X-ray Analysis and K-Ar Age Determination on Lava Bridge in Manjang-gul Cave

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ABSTRACT

Cheju volcanic island is situated at about 90km south of southern most tip of the Korean peninsula and the largest island consists of one major island in Korea. Its shape is an ellipse with size of 80 X 40㎞. That is, the total area is 1,824㎢, the length from West to East is 23. 9㎞. In the length from North to South, the main island is 15.4㎞ or the island is 16.6㎞. The shoreline cone of the island is 75.6㎞. Manjang-gul cave is located in Kimnyoung-ri, Kujwa-up, the Northeast of Cheju province; situated on latitude 33°31′26″N. and longitude 126°46′18″E.

It can be suggested that these facts on the third floor lava bridge are related to the quantitative analysis by X-ray fluorescent analysis method. The chemical compositions (Unit: wt.%) by XRF fundamental parameter analysis are as follows: SiO_2=52.60, TiO_2=1.74, Al_2O_3=14.30, Fe_2O_3=12.40, MnO=0.15, MgO=6.89, CaO=8.84, K_2O= 2.54, Na_2O= 0.36, P_2O_5=0.18. The third floor of lava bridge sample in Manjang-gul cave are triclinic and hexagonal system for the crystal structure by X-ray observation and basaltic andesite in intermediate for chemical classification. The K-Ar age of upper layer (3F) of lava bridge sample in Manjang-gul cave was determined to be 0.19Ma.

***key words**: lava bridge, K-Ar age determination, XRF analyses, X-ray diffraction*

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1 INTRODUCTION

Cheju volcanic island is situated at about 90km south of southern most tip of the Korean peninsula and is the largest island, one of major islands in Korea. Manjang-gul cave is located in Kimnyoung-ri, Kujwa-up, the Northeast of Cheju province; at latitude 33° 31′ 26″ N. and longitude 126°46′ 18″E. (***Fig.1***).

Cheju island is a volcanic island which is composed of lava of basalt, andesite and trachyte as land tax face rock quality that has 360 or more parasitic volcanoes, whose main peak is Mt. Hanla mountain (1950m). In addition, 62 lava caverns have been discovered there.

Manjang-gul cave has been investigated several times by Korea／Japan joint Cheju island cavern survey. (Hong, 1981 ; Ogawa, 1981). Many layered structures (2 ～ 5 layers) and the complicated aspects are seen characteristically in the inside of this cavern. With regard to the similar cavern Heldes cavern (Spain), Dynamited cavern (extension: 2,388m; USA) and Laviathan cave (extension: 12,400m; Kenya) are known.

Cheju volcanic island consists of alkali basalt (Sawa others 1996) and attention should be paid to its geology and rocks. The characteristic of the volcano geology was clarified by the studies of Lee, S.-M.(1966); Won, J.-K.(1975); and Lee, M.-W.(1982). The analyese of studies of compositions (Sawa and others, 1989, 1990, 1992, 1993, and 1996) and of mineral structures (Sawa, 1991; Sawa and others, 1997 and 1998) were reported. Furthermore, the K-Ar age determination (Won, J.-K and

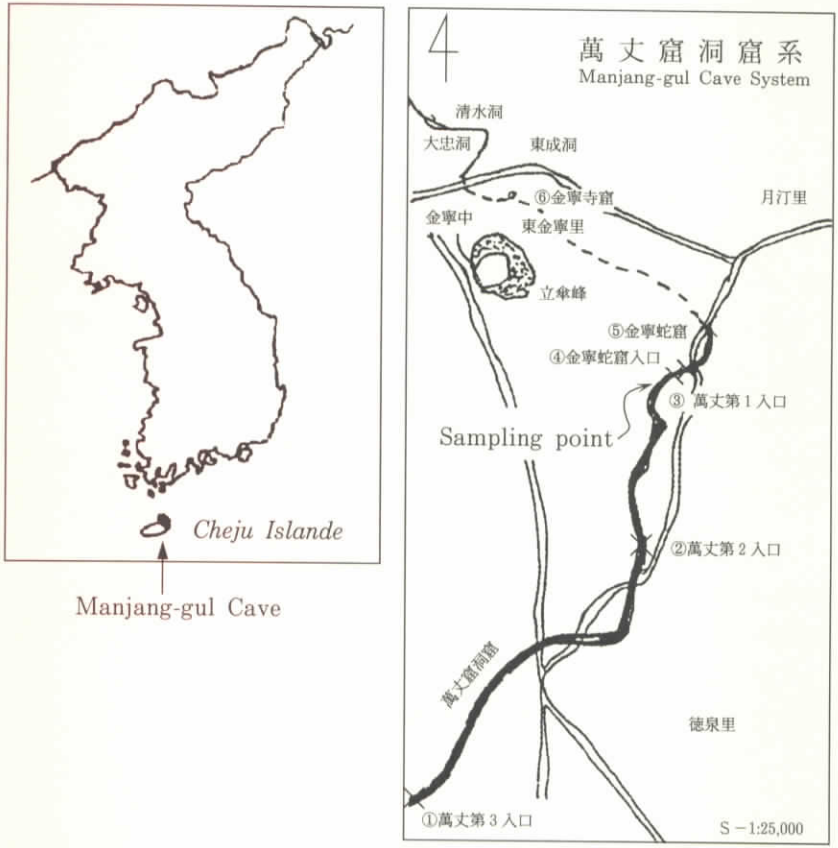

Fig.1 *Index and location maps of Manjang-gul Cave.*

others, 1986 and Okada and others, 1991) made the age of formation of Manjang-gul cave clear. The lava bridge in Manjang-gul cave exists about 1,000m from the 2nd entrance, which is becoming the entrance for sightseeing (***Fig.1***).

The lava bridge was formed in the way that the stream of lava fell to the lower layer from the upper layer (3F) and the weak upper part of the cavern was collapsed. In the lava bridge of Manjang-gul cave, as

Table1 The dimension of the lava bridge in Manjang-gul cave (cm)

Layer Name	Length	Thickness	Width	Height from base
Upper Layer (3F)	580±20	40±10	410±35	65
Middle Layer (2F)	700±20	33±10	545±15	238
Lower Layer (1F)	700±20	23±05	360±30	32

lava was streaming, the lower layer (1F) of the lava was rapidly solidified, the solidified layer turned into lava floor, and then a bridge style was formed. The length, thickness and width of the middle layer (2F) of the lava bridge are 700±20cm, 33±10cm and 545±15cm respectively (***Table1***). On the other hand, the length, thickness and width of the upper layer (3F) of the lava bridge are 580±20cm, 40±10cm and 410±35cm respectively (***Fig.2*** and ***Table1***). The authors report bulk rock chmistry, mineral compositions, and K-Ar age for the lava bridge samples in Manjang-gul cave.

