12*, 483. https://doi.org/10.3390/ cryst12040483

Academic Editors: Taijin Lu, Fei Liu and Tingting Gu

Received: 28 February 2022 Accepted: 29 March 2022 Published: 31 March 2022

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Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). Yanshanian granitic fine-grained rock and Cambrian manganese-bearing limestone [3]. The JingFenCui rhodonite deposit is located in the southeast of the Jundushan magmatic belt in the western part of the Yanshan platform fold belt of the North China platform. Folds and faults are developed, magmatic activity is strong, and geological conditions are complex. The Mesozoic intrusive rocks in the deposit are characterized by multistage activities, and the exposed rocks are mainly Heixiongshan granite, Heishanzhai monzonite, Humen (Xihu) syenite, and Xuejiashiliang and Shangzhuang diorite [4,5] (Figure 1).



Figure 1. The regional geological map of JingFenCui deposit (modified after Di, Y.-L. [4]).

The mining area is divided into eastern and western sections. The eastern section is dominated by Mn-ore and Pb-Zn ore. Mn-ore was predatorily mined during the period of Japanese invasion in China [3]. Ag-ore was mined in the western section. The rhodonite deposits occur locally in the eastern section. Due to the small scale of the rhodonite deposits, Mn-ore is currently mined with an annual output of about 20,000 tons [6].

3. Samples and Methods

A representative sample of the contact zone between rhodonite jade ore and the wallrock was selected (JFC-01), as well as some rhodonite ore and galena-bearing rhodonite ore. All samples were from the Changping district of Beijing, China and labeled as JFC-01 to JFC-06. In total, six samples were selected to observe the regular gemological characteristics, i.e., color, refractive index, transparency, luster, and texture (Figure 2).



Figure 2. Photos of JingFenCui rough materials.

The color of JingFenCui is from pink to fuchsia. The samples are of granular texture, massive structure, and translucent-to-opaque. The crystal faces of rhodonite with cleavage development can be seen on the fresh sample surface (Figure 2, JFC-03). The conchoidal fracture in the samples shows a greasy luster, and the polished-sample surface shows a vitreous luster (JFC-05). In the hand specimen, transparent and subtranslucent colorless granular minerals are visible, showing patchy or veinlet distribution, without bubbles after hydrochloric-acid dripping. The veinlet length is less than 2 cm, and the width is less than 0.5 cm. The white granular mineral lump area is less than 2×3 cm² with a rapid bubble escape after hydrochloric-acid dripping. The refractive index is 1.74–1.76, and the specific gravity is 3.10–3.62.

From the outside to the inside, four zones are divided according to the change of mineral compositions in JFC-01. The outermost region of the contact zone between rhodonite and the wallrock is Zone-A, followed by Zone-B, C, and D (JFC-01). Five polished thin sections from JFC-01 (JFC1-4) and JFC-02 (JFC5) were analyzed for mineral compositions and texture type at the China University of Geosciences, Beijing (CUGB), using an Olympus BX51 polarizing microscope in transmitted light (Tokyo, Japan). The photomicrographs were taken using a digital camera. The mineral compositions and backscattered electron (BSE) images were acquired using electron microprobe analysis (EPMA-1600) at the Laboratory Center, China University of Geosciences, Beijing, China. The analytical conditions employed an accelerating voltage of 15 kV, a beam current of 10 nA, and a beam diameter of 1–5 mm. EMPA standards include minerals: andradite for Si and Ca, rutile for Ti, corundum for Al, hematite for Fe, rhodonite for Mn, periclase for Mg, albite for Na, K-feldspar for K. Standard samples adopted the national standard of silicate minerals. The detection limit of a single element is about 0.01%. Using the data measured by EPMA, the oxygen-atom method was applied to calculate the cation numbers of each element of different minerals. The samples of amphibole, rhodonite, and galena were coarsely crushed; the purer single crystals were selected by naked eye and microscope, and ground into 200 mesh. The samples were melted by four-acid digestion. Trace-element and rare-earth-element (REE) compositions of major minerals were obtained using a 7900 inductively coupled plasma mass spectrometer (ICP-MS) at Hebei Research Center for Geoanalysis, China. The relative errors of the measured values of the samples were less than 10%, and the analysis errors of most trace elements were within 5%.

