Heavy Sand Deposits of Fergusonite and Columbite in the Kikune (Kukkun) Mine, Yŏnbaek-kun, Hwanghae-do, Korea

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I. Introduction

The Kikune mine has been worked as a gold mine during the past years. Gold occurs in both the quartz veins and the placer deposits. In 1942 the mine produced 78 kg of gold, 20% of which was placer gold. Fergusonite was discovered in this placer deposit in 1940. Until the mineral was confirmed to be fergusonite by KINOSAKI, it had been an unknown mineral, relatively coarse-grained, dull lustrous, and of high specific gravity; and it had been very difficult to separate fergusonite from other heavy sands (black sands) during the dressing. At that time, the writer received a similar sample from the mine and found the coarser part of the sands to be rich in fergusonite.

From the time of the Sino-Japanese conflict to the end of World War II, investigation for rare element minerals was proceeded actively in Korea. The writer was in charge of the investigation and surveyed this mine. Since the first field survey in May, 1943, the writer has visited the mine 6 or 7 times, to be engaged in prospecting of the deposits until the termination of the war. During these years, prospecting by drilling was continued for more than 40 days, and the writer found the existence of columbite in addition to fergusonite. From these investigations, the deposits were proved to be workable and then the exploitation was undertaken. Monthly production of the heavy sands reached several hundred kilograms by the end of the war.

II. Location and Accessibility (Fig. 1)

The mine belonged to the Kikune Mining Co., Ltd. at that time, and the mine office was at Kŭmsal-li (Kukkun-dong), Haewŏl-myŏn, Yŏnbaek-kun, Hwanghae-do, about 10 km south of the Paegch'ŏn-onch'ŏn station on the Hwanghae railroad. The road between the mine office and this station is good for transportation by truck.

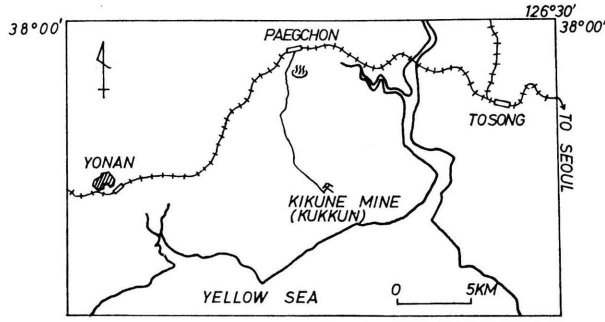

Fig. 1. Index Map of the Kikune (Kukkun) Mine.

The ore deposits are found in the Kŭmsal-li, Unsal-li and Songgye-ri regions.

III. Geology and Ore Deposits[5] (Figs. 2 and 3)

From both surface and subsurface investigations, the geology and the ore deposits of the mining area are summarized as follows:

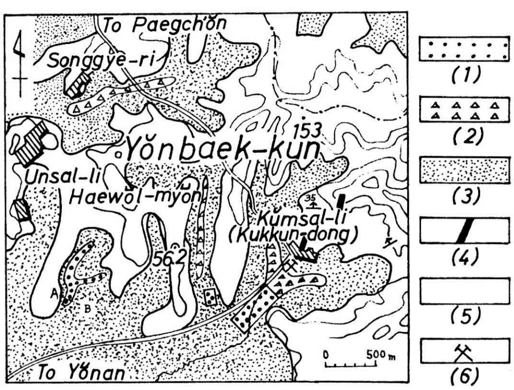

Fig. 2. Geologic Map of the Kikune Mine.

(1) Area for which the calculation of ore reserves was made.
(2) Old gold-mining site.
(3) Alluvium.
(4) Auriferous quartz vein.
(5) Gneiss, crystalline schists, granites and pegmatites.
(6) Mine office.