2 MEASURING METHOD

2.1 XRF and XRD analysis

Sample preparation was carried out mainly following Goto and Tatsumi (1994). Rock specimens were crashed by a hammer into coarse samplse, The coarse samples were washed in pure H_2O using a super-sonic wave washer, which process was repeated two or three times. The washed coarse samples were ground by a vibration mill with a tungsten carbide vessel into powdered samples. In this grinding process n-hexane was used to aid grinding. The resulting samples were dried at 105℃ overnight.

The powdered samples were fused into glass beads in the condition as follows, flux: $Li_2B_4O_7$, sample : flux=1:10 (0.4g : 4.0g), fusion tempera-

Fig.2 *Structure of lava bridge in Manjang-gul cave*

ture: 1200℃, fusion time: 2 minutes holding and 5 minutes swirling, cooling time: 1 minute leaving and 3 minutes cooling by air flow. The glass bead method can eliminate grain-size effect and mineralogical effect which disturb accurate quantification by XRF. Analysis of bulk rock chemistry was carried out with X-ray fluorescence spectrometer (RIGAKU RIX2100) by glass bead method using fundamental parameter (FT) method to quantify. Analysis of mineral compositions was porformed with X-ray diffraction spectrometer (RINT-2500+curved graphite monochromator).

2.2 K-Ar age determination

In K-Age determination by Hiruzen Institute for Geology & Chronology, the rock samples were crushed and sieved to take 60-80

mesh size fraction for the argon analysis. About 50-100 mg of powder specimens were used, for the fixed quantity of 1 time of potassium (K). The analysis of age determination is lowest to 1 specimen attachment, to confirm the reappearance nature et al., of the unhomogeneous and fixed quantity of the specimen we went over twice. A portion of each was ground separate in an agate mortar, and the resulting powder was analyzed for potassium. Potassium analysis was carried out by flame photometry using a 2000 ppm cesium(Cs) buffer. Powder samples were decomposed for analysis by flame photometry with HF and HNO_3 treatment in a teflon beaker. Multiple runs of two chemical standards (JG-1 and JB-1) indicated that the accuracy and reproducibility of this method were within 2%. An average value of duplicate runs was used in the calculation. Argon was analyzed using an isotopic dilution method with an ^{38}Ar spike. The specimen and the standards were measured in the same condition. The error with the medium value is within 1%.

3. CHEMICAL COMPOSITIONS and STUDY

The results of XRF analysis of bulk rock chemistry for the lava bridge and twin lava column samples are tabulated shown in ***Table2***, together with the composition range of volcanic eruptives in Cheju island.

In comparison with the composition range for Cheju volcanic island, the contents of TiO_2 and $Fe_2O_3{}^*$ are high. The lava bridge in Manjang-gul cave is composed of basaltic andesite, while the range of compositions of the volcanic eruptive in Cheju island is wide, With regard to alkalinity, the contents of SiO_2 vs. (Na_2O+K_2O) are plotted in ***Fig.3***. The boundaries in ***Fig.3*** are after Kuno (1966). The basaltic andesite of the lava bridge is non-alkaline, while the basalt of the twin lava column shows high alkalinity.

Table2 *Representative XRF analysis results for the lava in Manjang-gul, together with the composition range of volcanic eruptives in Cheju island (wt.%)*

Composition	Twin Lava Column[2)]	2F Lava Bridge	3F Lava Bridge	Lava Average	Cheju Province[3)]
SiO_2	50.99	53.10	52.60	52.85	41.2 ~66.31
TiO_2	2.15	1.79	1.74	1.77	0.00~ 3.57
Al_2O_3	15.17	14.30	14.30	14.30	13.84~25.20
Fe_2O_3[1)]	12.56	12.40	12.40	12.40	0.67~14.24
MnO	0.16	0.15	0.15	0.15	0.00~ 1.53
MgO	6.15	6.23	6.89	6.56	0.00~10.61
CaO	8.06	8.85	8.84	8.85	1.07~12.76
Na_2O	3.27	2.64	2.54	2.59	1.41~ 8.09
K_2O	1.04	0.38	0.36	0.37	0.36~ 5.63
P_2O_5	0.30	0.16	0.18	0.17	0.00~ 1.71

1) Fe_2O_3 : total iron as Fe_2O_3　　2) Sawa and others (1996)
3) Sawa

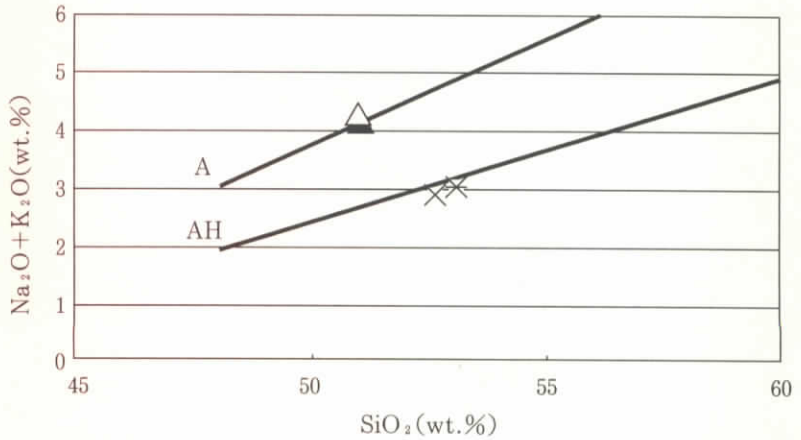

Fig.3 *Contents of SiO_2 and (Na_2O+K_2O) for the lava bridge in Manjang-gul Cave. The Letter A denotes for alkali rock-series; AH, high alumina series; cross and asterisk, 2F and 3F of the lava bridge respectively; open triangles, twin lava column.*

We requested the regression equation and decision coefficient of polynomial expression ($y=cx^2-bx+a$) in ***Fig.4***. In other words, it is as