4. Results

4.1. Petrographic Characterization

4.1.1. Texture and Compositions

The mineral changes in the contact zone between JingFenCui jade and the wallrock are obvious. The main observations of textural relations and petrography are described below. (1) Carbonates and Quartz

In the contact zone near the side of the limestone, porphyritic carbonates are commonly distributed (Figure 3a). Anhedral-granular quartz can be found around carbonates. The carbonates and quartz are also distributed in veinlets or lumps in JingFenCui ores.



Figure 3. Characteristics of JingFenCui under polarizing microscope (crossed-polarized light): (**a**) carbonate (Cbn), quartz (Qtz), and spessartine (Sps); (**b**) spessartine and pyroxene (Px) at the junction of Zone B and Zone C; (**c**) amphibole (Am) of fiber-columnar and sheet structure in Zone C; (**d**) parallel and near-rectangular cleavage of rhodonite; (**e**) inclusions of quartz, carbonates, and spessartine are present in rhodonite (Rdn); (**f**) quartz-rimmed spessartine encased in rhodonite.

(2) Spessartine

Megascopic spessartine is light yellowish-brown, anhedral-granular, with a mosaic texture, and without cleavage. Spessartine exhibits extremely strong positive relief with irregular cracks on the surface and full extinction under cross-polarized light (Figure 3b).

(3) Pyroxene

Pyroxene is idiomorphic-hypidiomorphic-granular, with second- to third-order interference color, showing a metasomatic-dissolved texture under cross-polarized light (Figure 3b).

(4) Amphibole

Columnar or fibrous-columnar amphiboles with rhombic transverse sections are directionally distributed with foliaceous structures (Figure 3c). The dissolved traces can be seen on the surface of amphiboles.

(5) Rhodonite

Rhodonites are light pink, light orange, thick-tabular and coarse-grained. Cleavage is developed in rhodonite by parallel or near-rectangular cleavage angles. Rhodonite exhibits high positive relief. The common interference color is first-order, and second-order interference color is occasionally observed (Figure 3d). Inclusions of quartz, carbon-ates, and spessartine are present in rhodonite. Quartz-rimmed spessartine is encased in rhodonite (Figure 3e,f).

4.1.2. Backscattered Electron (BSE) Observations

Some residual carbonates and quartz are found in spessartine in Zone B (Figure 4a), and some irregular residual spessartine and quartz are found in rhodonite in Zone D (Figure 4b). Pyroxene in Zone C is idiomorphic-hypidiomorphic-granular, with a metasomatic-dissolved texture (Figure 4c). The amphibole in Zone C is long-columnar and needle-columnar. The dissolved traces can be seen on the surface of amphiboles (Figure 4d).



Figure 4. BSE images of JingFenCui: (**a**) carbonate (Cbn), quartz (Qtz), and spessartine (Sps) in Zone B; (**b**) rhodonite (Rdn), quartz, and spessartine in Zone D; (**c**) carbonate (Cbn) and pyroxene (Px) in Zone C—Pyroxene is idiomorphic-hypidiomorphic-granular with metasomatic-dissolved texture; (**d**) the amphibole (Am) is long-columnar, needle-columnar in Zone C. The dissolved traces can be seen on the surface of amphiboles.

4.2. Electron Probe Microanalysis

4.2.1. Manganocalcite

According to EPMA (1600) data obtained from two points (Table 1), carbonates in Zone A (limestone) and Zone B are mainly manganocalcite.

Table 1. Electron microprobe analyses of rhodonite and other minerals wt %.

