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Discussion on Causes of Ubranium Ore and the Occurrence Characteristics of Ubranium Deposits in Lujing Area

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Abstract: The Lujing uranium ore field is one of the four major uranium ore fields in the Zhuguangshan rock mass. The tectonic position of Lujing uranium ore field is located in the South China multiphase composite Orogenic belt formed by the combination of the Huaxia plate and the Yangtze plate, which belongs to the Wugong-Zhuguang fault uplift area of the Cathaysian plate. The article explores the occurrence characteristics of uranium minerals and the genesis of uranium ore in the deposit by collecting samples from the Lujing uranium ore field, observing and identifying them under an electron microscope, and analyzing and testing them with an electron probe. The uranium minerals in the Lujing uranium deposit are mainly uranite, pitchblende and uranium thorite, all in the form of independent uranium minerals. In addition, a small amount of uranium exists in the form of isomorphism in thorite, Rutile, zircon, Xenotime and other accessory minerals. Uranium ore and pitchblende are the main uranium bearing minerals in the study area. The uranium ore mineral assemblage is mainly composed of four types: uranium ore metal sulfide, uranium ore fluorite, pitchblende uranium ore Pyrite, and uranium ore quartz. The characteristics of the paragenetic assemblage of uranium ore and other minerals reflect that the temperature of uranium mineralization is at the middle low temperature mineralization stage. Uranium ore is mostly formed and reduced in the environment, and the formation age of uranium ore is generally later than that of Pyrite. The main genesis of uranium ore is the transformation of primary uranium ore into pitchblende, which is then converted into uranium ore again through a reducing environment. Uranium in uranium bearing minerals is reactivated to form uranium ore.

Keywords: Electronic Probe, Origin of Uranium Ore, Isomorphism, Paragenetic Association, Uranium Mineral

1. Introduction

Lujing uranium orefield is one of the four major uranium ore fields in Zhuguangshan granite. In the ore field, the lower and middle Cambrian shallow metamorphic rock series, especially the carbonaceous slate rich in organic matter, has a relatively high uranium content [1, 2], and the granites of each stage belong to uranium rich granite [3]. Uranium rich strata or rock bodies provide uranium sources for the formation of ore deposits.

Previous studies in the Lujing uranium ore field have mostly focused on the study of diagenetic and metallogenic ages, ore types, wall rock hydrothermal alteration, self metamorphism and geochemical characteristics of rock masses, fluid inclusions, and genesis of ore deposits. The uranium mineralization age is between 47–128Ma, which is approximately the same as the active time of the tensional shear strike slip fault in the region [4, 5]. The diagenetic age of the late Yanshan granitic porphyry, alkali metasomatic rock and lamprophyre in the region is similar, and the ore-forming fluid originates from the magmatic activity of the late Yanshan period [6]. Xianfu Li et al. divided the ore types into breccia type, disseminated type, and veinlet-stockwork type [4]. Wanliang Zhang et al., Shao Fei etal., Changhe Ding et al. conducted comprehensive research on hydrothermal alteration in the early stage and divided the alteration stages. They believe that ores often develop strong hydrothermal alteration, and high-grade uranium ores often undergo the superposition of multiple alterations. The early alteration has a "acid up and alkali down" alteration rule; During the mineralization period, the main types of alteration are silicification, pyritization (colloidal), hematite mineralization, and carbonation, while in the later stage, the alteration is not developed, including light colored carbonation and fluoritization. It is also pointed out that alteration is an important prospecting indicator. The strong self metamorphism of granite in the area is the main influencing factor for uranium occurrence, migration, and mineralization. The typical phenomenon is a significant decrease in the number of uranium bearing accessory minerals (zircon, uranium-bearing phosphate minerals, etal.) in biotite. The uranium originally existing in these accessory minerals as isomorphism undergoes activation transfer and forms epigenetic uranium minerals, which occur in the internal fractures and grain gaps of mica [7, 8]. During the transformation of biotite into muscovite, the uranium released can reach 84% of the total uranium content of biotite [9]. Another important type of self metamorphism in the Lujing uranium ore field is alkali metasomatism, which can increase the uranium content in rocks, and potassium metasomatism can even increase the uranium content in rocks by 3-4 times [10]. The study of fluid inclusions mainly addresses the physical and chemical conditions for mineralization of uranium deposits, with a uniform temperature range of 90-270°C. Moreover, the mineralization temperature and pressure are related to the acidity and alkalinity of the fluid [6]. In terms of the genesis of uranium, the mineralization temperature is generally accepted as medium to low temperature. Jianwei Li etal. proposed that radioactive decay heat is one of the main ore-forming heat sources [11]. The above research results have basically solved the basic geological problems of the deposits in the ore field, but the study of the occurrence state and genesis of uranium minerals in the deposits has not been involved. In this article, the collected samples were carefully observed and identified under an electron microscope, the occurrence characteristics of uranium minerals in the Lujing uranium deposit are analyzed, and the genesis of uranium ores is discussed.

2. Regional Geological Background

The geotectonic location of the study area is within the South China multiphase composite orogenic belt formed by the amalgamation of the Huaxia plate and the Yangzi plate, It belongs to the Wugong-Zhuguang fault uplift area of the Huaxia plate, Mingan behind the western margin of the Caledonian uplift belt, and Xiangguiyue Beihaixi-Indo inserted part of concave belt, Wanyang - Zhuguangshan The concave turning point of the compound rock mass from north-south to east-west direction [12] (Figure 1).

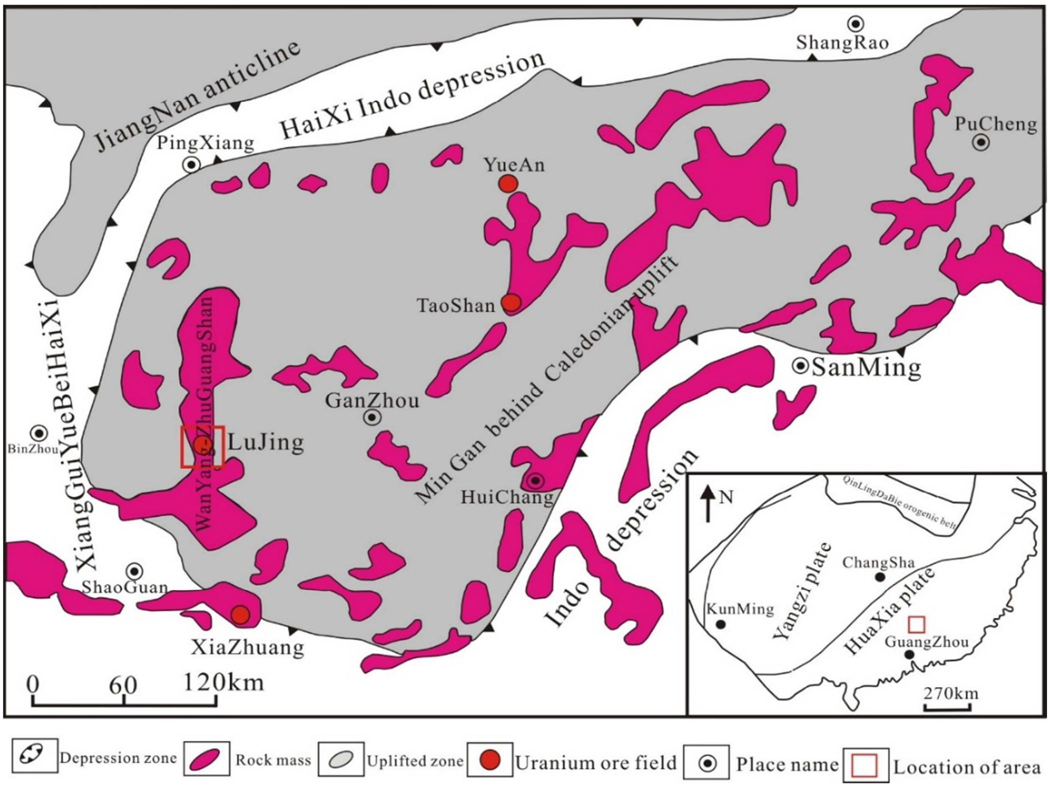

Figure 1. *Tectonic Location Map of Lujing Uranium Deposit (Changed from Deng Ping, 2002; Zhang Min etal., 2006).*

