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The Basalt of Patagonia

By

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with 4 Tables and 7 Text-figures

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ABSTRACT: The samples subjected to the microscopic examination and chemical analysis were provided by the 4th Scientific Expedition to Patagonia by Hiroshima & Hokkaido Univ., 1969. The party collected them on the continental side of the southern Andes between Mendoza and Santa Cruz in Argentina. The present writers tried in the first place to clarify the order of eruption, in the second place to define the petrological and chemical properties of the basalts, and at last some genetic considerations were pursued.

CONTENTS

I. INTRODUCTION

Patagonia is situated in the southern part of South America, between 35° (the south latitude) and 72° (west longitude) (Fig. 1). On the continental side of the southern Andes, shield volcanoes, cinder cones, and lava plateaux are present.

The basalt lavas which poured out in great quantities over wide areas of Patagonia were collected by the member of the 4th Scientific Expedition to Patagonia. These rocks were subjected to microscopical examination and chemical analysis.

The great basalt lava fields of Patagonia rest upon flatlying Mesozoic and Cenozoic sediment, of which the vast extra-Andean plains or pampas are composed. The basalts cover an area of about 100,200 km² to the south of Mendosa. Especially between Mendosa and the Rio Gallegos, they form extensive flat-topped plateau or mesas, in El Manzano, Bariloche, and Hotel Las Horquetas.

The writers believe that fissure eruption was the main type of activity of the Patagonian basalts, and that tuffaceous material played only a subordinate part in the building-up of the mesas. The basalts form lava-flows in the region of El Manzano. There are Mesozoic sediments similarly in the neighborhood of the Hotel Las Horquetas. The

(*) Contribution of the 4th Sciertific Expedition to Patagonia by Hiroshima & Hokkaido Univs., 1969.

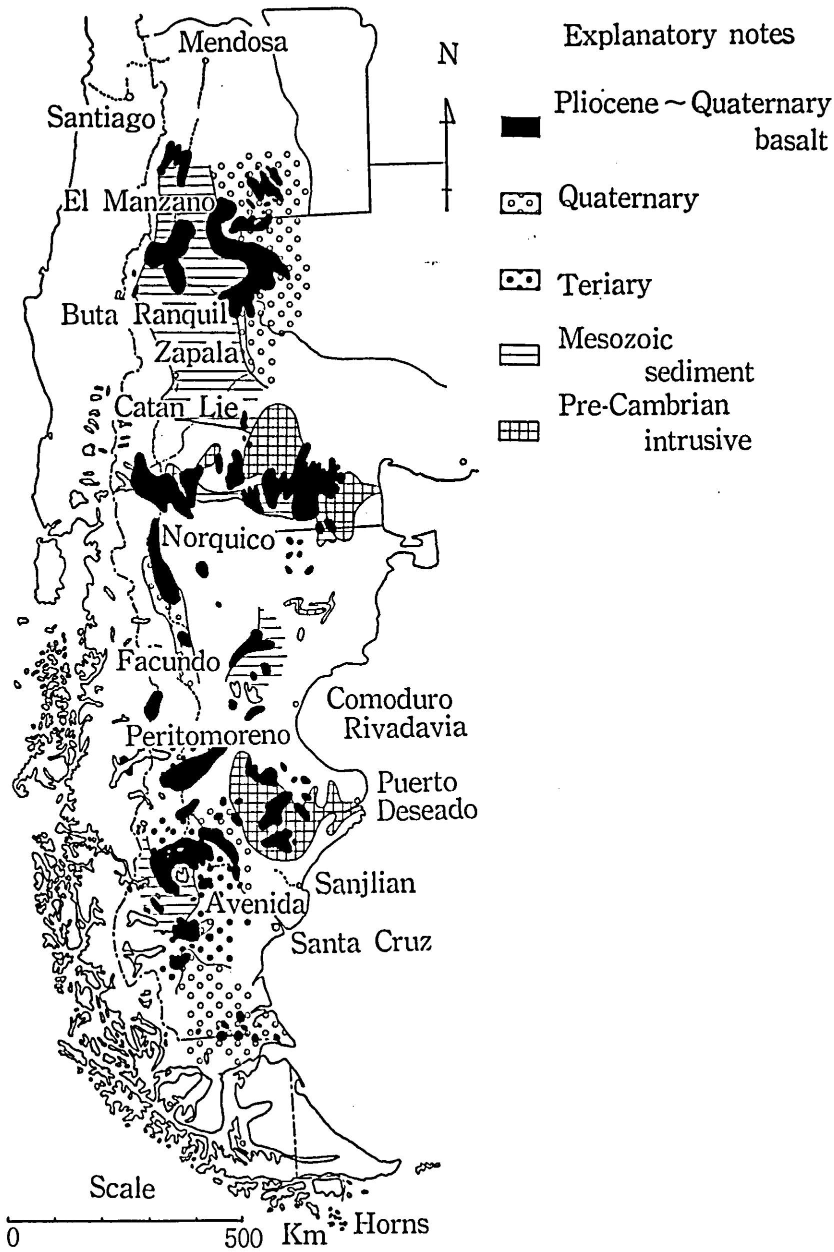

FIG. 1. Distribution of the basalts in Patagonia.

basalts are intercalated with sediments of the Santa Cruz Formation which is covered by the Quaternary gravels, especially in the southern part of the region. It seems that they had already ceased their activity before or in the Quaternary period. The major portion of the basalts belongs to the alkali rocks series which are accompanied by subordinate amounts of rocks belonging to the calc-alkali rock series.

The Patagonian basalts were studied previously by TYRRELL (1932) and recently QUARTINO (1957) has reported on the basalts of the Cerro El Pedrero district.

In order to clarify the origin of the Patagonian basalts, the present writers have tried in the first place to find out the order of eruption, and in the second place to define the petrological and chemical properties of the basalts.

II. ACKNOWLEDGEMENTS

The samples studied in the present paper were collected by the Hiroshima University and the Hokkaido University Patagonia Expedition Party to the Patagonian plateaux.

The writers wish to express their sincere thanks for the guidance, discussions, field survey, and encouragements kindly offered by the following persons.