Samples	Mineral	SiO ₂	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Al_2O_3	TiO ₂	Total
JFC1-1	Manganocalcite	0.21	0.69	13.17	0.61	45.49	N.D.	N.D.	N.D.	N.D.	60.17
JFC3-8	Manganocalcite	N.D.	0.36	8.18	0.19	47.95	0.02	0.01	N.D.	0.36	56.71
JFC1-2	Spessartine	33.76	4.21	33.73	N.D.	10.41	N.D.	N.D.	16.94	0.64	99.68
JFC1-3	Spessartine	31.56	7.01	39.49	1.34	4.03	N.D.	N.D.	16.94	0.22	100.59
JFC1-4	Augite	47.8	7.9	13.65	10.77	19.06	N.D.	N.D.	N.D.	0.19	99.36
JFC2-2	Diopside	49.72	5.85	10.16	12.15	22.24	0.08	0.15	N.D.	N.D.	100.36
JFC2-4	Diopside	51.12	4.83	11.33	10.14	21.56	0.08	0.13	0.06	0.1	99.34
JFC2-5	Augite	52.34	4.75	9.34	12.18	20.91	0.28	0.11	N.D.	N.D.	99.91
JFC2-1	Manganotremolite	52.92	7.79	14.22	17.09	6.95	0.88	0.46	N.D.	N.D.	100.31
JFC3-2	clino-suenoite	52.23	7.56	16.13	18.08	5.26	N.D.	0.18	0.08	N.D.	99.53
JFC3-4	clino-suenoite	55.2	7.99	15.52	16.42	4.08	0.11	0.16	N.D.	N.D.	99.49
JFC3-5	Manganotremolite	56.22	5.52	12.98	18.08	6.61	0.19	0.22	0.11	0.04	99.96
JFC3-6	Manganotremolite	56.21	5.29	11.09	19.66	6.65	0.12	0.03	0.31	0.08	99.44
JFC3-7	clino-suenoite	56.13	6.3	12.63	17.68	5.86	0.21	0.08	0.37	0.02	99.29
JFC4-1	Rhodonite	38.59	6.32	47.18	3.1	4.61	0.1	0.04	N.D.	0.05	100
JFC5-1	Rhodonite	38.75	5.62	46.62	1.37	7.62	0.17	N.D.	N.D.	N.D.	100.16
Shangxian, Shaanxi [7]	Rhodonite	40.92	2.39	40.79	2.13	5.45	0.02	N.D.	1.32	0.006	99.24
Makeng, Fujian [8]	Bustamite	47.72	4.47	27.98	1.09	16.99	N.D.	N.D.	0.1	0.01	98.36
Luziyuan, Yunnan [9]	Rhodonite	47.01	2.85	40.19	0.28	8.17	N.D.	N.D.	0.04	0.02	98.55
India [10]	Rhodonite	45.46	0.96	50.54	0.55	2.25	N.D.	N.D.	0.27	N.D.	100.03
New Zealand [10]	Rhodonite	46.42	1.60	47.62	0.92	3.26	N.D.	N.D.	0.07	N.D.	100.07
Sweden [10]	Rhodonite	47.78	14.62	29.20	1.93	6.55	N.D.	N.D.	0.08	N.D.	100.05

4.2.2. Spessartine

Garnet in Zone B shows high manganese content. The content of MnO is between 33.73 and 39.49 wt %, with an average value of 36.61 wt % (Table 1). The content of SiO_2 is between 31.56 and 33.76 wt %.

4.2.3. Rhodonite

The main mineral composition of JingFenCui was rhodonite in Zone D. Three points of EPMA data for the main chemical compositions of rhodonite were tested. The content of SiO₂ was between 38.59 and 38.75 wt %; the content of MnO was between 46.62 and 47.18 wt %; the content of FeO was between 5.62 and 6.32 wt %; the content of CaO was between 4.61 and 7.62 wt %; and the content of MgO was between 1.37 and 3.10 wt % (Table 1).