The strata in the area include: The early Proterozoic metamorphic rocks comprise the presinian crystalline basement strata, the pre devonian strata include the simian, Cambrian, ordovician strata, late paleozoic Devonian, carboniferous, Permian, mesozoic jurassic and cretaceous all exposed, In addition, there are also a small number of paleogene and quaternary developed in the area. The magmatic rocks in the area are widely exposed as acidic granite. There are many stages of magmatic intrusion activity, with Caledonian and Yanshan activities being the most intense, The lithology is relatively complex, and the rock walls and veins are also well developed.

Fold structures and faults are the most developed structural styles in the region. The fold structure can be divided into two types: basement fold and jurassic type fold. Fault structures (zones) are well developed, with a large scale, multiple active periods, and complex components, It controls the mineralization of uranium, tungsten, tin beryllium isopolymetallic mineralization. The main fault structures in the area include: The near northeast Suichuan - Reshui Deep Fault、Guidong - Yanshou fault zone (Huangao fault zone), The nearly North West trending Changde - Anren transition fault, The nearly east west trending Chongyi - Xianetang fault zone and the north west trending Tangwan fault zone, etal [13].

3. Geological Overview of the Deposit

3.1. Geological Characteristics of the Deposit

The Lujing deposit is located in the western contact zone of the Lujing uranium ore field, Southern margin of Fengzhou Basin. Cambrian strata are widely exposed in the central and western parts of the Lujing deposit (Figure 2), The Cambrian strata include the Xiangnan Formation and the Chayuantou Formation, They are the main ore-bearing horizons. The lithology of the Xiangnan Formation is mainly black carbonaceous slate, The lithology of the Chayuantou Formation is mainly feldspathic quartz sandstone, quartz sandstone, and fine sandstone. In the northwest of the Fengzhou sedimentary basin, it is covered by red debris of the Upper Cretaceous, The lithology is mainly red conglomerate and sandy conglomerate [7, 14]. The content of uranium in Cambrian strata is generally high, In particular, the uranium content in carbonaceous slate can reach 1.6 - 2.3 times the average uranium content of sedimentary rocks in South China [2].

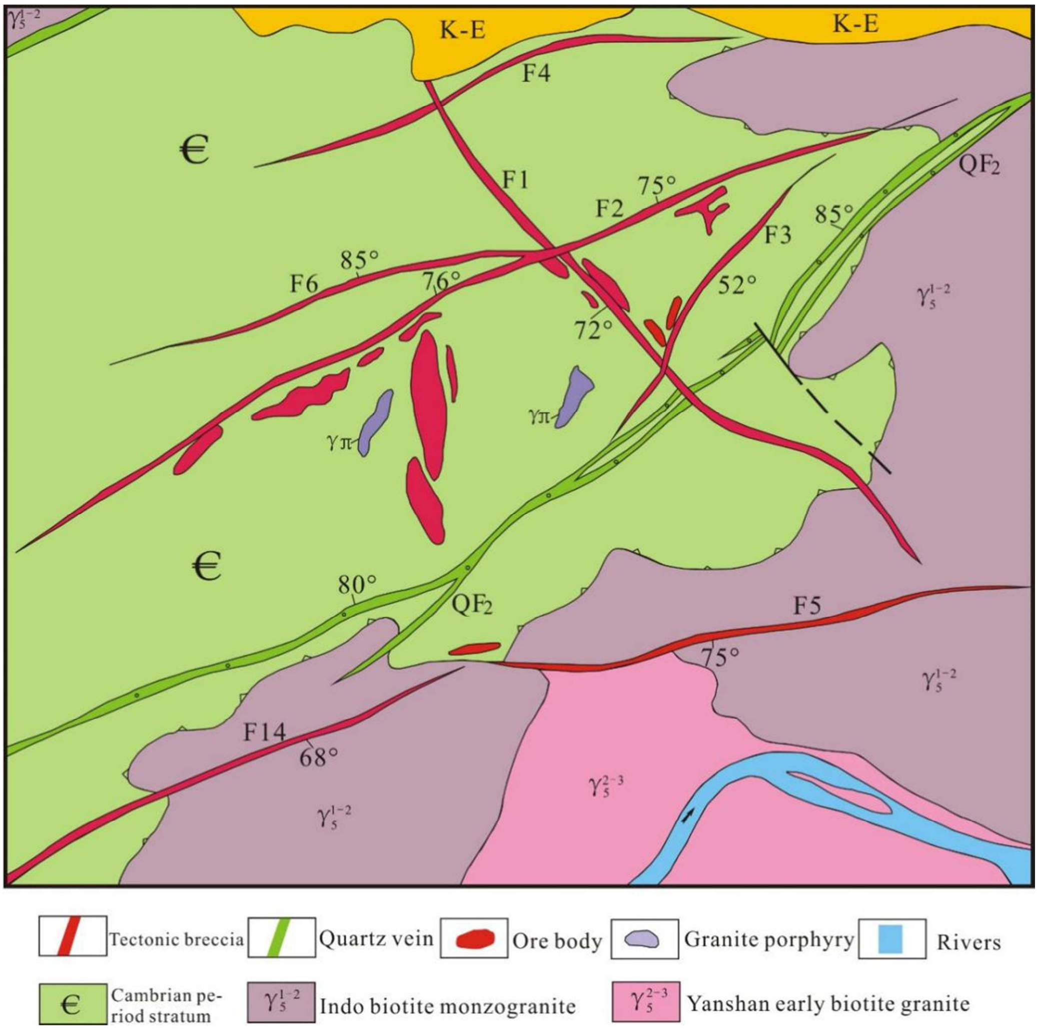

Figure 2. *Geological Sketch of Lujing Uranium Deposit.*

The lithology of the exposed rock mass in the Lujing uranium ore field is mainly granite, The main body consists of the second stage of the Indo period, medium to coarse grained porphyritic biotite monzogranite, and the third stage of the early Yanshan period oligoporphyritic biotite granite, Followed by a small amount of fine grained tourmaline bearing muscovite granite in the first stage of the late Yanshan period and the second stage quartz porphyry, granite porphyry, diabase, lamprophyre vein intrusions. The Indo and Yanshan granites are also important host rocks in the region. The granite of each stage belongs to uranium rich granite, The content of uranium is generally greater than 15×10^{-6}, which is four to five times that of normal granite [3].