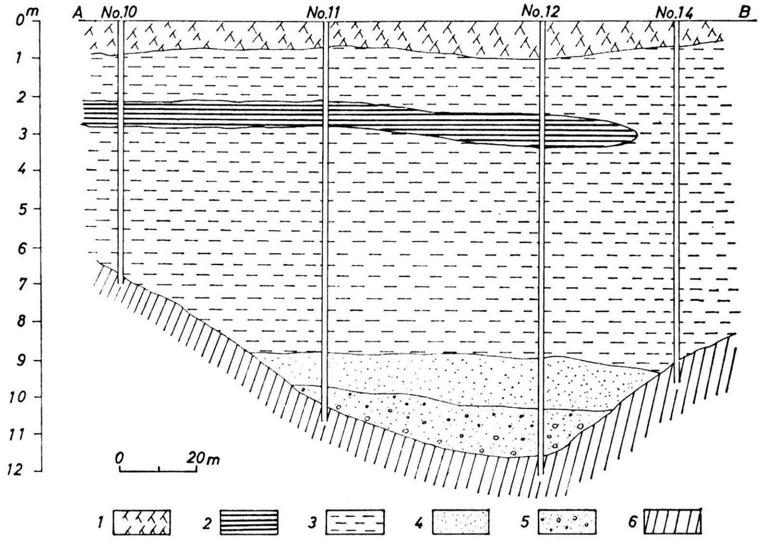

Fig. 3. Geologic Section along Line A–B of Fig. 2.

1. Overburden.
2. Peat bed.
3. Clay bed.
4. Sand bed.
5. Gravel bed.
6. Bed rock.

Gneiss and crystalline schists (including limestone)
Granites and pegmatites
Auriferous quartz veins
Alluvium (heavy sand deposits)

Gneiss is mainly granite gneiss. Crystalline schists are predominantly mica schist and quartz schist. These rocks trend east-west and dip gently (less than 50° in general) toward north. Gneiss and crystalline schists may be pre-Cambrian.

Of granites, biotite granite is predominant. Garnet-bearing granite and schistose granite are also found. The age of granites and pegmatites is unknown. The auriferous quartz veins cut all the above-described rocks in many places.

The alluvium consists of layers of overburden, peat, clay, sand and gravel in descending order. The thickness ranges from 4 m to 14 m within the surveyed area. Generally speaking, the alluvium in the lower reaches of the river of the area is thicker than that in the upper reaches. The alluvium is most extensive and thickest in the Kŭmsal-li region.

Though the alluvium is 4 m to 14 m thick, the heavy sands are concentrated in its lower part which is about 2 m thick; that is, they are contained in the basal auriferous gravel bed ("Kam" or "Kamt'o") and in the overlying gravel bed as well as in a part of the sand bed. In other words, the deposit is an alluvial deposit where fergusonite and columbite, together with placer gold, monazite, zircon, garnet, scheelite, ilmenite and magnetite, constitute the so-called heavy sand deposit.

As the surface of the bedrock is fairly even in the Kŭmsal-li region, the deposit extends roughly uniformly over a wide area, while in the Unsal-li region the bedrock is considerably rugged and the deposit is concentrated locally.

Of the constituent minerals of the heavy sand deposits, the ones with lower specific gravity such as monazite, zircon, garnet, ilmenite, rutile and magnetite are found in a considerable amount even in the upper part of the sand bed as well as in the gravel bed, while those with higher specific gravity such as gold, scheelite, fergusonite and columbite are usually restricted within the basal part and are smaller in amount.

IV. **Ores (Heavy Sands)**[5] (Tables 1 and 2)

The heavy sands consist chiefly of gold, monazite, zircon, garnet, scheelite, ilmenite, rutile, magnetite, fergusonite, columbite, etc., although the amount of each mineral, especially that of gold, fergusonite and columbite varies in some degree from region to region.

A. Placer Gold

The placer gold is concentrated in the auriferous gravel bed or "Kam", and occurs as granular, dendritic or flaky crystals. It is larger in size in the upper courses of the rivers in the surveyed area than in the lower courses. The largest nugget recently collected was about 41 gr in weight. The placer gold content in both the old claim and the heavy sand mining region averages about 7.5 gr per 3.3 m^2. The Kikune mine produced 78 kg of gold in 1942, 20% of which was from the placer deposit.

B. Monazite

Monazite occurs as brown to pale-brown crystals, granular or flattened parallel to a. The crystal planes such as a, m, x and v are observed. It attains to more than 2 cm in maximum size, although finer ones less than 1 mm are also abundant. The monazinte content of the heavy sands is roughly the same in each region, attaining a little over 12%. However, the content based on the grain size varies from region to region as shown in Table 1. The specific gravity of 15 samples was in the range of 5.0 to 5.31.