4.2.4. Pyroxene

Four points of EPMA data for the main chemical compositions of pyroxene in the contact zone were tested (Table 1). The content of SiO₂ was between 47.8 and 52.34 wt %; the content of MnO was between 9.34 and 13.65 wt %; the content of CaO was between 19.06 and 22.24 wt %; the content of MgO was between 10.14 and 12.18 wt %; and the content of FeO was between 4.75 and 7.9 wt % (Table 1). Obviously, the pyroxene contains high MnO content. Ca and Mn occupy mainly the M2 sites. The M1 sites were occupied mostly by Mg, Mn, and a small amount of Fe. The Wo-En-Fs graph illustrates that the pyroxene in Zone C belongs to manganese-bearing diopside and augite (Figure 5).



Figure 5. Diagram for classification of pyroxene in JingFenCui: Wo—wollastonite; En—enstatite; Fs—ferrosilite (modified after Morimoto, N. [11] and Liu, X.F. et al. [12]).

4.2.5. Amphibole

Six points of EPMA data for the main chemical compositions of amphibole in contact zone were tested (Table 1). The content of SiO_2 was between 52.23 and 56.22 wt %; the content of MnO was between 11.09 and 16.13 wt %; the content of CaO was between 4.08 and 6.95 wt %; the content of MgO was between 16.42 and 19.66 wt %; and the content of FeO was between 5.29 and 7.99 wt %.

According to the occupancy of the B sites as calculated arithmetically [13–16], when $0.50 < B (Mg^{2+} + Fe^{2+} + Mn^{2+} + Li^+) < 1.50$ and $0.50 \le B (Ca + Na) \le 1.50$ a.p.f.u., the amphibole is a member of the sodium-calcium-magnesium-iron-manganese-lithium group. Among the amphibole minerals in this experiment, the T sites are mainly occupied by Si (>7.00). The B sites are occupied mainly by Mn, Ca, and a small amount of Na. In C sites, few Mn and Fe replace Mg, Mg/(Mg + Fe²⁺) ≥ 0.5 . When ^BCa > 1 > ^BMn > 0.5, the amphibole belongs to manganotremolite (Figure 6), and when ^BMn > 1 > ^BCa > 0.5, it belongs to clino-suenoite (Figure 7).





Figure 6. Diagram for classification and nomenclature of amphibole series with Ca.





4.3. Trace Elements and REE in Rhodonite, Amphibole, and Galena

In order to understand the similarities and differences of the trace-element concentrations in minerals, the trace-element and rare-earth-element concentrations in rhodonite and adjacent amphibole and galena were tested (listed in Table 2). Primitive mantle-normalized trace-element diagrams and chondrite-normalized REE patterns are shown in Figures 8 and 9, respectively. Normalizing values are after Sun and McDonough (1989) and Boynton (1984) [17,18].