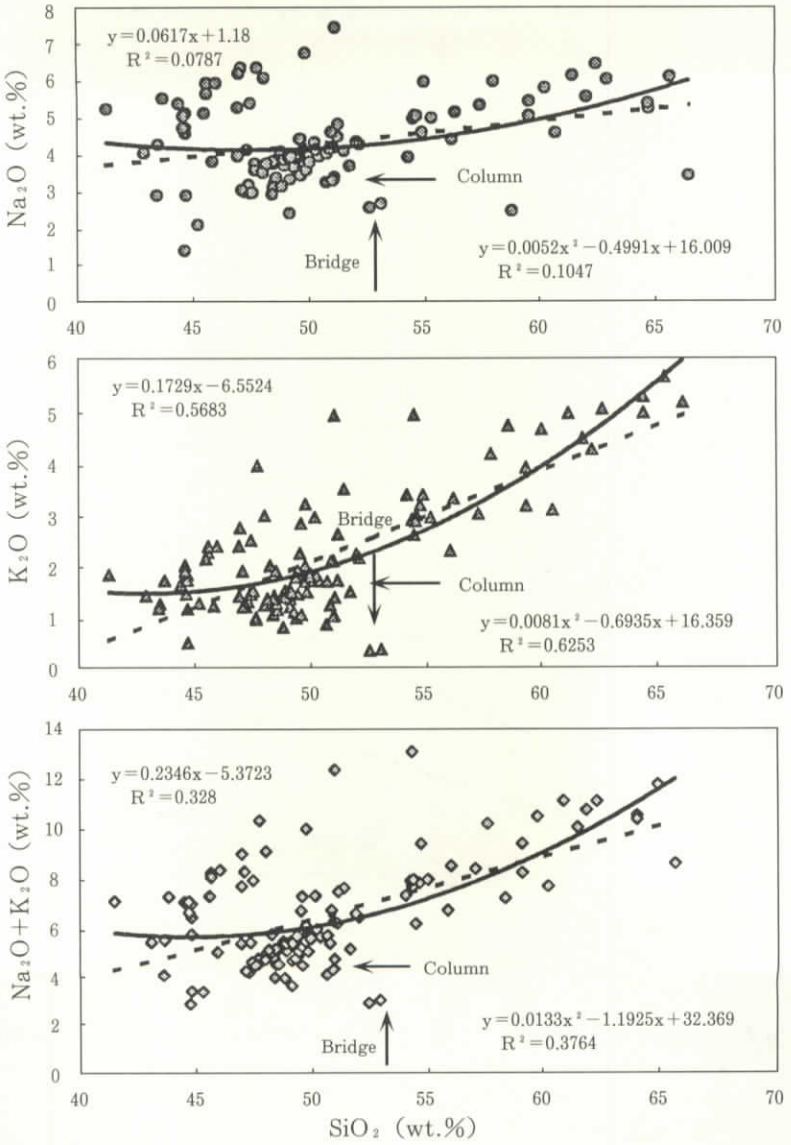

Fig.4 *Relation between SiO_2 and (Na_2O+K_2O) of lava bridge in Manjang-gul cave. This relation is displaying the regression coefficient and decision coefficient of polynomial expression.*

follows:

$$Na_2O \quad (wt\%) = 0.008(SiO_2)^2 - 0.747(SiO_2) + 22.1 \cdots (R^2 = 0.184) \cdots (1)$$

$$K_2O(wt\%) = 0.007(SiO_2)^2 - 0.565(SiO_2) + 13.1 \cdots (R^2 = 0.590) \cdots (2)$$

$$Na_2O + K_2O(wt\%) = 0.015(SiO_2)^2 - 0.249(SiO_2) + 35.3 \cdots (R^2 = 0.421) \cdots (3)$$

It was admitted that the decision coefficient of the polynomial expression is larger than the equation of the straight line. Therefore, In the relation figure between of SiO_2 and (Na_2O+K_2O). It was admitted that one of the polynomial expression is superior to the equation of the straight line. On the other hand, from the relation figure between SiO_2

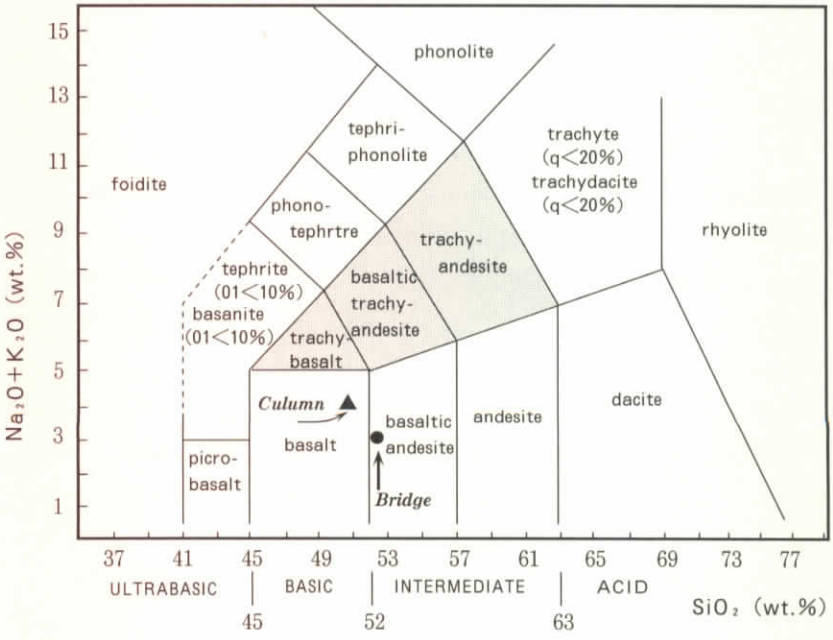

Fig.5 *Chemical classification and nomenclature of volcanic rocks using the total alkali versus silica (TAS) diagram (after Le Bas et al. 1986. **Fig.2**). Plot of SiO_2 vs. (Na_2O+K_2O) on Manjang-gul cave.*