The tectonic location of the Lujing uranium orefield determines that the orefield is a complex tectonic framework. It is held in the Zhuguangshan south, Between the northern rock mass, and is located in the northeast direction (Suichuan-Reshui Fault) and the intersection of the northwest (Changde-Anren fault), at the same time, there is also an east-west trend (Chongyi-Xian'etang Fault) passing through.

3.2. Ore Body Characteristics

Uranium ore bodies occur in complex internal and external contact zones between rock masses and Cambrian strata, It is controlled by the fault structure and has the characteristics of "three story building" (Figure 3). The outer zone type uranium ore body is jointly controlled by faults, contact zones, and ore-bearing horizons, Mainly controlled by fractures, the ore bodies are mostly lenticular, and locally layered and plate-like; The ore bodies in the inner contact zone are controlled by metallogenic faults, The shape, occurrence, and scale of ore bodies are generally consistent with them, Most of them are distributed in a northeast or northeast direction, The ore body is mainly steeply inclined, and the shape of the ore body is mostly lenticular, veined and lumpy [7].

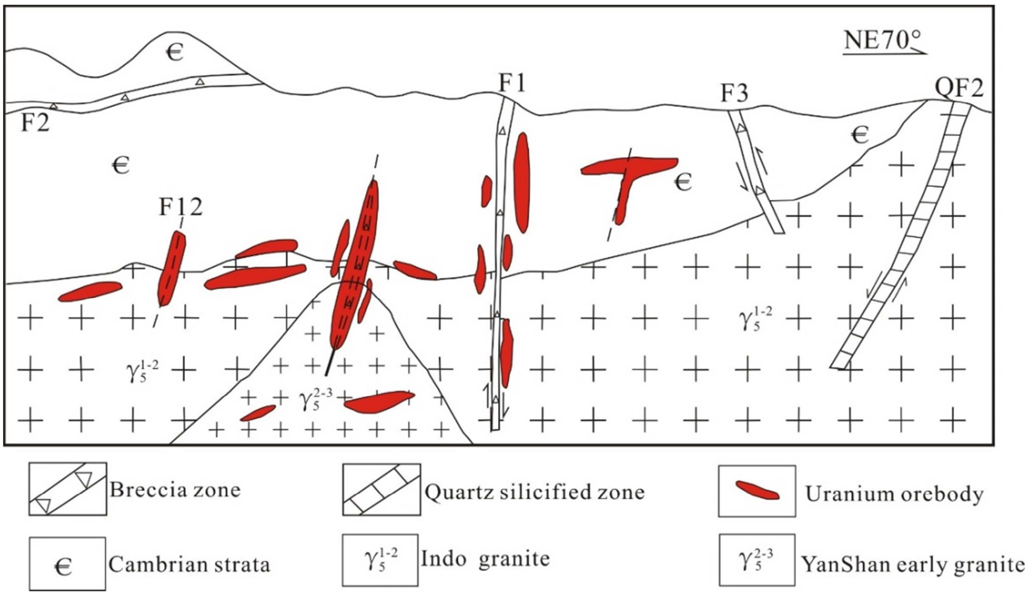

Figure 3. *Profile Diagram of Lujing Uranium Deposit.*

A total of 275 industrial ore bodies have been delineated in the Lujing deposit, There are 7 main ore bodies, The ore body is generally over 10 meters - 300 meters long. The width ranges from 10 meters - 200 meters, The thickness is no more than 10 meters. The highest grade of the ore is 0.226%, Individual intermediate ore grades can reach 0.6-0.7% [7, 15].

4. Uranium Minerals and Occurrence Characteristics of Uranium

4.1. Occurrence State and Morphological Characteristics of Uranium

Uranium in the Lujing uranium deposit exists in the form of independent minerals, isomorphismsand uranium-bearing phosphates, There are three types of independent uranium minerals: uraninite, pitchblende, and uranium thorite.

Uranite is the main uranium mineral ($U^{4+}(SiO_4)$), Most of them are cryptocrystalline structures, The degree of self formation is poor, and it is produced in a colloidal form, A few microgranular, veined, and disseminated granular minerals are commonly associated with minerals such as fluorite, pyrite, microcrystalline quartz, chlorite, pitchblende, rutile, galena, apatite, and sericite. Under an electron microscope, The distribution rules mainly include the following three types: 1) It is distributed along the edges of pyrite, rutile, quartz, and other minerals in a crusty, dense, and irregular shape (Figure 4A, 4C, 4E); 2) It is distributed in the internal cavities or particle gaps of pyrite, quartz, sericite, and other minerals in the form of obvious particles or scattered particles (Figure 4D, 4F); 3) Growing around the edges of minerals such as galena, pyrite, and sericite in the form of reaction edges (Figures 4B, 4D). Pitchblende is a simple oxide mainly composed of UO^2, A variety of uraninite, It closely coexists with uranium ore and pyrite, and is metasomatized by late formed pyrite and uranium ore, presenting a metasomatic residual structure. Uranium thorium stones exhibit significant color differences under microscope due to differences in the content of uranium and thorium. The uranium thorite in the Lujing uranium deposit has an cryptocrystalline structure, So that dense aggregates occur in the margins or grain gaps of quartz, sericite aggregates, and apatite.