Professor Kenzo YAGI of Hokkaido University for his kind advice and also for critical reading of the manuscirpt; Professor George KOJIMA of Hiroshima University who has been the constant advisor for the present study from the beginning; and Hiroko TSUJI Principal of Notre Dame High School who encouraged one of the authors (H. T.) to complete this study.

The writers are indebted to Dr. Isao MUROI of the Scientific Center of Osaka for the use of a magnetometer and his helpful advice for the magnetic measurements.

They owe much to these persons without whose help this study could not have been completed.

III. GEOLOGIC SETTING

Cretaceous formations consisting of continental sediments are developed in the northern part of Patagonia province, especially in Mendoza and Norquinco district. In the Rio Negro and Santa Cruz district, the Pre-Cambrian gneiss are distributed. The Tertiary Santa Cruz Formation are widely distributed in the Santa Cruz district, and the Quaternary river terrace deposits are developed in the Santa Cruz and Rio Gallegos.

The basal plane of the basalts is generally flat, parallel to the surface of the plateaux (Fig. 2).

The activities of these basalts lasted from Pliocene to Pleistocene. It is believed that volcanic eruptions took place in the north of Patagonia, followed gradually by the eruptions in the south, and ending in the southern point at Rio Gallegos was in the Pleistocene.

The present writers collected samples from these problematical points and measured the natural remanent magnetism to establish volcanostratigraphic correlation of the

TABLE 1. NATURAL REMANENT MAGNETIZATION OF THE ROCK SAMPLES.

Sample No.	S. Latitude	W. Longitude	Declination	Inclination
El Manzano	−35 13	290 16	359	−62
Zapala	−38 55	289 52	64	−42
Norquinco	−41 31	289 07	193	−11
Peritomoreno	−47 00	289 34	277	−38
Hotel Avenida	−49 06	290 37	261	37

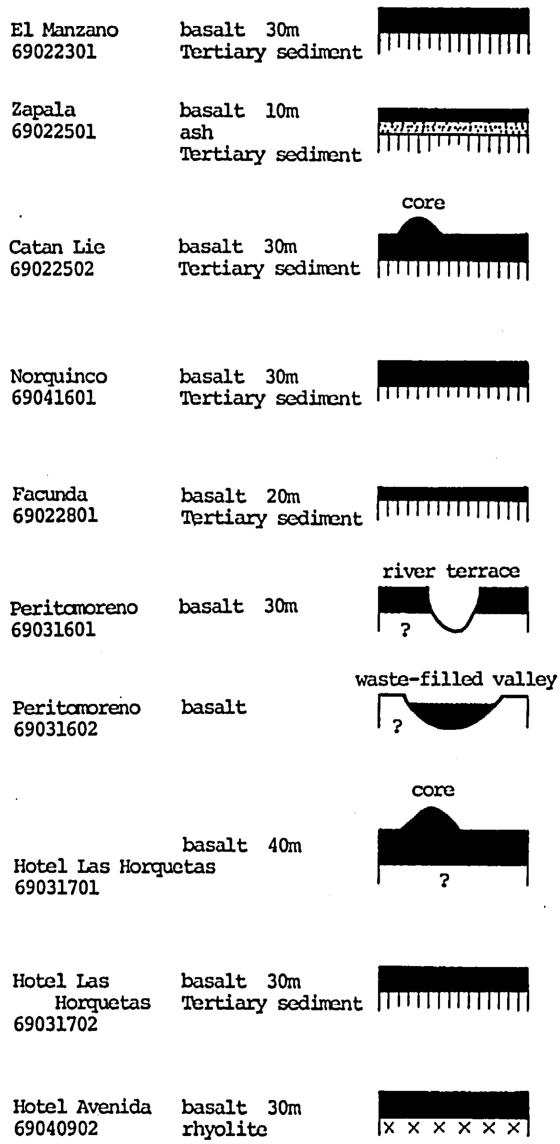

FIG. 2. Schematic sections of the Patagonian basalts at sample localities.

rocks. The results of the measurement of remanent magnetism are given in Table 1.

Generally speaking, the fact that the declination and the inclination have moved from the north to the south, or from the south to the north, may be explained as follows: the activity started in the north and moved toward the south, or to the contrary it started in the south and finished in the north.

The presence of one normal and all other reversed inclinations show that continual activities covered the period from the Reversed Epoch, or Vice Versa.

IV. Petrographic Description

The character in features of Patagonian basalts are given as follows:

No. 1	69022301	18 km. to the north of El Manzano, olivine basanitoid, intersertal texture.
No. 2	69022401	Buta Ranquil, olivine basanitoid, trachytic texture.
No. 3	69022501	20 km. to the south of Zapala, augite olivine basanitoid, trachytic-intergranular texture.
No. 4	69022502	5 km. to the south of Catan Lie, olivine basanitoid, intersertal-trachytic texture.
No. 5	69041602	Bariloche, olivine basanitoid, trachytic-intersertal texture.
No. 6	69041601	40 km. to the north of Norquinco, olivine basanitoid, doleritic texture.
No. 7	69022801	40 km. to the north of Facundo, augite olivine basanitoid, doleritic texture.
No. 8	69031601	40 km. to the south of Peritomoreno, augite olivine basalt, doleritic texture.
No. 9	69031602	72 km. to the south of Peritomoreno, augite olivine basanitoid, intergranular texture.
No. 10	69031701	Hotel Las Horquetas, olivine basanitoid, doleritic texture.
No. 11	69031702	9 km. to the south of Hotel Las Horquetas, olivine basanitoid, intersertal texture.
No. 12	69040902	4 km. to the north of Hotel Avenida, olivine augite basaltic andesite, intergranular texture.

Basanitoid...containing more than 5% normative nepheline but no modal one.

Alkali olivine basalt...containing 5% or more modal olivine and less than 5% normative nepheline.

Basaltic andesite...containing more than 52% SiO_2.

The classification following MacDonald and Katsura (1964) was adopted.