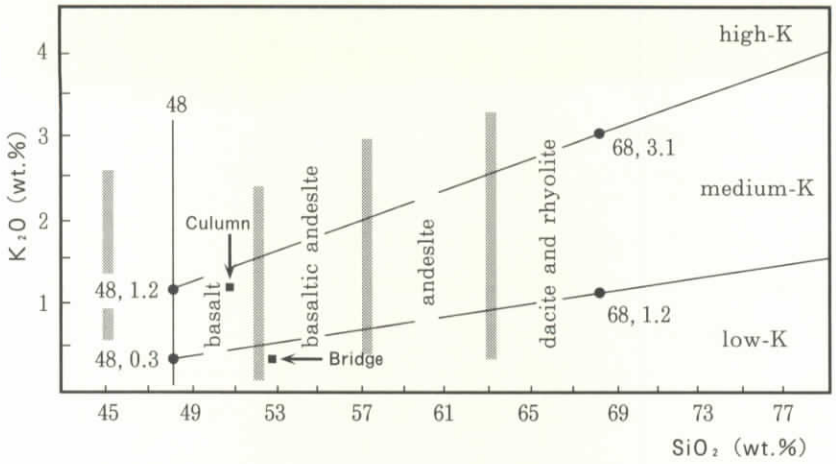

Fig.6 *Plot of SiO_2 vs. K_2O on Manjang-gul cave, together with composition range of volcanic eruptive in Cheju island*

and (Na_2O+K_2O), lava bridge was confirmed that it is smallest (Na_2O+K_2O) in Cheju volcano island.

Fig.5 is the diagram of chemical classification and nomenclature of volcanic rocks using the total alkali versus silica (TAS) diagram after Le Bas et al. 1986, in which SiO_2 vs. (Na_2O+K_2O) of Manjang-gul cave is plotted. The lava bridge in Manjang-gul cave consists of basalt, it andesite.

Fig.6 is displaying the relation between SiO_2 and K_2O of lava bridge in Manjang-gul cave and division of basalts (with $SiO_2>48\%$), basaltic andesites, andesites, dacites and rhyolites in low-K and high-K types. Twin lava column in Manjang-gul cave is basalt and medium-k. Lava bridge in Manjang-gul cave is basaltic andesites and low-K types.

4 CONTAINMENT MINERAL and DISCUSSION

4.1 X-ray analysis

The range of reliability factor in each mineral is albite (678), quartz (507) and also augite (453) in ***Table 4***. Besides, it was confirmed that the shifting and peak intensity ratio of peak differ even these, although we entered the substance that has existence possibility. The substance that entered to these qualitative analysis result the change of the structure associated with solution of the element are conceivable besides.

4.2 K-Ar age determination

The results of K-Ar age determination for the lava bridge and lava column samples are tabulated in ***Table3***. Eruption period by K-Ar age determination of upper layer (3F) samples was determined to be 0.19Ma. The K-Ar age of twin lava column samples was determined to be 0.03-0.42Ma.

The upper layer (3F) of lava bridge was formed between both eruption period of the twin lava column. Therefore, in the same cavern, the non-alkaline ejecta of the lava bridge was erupted between the alkaline activity of the twin lava column.

With regard to the volcanic activity in Cheju volcanic island, Lee, M.-W. (1982) reported that the eruption age of San Bong San trachyte and of Back Lock Dam trachyte was 0.74Ma and 0.025Ma, respectively. Therefore, after the eruption of San Bang San trachyte, one of the twin lava column was formed at 0.32-0.42Ma, and then the lava bridge was formed at 0.19Ma, which was followed by the formation of another column at 0.03-0.05Ma, and Back Lock Dam trachyte was erupted last.

Table3 *Qualitative analysis of 1st search-match on the middle layer (2F) lava bridge in Manjang- gul cave*

No.	Card No.	Chemical Formula	Mineral Name	Standard Number	Agreement Number	Reliability Factor
1	***41-1483***	***Ca(Mg, Fe+3, Al) (Si***	***Augite, aluminian***	***50***	***34***	*
2	46-1045	SiO_2	Quartz, Syn	28	15	*
3	***09-0456***	***(Na, Ca)(Si, Al)$_4$ O$_8$***	***Albite,calcian,disordere***	***19***	***18***	*
4	10-0393	$Na(Si_3Al)\ O_8$	***Albite, disordere***	42	35	*
5	36-0398	$MgFe_2O_4$	Magnesioferrite, disordere	15	10	*
6	09-0478	$(Na, K)(Si_3Al)\ O_8$	Anorthoclase, disordered	30	17	499
7	31-0795	$(Mg, Fe)_2\ SiO_4$	Forsterite, ferroan	40	20	417
8	41-1481	***(Ca, Na)(Si, Al)$_4$ O$_8$***	Anorthite,sodian,disorde	66	45	732
9	18-1202	***(Ca, Na)(Si, Al)$_4$ O$_8$***	Anorthite,sodian,interme	52	45	697
10	19-0629	$FeFe_2O_3$	Magnetite, syn	15	10	659
11	09-0465	***(Ca, Na)(Al, Si)$_2$ Si***	Anorthite,sodian,ordered	19	17	630
12	20-0528	***(Ca, Na)(Al, Si)$_2$ Si***	Anorthite,sodian,ordered	92	56	578
13	41-1480	***(Na, Ca)Al(Si, Al)$_3$***	Albite, calcian, ordered	71	45	565
14	17-0548	$FeSiO_3$	Clinoferrosilite, syn	12	8	559
15	29-0721	$FeSiO_3$	Ferrosilite, syn	28	16	548
16	24-0203	$Ca(Mg, Fe)Si_2O_6$	Augite	36	24	531
17	39-0386	$Na_2CaAl_4Si_4O_{16}$	Lisetite	26	15	520
18	***41-1486***	***$CaAl_2Si_2O_8$***	***Anorthite, ordered***	***82***	***44***	***520***
19	33-0664	Fe_2O_3	Hematite, syn	24	14	506
20	12-0197	$(K, Na)AlSiO_4$	Trikalsilite, syn	21	12	499
21	33-0285	$Ca_3(Fe, Ti)_2\ [(Si, T$	Schorlomite	18	12	497
22	37-0415	$(Mg, Fe)_2\ SiO_4$	Wadsleyite	12	6	490
23	31-1081	$(K, Na)AlSiO_4$	Panunzite	29	20	486
24	19-1250	Na_2TiSiO_5	Paranatisite, syn	28	15	485
25	13-0421	$(Fe, Mg, Ca)SiO_3$	Pigeonite	33	17	481
26	24-0201	$Ca(Fe, Mg)Si_2O_6$	Augite	24	12	470
27	47-1763	$Na_2CaNg_7(PO_4)_6$	Chladniite	23	16	465
28	33-0670	Fe_2P	Barringerite, syn	26	12	460
29	21-1096	$NaAl_{11}O_{17}$	Diaoyudaoite, syn	40	21	454
30	16-0406	Ca_3SiO_5	Hatrurite, syn	30	17	454
31	47-1877	$Ca_3TiFeSi_3O_{12}$	Morimotoite	13	7	447
32	34-0098	$CaFeSiO_4$	Kirschsteinite, syn	81	37	430
33	39-1425	SiO_2	Cristobalite, syn	40	14	428
34	34-0185	$NaFe(SiO_3)_2$	Aegirine, syn	36	13	425
35	39-0409	$Na_2Fe_2Al(PO_4)_3$	Ferrowyllieite	58	30	424