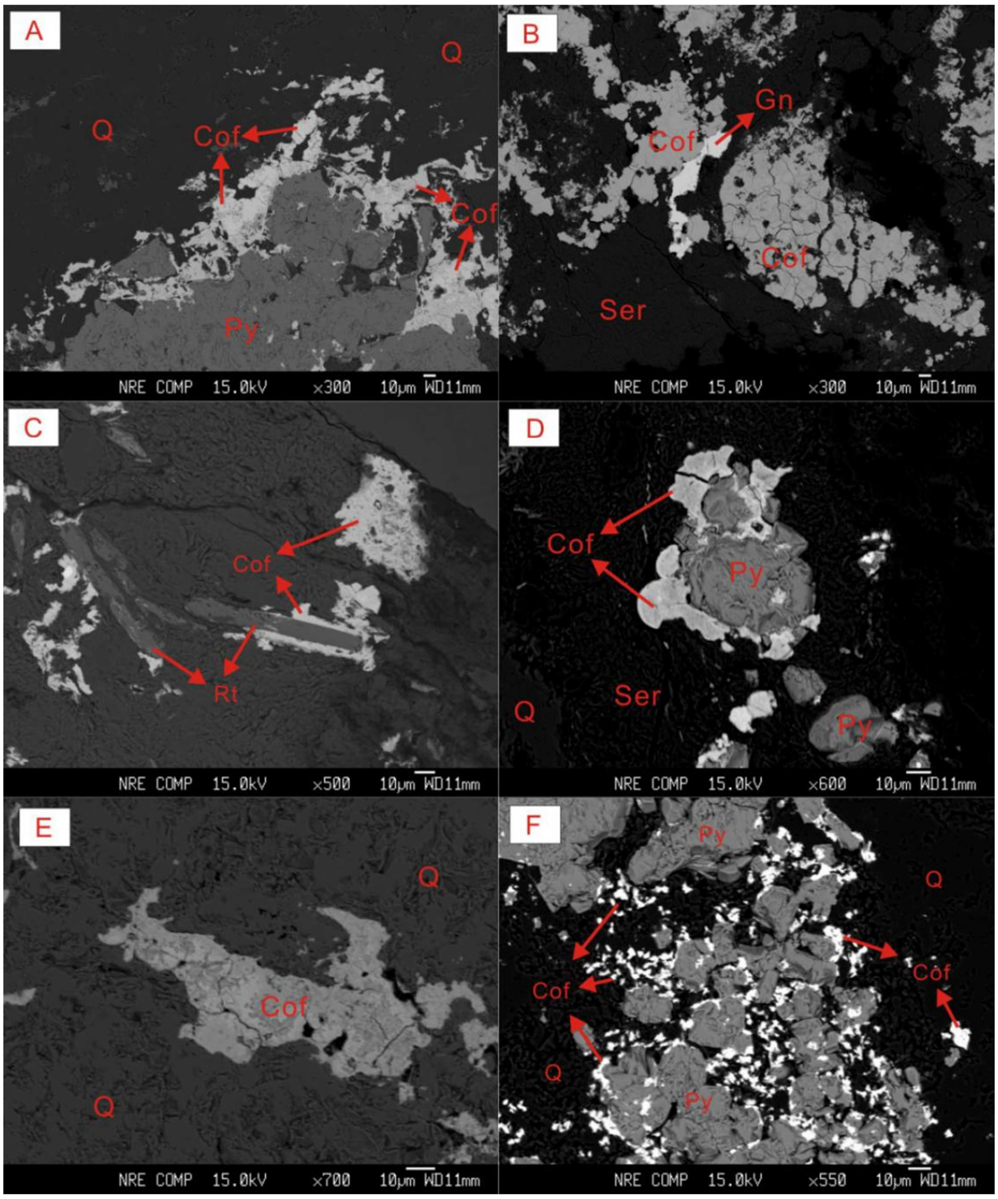

Figure 4. *The occurence characteristics of coffinite in Lujing uranium deposit.*

A-uranite is a crust like aggregate that grows irregularly along the edge of pyrite; B-uranium ore is in an irregular colloidal form coexisting with galena and sericite, with irregular dry cracks developed inside; C-uranite grows along the edge of acicular rutile in an irregular colloidal shape; D-globular uranium ore coexists with pyrite; E-uranite is in irregular colloidal form coexisting with microcrystalline quartz, with obvious color difference inside; F-uraninite occurs in the form of disseminated granular aggregates in the internal cavities or grain gaps of pyrite. Q, quartz; Cof, coffinite; Py, pyrite; Ser, sericite; Gn, Galena; Rt, rutile

According to the electron probe data of accessory minerals in the Lujing deposit (table 1), Uranium in the uranium ore of the Lujing deposit is often hosted in accessory minerals such as thorite, rutile, zircon, and phosphorite in the form of isomorphism. The main components of thorite are ThO_2, SiO_2, and UO_2, as well as a small amount of ZrO_2, CaO, P_2O_5 and REE, The content of Y_2O_3 in individual thorium stones is as high as 10.03%. The content of UO_2 in thorite is 10.84%-13.98%, The content of ThO_2 is 36.88% - 40.79%. Zircon can be divided into two types: One is zircon that is not associated with uranium minerals, This type of zircon accounts for the vast majority of the total amount of zircon, with the content of UO_2 and ThO_2 less than 0.3%; Another type of zircon is closely associated with uranium minerals, The contents of uranium and thorium in zircon are significantly increased, The content of UO_2 can reach 6.28%, Rutile TiO_2>95%. UO_2 in rutile coexisting with uranium minerals ranges from 3.19% - 9.62%. Uranium containing phosphates are mainly apatite and yttrium phosphate, while monazite is commonly found in inner zone type ores. Apatites associated with uranium minerals contain less than 0.1% uranium and thorium, and generally contain higher Y_2O_3. The content of uranium in phosphorite is 2.07%, and the content of thorium is 0.43%. Monazite generally contains a high content of rare earth elements, and some belong to thorium rich monazite. The content of uranium and calcium in thorium rich monazite is often relatively high.

Microscopically, these uranium bearing minerals are characterized by: Microscopically, it can be observed that thorite undergoes fragmentation of the surrounding minerals due to its increased volume during metamorphosis (Figure 5A). Thoratite is often associated with minerals such as zircon, pyrite, chlorite, sericite, and yttrium phosphate, and occurs in its granular and colloidal form in the internal gaps of zircon or at the edges of pyrite (Figures 5A, 5B). Zircon has been found in both the inner and outer contact zones, mostly in a semi idiomorphic - allomorphic granular structure, with a few tetragonal columnar or tetragonal biconical structures. Zircon in the Lujing deposit is mainly produced in the internal cavities or margins of rock forming minerals, and is often associated with pyrite, chlorite, apatite, uranium ore, and thorite (Figures 5A, 5C). Rutile is only found in the inner contact zone and occurs in idiomorphic needle shape (Figure 5D), while most of the remaining minerals are in allomorphic granular and colloidal shape (Figure 5E). Minerals commonly associated with rutile include chlorite, quartz, sphalerite, uraninite, and so on. The yttrium phosphate ore is distributed in an allochthonous shape along the edge of zircon, coexisting with zircon and chlorite (Figure 5A), Apatite is mostly produced in the internal cavities or edges of rock forming minerals in an allosteric granular structure, often coexisting with minerals such as pyrite and uranite (Figure 5F).