Tyrrell (1932) described the petrography of Patagonian basalt, i.e., a dark gray, compact basalt with a few, small, inconspicuous phenocrysts of plagioclase and olivine from the south of Lago Buenos Aires, and two other coarser, aphanitic rocks.

A. Basanitoid

Individual flows usually contain phenocrysts of olivine, together with less common plagioclase and very rare clinopyroxene. Plagioclase (An 66–54) is long prismatic, polysynthetic albite twin. Olivine is colorless, euhedral and fresh, or sometimes an incipient alteration to a pale green serpentine or brownish iddingsite. The augite is mostly euhedral, pale brown in color, showing faint trace of violet in a few crystals.

The groundmass minerals are olivine, plagioclase, titanaugite, titaniferous magnetite, apatite, untwinned alkali feldspar and interstitial zeolite. Basanitoids have textures given in Table 2. For example, those from Norquinco, Facundo, Peritomoreno, or Hotel Las Horquetas have doleritic texture, others show intersertal, intergranular or trachytic texture. The difference in these petrographic textures within basanitoid types may reflect the different modes of crystallization in these flows. Alkali feldspar is predominant over plagioclase laths.

B. Augite Olivine Basalt

Olivine is by far the most common phenocryst, and plagioclase and augite are less conspicuous. Plagioclase (An 59–47) is long prismatic, and forms polysynthetic twin.

Olivine is euhedral and fresh, but alterated to iddingsite along the margin. Augite is considerably larger than the others, while feldspar and augite of the groundmass possess distinct ophitic texture. This basalt was collected from near Peritomoreno.

C. Ultramafic Nodule

The basanitoids from Hotel Las Horquetas carry dense and ovalshaped ultramafic nodules. They belong to dunite since they consist only of olivine grains under the microscope.

D. Rock Forming Minerals

All the refractive indices were measured by the oil immersion method. The accuracy of measurement is ± 0.001 — 0.003. Errors in measurement are larger in the minerals of higher index. Axial angles were measured with a universal stage, with accuracy $\pm 3°$ max.

Compositions of olivines, orthopyroxenes, and clinopyroxenes were inferred from their optical properties, by the use of diagrams prepared by POLDERVAART and HESS (1951). For plagioclases, the diagram by TSUBOI (1923) was used and the compositions were determined from the refractive indices. The compositions of titanaugite and augite were estimated by optical properties.

Table 2 lists the optical properties of rock-forming minerals of Patagonian basalt.

1. *Plagioclase*. . Plagioclase, occurring as phenocrysts and in the groundmass, is the principal constituent of basalts of this province. On several occasions, Patagonian basalts lack phenocrystic plagioclase.

Phenocrysts of plagioclase are usually idiomorphic long prismatic crystals. Commonly about 1 — 0.1 mm. in length. Its composition range is An 47–66 content, but zonal structure is not developed: they are twinned on the albite, polysynthetic and rarely pericline laws. Generally it is fresh, occasionally including dust.

As to the groundmass plagioclase, it usually occurs in needle or lath-shaped crystal. Albite twinning is common in the lath-shaped crystal. It has the composition An 42–67.

2. *Pyroxene*. . Pyroxene is the most important mafic mineral and is found in all rock. Pyroxene are almost clinopyroxene, but orthopyroxene is found only at Hotel Avenida (No. 12).

Augite is idiomorphic or hypidiomorphic crystals. Phenocrystic augite is titaniferous diopsidic augite. Twinning on 100 is common. The refractive index β ranges from about 1.679 — 1.710, the optic axial angle 2 V_γ varies 50° — 40°. Optical data are shown in Table 2 with other rock minerals. Some fo the augite show poikilitic structure or hour-glass structure.

Optical properties of phenocrystic augite is as follows;

$$\beta=1.679 - 1.710 \quad 2\,V_\gamma=50° - 40°$$

Wo43 En47 Fs10...Wo36 En43 Fs16

The groundmass augite occurs in stumpy prisms or grains and its optical property is as follows;

$$\beta=1.680 - 1.730 \quad 2\,V_\gamma=46° - 40°$$

Wo40 En47 Fs13...Wo33 En37 Fs30

Orthopyroxene is rarely found in the rock from Hotel Avenida.

3. *Olivine*. .Olivine occurs as phenocrysts in Patagonian basalts. It is found also in the groundmass of such rocks. This mineral is most abundant in basalts of this province. The longer diameter of olivine phenocrysts is generally less than 5 mm. The composition of olivine is Fa 16 — 26 in the case of phenocryst, and Fa 18 — 29 in groundmass. It is altered to iddingsite along the cleavage but reraly to serpentine.

4. *Magnetite*. .Magnetite is contained in all rocks, its longer diameter is nearly always less than 1 mm.

5. *Ilmenite*. .In the groundmass of nearly all rocks ilmenite is contained as minute hexagonal plates or slender prismatic crystals. This mineral is black or opaque. Usually ilmenite coexists with magnetite, however, in some rocks of dolerite ilmenite is much more abundant than magnetite.

The mineral variation is generally much simple. Olivine bears no reaction relation to Ca-rich clinopyroxene which is usually the only pyroxenic phase. They occur both as phenocrysts and in the groundmass.

Olivine has compositional ranges of Fa 16 — 29. Augite ranges from diopsidic augite to titanaugite. Wo content of the pyroxenes is nearly constant, while Fs content varies only from 10 to 30%. Magnetite starts to crystallize in a fairly early stage. Plagioclase ranges in composition from calcic labradorite to andesine. Alkali feldspar is invariably present in the groundmass throughout the rocks.

TABLE 2. OPTICAL PROPERTIES OF CONSTITUENT MINERALS OF THE PATAGONIAN BASALTS.

