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GEOLOGY

Chronology of Eruptions, Composition, and Magmatic Evolution of the Paektusan Volcano: Evidence from K–Ar, $^{87}Sr/^{86}Sr$, and $\delta^{18}O$ Isotope Data

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Late Miocene to Pliocene basaltic plateaus, valley lava flows, and monogenic volcanoes are abundant in the Russian Far East. Neovolcanic activity is extremely limited and mainly restricted to the southern Far East, e.g., the Wudalianchi, Erkeshan, and Jinbohu volcanoes (northeastern China) and volcanoes of the Tokin Stanovik (northern Amur area, Russia). Some of these volcanoes erupted in the 18th century. The eruptive products are mainly composed of alkali basalts (basanite, leucite basanite, leucitite, and others) spread over a small area. The study region is considered inactive in terms of volcanism, and recent eruptions are thought to be nonhazardous. As was indicated by geological studies in the 20th century, Paektusan (Baitoushan) Volcano erupted in historical time. However, little is known about its activity in the past. No reliable data are available on the scale and activity of the eruptions at early stages, the composition of volcanic products, periodicity, and so on. Therefore, we cannot assess the volcanic hazard. Some geological problems of the volcano were considered in the works of Korean, Chinese, and Russian geologists [1–6 and others]. To reconstruct its structure and evolution in details, we need to study isotope geochronology and rock sections, distinguish cycles of the strongest eruptions, and reconstruct explosive activity in the past. Since volcanic events occurred in the late Pleistocene and Holocene, these rocks can be dated only with a new method developed at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (Moscow) [7].

The Paektusan Volcano is located between two countries (North Korea and China) near southern Primorye of Russia (Fig. 1). Its geographic coordinates are 42°06′ N and 128°04′ E.

Study of the northeastern and western slopes of the volcano in 2004–2005 allowed us to obtain original data on the structure, composition, and age of volcanic sequences from the base to the top. Data on the southern (North Korean) slope were taken from [3]. New geochronological and chemical data made it possible to distinguish stages and cycles in volcanic evolution, while strontium and oxygen isotope data provided insight into the genesis of alkaline sialic rocks.

The *stage of shield volcano formation* corresponds to the oldest basalt and trachyte eruptions restricted to the junction between the eastern branch of the Tanlu fault system and the Paektusan fault. The region also incorporates the older Paleogene and Miocene plateau basalts (Table 1). The shield volcano is made up of alkali basalts with high contents of Ti, Fe, total alkali metals, and predominance of Na over K. Upsection, they are replaced by basalts with lower contents of Fe and Ti and higher alkalinity (cycle I). These dense aphyric basalts grade upsection into porous and scoria facies. Cycle II was marked by subalkali basalts with higher contents of Mg and Na but lower contents of Ti. The upper part of the shield volcano (cycle III) is composed of thin sheets of trachyandesites and trachytes.

On the southern slope in the lower parts of the shield volcano, North Korean geologists recognized trachyte flows intercalated with late Pliocene (3.0–3.11 [3]) subalkali basalts. According to [3], the basaltic eruption centers gradually shifted northward along the Paektusan fault.

The total area of the shield volcano is $15–16 \times 10^3$ km^2, with the estimated volume of eruptive products no less than $10–15 \times 10^3$ km^3.

The *cone-shaped stratovolcano* began to form after an interval of 450–500 ka and involved eruption of trachyte flows for more than 400 ka. A periclinal strike of trachyte flows is seen clearly around the entire volcano. The section of the cone is composed of trachytic lava flows characterized by an increase in SiO_2 content, decrease in Mg#, and insignificant variations in the Na/K ratio. Thick sequences of trachyte flows cut by pipes (up to 200–300 m across) of alkali basalts were formed on the northern and western slopes of the vol-