Table4 *Qualitative analysis of 1st search-match on the upper layer (3F) lava bridge in Manjang- gul cave*

No.	Card No.	Chemical Formula	Mineral Name	Standard Number	Agreement Number	Reliability Factor
1	***10-0393***	***$Na(Si_3Al)\ O_8$***	***Albite, disordered***	***42***	***32***	***678***
2	46-1045	SiO_2	Quartz, syn	28	15	507
3	***24-0203***	***$Ca(Mg,\ Fe)\ Si_2O_6$***	***Augite***	***36***	***18***	***453***
4	25-1157	Mg_2TiO_4	***Qandilite, syn***	17	7	300
5	31-0615	$Fe_2Al_4Si_5O_{18}$	Sekaninaite, syn	43	17	258
6	09-0465	(Ca, Na)(Al, Si)$_2$ Si	Anorthite,sodian,ordered	19	16	708
7	18-1202	(Ca, Na)(Si, Al)$_4$ O_8	Anorthite,sodian,interme	52	39	619
8	41-1486	***$CaAl_2Si_2O_8$***	Anorthite, ordered	82	44	573
9	41-1481	***$(Ca,\ Na)(Si,\ Al)_4O_8$***	Anorthite,sodian,disorde	66	44	571
10	41-1480	(Na, Ca)Al(Si, Al)$_3$	Albite,calcian,ordered	71	38	552
11	20-0528	***$(Ca,\ Na)(Al,\ Si)_2Si$***	Anorthite,sodian,ordered	92	46	547
12	27-0250	***$Fe_3(PO_4)_2$***	Graftonite, syn	71	36	535
13	09-0456	***$(Na,\ Ca)(Si,\ Al)_4O_8$***	Albite,calcian,disordered	19	9	532
14	31-0795	(Mg, Fe)$_2$ SiO_4	Forsterite, ferroan	40	20	524
15	13-0421	(Fe, Mg, Ca) SiO_3	Pigeonite	33	20	508
16	34-0098	$CaFeSiO_4$	Kirschsteinite, syn	81	38	464
17	39-0341	$Fe_3(PO_4)_2$	Sarcopside, syn	39	17	460
18	***42-1329***	***Fe_3Si***	***Gupeiite***	***9***	***6***	***458***
19	35-0592	$Ca_2MgSi_2O_7$	Akermanite, syn	80	35	453
20	33-0670	Fe_2P	Barringerite, syn	26	14	429
21	31-1081	(K, Na)$AlSiO_4$	Pannzite	29	18	425
22	16-0406	Ca_3SiO_5	Hatrurite, syn	30	12	421
23	15-0445	Fe−Mg−Al−SiO	Unnamed mineral [NR]	36	18	419
24	40-0483	$K_2TiSi_6O_{15}$	Davanite	50	27	406
25	14-0260	SiO_2	Tridynite-20H, syn	58	24	405
26	19-1184	$NaAlSi_3O_8$	Albite, ordered	147	68	402
27	39-0382	$Na_2Si_4O_9$	Ertixiite	10	6	395
28	35-0610	$MgSiO_3$	Clinoenstatite, syn	100	48	380
29	10-0423	$AlPO_4$	Berlinite, syn	35	15	379
30	39-1425	SiO_2	Cristobalite, syn	40	16	374
31	47-1877	$Ca_3TiFeSi_3O_{12}$	Morimotoite	13	6	371
32	09-0466	$NaAlSi_3O_8$	Albite, ordered	45	24	369
33	46-1337	Na_3Fe_4 +2 Fe_1 +3 Si_8O_{20}	Wilkinsonite	67	33	369
34	41-1483	Ca(Mg, Fe +3, Al)(Si	Augite, aluminian	50	28	368
35	31-0616	$Fe_2Al_4Si_5O_{18}$	Sekaninaite	38	19	366

Table5 The results of K-Ar age determination for the lava bridge and column in Manjang-gul cave

Sample Name	Potassium (wt.%)	Rad.^{40}Ar (10^{-5}ccSTP/g)	K-Ar age (Ma)	Non Rad. Ar (%)	References
Twin lava column(A)	0.81±0.02	0.09±0.21	0.03±0.07	99.3	Sawa and others (1990)
		0.13±0.13	0.04±0.04	98.5	
		0.15±0.14	0.05±0.05	98.4	
3F lava bridge	0.32±0.02	0.91±0.03	0.19±0.14	97.7	This Paper
Twin lava column(B)	0.91±0.03	1.12±1.48	0.32±0.43	98.9	Sawa and others (1990)
		1.49±1.50	0.42±0.42	98.5	

5 SUMMARY and CONCLUSION

We understood the following as a result of lava bridge in Manjang-gul cave.

1) The lava bridge in Manjang-gul cave consists of basalt andesite.

2) About the containment rate of SiO_2, CaO, K_2O, the upper layer (3F) lava ridge is less than the middle layer (2F) lava bridge, and are more than twin lava column.

3) About the containment rate of TiO_2, Al_2O_3, Fe_2O_3, MnO, the middle layer (2F) lava bridge and the upper layer (3F) lava bridge are same almost, being less than twin lava column.

4) Lava bridge in Manjang-gul cave is non-alkaline.

5) As for the lava bridge minerals in Manjang-gul cave, albite, quartz and also augite are many.

6) The age of the formation of the upper layer (3F) lava bridge in Manjang-gul cave is 1.9Ma determined by K-Ar method.