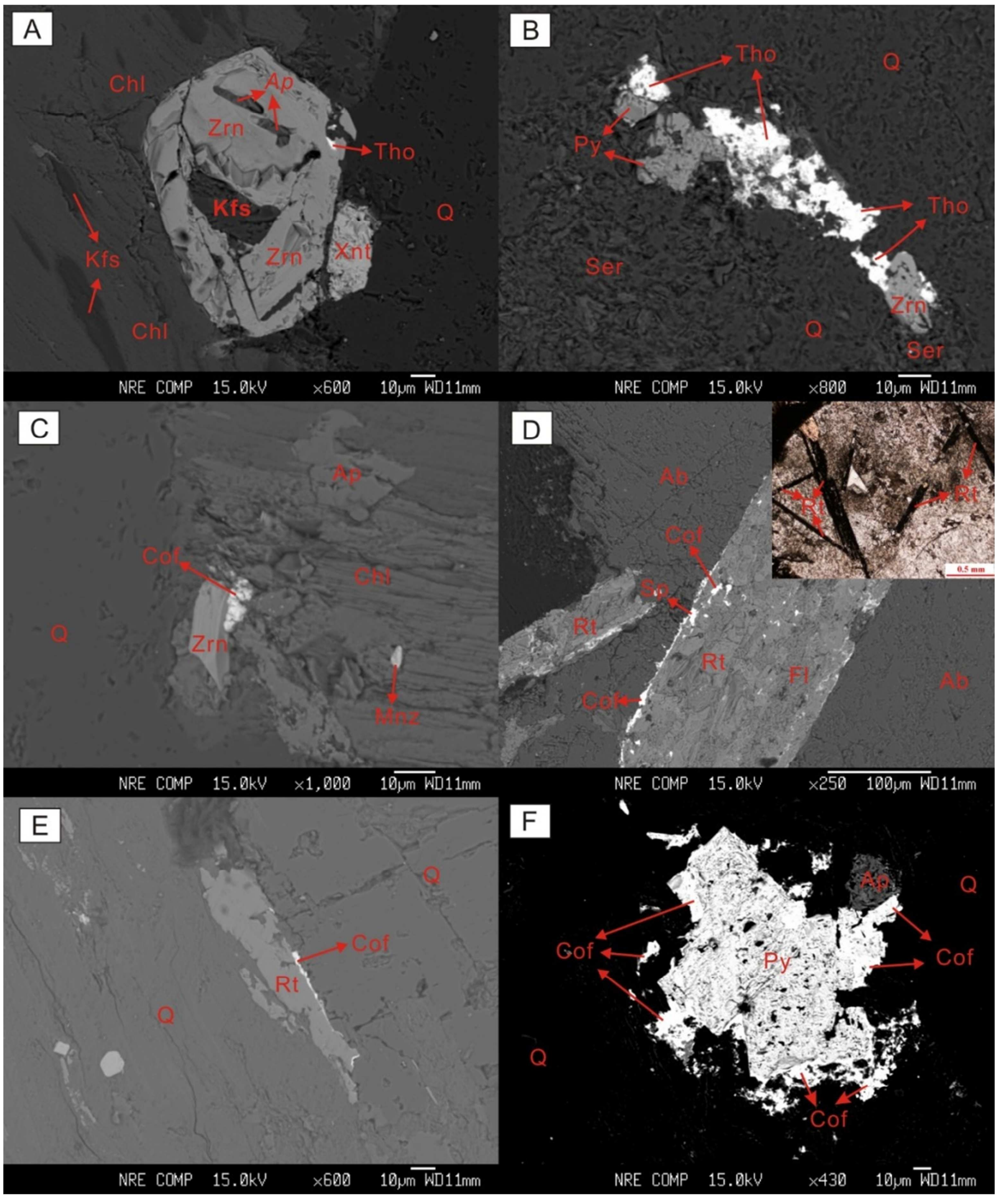

Figure 5. *The occurence characteristics of uranium-bearing accessory minerals in Lujing uranium deposit.*

A-thorite exists in zircon and is crushed around it; Eumorphic zircon particles occur at the edges of chlorite and quartz particles, and are associated with xenolite and thorite; B-thorite occurs in colloidal form at the edges of pyrite and zircon; C - distributed in the interior of rock forming minerals, with zircon coexisting with chlorite, uranite, and monazite; D-rutile occurs in an idiomorphic needle shape, occurs in granite, and is associated with uraninite and sphalerite; E-uraninite is distributed along the edge of rutile; Q, quartz; Ap, apatite; ChI, ChIorite; Kfs, K-feldspar; Zrn, zircon; Tho, Thorite; Ser, Sericite; Mnz, Monazite; Rt, rutile; Ab, Albite; FI, Fluorite; Py, Pyrite.

Table 1. *Results of electronic probe analysis of accessory minerals (%).*

Sample No	Na_2O	K_2O	MgO	FeO	HfO_2	Al_2O_3	MnO	CaO	SiO_2	V_2O_3
1006-1.3	0.01	-	-	0.27	0.47	-	-	0.01	32.85	0.04
LJ-4-4.1	-	-	0.03	0.07	0.03	0.01	0.01	0.04	36.14	-
LJ-4b-1.7	-	0.01	0.01	0.03	0.08	-	-	0.01	34.14	-
LJ-4b-2.3	0.05	-	-	0.42	0.72	0.03	-	0.06	35.69	-
LJ-4b-1.3	0.02	0.18	0.04	0.43	0.22	0.34	0.05	0.11	0.82	1.34
Lk-11b-1b.2	0.49	-	0.03	0.52	0.48	1.10	0.07	0.48	4.29	1.10
1006-1.6	0.04	-	0.02	0.79	0.02	0.09	0.02	0.05	0.22	1.28
LJ-2-4.2	-	0.16	-	0.52	-	0.05	0.04	0.02	0.27	1.44
LJ-4-2.1	0.01	0.05	-	0.20	0.08	0.15	0.05	0.12	0.81	1.36
LJ-4-3.2	0.02	0.13	0.03	0.11	0.14	0.24	0.02	0.03	0.45	1.31
Lk-11b-2.1	0.02	-	-	0.56	-	0.19	0.02	1.73	0.28	1.32
Lk-11b-2.6	0.03	-	-	0.48	-	0.16	0.03	0.05	0.10	1.22
LJ-4-2.2	0.07	0.05	0.09	0.29	-	0.10	0.30	55.84	-	0.03
LJ-4-3.1	-	-	0.02	0.18	-	0.01	0.35	52.77	-	0.01
LJ-4b-1.1	0.04	0.06	0.02	0.36	-	0.01	0.20	55.92	-	0.05
LJ-4b-4.1	0.02	0.01	-	0.36	-	0.02	0.17	56.89	-	0.08
1006-1.5	-	-	0.02	0.54	-	-	0.08	2.02	13.70	0.04
LJ-4b-3.1	-	-	0.03	0.37	-	0.22	0.03	2.65	18.44	-
LJ-4b-3.2	-	-	0.05	0.70	-	0.55	-	2.28	20.91	0.03
1006-1.4	-	-	-	0.27	-	-	-	0.20	0.47	-

Table 1. *Continued.*

Sample No	PbO	ThO_2	UO_2	Y_2O_3	TiO_2	MoO_3	P_2O_5	ZrO_2	Total	Mineral
1006-1.3	0.04	1.02	6.28	-	0.05	-	0.04	56.57	97.66	Zircon
LJ-4-4.1	-	-	0.24	-	0.11	-	0.09	62.49	99.26	Zircon
LJ-4b-1.7	-	0.22	0.08	-	-	-	0.27	61.20	96.06	Zircon
LJ-4b-2.3	-	-	0.17	-	0.01	-	0.03	62.03	99.20	Zircon
LJ-4b-1.3	-	0.02	3.19	-	95.06	0.02	-	0.08	101.92	Rutile
Lk-11b-1b.2	-	0.02	9.62	-	79.74	-	0.17	0.01	98.12	Rutile
1006-1.6	-	-	-	-	98.74	-	-	-	101.26	Rutile
LJ-2-4.2	0.03	-	-	-	97.45	-	-	-	99.98	Rutile
LJ-4-2.1	0.04	-	-	0.04	96.64	0.07	0.03	-	99.63	Rutile
LJ-4-3.2	-	0.03	0.02	-	97.99	-	0.02	0.15	100.70	Rutile
Lk-11b-2.1	0.03	-	-	0.02	98.32	-	0.01	0.03	102.52	Rutile
Lk-11b-2.6	0.01	-	0.02	-	99.57	-	-	-	101.68	Rutile
LJ-4-2.2	0.02	-	-	-	0.02	0.04	41.58	0.10	98.52	Apatite
LJ-4-3.1	-	0.06	0.05	-	0.01	0.01	35.33	-	88.80	Apatite
LJ-4b-1.1	0.03	0.03	0.07	-	-	-	41.58	0.10	98.47	Apatite
LJ-4b-4.1	-	-	0.09	-	0.02	0.12	39.88	0.08	97.74	Apatite
1006-1.5	0.37	36.88	10.84	10.03	-	0.08	4.84	4.57	84.01	Thorite
LJ-4b-3.1	0.05	40.79	12.00	0.48	0.05	-	2.26	2.56	79.92	Thorite
LJ-4b-3.2	0.19	40.46	13.98	2.28	0.01	-	2.36	2.96	86.73	Thorite
1006-1.4	0.21	0.43	2.07	58.96	-	0.02	34.50	-	97.12	Yttrium phosphate ore

4.2. Characteristics of Uranium Mineral Composition

The chemical composition of uranium minerals is measured by electron probe point analysis, Before analysis, carefully observe the particles to be analyzed through a backscatter map, and then select multiple areas on the target uranium mineral for point analysis. The sample analysis and testing site is the Key Laboratory of the Ministry of Nuclear Resources and Environment of East University of Technology, The model of the electron probe instrument used is JXA-8100, The energy spectrometer model is Inca Enery, Acceleration voltage 15KV, electron beam spot 1μm. Probe beam 2.00×10^{-8}A. See Table 2 for analysis and test results.