Locality No.	Phenocrysts Feldspar	Phenocrysts Olivine	Phenocrysts Pyroxene	Groundmass Feldspar	Groundmass Olivine	Groundmass Pyroxene	Xeno-crysts
1 El Manzano 69022301	$n_1=1.562\sim n_2=1.569$ An 64~66	$\alpha=1.677\sim\gamma=1.718$ $2V_\alpha=86\sim87°$ Fa 22~23	$2V_\gamma=50°$	$n_1=1.561\sim n_2=1.569$ An 63~65	$\alpha=1.679\sim\gamma=1.729$ $2V_\alpha=84\sim86°$ Fa 23~29	fine	
2 Buta Ranquil 69022401	$n_1=1.559\sim n_2=1.556$ An 58~60	$\alpha=1.667\sim\gamma=1.717$ $2V_\alpha=87\sim89°$ Fa 16~22		$n_1=1.558\sim n_2=1.565$ An 56~59	$\alpha=1.674\sim\gamma=1.724$ $2V_\alpha=85\sim88°$ Fa 20~26	$2V_\gamma=44°$	Plagio-clase
3 Zapala 69022501	$n_1=1.558\sim n_2=1.567$ An 56~62	$\alpha=1.657\sim\gamma=1.724$ $2V_\alpha=85\sim87°$ Fa 21~26	$2V_\gamma=44\sim46°$	$n_1=1.554\sim n_2=1.565$ An 49~58	$\alpha=1.680\sim\gamma=1.728$ $2V_\alpha=84\sim86°$ Fa 23~28	$2V_\gamma=44°$	
4 Catan Lie 69022502		$\alpha=1.678\sim\gamma=1.722$ $2V_\alpha=85\sim87°$ Fa 22~25		$n_1=1.553\sim n_2=1.565$ An 48~57	$\alpha=1.682\sim\gamma=1.730$ $2V_\alpha=83\sim86°$ Fa 24~29	fine	
5 Facunda 6902801	$n_1=1.557\sim n_2=1.565$ An 54~58	$\alpha=1.678\sim\gamma=1.722$ $2V_\alpha=85\sim87°$ Fa 22~25	$\alpha=1.685$	$n_1=1.551\sim n_2=1.564$ An 45~55	$\alpha=1.682\sim\gamma=1.728$ $2V_\alpha=84\sim86°$ Fa 24~28	$2V_\gamma=40°$	
6 Bariloche 69041602		$\alpha=1.665\sim\gamma=1.710$ $2V_\alpha=88\sim90°$ Fa 16~19		$n_1=1.560\sim n_2=1.569$ An 60~67	$\alpha=1.670\sim\gamma=1.719$ $2V_\alpha=86\sim88°$ Fa 18~24	$\gamma=1.730$	
7 Norquinco 69041601	$n_1=1.558\sim n_2=1.566$ An 55~59	$\alpha=1.675\sim\gamma=1.715$ $2V_\alpha=87\sim88°$ Fa 21~22	$2V_\gamma=46\sim48°$	$n_1=1.556\sim n_2=1.564$ An 53~55	$\alpha=1.685\sim\gamma=1.728$ $2V_\alpha=84\sim85°$ Fa 25~28		
8 Peritomoreno 69031601	$n_1=1.552\sim n_2=1.566$ An 47~59	$\alpha=1.670\sim\gamma=1.720$ $2V_\alpha=86\sim88°$ Fa 18~24	$2V_\gamma=40\sim42°$		$\alpha=1.680\sim\gamma=1.728$ $2V_\alpha=84\sim86°$ Fa 23~28		
9 Peritomoreno 69031602		$\alpha=1.668\sim\gamma=1.721$ $2V_\alpha=88\sim90°$ Fa 16~20	$2V_\gamma=44\sim48°$	$n_1=1.554\sim n_2=1.566$ An 49~59	$\alpha=1.672\sim\gamma=1.725$ $2V_\alpha=85\sim88°$ Fa 19~27	fine	Plagio-clase Olivine $2V_\alpha=88°$
10 Hotel Las Horquetas 69031701	$n_1=1.558\sim n_2=1.564$ An 55~56	$\alpha=1.670\sim\gamma=1.716$ $2V_\alpha=87\sim88°$ Fa 18~22	$2V_\gamma=42°$ $\alpha=1.679$	$n_1=1.556\sim n_2=1.563$ An 52~53	$\alpha=1.678\sim\gamma=1.726$ $2V_\alpha=84\sim87°$ Fa 22~27	fine	
11 Hotel Las Horquetas 69031702		$\alpha=1.668\sim\gamma=1.716$ $2V_\alpha=87\sim89°$ Fa 17~22		$n_1=1.549\sim n_2=1.563$ An 42~53	$\alpha=1.674\sim\gamma=1.730$ $2V_\alpha=84\sim88°$ Fa 20~29	fine	
12 Hotel Avenida 69040902	$n_1=1.555\sim n_2=1.565$ An 50~57	$\alpha=1.670\sim\gamma=1.710$ $2V_\alpha=88°$ Fa 18~19	(hyper-sthene)	$n_1=1.553\sim n_2=1.562$ An 48~52	$\alpha=1.684\sim\gamma=1.725$ $2V_\alpha=85°$ Fa 25~26	$2V_\gamma=46°$ (hyper-sthene)	Plagio-clase

V. Petrochemistry

In order to understand the petrochemical character of basalts from Patagonia, samples collected from various localities have been chemically analized. The analytical method is as follows: Fe_2O_3 (total iron), MgO, CaO and Al_2O_3 were determined by chelatometric titration. Na_2O and K_2O were determined by flame photometry, and P_2O_5, TiO_2 and MnO by colorimetric analysis, SiO_2 and H_2O by weight analysis, and FeO by the permanganate-method.

Chemical compositions and norms of the twelve basalts are shown in Table 3, together with their average chemical composition.

Table 3. Chemical Composition and CIPW Norm of the Patagonia Bbasalts.