Table 2. Trace elements and REE compositions (ppm) of the modonite, amphibole, and galer	Table 2. Trace elements	and REE con	npositions	(ppm)	of the 1	rhodonite	, amphibole	e, and	galena
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Mineral	Amphibole1	Amphibole2	Rhodonite1	Rhodonite2	Galena	Heixiongshan Granite [19]
Li	25.3	37.3	0.59	0.15	4.32	N.D.
Be	0.14	0.13	2.48	1.31	0.02	N.D.
Sc	6.40	6.55	0.77	0.49	0.55	1.33
Cr	5.07	5.84	3.68	4.05	2.70	15.0
Co	0.00	0.20	0.87	0.34	0.62	0.27
Ni	0.82	0.95	2.34	1.23	1.87	4.75
Cu	2.84	1.07	1.98	3.07	182	N.D.
Ga	16.5	18.6	4.52	3.90	3.78	22.1
Rb	6.74	6.56	8.37	6.60	0.35	185
Sr	26.2	37.2	15.6	14.4	25.9	19
Zn	17.2	7.61	1107	1393	2803	N.D.
Pb	175	225	366	523	14962	24.8
Th	20.2	16.9	1.14	0.91	0.36	24.4
U	5.37	4.41	2.93	1.13	0.22	4.39
La	17.0	28.0	1.49	1.05	6.97	38.3
Ce	22.1	34.7	3.60	3.12	9.34	36.0
Pr	1.36	2.32	0.49	0.46	0.92	5.63
Nd	3.35	5.59	2.77	2.81	3.72	14.1
Sm	0.41	0.87	0.47	0.54	0.53	1.67
Eu	0.04	0.04	0.51	0.55	0.40	0.15
Gd	0.72	0.82	0.57	0.63	0.73	1.70
Tb	0.17	0.15	0.09	0.11	0.14	0.30
Dy	1.26	1.05	0.46	0.51	0.78	1.97
Ho	0.37	0.31	0.09	0.10	0.16	0.46
Er	1.32	1.09	0.22	0.22	0.38	1.69
Im	0.26	0.21	0.03	0.03	0.05	0.31
Yb	1.88	1.50	0.17	0.15	0.28	2.41
Lu	0.34	0.28	0.03	0.02	0.04	0.39
Y	9.89	8.06	2.49	2.82	4.50	13.8
∑ REE	50.5	76.9	11.0	10.3	24.4	105
LKEE	44.2	71.5	9.33	8.53	21.9	95.8
HKEE	6.32	5.42	1.67	1.77	2.56	9.23
LKEE/HKEE	7.00	13.2	5.57	4.81	8.53	10.4
δEu SC-	0.20	0.16	3.01	2.90	1.96	0.27
oCe	11.2	11.2	1.94	1.49	4.18	5.89
Y/Ho	26.8	26.4	27.9	28.5	28.0	29.9



Figure 8. Spider diagrams of trace elements in JingFencui deposit (primitive mantle normalization values after Sun and McDonough, 1989 [17]).



Figure 9. REE patterns of the mineral in JingFenCui deposit (c1 chondrite normalization values after Boynton, 1984 [18]).

(1) The contents of Cu, Zn, and Pb in rhodonite and amphibole were significantly lower than those in galena with a certain positive correlation, indicating that the formation of rhodonite and amphibole were earlier than that of galena. Skarn minerals such as garnet, pyroxene, amphibole and rhodonite were formed by early high-temperature fluid metasomatism of carbonate rock. With the change in physicochemical conditions such as temperature and PH, the fluid evolved continuously, and the metal sulfide began to precipitate.

(2) Total REE content of rhodonite was between 10.3~11.0 ppm; the LREE/HREE ratio was 4.81~5.5,7 showing obvious differentiation. Rhodonite had positive δ Eu values of 2.90~3.01 and δ Ce values of 1.49~1.94 without obvious anomalies. The REE characteristics of galena were similar to those of rhodonite by relatively strong fractionation of LREE and HREE [20,21]. The amphibole had strong negative δ Eu values of 0.16~0.20. As it can be seen, LREE were relatively enriched in rhodonite, amphibole, and galena.

(3) Primitive mantle-normalized trace-element diagrams show enrichment in Th, U, and Li (Figure 8). The normalized value of Sr was close to 1. Except for Eu, the diagrams show good consistency, indicating similar sources of minerals which were the product of the same metallogenic fluid. The order of the five curves in Figure 8 is consistent with the position of the sample from the outer wallrock to deep galena.

(4) Chondrite-normalized REE patterns of minerals show generally right-leaning Vshaped patterns with enriched LREE and depleted HREE (Figure 9). There are Xuejiashiliang, Heishanzhai, Heixiongshan, Shangzhuang, and Humen rock masses near the JingFenCui deposit [4]. In comparison, it can be seen that the characteristics of trace elements and REE patterns of JingFenCui deposit are consistent with those of the Heixiongshan rock mass.

5. Discussion

(1) The pink color of rhodonite jade is generally attributed to Mn ions. The Mn content of rhodonite in JingFenCui is the highest in China, but slightly lower than that in India and New Zealand. The color of JingFenCui is rose-red, pink, or fuchsia [6], which is richer and brighter than that of rhodonite jade from other Chinese places. Rhodonite jade from Luziyuan in western Yunnan contains dust-dot iron and manganese [22], while the iron and manganese in JingFenCui are dendritic, which displays an outstanding appearance after carving. According to the quality classification of JingFenCui, purple red is preferred, and dendritic black manganese-oxide distribution would enhance the artistic value [7]. Due to the coarser textures, JingFenCui belongs to medium-grade jade.