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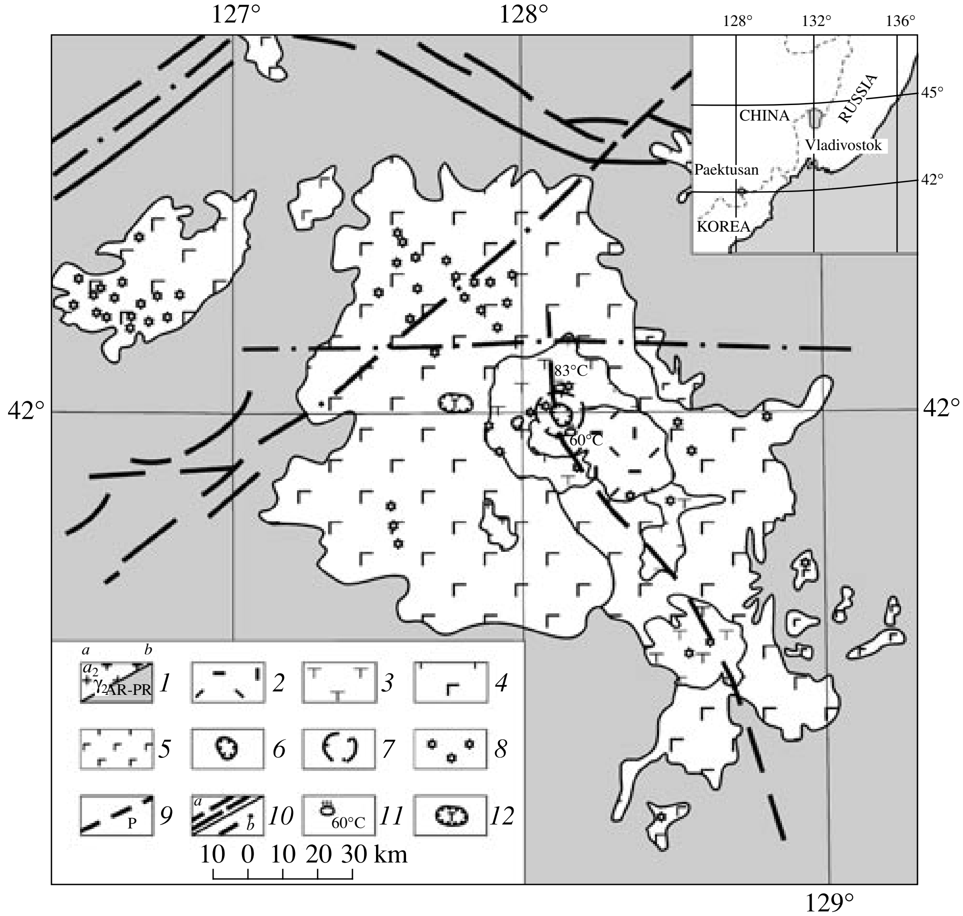

Geological scheme of Paektusan Volcano modified after geological maps and satellite images in (*Magmatic Map of Jilin Province, China*, Scale 1 : 1000000, 1989). (*1*) Basement: (*a*) Mesozoic granites, (*b*) Archean–Proterozoic complexes; (*2*) comendite ashes (eruption of 1903); (*3*) trachytes; (*4*) shield volcano basalts; (*5*) basaltic plateau (Miocene–Paleogene); (*6*) caldera (Lake Tianche); (*7*) outer caldera; (*8*) vents of monogenous basaltic volcanoes; (*9*) Paektusan fault (P); (*10*) Tanlu fault system; (*11*) hot springs and their temperature; (*12*) diatremes.

cano. The age of alkali basalts is 240–245 ka. This stage was terminated by eruptions of trachydacite ignimbrites interbedded with trachytic lava flows. The height of the volcano at this stage was no less than 3000–3500 m.

The *caldera stage*. The formation of the volcanic cone was completed with explosive eruptions of trachyte ashes, breccias, and ignimbrites. Trachybasalt and trachyandesite pipes found as remains near the outer caldera rim on the western slope are dated at 100–125 ka BP; i.e., they predated caldera formation (vigorous explosive eruptions). After an insignificant interval, the volcanic activity was resumed by eruption of tuff breccia and ignimbrites at 65–95 ka BP. Trachyte lavas erupted concurrently from a bocca on the western slope. The cycle was completed after the eruption of black trachyte pumice (40 ka BP) with large K-feldspar phenocrysts. K-feldspar in the trachyte has an older age of 90 ka.