No	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	47.05	49.49	48.80	49.29	46.74	48.48	48.09	50.75	47.33	48.76	46.64	52.39
TiO_2	1.26	1.30	0.81	1.60	0.95	0.94	0.85	1.23	1.66	1.03	1.61	1.33
Al_2O_3	16.11	15.50	14.34	15.40	15.60	15.86	16.98	15.20	14.75	16.42	14.96	15.45
Fe_2O_3	2.04	2.69	0.82	3.03	3.02	2.45	1.34	2.13	1.42	2.40	3.75	1.54
FeO	8.16	5.25	10.15	6.51	7.68	7.96	8.98	8.55	8.81	8.59	7.88	8.17
MnO	0.12	0.09	0.10	0.09	0.09	0.10	0.08	0.09	0.09	0.08	0.11	0.07
MgO	8.06	7.42	8.87	7.34	9.19	8.11	6.77	7.34	8.14	7.10	7.42	6.41
CaO	10.32	9.64	8.75	8.85	8.75	8.94	8.29	7.51	10.00	7.96	8.14	7.74
Na_2O	4.87	5.28	5.23	5.63	4.66	5.27	5.39	5.13	5.23	5.87	5.33	5.06
K_2O	0.88	1.75	0.72	0.80	1.54	1.03	1.68	0.88	1.85	0.38	2.67	0.43
P_2O_5	0.28	0.28	0.26	0.21	0.37	0.27	0.38	0.12	0.30	0.30	0.32	0.28
H_2O^+	0.70	0.59	0.72	0.85	0.90	0.35	0.56	0.44	0.24	0.61	0.60	0.62
H_2O^-	0.58	0.28	0.28	0.30	0.28	0.25	0.20	0.26	0.26	0.31	0.31	0.23
Total	100.43	99.56	99.85	99.88	99.97	100.01	99.59	99.63	100.08	99.81	99.74	99.72
Or	5.23	10.34	4.28	4.73	9.12	6.12	9.95	5.23	10.95	2.22	15.79	2.56
Ab	16.35	19.39	22.79	28.19	16.30	22.06	18.71	34.16	9.85	30.18	11.21	42.76
An	19.46	13.40	13.13	14.37	17.04	16.54	17.15	15.82	11.26	17.32	8.98	18.15
Q												0.10
Ne	13.43	13.69	11.62	10.51	12.52	12.18	14.54	4.97	18.63	10.54	18.35	
Wo	12.49	13.61	11.82	11.75	10.02	10.88	8.98	8.65	15.22	8.46	12.24	7.69
En	7.52	11.11	6.48	7.87	6.47	6.61	4.75	4.98	8.97	4.79	7.74	7.69
Fs	4.29	3.26	4.90	2.98	2.86	3.66	3.95	3.27	5.48	3.30	3.71	3.10
Fo	8.84	5.21	10.99	7.34	11.56	9.57	8.53	9.36	7.97	9.07	7.57	8.23
Fa	5.55	1.68	9.19	3.08	5.66	5.83	7.82	6.79	5.36	6.89	4.01	6.61
Mt	2.97	3.90	1.18	4.38	4.38	3.55	1.95	3.09	2.06	3.48	5.43	2.32
Il	2.33	2.48	1.54	3.04	1.81	1.79	1.61	2.34	3.16	1.96	3.06	2.52
Ap	0.65	0.65	0.59	0.49	0.85	0.62	0.88	0.26	0.69	0.69	0.75	0.65
CI	44.64	38.90	46.69	40.93	43.61	42.51	38.47	38.74	43.55	38.64	44.51	35.31

CI...Colour index

1...El Manzano 2...Buta Ranquil 3...Zapala 4...Cata Lic 5...Bariloche 6...Norquinco 7...Facundo 8...Peritomoreno 9...Peritomoreno 10...Hotel Las Horquetas 11...Hotel Las Horquetas 12...Hotel Avenida

As shown in the table, SiO_2 contents cover the range from 46.64% to 52.39%; Al_2O_3 contents vary from 14.34% to 16.98%; other oxide contents are as follow; TiO_2 0.81–1.66%; Fe_2O_3 0.82–3.75%; FeO 5.25–10.15%; MnO 0.07–0.12%; MgO 6.41–9.19%; CaO 7.51–10.32%. Na_2O contents are extremely high, ranging from 4.66 to 6.43%; K_2O 0.38–2.67%; P_2O_5 0.12–0.38%; and the solidification indices of KUNO vary from 27.4 to 35.2; colour indices range from 35.31 to 44.64. The alkali-lime index is 48.2 to 51.7.

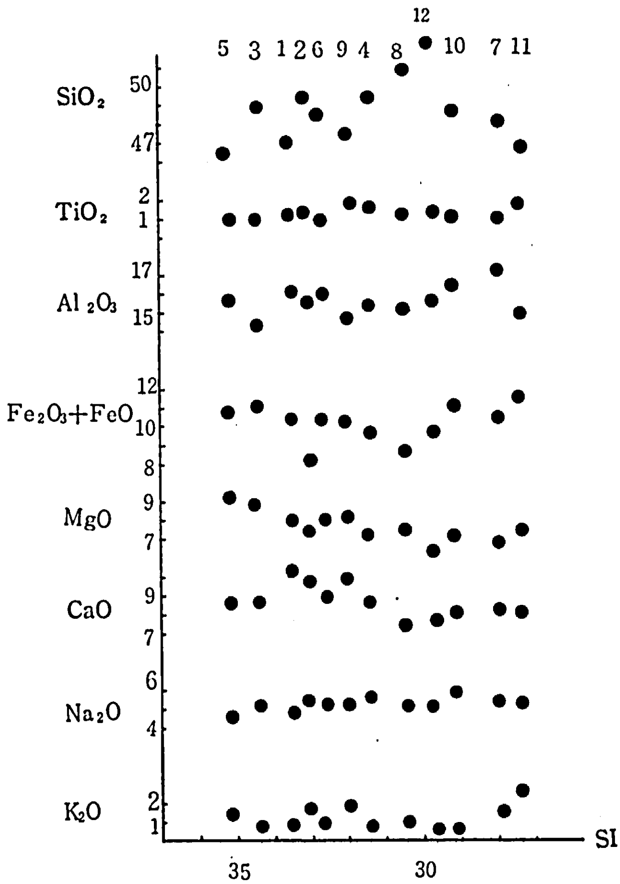

FIG. 3. Variation diagram for major oxides use solidification indices in the Patagonian basalts.

Eight main oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O and K_2O) are plotted against KUNO's solidification index in Fig. 3. When compared with the variation curves of the average alkalic rock series of the Circum-Japan Sea Region (TOMITA, 1935), it is shown that Na_2O is much higher, but TiO_2 is lower. A glance at the figure will show that the main oxides change gradually, and that the tendency of the other oxides are explained as follows.