(2) Manganic skarns always occur in carbonate rocks with a certain distance from the causative intrusions, and are closely related to Pb-Zn mineralization [23]. Manganic skarns and associated mineralization are typically zoned at the deposit to district scales. The minerals in the contact zone between JingFenCui and the wallrock have obvious alteration, and are affected by composition zoning [24,25]; the mineralogy zones in the contact zone can be divided into four zones, named Zone A, Zone B, Zone C, and Zone D based on the distance away from the wallrock. Quartz and manganocalcite are the dominant minerals present in Zone A (limestone). Zone B is mainly distributed by spessartine, and locally by manganocalcite and quartz remnants. Zone C is mainly composed of diopside and augite, manganotremolite, and clino-suenoite. Zone D is mainly distributed with rhodonite, containing inclusions of spessartine and quartz. From Zone A to Zone D, the structure of silicate minerals change from island to chain and complex chain. In general, spessartine, pyroxene, and amphibole formed in the early stage of skarnization, whereas rhodonite and galena formed in the late stage. The mineralization of JingFenCui shows an obvious mineral zoning pattern. Spessartine, Mn-rich pyroxene, and Mn-rich amphibole are distributed in the alteration zone between rhodonite and the wallrock, forming characteristic zone patterns from limestone \rightarrow alteration zone \rightarrow rhodonite \rightarrow Pb-Zn-Ag deposit [2].

(3) Compared with the bustamite [8] from skarns in the outer contact zone of the Makeng iron deposit in Fujian Province and the rhodonite from Luziyuan in Yunnan Province [9], the rhodonite from the JingFencui deposit is more enriched with $MnSiO_3$ (vittinkiite) and depleted of $CaSiO_3$ molecules, which is similar to that from Shizhuyuan in Hunan Province [26], India, and New Zealand [10]. According to Wang's (1998) study and the EPMA date (JFC1-1,3-8), Mn in JingFenCui ore is mainly provided by the wallrock, which is different from the source of Mn in other rhodonite deposits, and the metallogenic hydrothermal fluid is mainly from magma. By comparison, distribution patterns of rareearth elements and trace elements of the skarn minerals in JingFenCui show considerable similarity to the Heixiongshan granite nearby, indicating that the causative intrusion is associated with Heixiongshan granite, which is also known as Heixiongshan iron granite, showing relative Th- and U- enrichment, an obviously negative Eu anomaly, and depletion of MREE. The composition of source rock of Heixiongshan is close to that of the upper crust, with its origin depth at about 23~50 km [19]. Heixiongshan granite has fine medium-grained textures; a massive structure; main minerals including potassium feldspar, plagioclase, and quartz; and an age of 123.7 Ma [27]. The similarity of REE composition

characteristics of skarn minerals in JingFenCui and Heixiongshan granite indicates contact metasomatism [28]. The metallogenic hydrothermal fluid of the JingFenCui deposit is related to the Heixiongshan granite. Because JingFenCui is located in the transition zone between the Pb-Zn-Ag ore body and the wallrock, the mineral zoning is obvious, and the manganese element of the deposit is mainly derived from limestone, JingFenCui occurs in skarn deposits formed by contact metasomatism of manganese-bearing limestone and Heixiongshan fine-grained granite.