In table 2, the main components of uranium ore are UO_2 and SiO_2, among UO_2 48.39% - 75.21%, average of 65.17%, SiO_2 8.74% - 21.21%, average of 14.45%. Impurities include Th, Zr, P, Ti, Y, Ca, Al, Fe, and Na. The total oxide content of uranium ore analyzed by electron probe microanalysis ranged from 80.66% - 94.53%, average of 87.26%. The content of ore forming elements Th and Pb in uranium ore is relatively low, but the content of rock forming elements such as Si, Al, Ca is relatively high, This reflects the characteristics of low formation temperature and poor purification ability of uranium ores in this area. In pitchblende, UO_2 82.04% -

85.68%, average of 84.45%, Impurities include Si, Ca, Na, Fe, Mn, Ti. In the impurities, except for Ca^{2+} and Ti^{4+}, which can be isomorphically replaced with U^{4+}, the remaining elements are brought in by wall rock components and cemented in pitchblende during the mineralization process. In addition, pitchblende generally contains 1.31% - 2.77% of PbO, average of 1.82%, The content of ThO_2 in individual pitchblende ores is relatively high, up to 5.32%. The main components of uranium thorite are UO_2, ThO_2, SiO_2, with contents respectively of 17.47%, 39.99%, and 18.03%, Impurities include Al, Fe, P, Ca, etal. Therefore, based on the analysis of the composition of uranium containing minerals, uraninite and pitchblende are the main uranium containing minerals in the region.

Table 2. *Results of electronic probe analysis of uranium minerals (%).*

Sample No	Na_2O	K_2O	MgO	FeO	HfO_2	Al_2O_3	MnO	CaO	SiO_2	V_2O_3
1008-1B-1	0.01	-	0.04	1.60	0.15	-	-	0.34	3.25	-
LJ14-17-3B.3	0.19	-	-	1.50	-	0.01	-	0.67	1.71	-
LJ14-17-3B.1	0.21	-	-	1.99	0.05	0.05	0.15	0.70	4.04	-
LJ14-17-3C.2	-	-	-	0.16	-	0.36	0.37	2.33	9.87	-
LJ14-33(3)-3.3	0.09	-	-	0.40	-	0.43	0.23	2.56	9.94	-
LJ14-17-3C.1	0.05	-	-	0.36	-	0.39	0.30	2.54	10.05	-
LJ14-17-3D.1	0.13	-	-	0.76	-	0.42	0.36	2.64	8.74	-
Lk-11b-4.1	0.39	-	-	0.33	-	0.81	0.13	2.52	12.45	-
LJ14-17-3D.2	0.12	-	-	0.86	-	0.41	0.25	2.18	11.50	-
Lk-11b-1b.1	0.16	-	-	0.14	-	0.63	0.07	1.85	14.53	0.01
LJ-4-3.3	0.05	-	-	0.17	-	0.50	0.06	1.95	13.32	-
Lk-11b-2.4	0.17	-	0.03	0.15	-	0.74	0.16	2.29	15.08	-
Lk-11b-2.5	0.06	-	0.03	0.65	-	0.64	0.01	1.94	12.44	-
LJ14-17-3A.1	0.01	-	-	0.14	-	0.48	0.04	1.24	15.34	-
LJ14-33(3)-3.1	0.07	-	0.01	0.14	-	0.80	0.05	1.87	14.98	-
LJ-14-12-3.3	0.05	-	0.02	0.83	-	0.37	0.06	1.69	14.68	-
LJ14-17-3B.2	0.01	-	-	2.07	0.02	0.29	-	0.76	16.91	-
LJ-4-1.1	0.19	-	0.01	0.47	-	0.96	-	1.89	16.54	-
LJ-4-1.3	0.20	-	0.03	1.99	-	0.49	0.05	1.63	16.87	-
Lk-11b-2.2	0.06	-	-	0.13	-	0.55	0.17	1.89	10.30	-
LJ-4b-2.1	0.11	-	-	1.72	-	0.46	0.03	1.75	11.18	0.01
LJ14-17-3D.3	0.32	-	-	1.05	-	0.58	0.06	0.92	16.40	-
LJ-4b-1.4	0.09	-	0.04	1.48	0.29	0.80	0.03	1.85	19.98	0.01
LJ-14-12-5.1	0.12	-	0.03	1.27	-	0.60	0.06	1.59	16.90	-
LJ-2-3.1	0.05	-	0.04	1.67	-	0.63	0.03	3.36	15.15	0.04
LJ-14-12-3.4	0.08	-	0.05	1.25	-	0.39	-	1.57	16.67	-
LJ-4-2.6	0.53	-	0.04	2.34	-	0.83	0.07	1.73	11.14	0.06
1008-2-1	0.04	-	0.06	0.08	0.33	1.16	-	1.91	21.21	-
LJ14-17-4A.1	0.02	-	0.03	2.05	-	0.51	0.02	1.40	15.46	-
LJ-4-5.1	0.14	-	-	0.75	0.03	0.51	-	1.21	18.28	-
LJ-4b-4.2	0.11	-	0.01	1.86	-	1.19	-	1.71	18.40	-
1008-1.1	0.02	-	0.04	0.07	0.11	1.61	0.05	2.78	19.70	0.05
LJ-2-3.5	0.03	-	0.11	2.31	-	2.16	0.07	2.58	14.80	-
LJ-14-12-3.2	0.18	-	-	4.42	-	0.38	0.07	1.60	12.52	-
LJ14-33(3)-2.2	0.01	-	0.05	1.12	-	0.82	0.20	2.02	12.19	-
LJ14-31-6.1	0.24	-	-	0.14	-	0.92	0.07	1.80	14.52	-
LJ14-33(3)-2.1	0.03	-	0.04	0.97	-	1.46	0.16	2.39	13.36	-
LJ-4b-1.5	-	-	0.02	0.19	0.25	0.50	-	1.47	18.03	0.05

Table 2. *Continued.*

Sample No	PbO	ThO_2	UO_2	Y_2O_3	TiO_2	MoO_3	P_2O_5	ZrO_2	Total	Mineral
1008-1B-1	2.77	5.32	85.62	0.02	0.03	-	0.02	-	99.17	Pitchblende
LJ14-17-3B.3	1.39	-	85.68	-	0.17	-	0.23	-	91.55	Pitchblende
LJ14-17-3B.1	1.31	-	82.04	-	0.14	-	0.25	-	90.91	Pitchblende
LJ14-17-3C.2	0.03	-	75.21	-	0.09	-	0.45	-	88.88	Coffinite
LJ14-33(3)-3.3	-	-	73.40	-	0.04	-	0.66	-	87.74	Coffinite
LJ14-17-3C.1	0.05	-	72.71	-	0.01	-	0.82	-	87.29	Coffinite
LJ14-17-3D.1	0.04	-	72.32	-	0.07	-	0.90	-	86.38	Coffinite
Lk-11b-4.1	0.16	-	71.61	-	0.07	-	0.26	-	88.72	Coffinite