C. Zircon

The mineral occurs usually in good crystal form less than 1 mm in length. It is colorless, white, pale-brown or purplish. The zircon content of the heavy sands is about 10%.

D. Garnet

The distribution of garnet in each region is generally uniform. It is pink, red, or reddish-brown; finer grains are usually pink or red crystals with crystal plane e or n, while coarser ones are reddish-brown and commonly exhibit no distinct crystal forms.

The specific gravity measured on six samples was 3.43–3.76. The SiO_2 content of a sample of the reddish-brown kind from the Kŭmsal-li region was 37.80%. Many of the garnets are considered to be grossularite or andradite. The garnet content of the heavy sands is less than 5% at most.

E. Scheelite

The mineral was found first in the writer's investigation; it is amber-yellow, pale-brown or white. It attains to about 2 cm in maximum size and sometimes occurs as a crystal consisting of e on which striations are developed. The mineral is found in abundance generally in the coarser part of the heavy sands; e. g., in a sample collected from the Kŭmsal-li prospect, it was reported that the coarse grains over 14 mesh contained 4.8% scheelite.

F. Ilmenite and Rutile

Ilmenite occurs in two ways; (i) as a platy or granular crystal, (ii) as a single crystal combined with rutile.

In the case of (ii), the crystal occurs in a short columnar form of rutile, and ilmenite constitutes the outer part of that crystal. The boundary of the two minerals is irregular in general, and occasionally rutile is penetrated by veinlets of ilmenite. The ratio of the two composing minerals in a single crystal is unfixed, and, therefore, the specific gravity of the crystal is also inconstant, and generally shows the intermediate value between that of the two minerals; i.e., the value ranges from 4.4 to 4.6. The specific gravity of ilmenite of type (i) measured on three samples was 4.74–4.99. Ilmenite of type (i) is generally smaller in size than that of type (ii). The largest crystal of the latter attains to about 2 cm in length.

Ilmenite of the second type appears to be the alteration product from rutile; however, further studies may be necessary for determining whether all the ilmenite of the first type are also of the same origin. These minerals, comprising both of the two types, are contained in roughly equal amounts in the heavy sands in each region, attaining to about 60% on an average, which is the largest amount of all the mineral contents of the heavy sands.

G. Magnetite

Magnetite, together with zircon, occurs as the smallest crystal among the heavy sand minerals and is usually found as a granular crystal with the octahedral plane o. The magnetite content of the heavy sands is very low, less than 2% in maximum.

H. Fergusonite

The surface of the mineral is dark-gray to black and has almost no luster due to weathering which yields a gray to brown material along the cleavages; however, a fresh portion is black and exhibits a strong vitreous luster; H=6 (measured by KINOSAKI); streak pale-brown; radioactivity remarkable.

Fergusonite occurs as a columnar crystal, relatively larger in size as compared with the other heavy sand minerals, and attains a maximum of 3.2 cm in length and 1.4 cm in width, which may record the largest ever known in Korea. The crystal planes are c, g, s, and z; Sp. gr.=5.58–5.82 (measured by T. MIZUMA) (5.76 for a specimen studied by KINOSAKI). The slight difference in specific gravity as compared with the ordinary value for fergusonite may be due to a weathering product which adhered to the crystal surface. According to KINOSAKI[4], the mineral is optically isotropic and the index of refraction is distinctively higher than 1.77. In a thin section the color is brown; but when it is heated to glowing white, the mineral becomes anisotropic and the refractive index becomes higher and higher.

The chemical composition of fergusonite is generally represented as R(Nb, Ta)O_4, where R=Y, Er, Ce, etc., although it is not consistent originally. Because of the high contents of Nb and Ta, fergusonite, together with columbite and tantalite, is regarded as the Nb and Ta ores; in addition, fergusonite is relatively rich in rare elements such as U, Ce, Y and Er, which are rarely contained in columbite and tantalite, so it may be considered as an ore of these elements. Thus, fergusonite has been referred to as the so-called rare element mineral which is found only very rarely in the world; and, in Korea, the deposit in the Kikune mine is the first occurrence worthy of being called a fergusonite deposit.