This eruption was very intense. Thick sequences of breccias and agglomerates with fragments of pumice, trachytes, and basement basalts are exposed near the summit of the outer caldera. The thickest deposits occur on the eastern and northern slopes of the volcano. This explosion of probably catastrophic scale formed the outer caldera. Fragments of the caldera of this cycle were deciphered from satellite images.

Datings for the interval between caldera formation cycles II and III are lacking. Therefore, trachyte ignimbrites and ashes that overlie pumice and breccia are conditionally distinguished. Subsequent cycles are distinguished from radiocarbon datings [1, 5, 6, 8, 9].

According to [5], eruptions were repeated within 4000–2000 yr BP. One should mention the catastrophic eruption in 2130 BC. Ashes of this eruption were found in Japan and dated by the radiocarbon method [8, 5].

Cycle IV was marked by catastrophic eruptions of tephra 1 ka BP (969 ± 20 AD) and ejection of ~100 km^3 of pantellerite–comendite tephra (~20 km^3 of solid rocks). The eruptions were directed to the east, and the ashes reached the northern islands of Japan. The tephra precipitated mainly in the Sea of Japan [10] and partially in southern Primorye of Russia. The eruptions

Table 1. Petrochemical (wt %), Sr and O isotopic compositions, and absolute age of representative rocks from the Paektusan Volcano

Stage	Cycle	Rock, facies	Sample no.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	H_2O^-	L.O.I.	Total	$^{87}Sr/^{86}Sr$	$\delta^{18}O$	Age, Ma (K–Ar), ka (^{14}C)
Postcaldera	I	Pumice of alkali rhyolite	4	71.72	0.15	10.76	3.61	1.01	0.08	0.44	0.04	5.37	4.18	0.04	0.22	2.22	99.88		5.9	1903*
		Black trachyte in comendite pumice	26-1b	57.62	0.88	17.79	3.84	1.61	0.11	4.01	1.69	6.04	4.71	0.13	–	0.80	99.43	0.70516 ± ± 11	6.1	1903*
		K-Fsp from trachyte 26-1b	26-1b																6.4	
		Breccia, pumice fragment, comendite	26-1a	70.24	0.31	9.86	4.59	0.12	0.09	0.64	0.39	5.20	4.61	0.03	–	3.50	99.58	0.70496 ± ± 13	5.9	1903*
		K-Fsp from comendite 26-1a	26-1a																	
		Comendite breccia	1e	70.70	0.21	12.31	1.75	2.27	0.06	0.27	0.04	4.93	4.41	0.05	0.10	2.58	99.68		6.6	1903*
		Ignimbrite	3-1	65.91	0.31	15.56	2.74	2.63	0.10	1.00	0.12	5.81	5.14	0.05	0.12	0.30	99.80		6.1	1702*
		Ignimbrite flow	3a	65.73	0.45	14.40	3.19	2.76	0.09	0.55	0.47	6.70	5.18	0.15	0.10	0.48	100.25		4.5	1702*
Naldera	IV	Scoria, fragments; pantellerite and comendite ashes	1b	68.07	0.29	14.29	4.65	1.32	0.12	0.55	0.08	5.43	4.82	0.05	0.03	0.16	99.85		5.8	969 ± 20AD**
		Weakly welded pantellerite ignimbrite	1d	68.05	0.27	14.06	5.00	0.36	0.11	0.66	0.03	5.70	4.75	0.05	–	0.20	99.89		5.0	969 ± 20AD**
	III	Pantellerite tephra and ashes																		4000Çê (2130Çê)**
		Trachyte ignimbrites and ashes	28/4b	66.41	0.28	11.23	5.68	0.17	0.13	0.65	0.30	6.51	4.71	0.03	–	3.50	99.59	0.70527 ± ± 22	6.2	
	II	Trachyte, black tephra, fragments in breccia	1a	63.98	0.52	16.57	4.45	1.02	0.11	1.64	0.24	5.65	5.13	0.12	0.05	0.11	99.55		4.7	0.040 ± 0.03
		Black trachyte pumice from breccia	1i/os	63.18	0.44	17.25	2.20	2.62	0.11	1.72	0.32	5.55	5.34	0.13	–	0.67	99.53	0.70547 ± ± 13	5.8	0.065 ± 0.015
		K-Fsp from black pumice	1/m																6.0	0.090 ± 0.015
		Trachyte, bocca, flow	26/16	64.97	0.49	14.20	3.20	2.88	0.19	1.53	0.21	5.61	5.56	0.09	–	0.50	99.44		5.4	0.065 ± 0.015
		Trachyte ignimbrite, flow, northern slope	29/3c	63.89	0.43	15.10	3.21	2.43	0.13	1.38	0.64	5.81	6.12	0.09	–	0.60	99.83		6.3	0.040–0.065 ± ± 0.03
		Flows and breccias of trachyte	26/12	66.85	0.46	15.10	2.96	2.60	0.14	1.17	0.08	5.37	4.58	0.06	0.16	0.29	99.82		7.1	0.095 ± 0.015
	I	Trachybasalt pipes	28/1	54.86	2.10	16.78	2.91	5.51	0.10	6.38	3.37	3.82	2.83	0.05	–	0.61	99.49		5.1	0.100 ± 0.025
		The same	28/2	55.04	1.70	15.92	3.43	4.40	0.13	5.69	3.76	4.29	3.41	0.42	–	1.40	99.59		6.3	0.125 ± 0.025