Sample No	PbO	ThO_2	UO_2	Y_2O_3	TiO_2	MoO_3	P_2O_5	ZrO_2	Total	Mineral
LJ14-17-3D.2	0.11	-	71.29	-	0.01	-	0.68	-	87.39	Coffinite
Lk-11b-1b.1	0.06	-	68.97	0.14	-	0.07	0.84	0.12	87.57	Coffinite
LJ-4-3.3	0.10	-	68.97	1.51	0.03	0.01	0.55	-	87.22	Coffinite
Lk-11b-2.4	0.02	0.06	68.60	-	4.38	-	0.25	0.93	92.84	Coffinite
Lk-11b-2.5	-	-	67.96	-	0.29	-	0.62	0.01	84.64	Coffinite
LJ14-17-3A.1	0.12	-	67.73	-	0.36	-	1.17	-	86.62	Coffinite
LJ14-33(3)-3.1	0.05	-	67.69	-	0.43	-	0.75	-	86.83	Coffinite
LJ-14-12-3.3	0.04	0.05	67.57	-	0.05	-	2.34	-	87.74	Coffinite
LJ14-17-3B.2	0.27	-	66.74	-	0.02	-	0.51	-	87.58	Coffinite
LJ-4-1.1	0.06	-	66.47	1.89	0.07	0.04	0.50	0.12	89.21	Coffinite
LJ-4-1.3	-	-	66.46	2.51	0.03	-	0.37	0.05	90.67	Coffinite
Lk-11b-2.2	0.20	-	66.35	-	2.46	-	0.22	0.32	82.64	Coffinite
LJ-4b-2.1	-	0.13	65.73	0.12	0.14	0.08	0.48	0.21	82.12	Coffinite
LJ14-17-3D.3	0.06	-	65.16	-	0.09	-	1.04	-	85.66	Coffinite
LJ-4b-1.4	-	-	64.38	1.06	0.07	-	0.83	0.13	91.03	Coffinite
LJ-14-12-5.1	0.07	0.17	64.34	-	0.21	-	2.83	0.45	88.64	Coffinite
LJ-2-3.1	0.08	-	64.26	4.91	0.34	-	3.04	0.93	94.53	Coffinite
LJ-14-12-3.4	0.07	0.03	63.30	-	-	-	2.36	-	85.78	Coffinite
LJ-4-2.6	1.39	0.27	63.19	-	3.69	-	0.21	0.25	85.73	Coffinite
1008-2-1	-	-	61.78	3.85	-	0.05	1.78	-	92.25	Coffinite
LJ14-17-4A.1	0.07	-	61.41	-	0.01	-	1.88	-	82.85	Coffinite
LJ-4-5.1	0.08	0.02	61.20	1.35	0.08	0.04	0.64	0.09	84.41	Coffinite
LJ-4b-4.2	0.13	-	61.05	0.61	0.02	0.02	0.92	0.13	86.14	Coffinite
1008-1.1	0.03	-	60.92	5.78	-	-	2.62	-	93.78	Coffinite
LJ-2-3.5	0.31	-	60.59	4.57	0.10	-	3.68	0.01	91.31	Coffinite
LJ-14-12-3.2	0.21	0.34	58.85	-	0.34	-	2.45	0.36	81.71	Coffinite
LJ14-33(3)-2.2	0.10	6.30	61.06	-	0.13	-	0.42	4.74	89.15	Thorium uraninite
LJ14-31-6.1	0.10	7.13	50.22	-	2.98	-	0.80	3.83	82.75	Thorium uraninite
LJ14-33(3)-2.1	0.17	7.60	48.39	-	0.21	-	0.47	5.43	80.66	Thorium uraninite
LJ-4b-1.5	0.11	39.99	17.47	0.50	0.19	-	1.19	1.83	81.76	uranothorite

4.3. Characteristics of Uranium Mineral Assemblages

There are four forms of symbiotic association of uranium ore minerals: Uranium ore - metal sulfide, uranium ore - fluorite, pitchblende - uranium ore - pyrite, uranium ore - quartz.

The uraninite metal sulfide association is a common symbiotic association in the inner and outer contact zones. The metal sulfides closely associated with uranium ore are mainly pyrite, followed by a small amount of galena and sphalerite, mostly occurring in vein form, and partially in disseminated form (Figure 6A, 6B). The characteristic of this symbiotic association relationship is that it shows a medium temperature mineralization and reduction environment [16]; Uranite-fluorite assemblages are also common in the inner and outer contact zones. Fluorite is mostly purplish black, with fine particles, poor crystallinity, and poor transparency. It is mostly produced in the form of veins or network veins, or filled in the microcracks of rock forming minerals in the form of fine veins, Uranium ores occur mostly in the form of disseminated granular aggregates, microgranular, veined, or colloidal aggregates in the edges, internal cavities, and fractures of veined fluorite (Figure 6B, 6C, 6D), Fluorite is mostly metasomatized or filled in pyrite fractures (Figure 6D), and its formation time is slightly later than that of pyrite; Pitchblende- uranite-pyrite combination:

Bituminous uranium ore is mostly associated with uranium ore and pyrite, Surrounded by uranite in a metasomatic residual structure, other associated minerals are mainly fluorite, quartz and sericite; Uranite - quartz combination: It is relatively rare in the Lujing deposit. The particle size of microcrystalline quartz is about 0.1mm, most of which are produced in vein shape, and some of them are irregular (Figure 6C, 6D, 6E, 6F). Uranium ores are mostly distributed in the granular and colloidal aggregates of microcrystalline quartz or filled in the cracks of veined microcrystalline quartz in the form of fine veins (Figure 6E, 6F). The symbiotic minerals include pyrite, fluorite, apatite, chlorite, etal, Pyrite is mostly filled in fine veins along the cracks of microcrystalline quartz, indicating that its formation time is significantly later than microcrystalline quartz, The replacement of pyrite with uranium ore indicates that the generation time of uranium ore is later than that of pyrite. Other symbiotic minerals such as rutile and chlorite mainly occur in the internal cavities or grain gaps of veined microcrystalline quartz.

The characteristics of paragenesis and association of uranium ore and other minerals reflect that the temperature of uranium mineralization is at a moderate to low temperature stage, and the reduction environment is generally later than the formation of pyrite.