The chemical composition of fergusonite from the mine is tabulated below in comparison with those from Japan and other countries (only the main components are quoted).

Chemical Analysis of Fergusonite

Locality	Nb_2O_5	Ta_2O_5	UO_2	Y_2O_3	Er_2O_3	Ce_2O_3	ThO_2	CaO	H_2O
Kikune mine[2]	31.1	17.4	8.4	33.5	–	1.5	3.4	2.6	–
Hakata, Iyo, Japan[3]	44.97		3.14	40.39(Y_2O_3 etc.)			—	1.40	3.92
Greenland[1]	44.45	6.30	2.58	24.87	9.81	7.64	—	0.61	1.49
Lockport, U.S.A.[1]	48.73		0.25	46.24		4.24	—	—	1.65

As shown in the above table, fergusonite from the Kikune mine is characterized by high UO_2 content.

The fergusonite content of the heavy sands varies from region to region; e.g., the heavy sands in the Songgye-ri region contain only a very small amount of fergusonite, while those in the Kŭmsal-li and the Unsal-li regions similarly contain about 7% fergusonite. However, the fergusonite content in the latter two regions varies remarkably according to the grain size as shown in Tables 1 and 2. Fergusonite, generally speaking, occurs mostly in coarse-grained crystals and is rarely found in

Table 1. Composing Ratio of Principal Heavy Sand Minerals based on the Grain Size (gold is excluded).

(1) Kŭmsal-li (working face)

No.	Grain size (mesh)	Fergusonite	Columbite	Ilmenite and Rutile	Magnetite	Monazite	Zircon, Garnet, Scheelite, etc.
3	-28	27.0%	41.5%		4.5%	13.0%	14.0%
4	28-48	2.0	43.0		5.0	16.0	34.0
5	48-	0.0	9.1	65.2	0.7	10.0	15.0
Unsorted		7.0	7.0	60.0	2.0	12.0	11.8

Note: The value of 9.1% columbite in No. 5 was calculated from the chemical composition $Nb_2O_5+Ta_2O_5=4.40\%$. In fine-grained sands, fergusonite is generally much less than columbite.

(2) Kŭmsal-li (old pit of placer gold)

No.	Grain size (mesh)	Fergusonite	Columbite	Ilmenite, Rutile, Magnetite	Monazite	Zircon	Garnet, Scheelite, etc.
6	-14	13.0%	73.0%		12.0%	2.0%	
7	14-28	11.0	3.3	65.0	12.0	4.0	4.7
8	28-	2.0	3.3	65.0	12.0	12.0	5.7
Unsorted		6.3	4.5	64.2	12.0	8.0	4.0

Note: The fergusonite and columbite contents of both No. 7 and No. 8 are calculated in consideration of their chemical compositions.

(3) Kŭmsal-li (working face)

No.	Grain size (mesh)	Fergusonite	Columbite	Ilmenite, Rutile, Magnetite	Monazite	Zircon	Garnet, Scheelite, etc.
9	8	17.0%	61.0%		8.0%	14.0%	
10	8-14	8.0	77.0		8.0	7.0	
11	14-28	14.0	4.0	50.0	8.0	18.0	5.0
12	28-	3.0	6.0	48.0	20.0	20.0	3.0
Unsorted		8.0	6.0	53.0	14.0	13.0	6.0

Note: The fergusonite and columbite contents of both No. 11 and No. 12 are calculated in consideration of their compositions.

(4) Kŭmsal-li (working face)

No.	Grain size (mesh)	Fergusonite	Columbite	Ilmenite, Rutile, Magnetite	Monazite	Garnet	Scheelite	Zircon, etc.
13	-14	18.5%	59.3%		9.7%	7.7%	4.8%	0.0%
14	14-28	11.0	58.0		8.0	3.0	20.0	

Note: The fergusonite and columbite contents are roughly equal to those of (3).

fine sands less than 30 mesh. A sample from the Kŭmsal-li region contains about 27% fergusonite in its sand portion which is coarser than 28 mesh.