As for the lava bridge mineral in Manjang-gul cave, Albite, Quartz and also Augite are many. There are the cave (Sawa et al., 1996) of a

volcano in Cheju volcanic island (Sawa et al, 1990), Mt. Peakdu-san (Sawa et al., 1996F), Mt. Fuji mainly in Northeast Asia. As for these lava caverns high alkali basalt is distributing it. That even lava bridge in Manjang-gul cave was found is conceivable that there is an important meaning in these lava bridges.

要　　約

沢勲・井上央：萬丈窟洞窟の溶岩橋における蛍光X線分析とK-Ar年代測定

——済州火山島には360余個の寄生火山があるが、いずれも玄武岩質～粗面岩質溶岩より構成され、60余本の溶岩洞窟が発見されているるその中で、萬丈窟は、済州火山島の北東部、北済州群旧左邑金寧里、北緯126°46′18″・東経33°31′26″に位置し、洞窟の長さは8,928mである。

蛍光X線分析の結果より、萬丈窟における溶岩橋は、玄武安山岩質であるが萬丈窟の双子石柱とは異なり非アルカリ岩であることが分かった。

K-Ar年代測定の結果より、萬丈窟の上層部溶岩橋は約19万年前（0.19Ma）に形成されたことが分かった。済州火山島の活動年代については、まず山房山粗面安山岩の活動が約74万年前にあり、萬丈窟の溶岩橋の形成（約19万年前）を挟んで萬丈窟の双子石柱が形成され（32～42万年前および3～5万年前）、白鹿潭粗面安山岩が約2万5千年前（0.025Ma）に噴出した。

REFERENCES

GOTO, A., & Y.TATSUMI, 1994. Quantitative analysis of rock samples by an X-ray fluorescence spectrometer (I). The Rigaku Journal, 11(1), 40-59.

HONG, S.-H., 1981. A report of academic investigation about lava cave system of Manjang cave in Jeju island. CAVE (J. Speleol. Soc., Korea), 6(7):32-37

LEE, M.-W.,1982. Petrology and geochemistry of Jeju volcanic island, Korea. Tohoku Univ. Sci. Rept., Ser. 3,13(2),:177-256

LEE, S.-M., 1966. Volcanic rocks in Cheju island, Korea. J. Geol. Soc. Korea, 2(2),:1-7

OGAWA, T., 1981. A report of investigation about lava cave system of Manjang-gul Cave in Jeju island. CAVE (J. Speleol. Soc., Korea), 6(7):38-48

OKADA, T., T. ITAYA, I, SAWA & S,-H. HONG, 1991. K-Ar determination of a lava stalagmite in Manjang-gul, Jeju island Korea. J. SE Asian Earth Sci., 6:127-130

SAWA, I., 1991. Qualitative analysis of rock sample form the lava stalagmite in Manjang-gul cave by X-ray diffraction method. The Review OUEL, 45:1-9 (In Japanese)

_____, 1992. The relation between the chemical composition analysis on Manjang-gul cave and the localities of rock in Jeju volcanic island . The Review OUEL, 50:5-26 (In Japanese)

_____, & S.KATAYAMA, 1989. The bulk chemical composition of Manjang-gul cave with lava twin column in Cheju island . The Review OUEL, 36:1-26 (In Japanese)

_____, M. MURATA., S.-H., HONG & N. KASHIMA, 1990. Analysis of twin lava column sample from Manjang-gul cave Korea. J. Speleol. Soc.,Japan, 15:42-46 (In Japanese)

_____, _____ & H. KOHNO, 1996. A comparison of chemical components of lavas from Luti-dong cave on the Paekdu-san volcanoes and Manjang-gul cave on Cheju island. J. Speleol. Soc.,Japan, 21:65-70 (In Japanese)

_____, & S.-H.HONG, 1993. Quantitative analysis on the lava twin pillar of Manjang-gul cave and the volcanic locks of Cheju island . The Review OUEL, 54:35-62 (In Japanese)

_____, _____ & H. KOHNO, 1997. A comparison of chemical components and lattice constants with triclinic system of lava from Manjang-gul cave on Cheju island and Luti-dong cave on Peakdu-san. The Review OUEL, 68:27-49 (In Japanese)

_____, _____ & _____, 1998. Monoclinic and cubic system by X-ray diffraction method on twin lava column sample from Manjang-gul cave, Cheju volcanic island . The Review OUEL, 70:55-78 (In Japanese)

WON,J.-K., 1975. Study of Geologic development and the volcanic of the Jeju island Jull. Kon- kuk Univ. Seoul. Korea, 1:7-48

_____, J. MATSUDA, K.NAGAO, K.-H.KIM & M.-W. LEE, 1986. Paleomagnetism and radiometric age of Trachytes in Jeju island, Korea. J. Korean Inst. Mining Geology, 19:25- 33

Appendix *Analysis value of the lava in Cheju volcano island* (*wt.%*)