Table 1. (Contd.)

Stage	Cycle	Rock, facies	Sample no.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	H_2O^-	L.O.I.	Total	$^{87}Sr/^{86}Sr$	$\delta^{18}O$	Age, Ma (K–Ar), ka (^{14}C)
Formation of volcanic cone	III	Trachytes, flow	20	64.72	0.44	16.60	3.47	1.24	0.09	1.66	0.35	5.31	5.35	0.08	0.18	0.11	99.60	0.704898 ± 17	5.1	0.135 ± 0.025
		Weakly welded ignimbrites	17b	66.18	0.31	14.77	4.04	1.77	0.12	0.49	0.35	6.04	4.90	–	0.14	0.43	99.97			
	II	Pipe of alkali basalts with K-Fsp	28/19a	51.27	1.72	16.05	3.37	7.40	0.18	8.22	7.05	3.08	0.93	0.28	–	0.30	99.85	0.70472 ± 10	6.5	0.245 ± 0.03
		Pipe of alkali basalts, northern slope	28/20b	50.06	2.29	16.32	4.04	6.25	0.17	8.04	6.03	3.94	1.72	0.52	–	0.50	99.85	0.70491 ± 11	6.0	0.240 ± 0.03
		Pipe of alkali basalts	21/1	50.83	2.92	16.96	2.65	7.22	0.13	8.29	4.86	3.27	2.34	0.58	–	–	100.05	0.70483 ± 13	6.0	0.245 ± 0.03
	I	Trachyte, flow	7	67.63	0.37	14.61	4.83	0.23	0.09	0.33	0.08	6.55	5.22	0.12	0.07	0.15	100.28		5.5	
		The same	12	67.27	0.29	14.83	4.40	0.75	0.11	0.55	0.08	6.31	4.84	0.05	0.07	0.15	99.70	0.70529 ± 22		
		″	24/1	67.10	0.32	14.76	2.60	3.03	0.14	0.45	0.22	5.92	4.95	0.04	0.05	0.22	99.68	0.70855 ± 15	5.5	0.33–0.28 (San)***
		″	18	66.74	0.34	14.01	4.07	1.83	0.14	0.77	0.08	6.10	4.60	0.09	0.14	0.62	99.53			
		″	30	67.24	0.39	13.81	4.40	2.77	0.08	0.52	0.24	5.65	4.51	0.05	–	0.38	100.07		5.8	0.545 ± 0.05
		Scoria and breccia	9	64.80	0.36	17.36	2.92	1.70	0.09	1.02	0.24	5.66	5.28	0.09	0.08	0.04	99.64		5.6	
Shield volcano	III	Trachyte, flow	19/2	64.68	0.40	15.93	3.30	1.75	0.10	0.80	0.65	6.00	5.56	0.47	0.00	0.25	100.10	0.70527 ± 13	5.5	
		Trachyte	14/1	64.72	0.44	16.60	3.47	1.24	0.09	1.66	0.36	5.31	5.35	0.08	0.18	0.11	99.60	0.70513 ± 15	6.4	1.00 ± 0.05
		Trachyandesite, flow	15/1	59.44	0.97	17.63	6.05	1.20	0.15	0.21	1.07	6.19	4.61	0.50	–	0.13	100.18	0.70773 ± 15	7.6	1.08 ± 0.05
	II	Subalkali basalt	32	51.91	1.79	14.25	3.64	7.70	0.13	7.81	7.27	3.33	0.93	0.26	0.25	0.87	99.85	0.70455 ± 15	6.3	1.01 ± 0.2
		The same	23/1	51.67	1.64	14.36	4.18	7.95	0.16	7.32	7.78	3.00	0.75	0.21	0.12	0.45	99.67		6.1	
		″	23/2	53.46	1.69	14.97	1.67	8.29	0.17	7.72	7.21	2.91	0.85	0.25	0.58	–	99.77	0.70452 ± 22	6.3	1.20 ± 0.25
	I	Fe–Ti alkali basalt	26/14a	50.24	2.53	15.93	3.09	6.67	0.15	7.76	3.80	4.50	2.57	0.59	–	1.90			6.2	
		The same	27/7	46.74	2.69	16.27	10.51	3.43	0.17	6.08	5.20	4.02	2.96	0.65	–	1.20	99.87	0.70527 ± 15	6.1	1.41 ± 0.05
		″	27/10	48.56	2.70	15.81	10.28	3.31	0.17	7.06	4.43	3.57	2.20	0.75	–	0.70	99.54	0.70456 ± 23	6.3	1.43 ± 0.05
		Fe–Ti alkali basalt	26/14·	46.62	4.45	13.09	13.56	4.05	0.18	7.21	5.40	2.75	1.83	0.63	0.14	0.49	100.05	0.70523 ± 13	6.6	1.70 ± 0.05