Fergusonite in the heavy sands occurs usually as a single crystal, but occasionally it is associated with quartz, monazite, or columbite. This fact gives us an important suggestion on the original occurrence of these rare element minerals; e.g., they were associated with one another in the primary ore deposits. In fact, in later days of the survey, the writer found a tourmaline pegmatite in a mountain region near the deposit and detected such minerals as fergusonite, monazite and columbite in it though in small amounts.

Table 2. Nb_2O_5+ Ta_2O_5, Fergusonite, and Columbite Contents.

Analysis No.	Sampling location	Heavy sand / Crude sands	Nb_2O_5+ Ta_2O_5 / Heavy sands	Fergusonite & columbite / Heavy sands	Fergusonite & columbite / Crude sands	Remarks
9130	Drill Kŭmsal-li No. 10	0.19%	2.25%	3.7%	0.0069%	The heavy sand analysed contains 30–50% light sand. (9130, 9133)
9133	Drill Unsal-li No. 12	0.61	1.80	2.9	0.0178	
9128	Drill East No. 3	0.04	1.40*	14.44	0.0055	*The content in the heavy sand
9129	Drill West No. 3	0.03	3.45*	12.65	0.0036	less than 30 mesh in grain size
9515	Drill (1)-5		4.40	9.1		Less than 48 mesh in grain size
9134	Drill (2)-7		8.15	14.3		14–28 mesh in grain size
9131	Drill (2)-8		3.60	5.3		Less than 28 mesh in grain size
9135	Drill (3)-11		8.00	18.0		14–28 mesh in grain size
9132	Drill (3)-12		4.80	9.0		Less than 28 mesh in grain size
	Drill Unsal-li No. 12			9.7		The value for fergusonite more than 28 mesh in grain size
	Drill (3) & (4)			12.0		The columbite content of the black sand more than 8 mesh in grain size

I. Columbite

Columbite in the district was discovered for the first time by the writer. It is black in color, blackish-brown in streak, and has a metallic luster.

The columbite content of the heavy sand also varies more or less from region to region, and the Songgye-ri region has the least of it. The columbite contents in both the Kŭmsal-li and Unsal-li regions are nearly equal, a little over 5% which is somewhat less than the value for fergusonite. Although a considerable amount of columbite is contained in the fine sand less than 30 mesh in grain size, occasionally attaining to about 5% of the heavy sand in the Kŭmsal-li region, it occurs often in coarse crystal or granular forms similar to fergusonite, and it was reported that the columbite content of the heavy sand more than 8 mesh in grain size attained to about 12% in some places in the Kŭmsal-li region.

The crystal is flat and platy, and attains a maximum length of about 1.5 cm. The crystal planes are a, b, c, n, m, and d(?).

The specific gravity measured on 17 specimens ranged from 5.31 to 7.14. Of them, the specific gravity of 10 specimens is less than 6; 5 specimens are 6–7; and 2 specimens are more than 7. Those having especially high specific gravity may possibly be tantalite, although they are grouped here tentatively as columbite because of lack of chemical data. In general, the ones with smaller specific gravity tend to have better crystal planes.

As mentioned above, columbite is often associated with fergusonite, but sometimes it is also associated with quartz and mica.

Columbite, as well as fergusonite, belongs to the so-called rare element mineral, and the world production of it is quite small. In Korea, there are only a few columbite deposits worthy of the name besides the Kikune mine, e.g., the Ŭngok mine in North P'yŏngan-do and the Tannok mine in Kangwŏn-do.

V. Ore Grade and Ore Reserves[5)]

A. Ore Grade

A dressing test was carried out using the Wilfley table at the Fuel and Ore Dressing Institute of the Mining and Engineering Bureau, the Government-General of Korea. The samples tested had been collected from drill holes and mining sites in both the Kŭmsal-li and the Unsal-li regions, and crushed into fine grains less than 30–40 mesh in size. The crude sand used in the test had once been washed and separated from the placer gold before it was desiccated, so it differs to some degree from the natural state. That is, the test material weighs about 60–70% as much as the sample of the natural state. The 30–40% diminution is due to the loss of clay and moisture.