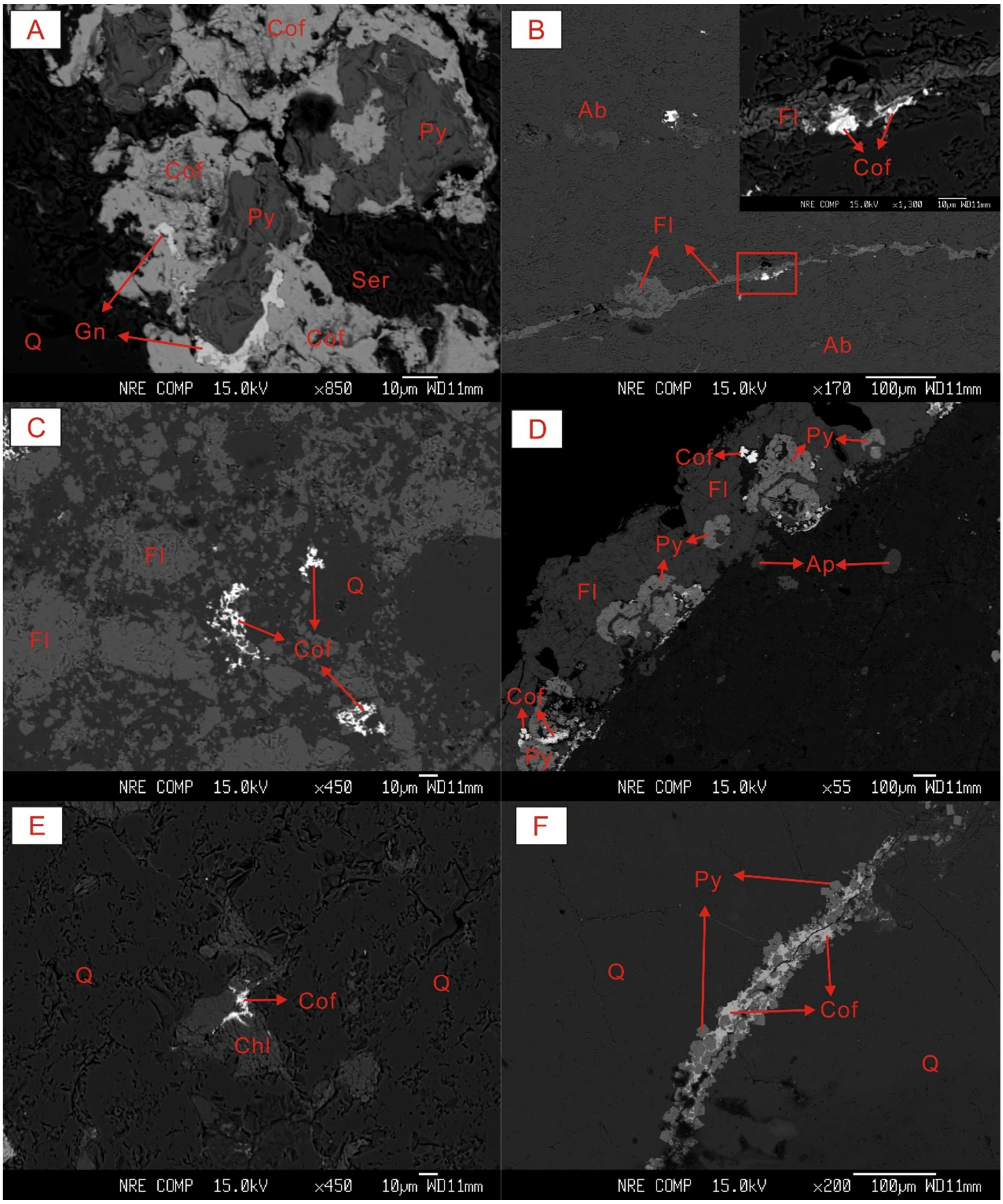

Figure 6. *Uranium minerals and associated minerals in Lujing uranium deposit.*

A-uranium ore coexists with pyrite and galena; B-fluorite is filled in the microcracks of albite in the form of fine veins, and uraninite is intergrowth with fluorite in the form of particles; C-uranite coexists with fluorite and quartz in the form of colloidal aggregates; D-veined fluorite metasomatizes pyrite and fills in pyrite fractures, and uranium ore coexists with fluorite and pyrite; E-uranite coexists with chlorite and microcrystalline quartz; F-pyrite and uranite are filled in the fractures of veined microcrystalline quartz in the form of fine veins. Q, quartz; Cof, Coffinite; Gn, Galena; Py, Pyrite; Ser, Sericite; FI, Fluorite; Ab, Albite; Ap, Apatite

5. Discussion on the Genesis of Uranium Ore Minerals

The formation of primary uranium ore mainly depends on the content of SiO_2 in the solution, Uranite is only generated when soluble $SiO_2 \geq$ 60mg/L (the average content of SiO_2 in ordinary groundwater is about 17mg/L), otherwise pitchblende is generated [18-21]. In the Lujing uranium deposit, uranium ores are mostly cryptocrystalline in texture, with poor self formation, and occur in colloidal form, with a few occurring in the form of highly granular or disseminated particles. Uranyl carbonate complex ions in ore forming hydrothermal fluids, When SiO_2 ≥ 60mg/L, Under the conditions of neutral weak acid reducing environment (PH=5-9), medium and low temperature, normal pressure (≤100MPa), After decomposition, it will precipitate in the form of uranite.

Uranite minerals in the Lujing uranium deposit are transformed from pitchblende: Under the influence of late hydrothermal process, the quality and quantity of pitchblende in the mining area have changed, leading to a process of transformation from pitchblende to uranite [22-26]. It is found that uranium ore is surrounded by residual pitchblende, which presents a metasomatic residual structure, and some uranium ores still retain the morphological characteristics of pitchblende, occurring in a crusty and spherical shape, with irregular dry cracks developed inside (Figures 4A, 4B, 4D). In addition, some uranium ores in this area are distributed along the edges of colloidal and veined pyrite in the form of crusts and spherulites, these uranium ores were transformed from early pitchblende, indicating that hydrothermal pyrite in this area was not formed later than pitchblende [27-33].

Activation of uranium in uranium minerals: A few uranium ores grow around the edges of minerals such as pyrite, apatite, and rutile in the form of reactive edges, or filled in veins in the cleavage or fractures of chlorite、quartz, fluoriteand other minerals. This type of uranium ore is formed by the activation of uranium in uranium minerals, There are often early formed uranium minerals near the location of their occurrence, indicating that the activity of uranium after activation in this period is not strong [34-36]. The presence of uranium ore in a reactive edge shape mainly surrounds the edge of pyrite, indicating that uranium ore or pyrite is a product of the same mineralization stage, but its formation time is slightly later than pyrite.

In summary, primary uranium ore, pitchblende and pyrite were formed at the same time or later, The pitchblende is partially transformed into uraninite minerals by late hydrothermal action, and the uraninite formed during reaction is later formed than pyrite.

6. Conclusion

1) The uranium minerals in the Lujing uranium deposit are mainly uranium ore、 pitchblende and uranium thorite, all of which exist in the form of independent uranium minerals, In addition, a small amount of uranium exists in accessory minerals such as thorite, rutile, zircon, and xenolite in isomorphic form.
2) Uranite and pitchblende are the main uranium bearing minerals in the area. There are four types of uranium mineral assemblages: uraninite—metal sulfide, uraninite-fluorite, pitchblende-uraninite-pyrite, uraninite-quartz, The characteristics of paragenesis and association of uranium ore and other minerals reflect that the temperature of uranium mineralization is at a moderate to low temperature stage, and the reduction environment is generally later than the formation of pyrite. The main genesis of uranium ore minerals in this area is the conversion of primary uranium ore and pitchblende into uranium ore by hydrothermal action, and the reactivation of uranium in uranium bearing minerals to form uranium ore.

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Biography

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