(4) Rare-earth elements are easy to enter the crystal lattice by isomorphism to replace Ca^{2+} , but it is difficult to replace some larger cations such as Zn^{2+} and Pb^{2+} [29]. In the JingFenCui deposit, when magmatic hydrothermal fluid ascends and migrates, it reacts with manganese-bearing limestone via water-rock reaction. Consequently, a large amount of Fe^{2+} and Mg^{2+} enters the wallrock to form skarn minerals such as spessartine, Mn-rich pyroxene, Mn-rich amphibole, and rhodonite. At the same time, rare-earth elements enter the lattice of manganocalcite by isomorphism, and the composition of rare-earth elements is superimposed and reformed. The galena inherits the rare-earth elements of the ore-forming fluid at the same time as the precipitation. The composition characteristics of galena are not easily reformed by later geological processes, which can represent the composition characteristics of rare-earth elements of ore-forming fluids. Due to the same valence state and ionic radius, Y and Ho are considered to have similar geochemical behavior. The Y/Ho values remain unchanged in many geological processes [30]. The Y/Ho values of original magmatic rocks and detrital materials are similar to those of chondrites, ranging from 24 to 34 with an average of 28 [31]. The Y/Ho ratio of modern seawater is high and varies from 44 to 74 [32]. The Y/Ho value of JingFenCui ore is 26.4~28.5, and the Y/Ho values of rhodonite, amphibole, and galena are close. The Y/Ho value of JingFenCui and associated minerals is consistent to that of Heixiongshan granite with an average of 29.9, further indicating that the metallogenic materials are mainly from causative magmatic intrusion.

(5) At present, the formation mechanism of the positive Eu anomaly is still controversial, including magmatic differentiation, water–rock reaction, rock adsorption of Eu^{2+} from fluid, and adsorption of Eu^{2+} -bearing complexes. Meanwhile, the redox environment, temperature, and pH value of rock formation and mineralization are also important conditions for the occurrence of Eu anomalies [9]. Rhodonite and galena show positive Eu anomalies, whereas amphibole shows an obviously negative Eu anomaly. The Eu anomaly shows an increasing trend from amphibole to rhodonite and to galena, and changes from a negative anomaly to weak positive anomaly, which may be caused by the change in metallogenic environment.

6. Conclusions

(1) The JingFenCui mine is a manganese skarn deposit. The contact zone between the rhodonite and the wallrock has a zoning phenomenon from the outside to the inside, and a set of manganese-containing skarn mineral assemblages mainly develops, including spessartite, diopside and augite, manganotremolite and clino-suenoite, rhodonite and galena, etc.

(2) Compared with the mining areas of Makeng in Fujian and Luziyuan in western Yunnan, the JingFenCui deposit is affected by manganese-bearing limestone, and the rhodonite is more enriched in vittinkiite (MnSiO₃) and has a higher manganese content. The JingFenCui deposit and Heixiongshan granite are characterized by high Pb, Zn, etc. The mining area of JingFenCui is a Mn-Ag-Pb-Zn-Fe polymetallic deposit.

(3) The spider diagrams of trace elements of the rhodonite in JingFenCui deposit are in good agreement with those of amphibole in transitional zone and galena at the bottom. The trace elements and rare-earth elements show that the ore-forming fluid of JingFenCui deposit mainly comes from deep magmatic rocks. Based on the geological characteristics of the deposit and previous research results, it is believed that the JingFenCui deposit is formed by the contact metasomatism of manganese-bearing limestone and fine-grained granite of Heixiongshan. **Author Contributions:** Conceptualization, Z.-J.K. and G.-H.S.; data curation, L.L. and F.L.; formal analysis, C.-X.A. and L.L.; methodology, Z.-J.K., G.-H.S. and W.-Y.L.; supervision, W.-Y.L. and C.-X.A.; writing—original draft, Z.-J.K., W.-Y.L. and S.-H.L.; writing—review and editing, Z.-J.K., W.-Y.L. and L.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The content presented here was sourced from existing published literature; hence, this clause is not applicable.

Acknowledgments: We would like to extend our gratitude to Fei Liu, Yan Li, Li-Jun Shi, Meng-Hua Sun, Ye Zhao for providing help during the work in this paper. We would like to thank the Journal Editor for the helpful, detailed comments, editorial changes, and handling; and two anonymous referees for their thoughtful and constructive reviews.

Conflicts of Interest: The authors declare that they have no known conflict of interest.

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