名称	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	合 計
101	61.36	0.37	18.12	2.08	0.12	0.06	3.21	6.08	4.95	0.23	96.58
102	60.65	0.44	18.20	4.00	0.00	0.86	6.81	4.54	3.08	0.98	99.56
103	59.51	1.13	18.52	2.84	0.22	0.78	4.19	5.02	3.16	0.14	95.51
104	58.75	1.00	23.65	4.51	0.19	0.00	4.02	2.42	4.73	0.07	99.34
105	54.87	1.33	17.91	4.68	0.00	1.21	7.38	4.58	3.20	1.02	96.18
106	54.72	1.33	23.50	2.20	0.16	1.17	4.50	3.19	2.99	0.15	93.91
107	54.28	1.23	17.82	2.66	0.18	1.57	6.49	3.91	3.40	0.29	91.83
108	51.10	0.53	18.80	5.33	0.01	1.54	6.43	7.41	4.94	0.01	96.10
109	49.61	2.12	15.20	6.81	0.24	5.04	6.37	4.42	2.85	0.00	92.66
110	47.70	1.07	22.50	4.95	0.01	2.09	6.09	6.34	3.98	0.02	94.75
111	46.86	2.69	16.37	6.01	1.23	4.25	6.81	5.28	2.41	1.71	93.62
112	44.61	0.56	18.55	13.36	0.35	7.06	9.21	2.89	0.53	0.08	97.20
113	44.60	0.95	25.20	3.32	0.01	2.52	8.24	4.58	1.20	0.01	90.63
114	44.30	1.85	20.50	7.67	0.02	4.00	8.35	5.39	1.67	0.02	93.77
115	43.41	2.58	15.52	3.99	1.38	6.78	10.77	4.28	1.30	1.29	91.30
116	41.20	1.28	24.70	9.77	0.01	2.74	9.24	5.25	1.87	0.01	96.07
117	56.34	0.94	17.43	3.52	0.25	0.84	3.80	5.13	3.32	1.24	92.81
118	56.19	2.14	16.12	2.44	0.30	3.70	7.63	4.39	2.30	0.55	95.76
119	49.80	0.98	19.00	5.88	0.01	1.31	5.76	6.74	3.23	0.01	92.72
120	49.56	0.31	21.17	8.52	0.23	2.79	6.09	4.42	2.27	0.17	95.53
121	47.26	0.53	18.07	13.04	0.10	4.31	8.22	4.13	1.33	0.20	97.19
122	45.74	0.31	21.06	13.82	0.19	4.41	8.14	3.81	1.25	0.09	98.82
123	45.50	1.51	22.80	8.02	0.01	1.64	7.39	5.93	2.29	0.20	95.29
124	45.40	1.59	22.80	8.81	0.02	2.16	8.13	5.12	2.17	0.09	96.29
125	44.60	1.39	24.00	7.68	0.02	2.64	5.81	5.12	1.87	0.02	93.15
126	44.54	2.97	23.53	0.67	1.53	4.35	7.46	1.41	1.49	0.02	87.97
127	44.50	1.28	21.50	5.31	0.01	3.17	8.69	5.05	2.05	0.59	92.15
128	43.60	1.23	22.00	7.71	0.01	3.71	8.92	5.53	1.75	0.01	94.47
129	66.31	0.00	18.55	2.29	0.09	0.00	2.03	3.35	5.14	0.00	97.76
130	64.62	0.27	17.90	1.86	0.08	0.16	2.31	5.19	5.25	0.02	97.66
131	64.61	0.43	17.53	1.46	0.19	0.00	4.22	5.33	4.95	0.00	98.72
132	57.42	0.32	17.44	9.32	0.12	1.33	4.71	5.32	3.02	0.08	99.08
133	54.98	0.93	21.13	3.49	0.21	1.15	3.27	5.94	3.40	0.97	95.47
134	54.60	0.83	16.80	5.52	0.00	1.70	3.84	8.09	4.94	0.00	96.32
135	51.04	0.71	16.82	11.32	0.11	8.65	7.58	3.31	1.05	0.11	100.70
136	50.20	2.25	15.08	6.42	0.20	5.08	6.40	4.33	2.97	0.00	92.93
137	49.38	0.73	17.09	10.01	0.13	4.88	7.65	3.88	1.01	0.05	94.81
138	48.33	2.31	16.13	4.60	0.12	4.13	10.67	3.74	1.07	1.46	92.56
139	48.00	1.32	16.08	8.22	0.01	4.06	7.22	6.07	3.01	0.01	94.00
140	47.60	1.72	14.77	2.78	0.61	4.64	12.76	3.76	1.03	1.40	91.07

141	47.40	1.85	16.50	7.77	0.01	5.49	8.01	5.39	2.53	0.03	94.98
142	47.00	1.75	20.50	4.34	0.01	3.20	8.92	6.34	1.93	0.03	94.02
143	46.90	1.33	20.10	7.24	0.01	3.12	7.22	6.20	2.77	0.04	94.93
144	45.90	1.55	17.50	8.87	0.01	4.95	8.13	5.93	2.41	0.05	95.30
145	45.50	1.62	17.20	8.16	0.01	4.92	8.75	5.66	2.41	0.04	94.27
146	44.60	1.80	17.60	7.71	0.01	7.21	9.03	4.72	1.75	0.01	94.44
147	44.50	1.62	20.80	8.11	0.01	7.58	4.63	4.72	1.93	0.01	93.91
148	43.36	0.32	16.14	14.24	0.35	7.87	9.28	2.89	1.21	0.08	95.74
149	42.80	1.59	17.40	5.91	0.01	8.68	8.80	4.04	1.45	0.01	90.69
150	51.50	0.00	15.45	1.82	0.00	4.93	9.19	4.09	3.52	0.00	90.50
201	48.22	2.36	14.42	2.44	0.16	8.93	8.12	3.74	2.03	0.54	90.96
202	48.49	2.39	15.14	1.62	0.17	9.00	8.19	3.25	1.93	0.55	90.73
203	45.11	2.67	13.84	3.39	0.17	10.61	10.17	2.10	1.31	0.53	89.90
204	49.13	2.38	14.58	1.98	0.15	8.43	8.89	3.31	1.38	0.48	90.71
205	48.41	2.27	14.49	1.84	0.17	9.61	9.44	3.10	1.43	0.47	91.23
206	49.10	2.15	14.15	1.79	0.15	9.78	9.51	2.40	1.23	0.38	90.64
207	47.17	2.18	14.58	3.37	0.17	10.25	8.25	2.96	1.23	0.39	90.55
208	48.79	2.14	15.21	1.71	0.15	8.98	8.48	3.12	0.83	0.35	89.76
209	47.32	2.45	14.22	3.54	0.15	9.09	8.77	3.16	1.49	0.49	90.68
210	47.02	2.79	17.06	1.10	0.16	8.59	8.67	3.03	1.23	0.27	89.92
211	51.07	2.48	14.70	2.51	0.15	6.14	7.78	3.36	1.41	0.57	90.17
212	50.70	1.93	16.06	1.36	0.14	7.11	8.28	3.23	0.88	0.29	89.98
213	48.00	3.08	17.56	3.25	0.16	5.55	8.11	3.72	1.31	0.33	91.07
214	49.45	2.70	16.93	4.77	0.17	4.90	7.67	3.60	1.48	0.67	92.34
215	49.77	2.56	16.77	2.72	0.15	5.44	7.29	4.10	2.03	0.66	91.49
216	49.60	2.59	15.21	2.71	0.15	7.06	8.00	3.41	1.86	0.68	91.27
217	48.19	2.97	17.04	5.33	0.16	4.90	8.48	3.76	1.31	0.67	92.81
218	48.36	2.63	14.52	2.43	0.15	8.40	8.80	2.90	1.09	0.57	89.85
219	49.82	2.44	17.14	3.92	0.15	5.07	7.30	3.94	1.74	0.49	92.01
220	49.28	2.77	17.57	1.81	0.14	5.14	8.57	3.66	1.13	0.54	90.61
221	48.74	2.29	19.21	2.00	0.12	3.81	8.85	4.08	1.43	0.88	91.41
222	48.41	3.35	17.15	2.69	0.18	4.45	7.00	3.74	1.44	0.95	89.36
223	50.01	2.26	17.16	3.15	0.16	5.62	7.90	3.91	1.88	0.66	92.71
224	48.53	2.77	14.89	1.41	0.22	7.89	8.41	3.37	1.17	0.48	89.14
225	52.17	1.96	16.05	1.40	0.15	5.96	6.74	4.26	2.18	0.62	91.49
226	47.59	2.60	17.37	3.84	0.15	6.61	8.53	3.56	0.98	0.43	91.66
227	49.61	2.41	15.46	2.33	0.17	6.90	8.05	3.42	1.07	0.47	89.89
228	49.99	2.37	16.27	1.72	0.15	5.91	7.42	3.92	1.73	0.54	90.02
229	49.75	2.70	16.33	3.58	0.17	4.92	8.07	3.79	1.72	0.71	91.74
230	49.45	2.53	16.14	1.60	0.16	5.83	8.01	3.89	1.93	0.72	90.26
231	49.85	2.48	14.72	1.75	0.14	6.99	8.00	3.57	1.52	0.53	89.55