Note: (*) Historical data; (**) ^{14}C ages (Horn and Schmicke, 2000; Wei et al., 2003, Chichagov et al., 1989); (***) K–Ar sanidine datings (*Geology of Korea*, 1993). Chemical and oxygen isotopic compositions were determined at the Analytical Center of the Far East Geological Institute, Vladivostok (L.I. Alekseeva, L.V. Nedashkovskaya, and T.A. Velivetskaya, analysts); Sr isotopic composition was analyzed at the Vinogradov Institute of Geochemistry, Irkutsk (G.P. Sandimirova, analyst); K–Ar ages were determined in the Laboratory of Isotope Geochemistry and Geochronology, Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Moscow (V.A. Lebedev and M.M. Arakelyants, analysts).

Table 2. Results of K–Ar isotope dating of lavas of Paektusan Volcano

Sample no.	Rock, mineral	Potassium, ‰ ± σ	$^{40}Ar_{rad}$ (ng/g) ± σ	$^{40}Ar_{air}$, % in sample	Age, Ma ± 2σ	Remark
Postcaldera eruptions						
29/1a	Pumice fragments, comendite	4.60	–	–	–	1903*, Historical data
3-1	Trachyte ignimbrite, flows	5.14	–	–	–	1702*, Historical data
Formation of stratovolcano cone and caldera						
1b	Pantellerite and comendite, scoria	4.82 ± 0.05	–	–	–	969 ± 20 AD**, 2130 BP**, ***
1a	Trachyte pumice from breccia	5.13	0.015 ± 0.012	99.8	0.40 ± 0.03	Peak of caldera, northern slope
1i/os	Pumice, glass	4.44 ± 0.06	0.012 ± 0.010	99.9	0.040 ± 0.03	Black trachyte pumice
1i/m	K-Fsp from pumice	5.94 ± 0.06	0.038 ± 0.004	93.4	0.090 ± 0.02	Large crystal from black trachyte pumice
26/16	Trachyte, flow	4.50 ± 0.05	0.0198 ± 0.0024	88.8	0.065 ± 0.015	Western slope, foothill, bocca
26/12b	The same	4.41 ± 0.05	0.0291 ± 0.0020	69.1	0.095 ± 0.015	Western slope, caldera rim
28/1	Trachybasalt	2.61 ± 0.03	0.0181 ± 0.0021	87.7	0.100 ± 0.025	Pipe, western slope
28/2	The same	2.94 ± 0.03	0.0253 ± 0.0021	89.6	0.125 ± 0.025	Fragment in trachyte breccia (1a)
20	Trachyte ignimbrite	4.28 ± 0.05	0.041 ± 0.004	94.9	0.135 ± 0.025	Flow, foothill of the northern slope
21/1a	Alkali basalt (pipe)	1.87 ± 0.02	0.031 ± 0.002	88.9	0.240 ± 0.03	Pipe, glass, northern slope
28/20b	The same	1.72 ± 0.03	0.035 ± 0.003	87.4	0.245 ± 0.03	Pipe, northern slope
28/19b	Trachyte	4.31 ± 0.03	0.0732 ± 0.0020	73.0	0.245 ± 0.015	Flow, northern slope
30	The same	4.04 ± 0.05	0.152 ± 0.006	93.5	0.545 ± 0.050	The same
Shield volcano						
14/1	Trachyte	5.35 ± 0.04	0.265 ± 0.005	58.2	1.00 ± 0.05	Flow, northern slope