Through the test dressing, it was clarified that the heavy sand content of the crude sand averages a little over 0.15% in Kŭmsal-li and a litter over 0.21% in Unsal-li. However, the heavy sand obtained in this test still contained 30–50% light sand, so the true percentage of the heavy sand in the crude sand may be safely estimated at about 0.10% equally in each region. The contents of the respective minerals in the heavy sands have already been listed; therefore, only the percentage of the principal constituents of the heavy sand are tabulated as follows:

1.	Fergusonite	0.007%
2.	Columbite	0.005
3.	Monazite	0.012
4.	Zircon	0.010
5.	Ilmenite and rutile	0.060

B. Ore Reserves

The reserves of the chief minerals in the investigated area (168,000 m²) were computed on the basis of the results of drilling, pit and trench tests, ore dressing test, and chemical analysis:

1.	Fergusonite	32.200 tons
2.	Columbite	23.000
3.	Monazite	55.200
4.	Zircon	46.000
5.	Ilmenite and rutile	276.000
6.	Gold	0.255
	Total	432.655

VI. Magnetic Concentration of Heavy Sands[6)]

A. Purpose

The heavy sand, as stated above, consists of a variety of minerals which differ in nature from one another. So, for exploiting the deposit, methods of mineral dressing should be considered first. If the dressing problem remained unsolved, one cannot expect to develop the deposit, even if the ore grade was high and the reserves were large.

The dressing problem of some heavy sand minerals has been solved by using the floatation and other methods; however, for such complex heavy sand as that which contains fergusonite and columbite, in addition to ordinary heavy sand minerals, no beneficial method seems to have been determined.

Under these conditions it was concluded that the magnetic concentration method should be tried at any rate and this method might solve the problem as in all probability. The primary object of employing this method was to separate columbite and fergusonite from ilmenite.

As to the magnetism of the minerals, only the data shown in Table 3 had been given at that time and the positions of columbite and fergusonite were not pointed out on the magnetic strength table.

Thus, using an assorter of the Research Institute of the Korea Mining Promo-

Table 3. Comparison of Magnetic Strength of Minerals

Mineral	Composition	Magnetic strength
Iron	Fe	100.00
Magnetite	$FeO \cdot Fe_2O_3$	40.18
Ilmenite	$FeO \cdot TiO_2$	24.70
Pyrrhotite	FeS	6.69
Hematite	Fe_2O_3	1.32
Zircon	$ZrO_2 \cdot SiO_2$	1.01
Limonite	$2Fe_2O_3 \cdot 3H_2O$	0.84
Corundum	Al_2O_3	0.83
Garnet	$3RO \cdot R_2O_3 \cdot 3SiO_2$*	0.40
Quartz	SiO_2	0.37
Rutile	TiO_2	0.37
Orthoclase	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	0.05

Note: * R=Ca, Mg, Fe, Mn.
R_2=Al, Fe, Mn, Cr, Ti.

tion Co., the writer obtained an interesting result (Table 4). The writer is greatly indebted to Mr. T. NAKANO, a technician of the Rare Element Section of the Mining Association of Korea, for his earnest effort and skillful technique which made the experiment successful.

B. Apparatus and Operation

The apparatus was the simplest one consisting of six wrought iron cores coiled 330 times with copper wire charged with direct current of 3.9 amperes and 100 volts (about 2,000 ampere turn). The mineral grains were sorted by electric bell vibrations which were adjusted by changing the distance between the electromagnet and the sample; the length of time operated was not considered. It was also reported that when the sample was fine-grained, the sorting would gain good results by using alternating current as well as direct current.

C. Sample

In the experiment, ten kinds of samples of various grain size from the Kŭmsal-li and Unsal-li regions were used. However, the record of only 4 kinds remains now, i.e., one 8–14 mesh, two 12–28 mesh, and one less than 48 mesh. The samples had been hand-sorted in advance at the mine, and they were rather high in grade for heavy sand. Care must be taken to select grains of uniform size as far as possible.

D. Results of Magnetic Concentration

The experiment was rather easy and good results were obtained as shown in Table 4. Especially, the writer unexpectedly succeeded in separating columbite

Table 4. Results of Magnetic Concentration.