Al_2O_3...Al_2O_3 shows scattering of the plotts, mainly owing to the difference of the amounts of phenocrystic plagioclase; the basaltic rocks, No. 3 (Zapala) and

No. 11 (Hotel Las Horquetas) are rather poor in Al_2O_3.

TiO_2 ...In general, TiO_2 contents are low.

$FeO+Fe_2O_3$...Of these, basalt No. 2 (Buta Ranquil) is especially poor in iron.

MgO ...Generally MgO shows a rather smooth curve.

CaO ...CaO contents are fairly scattered, owing probably to the variation in the amounts of augite, rather than plagioclase.

Na_2O...Na_2O contents of all rocks are very high and show a fairly smooth curve.

K_2O ...Although contents are scattered, there is a distinct trend that basalts of Patagonia are moderate in K_2O.

Normative compositions shown in Table 3 indicate that the basalts of Patagonia are unsaturated with silica. Thus normative quartz is absent, except for No. 12 (Hotel Avenida, Q 0.10), while normative nepheline is always present, except for No. 12, ranging from 4.97 to 14.81. Normative forsterite and fayalite are present in all the rocks.

Normative feldspar composition is plotted in An–Ab–Or diagram (Fig. 4). No. 1 is found lying within the area of the parent magma of alkali olivine basalt from Circum-Japan Sea province (TOMITA, 1951; YAGI, 1959; KUNO, 1959). It is also noticed that

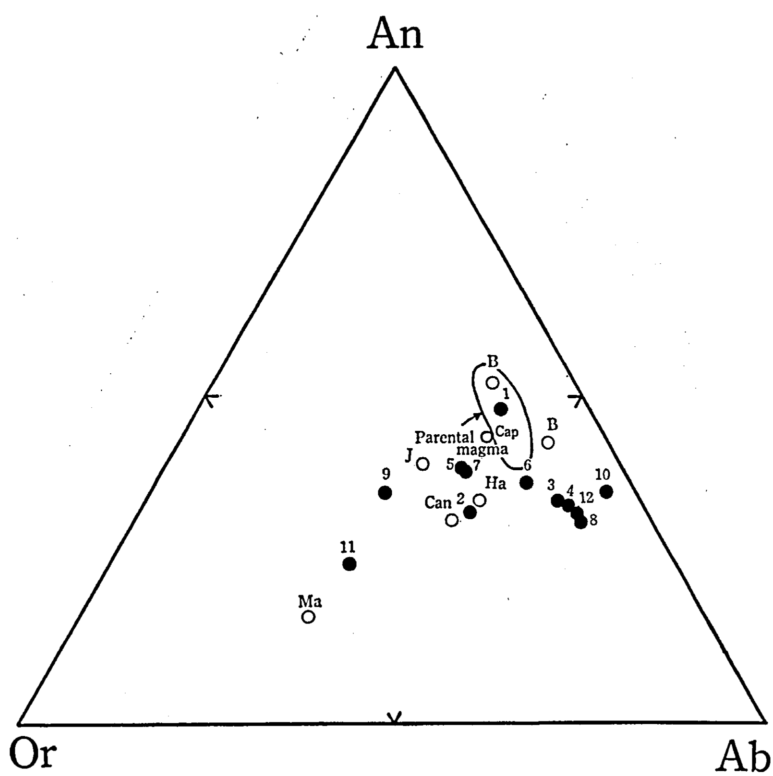

FIG. 4. Normative feldspar composition in the system albite-anorthite-orthoclase (wt percent). Open circles — B. . Bombay, Ma. . Manchuria, J. . Jan Mayen, Ha. . Hawaii, Can. . Canary, Cap. . Cape Verde.

Solid line — Field of the parental magma of alkali olivine basalt (TOMITA, 1951; YAGI, 1959; KUNO, 1959).

the basalts become enriched first in Ab and later also in Or, and that the basalts in the southern part of Patagonia are enriched in Ab and Or. Probably the evolution started in the north, and gradually progressed toward the south Patagonia. Thus, it is evident from the Or–Ab–An diagram that the basalts of Patagonia belong to the alkali olivine basalt series.

In $MgO-(Fe_2O_3+FeO)-(Na_2O+K_2O)$ diagram (Fig. 5) basalts of Patagonia are plotted in the area of the parent magma of alkali olivine basalt, and the exceptional rocks, such as No. 2 (Buta Ranquil) and No. 9 (Peritomoreno) are plotted near its area.

All these rocks indicate an iron-poor fractionation trend, in which contents of Fe_2O_3+FeO are always less than 50%.

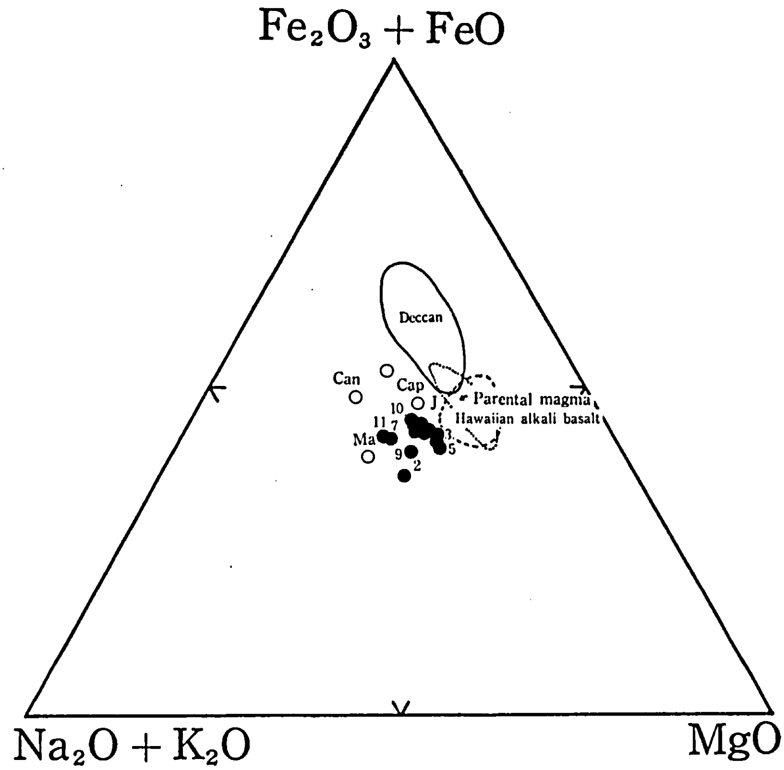

FIG. 5. F–A–M diagram for Patagonia lavas.
Broken line shows field of the Hawaiian alkalic tred (MACDONALD & KATSURA, 1964).
Solid line shows field of the Deccan Trap.
Dotted line shows field of the parent magma of alkali olivine basalt (TOMITA, 1951; YAGI, 1959; KUNO, 1959).