15/1	Trachyandesite	3.65 ± 0.04	0.275 ± 0.005	59.1	1.08 ± 0.05	The same
32	Subalkali basalt	0.59 ± 0.015	0.042 ± 0.004	89.4	1.0 ± 0.2	Flow, northern slope
23/2	The same	0.60 ± 0.015	0.049 ± 0.005	86.3	1.20 ± 0.25	The same
27/7	Fe–Ti alkali basalt	2.07 ± 0.03	0.203 ± 0.003	82.7	1.41 ± 0.05	Lower parts of the flow
27/10	The same	2.07 ± 0.03	0.205 ± 0.002	74.0	1.43 ± 0.05	The same
27/14b	Ti–Fe alkali basalt	1.84 ± 0.02	0.217 ± 0.002	78.9	1.70 ± 0.05	Fragments in trachyte breccia

Note: (*) Data based on historical documents (Wei et al., 2003); (**) ^{14}C ages (Horn and Schmincke, 2000); (***) K–Ar and radiocarbon data are absent.

yielded 1796 ± 453 Mt H_2O, 45 ± 10 Mt Cl, 42 ± 11 Mt F, and 2 ± 0.6 Mt S. These calculations are based on the study of mineral inclusions [8]. This explosion formed the inner caldera partially filled with water of Lake Tianche. The caldera has steep walls, and its depth is ~400 m. It is supposed that the eruption had a global impact and was one of the strongest eruptions over the last 2 ka.

The *postcaldera stage* is marked by repeated eruptions of comendite and trachyte ashes in historical time (1688 and 1903 AD) and black trachyte tephra and ignimbrites in 1702 AD [5, 2, and others]. Ignimbrite flows are deciphered clearly on the volcanic slopes from the caldera rim to its base. In 1898, Russian traveler N.M. Garin-Mikhailovskii noted a weak phreatic–magmatic eruption from the lake crater. The last eruption in 1903 AD produced white and pink comendite–rhyolite pumices and ashes with fiammelike inclusions of black trachyte and trachyandesite rocks (Table 1). White pyroclastics are deposited on the southern and eastern slopes of the volcano and distinctly visible on satellite images.

After the eruption in 1903, Paektusan Volcano is situated in quiescence. Hot springs are known along the rims of the inner caldera, on the northern slope, and in the rift valley. The spring on the northern slope has a temperature of >80°C. The temperature has increased by a few degrees over the past few decades.

In conclusion, let us consider the genesis of the cone-forming trachyte–comendite rocks and the evolution of melts. Geochronological, petrochemical, and isotope data indicate that genesis of the trachyte mag-

Table 3. Periodicity of eruptions and formation stages of Paektusan stratovolcano