Location	Unsal-li					
Grain size	8–14 mesh			14–28 mesh		
Magnetic strength	Mineral	%	Remarks (Percentages are those of the materials mixed in each heading mineral)	Mineral	%	Remarks (Percentages are those of the materials mixed in each heading mineral)
Strong	Magnetite	0.6	With limonite	Magnetite	1	Mostly magnetized limonite
↑	Ilmenite	40.1	Columbite 1.0%	Ilmenite	34	
	Columbite	21.8	Ilmenite (fine grain) 2.5% Fergusonite (coarse grain) 3.2% Limonite, monazite, zircon (coarse grain), etc. 8.7%			Ilmenite (fine grain) 4.1 Fergusonite 1.3 Limonite 12.9 Monazite, garnet, etc. 5.2 } 23.5%
	Fergusonite	4.5	Columbite 13.5% Monazite, etc. 27.0%	Fergusonite	14	Columbite 6.1% Monazite, etc. 39.4%
	Fergusonite	9.1	Monazite, garnet, etc. 41.6%	Monazite	13	Fergusonite 22.9%
	Monazite	6.8	Fergusonite 34.0%	Monazite	4	Fergusonite, reddish-brown 3.2% garnet, etc.
↓	Monazite	14.6	Fergusonite 19.7%	Zircon	5	Contains fergusonite, monazite, etc.; sorting unsatisfactory
Weak	Zircon	2.5	Contains rutile, etc.	Zircon, Quartz	15	Zircon 17.0%
		100.0			100.0	
	Columbite content of heavy sand ca. 19.3%			Columbite content of heavy sand ca. 11.6%		
	Fergusonite content 〃 〃 ca. 13.9%			Fergusonite 〃 〃 〃 ca. 11.0%		

and fergusonite from ilmenite—the highest aim of the work. The recovery percentage of both columbite and fergusonite was about 95%.

However, separation of hornblende from columbite, fergusonite or monazite was not so good in the samples below 40 mesh in grain size, but this is not a serious question because hornblede can be separated by the gravity method. Similarly the co-existence of quartz may also cause no serious question.

The garnet is classified into two kinds in regard to the magnetism; the stronger is pink or red and rich in iron, the weaker is reddish-brown and probably poor in iron.

As fergusonite occurs in columnar crystals, it was difficult to select grains of fergusonite which are uniform in size to grains of other minerals; accordingly, the separation of fergusonite from both monazite and reddish-brown garnet was disturbed. This, however, may probably be due to the irregularity of magnetism caused by weathering which fergusonite underwent to some degree; moreover, such minerals of indefinite chemical composition as fergusonite and columbite may

Kumsal-li					
14–28 mesh			Less than 48 mesh		
Mineral	%	Remarks (Percentages are those of the materials mixed in each heading mineral)	Mineral	%	Remarks (Percentages are those of the materials mixed in each heading mineral)
Magnetite	0.2	Mostly magnetized limonite	Magnetite	0.6	
Ilmenite	47.8	Contains a few red garnets	Ilmenite	41.2	Contains a few red garnets (coarse grain)
Red garnet	0.9	Ilmenite (fine grain) ca. 50% Columbite ca. 3.2%	Red garnet	5.6	Ilmenite (fine grain) ca. 40%
Columbite	13.1	Garnet, Fergusonite, Limonite, Rutile, Hornblends } 9.5%	Hornblende Columbite	0.9	Columbite ca. 30% Contains monazite and brown garnet
Monazite	4.5	Columbite, fergusonite 19.4% Reddish-brown garnet containing rutile 7.0%	Hornblende	2.8	Columbite, fergusonite, monazite 14.6% Reddish-brown garnet ca. 20%
Monazite	7.2	Fergusonite 8.7% Contains reddish-brown garnet, etc.	Monazite	9.1	Fergusonite 0.4% Contains hornblende and reddish-brown garnet
Reddish-brown garnet	1.9	Contains fergusonite, monazite, zircon, quartz, etc.	Reddish-brown garnet	4.4	Contains monazite, feldspar, quartz, etc.; sorting unsatisfactory
Zircon Quartz	24.4	Contains feldspar, mica, corundum, tourmaline, rutile, gold, etc.	Zircon Quartz	35.4	Zircon 4.5%
	100.0			100.0	
$(Nb,Ta)_2O_5=8.15\%$ (in heavy sand) (Analysed by T. Mizuma, Geol. Surv. Korea)					

differ in magnetic strength from one another even in the same kind of mineral species.