232	50.41	2.28	14.68	2.60	0.17	5.83	8.27	3.94	1.73	0.55	90.46
233	50.26	2.69	17.91	2.86	0.12	3.64	7.87	4.13	1.84	0.66	91.98
234	50.74	2.40	15.89	1.38	0.15	4.55	8.39	4.02	1.72	0.55	89.79
235	48.88	2.56	17.23	2.18	0.18	5.62	7.43	3.69	1.42	0.60	89.79
236	48.51	2.55	18.81	1.75	0.13	5.28	8.26	3.85	1.30	0.55	90.99
237	49.98	2.36	16.83	1.81	0.16	5.79	7.35	3.78	1.82	0.66	90.54
238	51.03	2.20	17.22	2.19	0.16	4.42	6.73	4.17	2.12	0.63	90.87
239	51.20	2.39	18.35	4.58	0.15	3.27	6.92	4.48	1.74	0.82	93.90
240	48.88	2.34	18.01	9.14	0.13	3.40	8.26	3.86	1.54	0.64	96.20
241	49.36	2.40	16.84	1.74	0.16	5.23	8.27	3.92	1.80	0.51	90.23
242	51.75	2.36	15.65	2.59	0.16	4.94	8.31	3.67	1.52	0.41	91.36
243	47.94	2.67	15.78	3.24	0.14	7.70	8.64	3.49	1.26	0.40	91.26
244	49.09	3.51	15.86	4.39	0.19	4.09	7.63	3.92	1.58	0.64	90.90
245	49.17	3.50	16.39	2.74	0.16	4.67	8.01	3.90	1.52	0.48	90.54
246	48.37	3.57	16.47	2.31	0.17	4.53	7.69	3.82	1.38	0.50	88.81
247	46.85	3.09	18.50	1.69	0.15	5.42	7.96	3.96	1.44	0.47	89.53
248	48.10	3.18	17.33	3.25	0.15	5.21	7.88	3.76	1.39	0.56	90.81
249	50.93	2.40	18.00	2.36	0.15	3.21	6.41	4.61	2.11	0.58	90.76
250	54.57	1.67	18.51	2.30	0.15	2.25	5.52	5.05	2.62	0.83	93.47
251	54.50	1.66	17.81	6.36	0.14	1.82	5.05	4.95	2.92	0.93	96.14
252	50.86	2.50	14.96	2.86	0.16	4.05	9.08	4.15	1.26	0.44	90.32
253	52.03	2.11	16.96	3.80	0.14	3.75	5.60	4.34	2.25	0.92	91.90
254	54.66	1.56	17.79	2.38	0.16	2.02	5.55	5.03	2.88	0.83	92.86
255	51.24	1.88	18.38	3.66	0.17	2.89	6.04	4.82	2.64	1.00	92.72
256	55.31	1.48	18.15	1.89	0.14	2.27	4.48	4.97	2.95	0.97	92.61
257	57.99	0.97	18.56	4.80	0.24	0.46	3.24	5.95	4.18	0.52	96.91
258	62.38	0.50	17.73	1.89	0.25	0.19	2.69	6.39	4.26	0.25	96.53
259	59.51	0.94	17.82	4.19	0.13	0.86	2.55	5.41	3.91	0.48	95.80
260	60.19	0.68	17.68	2.53	0.13	0.91	2.38	5.76	4.65	0.26	95.17
261	62.84	0.46	17.84	1.90	0.14	0.28	1.78	5.98	5.03	0.22	96.47
262	61.98	0.64	17.51	5.67	0.12	0.62	1.57	5.51	4.47	0.47	98.56
263	65.54	0.28	16.73	2.50	0.12	0.13	1.07	6.04	5.63	0.03	98.07
翰林横臥	47.40	2.58	14.60	12.60	0.16	8.57	9.13	2.93	1.48	0.60	100.05
翰 林 竪	47.50	2.58	14.40	12.60	0.16	8.63	9.12	2.95	1.54	0.51	99.99
萬丈 2 F	53.10	1.79	14.30	12.40	0.15	6.23	8.85	2.64	0.38	0.16	100.00
萬丈 3 F	52.60	1.74	14.30	12.40	0.15	6.89	8.84	2.54	0.36	0.18	100.00
萬丈石柱	50.99	2.15	15.17	12.56	0.16	6.15	8.06	3.27	1.04	0.30	99.85
MAX	66.31	3.57	25.20	14.24	1.53	10.61	12.76	8.09	5.63	1.71	100.70
AVG	50.60	1.82	17.51	4.68	0.17	4.53	7.16	4.30	2.20	0.43	93.40
MIN	41.20	0.00	13.84	0.67	0.00	0.00	1.07	1.41	0.36	0.00	87.97
STDEV	5.21	0.88	2.48	3.37	0.22	2.70	2.15	1.15	1.20	0.36	3.15