Rock of No. 2 (Buta Ranquil) shows an advanced stage of differentiation, the content of Fe_2O_3+FeO is lowest. The majority of the rocks are plotted in the field of 25–30% Na_2O+K_2O.

Total alkalis versus SiO_2 diagram for Patagonian lavas is given in Fig. 6. Those basalts have higher alkali contents than the variation curves of the average alkalic rock series

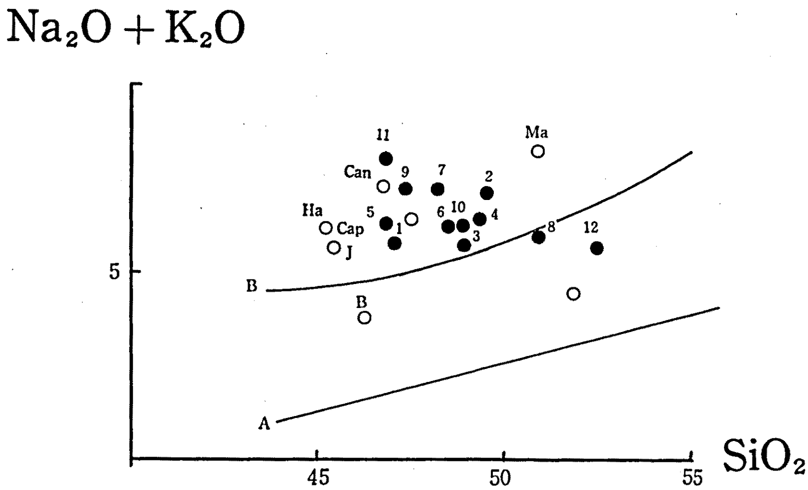

FIG. 6. Total alkalis versus Si_2O diagram for Patagonia lavas.
Symbols are the same as in Fig. 4. (A) Lower solid line marks the boundary between Hawaiian tholeiites and alkali basalts (MACDONALD & KATSURA, 1964). (B) Upper solid line the lower boundary of the Circum Japan Sea alkali rock province (TOMITA, 1935).

of the Circum-Japan Sea Region. On the other hand, No. 12 (Hotel Avenida) has lower alkali contents than the variation curves of the average alkalic rock series of the Circum-Japan Sea Region, suggesting an origin due to contamination of magma in which crystallization differentiation is less advanced.

Variation diagram of the K_2O/Na_2O versus SiO_2 is shown in Fig. 7. All rocks from

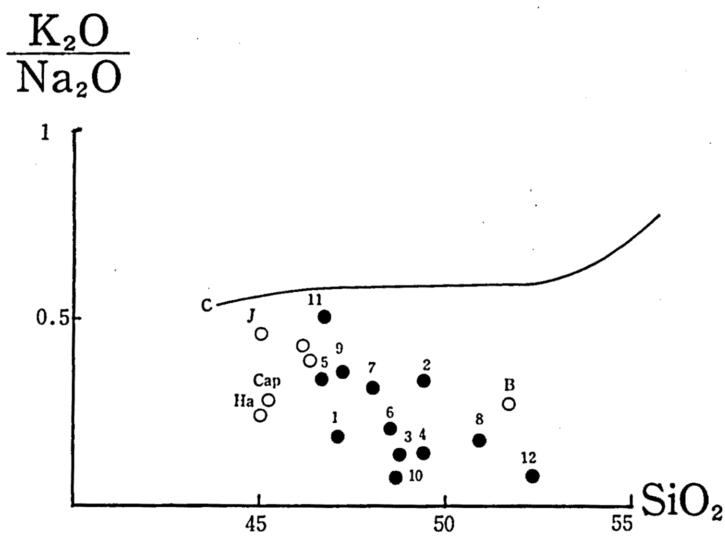

FIG. 7. KO_2/Na_2O versus SiO_2 for Patagonia lavas. Symbols are the same as in Fig. 4.
(C) of the average alkalic rock series of the Circum Japan Sea Rigion (TOMITA, 1935).

Patagonian basalts are plotted in the area lower than the variation curve (C) of the average alkalic rock series of the Circum-Japan Sea Region.

VI. GENETIC CONSIDERATION

Based on many chemical analyses of the basaltic rocks from the Patagonian plateau, and their microscopic observation it is clarified that the parental magma of the volcanic zone in Patagonia is rich in Na_2O.

Microscopic characters of the rocks are as follow: Phenocrystic labradorite, olivine, and augite are present in the groundmass, consisting of plagioclase, olivine, augite, iron ore, and anorthoclase. Olivine has not a reaction rim, and silica minerals do not exist. Augite has a titaniferous component.

These facts show the characteristics of the alkali basalt type. On the one hand, the chemical compositions of these rocks are rich in Na_2O and their norms are shown in Table 3. These specimens have very similar characteristics to each other. All of them except No. 12 have no normative quartz, but have normative olivine and nepheline.

From these facts, it is estimated that the parental magma of Patagonian plateau belongs to alkali basalt magma, from which the rocks of the Patagonian plateau have been producted by the normal differentiation. In this trend rocks of IIIb type appeared at first, and were followed by the rocks of IV type. This series represents the evolution of alkali rock series.