According to the result of this experiment, the magnetic strength of the heavy sand minerals may be arranged in order from the stronger to the weaker as follows:

Magnetite—ilmenite—pink or red garnet—columbite—fergusonite—monazite—reddish-brown garnet—zircon

As previously stated, some of ilmenite from this mine is believed to be an alteration product of rutile. Sometimes a single crystal of ilmenite having unalterd rutile in the core is found. Its magnetic strength varies according to the ratio of the two minerals composing a single crystal; generally speaking, the lower the degree of alteration, the weaker the magnetism, and the weaker ones, if not abundant, are found mixed with minerals whose magnetic strength is less than that of columbite.

The minerals are more easily sorted in proportion to the increase of the grain size. According to the result of the experiment, the minerals rich in iron are concluded to be stronger in magnetism. Though this may have been expected, it must be noticed that the positions of columbite and fergusonite were roughly determined on the magnetic strength table.

The experiment on the heavy sand of the Kikune mine is only a fundamental and preliminary one and the problems regarding the quantity of the sample and the time required for operations were not considered, so the writer does not think that the obtained results would point to an industrial success. Nevertheless, so far as the experiment is concerned, it may be considered to have succeeded in clarifying some unknown points, especially the possibility of separating columbite and fergusonite from rutile. Judging from the results of the experiment, even such complex heavy sand as that of the Kikune mine could possibly be sorted industrially into 4 classes, namely, (ilmenite, columbite), (fergusonite), (monazite), and (zircon), or at least into three classes such as (ilmenite, columbite), (fergusonite), and (monazite, zircon).

In conclusion, the best process for mineral dressing of such heavy sand as described here should be started with the sluicing or the table method and, if possible, it would be better to sieve the sand at the site of collection, to be followed by the magnetic concentration at the main dressing mill.

VII. Conclusion

Details pertaining to fergusonite and columbite are summarized as follows:

(1) The deposit is an alluvial deposit containing placer gold.

(2) Both fergusonite and columbite are the so-called rare element minerals and are found only rarely in the world. The Kikune mine is the first occurrence worthy of the name of a fergusonite deposit found in Korea. As for columbite, there are only a few other known occurrences except this mine, e.g., the Ŭngok mine in North P'yŏngan-do, the Tannok mine in Kangwŏn-do, etc.

(3) The fergusonite content in the heavy sand is about 7% and the columbite content is a little over 5%.

(4) Even in the limited area investigated, the ore reserves are estimated at about 55.2 tons, so the total reserves in the district would be rather large.

(5) Monthly production of heavy sands was several hundred kilograms by the end of the war.

(6) Mineral dressing is the problem to be considered in the future. According to the result of the writer's experiment, at least it is relatively simple to separate fergusonite and columbite from rutile.

In mineral dressing, it would be better to employ first the gravity method to concentrate the heavy sand, and afterwards magnetic concentration might be applied by using the electro-magnetic assorter.

(7) According to the result of the investigation of the deposit near the Kikune mine, it is most likely that new deposits will be discovered under the widely distributed alluvium in the uninvestigated area in the vicinity. The writer has found

a considerable amount of fergusonite and columbite in the heavy sand from the placer gold claim of the Totaku Yulp'o Mining Office (Yulp'o-dong, Munsal-li, Haewŏl-myŏn, Yŏnbaek-kun) about 3 km northeast of the mine. Generally speaking, the heavy sand rich in placer gold appears to form a high grade deposit of fergusonite and columbite.

(8) The natural surface of fergusonite is remarkably dull in luster and the crystal is relatively coarse-grained as compared to other heavy sand minerals. On the other hand, the fine-grained columbite sands tend to be overlooked because of the difficulty in distinguishing it from ilmenite and other black minerals. If attention is given to this point in future investigations, heavy sand deposits as promising as that of this mine would possibly be discovered from other regions in Korea.

(9) At least some of the primary deposits of fergusonite and columbite would be pegmatites of unknown age in the mountain region near the mine. These pegmatites, although low in fergusonite and columbite contents according to the results of present investigation, should also be studied.

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