Stage	Cycles	Age (Ma, ka)	Eruption type, rock	Character, thickness, area (km^2)	Reference
Postcaldera	I	1903 AD	Comendite and trachyte pyroclastics	~5 m, southern and eastern slopes	Wei et al., 2003; Historical data
		1898 AD	Weak phreatic–magmatic eruptions in the crater lake	Area 10 · 10^3 km^2	*Geology of Korea*, 1993; Chichagov et al., 1989; Liu, 1983, 1987; Macida et al., 1990; Historical data
		1702 AD	Explosive eruption. Black trachyte tephra. Ignimbrite flows on slopes and in the caldera		
		1688 AD	Comendite and trachyte pyroclastics	~5 m	Wei et al., 2003
Caldera	IV	964 ± 20 AD	Thick eastward explosions; flows of ignimbrites, pumice, and tephra. Pumice and ashes of comendites	Tephra volume ~100 km^3, area 1.5 · 10^6 km^3. (^{14}C)	Horn, Schmincke, 2000; Wei et al., 2003
	III	1000 BC 2040 ± 70 BP	Ignimbrite, flows	Thickness ~30 m, volcanic slopes. (^{14}C)	Wei et al., 2003
		2130 ± 80 BP	Ashes	Found in Japan (^{14}C)	
		4105 ± 9 BP	Ignimbrites overlying ancient soil, ashes	^{14}C	Wei et al., 2003
		5000–4000 BP	Data are absent		
	II	0.04^1; 0.09^2*	Explosions of black tephra and scoria of comendite and trachyte		
	I	0.065–0.095*	Eruptions of alkali rhyolites, trachydacites, black obsidians. Flows of thin tephra and extrusion on the volcanic slopes, trachytes (flows)	Northern and western rims of crater. Thickness 190–214 m. Eastern slope. Changun peak	Macida et al., 1990; Wei et al., 2003; *Geology of Korea*, 1993; and others
		0.100–0.125*	Fragments of alkali basalts and trachytes in scoria; trachybasalt and trachyandesite pipes	Fragments (10–30 cm) in scoria with an age of 0.4–0.09; western slope	
Formation of volcanic cone	III	0.135*	Trachyte flows and ignimbrites	Volcanic slope	
	II	0.240–0.245*	Pipes of alkali basalts	Diameter 100–200 m	
	I	0.545*	Trachyte lavas and tuffs on the cone base and inner walls of caldera, scoria-like pumice	Thickness ~650–850 m, area 63.2 km^2. Flows and explosions	
Formation of shield volcano	III	1.0–1.02* Ma	Trachyte and trachyandesite flows	~0–20 m. Flows	
	II	1.08–1.20*	Intercalated massive aphyric and porous basalts	Flows. Thickness ~300 m.	
	I	1.41–1.43* Ma	Scoria lavas and flows of alkali basalts	150 m	
		1.70*–2.2 Ma	High Ti–Fe alkali basalts	~170 m	*Geology of Korea*, 1993; Liu, 1999
		3.0–3.11 Ma	Trachyte lavas, volcanic base. Subalkali basalts	~400 m 400–500 m	*Geology of Korea*, 1993; and others
Plateau		19.9–15.1 Ma	Moderately alkali basalts of the Pekam Formation	Flows	*Geology of Korea*, 1993; and others

Note: (*) K–Ar ages from Table 2; (^{1}) dates, glass of black tephra; (^{2}) dates based on sanidine (black tephra of trachytes).

mas is related to the differentiation of alkaline basaltic melts of the shield volcano. The trachyte ejecta accounts for ~3 vol % of basic eruptions. Similar Sr and O isotopic compositions of basalts and trachytes suggest that differentiation was the main mechanism of their formation. Differentiation of the trachyte melt in the magma chamber was responsible for the formation of comendite and pantellerite pyroclastics, which commonly appear at the last stages of the caldera process.

Differentiation of the trachyte melt in the intermediate chamber produces more siliceous–alkaline–salic melts with high contents of volatiles (especially Cl, F, and H_2O).

The eruptions could be caused by the emplacement of high-temperature basaltic melts in the intermediate chambers and the consequent disturbance of the equilibrium state and explosions. This assumption is confirmed by the fact that basalts predated strong explosions. Thus, emplacement of basalts served as a trigger. This mechanism was proposed based on the study of the catastrophic explosion of Krakatau Volcano in 1883 [11, 12].

Analysis of the chronology of eruptions (Tables 1–3) indicates an increase in the frequency of catastrophic eruptions since the late Pleistocene, reduction in the quiescent periods, and periodicity of explosions (approximately 1 ka each) over the last 5000–4000 yr.

To solve this important problem, we should carry out detailed study of the structure of the volcano and obtain data on the absolute age of pyroclastics and evolution of the fluid regime, particularly at the last stage of volcanic activity.

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