Hotel Avenida rock is Va type which contains hypersthene in the groundmass as well as in the phenocrysts. If the parental magma followed the normal differentiation course, IIIb and IVb type would have appeared. Actually these types have not appeared in Hotel Avenida rock. Some of them contain clearly xenocrystic crystals and many porphyritic plagioclase with dust inclusion. From the above-mentioned petrographic features of the Hotel Avenida rocks, it is concluded that hypersthenic rock series produced Va type rocks by the further fractional crystallization.

Patagonian magma versus Montanan, Manchurian and Deccan magmas.

On the continental side of the Southern Andes, shield volcanoes, cider cones and lava plateaus are present, all of which seem to have already ceased their activity. These Patagonian volcanoes are mostly composed of alkali olivine basalt. In the same way, shield volcanoes, and cinder cones are present on the eastern edge of the Rocky. These Montana volcanoes are partly composed of alkali basalt. On the continental side of the Japanese arc, Manchurian plateaux are present, which are completely composed of alkali basalts and their differentiates. Basalts found in Bombay district of Deccan plateaux are present, which are also partly composed of alkali basalt.

The basalt of Bombay does not agree well with that of the group of Patagonia as to MFA diagram, but the basalt of Manchuria agree very well. In the normative feldspar diagram Manchuria and Bombay basalt does not agree well with each other, since Manchuria basalt is rich in Or and Bombay basalt is rich in An. As to $(K_2O+Na_2O)-SiO_2$ diagram the basalts of Patagonia do not agree at all with basalt of Manchuria, but do agree with basalt of Bombay. In the total alkali-SiO_2 diagram, Patagonia basalts do not agree with both Manchuria and Bombay basalt.

The basalt of Patagonia does not agree well with that of the group of shield volcanoes (Deccan, Montana and Manchuria) as to the chemical character. On the contrary, there are cases when alkali basalts of island arc and volcanic islands (Jan-Mayaen, Cape-Verde, Canary, Hawaii...) show closer agreement to each other than with that of the group of shield volcanoes.

Essential constituent minerals of the Patagonian basalts are olivine, augite, plagioclase and in addition to these minerals, the groundmass often contains anorthoclase and ore minerals. Xenocrystic plagioclases are found sometimes, and the rock of Hotel Avenida contains many xenocrysts. The rock of Hotel Las Horquetas contains many olivine nodules. These olivine nodules have rounded forms, mostly 1 to 2 cm. in diameter, and occasionally range up to 5 cm. Olivine nodules are granular and are greenish yellow in color in hand specimens. In thin sections, olivine makes an equigranular mossaic texture, of which the grain size ranges from 0.3 to 0.7 mm. in diameter. Olivine has cleavages imperfectly parallel to (100) and (010) plane. Chemical composition of the olivine and its atomic proportion based on O–4.000 are shown in Table 7, from which chemical formula of the olivine is represented by

$$Mg\ 1.776,\quad Fe'''\ 0.065,\ Fe''\ 0.16,\quad Si\ 0.92,\quad O\ 4.00$$

$$Mg:\ Fe'''+Fe''=1776:225=89:11$$

Table 4. Chemical Composition of Olivine in Olivine Nodule from Hotel Las Horquetas.

		Atomic ratios,	when 0=4.000	
SiO_2	37.50			
TiO_2	0.02			
Al_2O_3	0.71	Si	0.918	0.938
Fe_2O_3	3.56	Al	0.020	
FeO	7.90	Fe'''	0.065	1.034
MnO	0.03	Fe''	0.161	
MgO	48.38	Mg	1.776	
CaO	0.45	Ca	0.012	
Na_2O	0.38	Na	0.018	
K_2O	0.07	K	0.002	
P_2O_5	0.02			
H_2O^+	0.36			
H_2O^-	0.51			
Total	99.89			

The nodules of the Hotel Las Horquetas are characterized by olivine only, without pyroxenes and plagioclase.

The volcanic rocks related to alkali olivine basalts which are present extensively in Patagonia have been erupted along a vast zone extending from the Antarctic Continent, through the eastern base of Andean Orogene, and ending at the Sumaco district of the Northern Andes.

VII. Conclusion

Patagonia is situated on the southern part of South America, demarcated by the lines of 35° (S) and 72° (W) (Fig. 1). On the continental side of the southern Andes, shield volcanoes, cinder cones, and lava plateaus are distributed.

The great basalt lava fields of Patagonia rest upon flatlying Mesozoic and Cenozoic sediments, of which the vast extra-Andean plains or pampas are composed. The basalts cover an area of about 101,200 km^2 to the south of Mendosa. Especially, between Mendosa and the Rio Gallegos, they form extensive flat-topped plateaus or mesas in El Manzano, Bariloche, and Hotel Las Horquetas.

The basal surface of the basalts is generally flat, parallel to the surface of the plateaus (Fig. 2).

The activity of these basalts lasted from the Pliocene to the Pleistocene. According to the remanent magnetism, the activity seems to have begun on the north and moved toward the south. The period of this movement may be presumed from the Matsuyama's Reversed Epoch to the Erunhes Normal Epoch.

The characteristic features of the Patagonian basalts are given as follows. They can be divided into basanitoids, basalts and basaltic andesites. These rocks show intersertal, intergranular, trachytic, and doleritic textures.

The mineral variation is generally simple. Olivine bears no reaction relation to Ca-rich clinopyroxene by which only the pyroxenic phase is represented. Both minerals occur as phenocrysts and in the groundmass as well.

Orthopyroxene seems to be very rare, and has been found only in Hotel Avenida.

Olivine changes its composition from Fa 16–29. Augite ranges from diopsidic augite to titanaugite. Wo content of the pyroxene is nearly constant, while Fs content varies from 10 to 30%. Magnetite starts to crystallize in a fairly early stage. Plagioclase ranges in composition from calcic labradorite to andesine. Alkali feldspar is invariably present in the groundmass throughout the rocks.

The result of chemical analysis and the norm of the twelve basalts are shown in Table 3, the solidification index after KUNO varying from 27.4 to 35.2; colour indices range from 35.31 to 44.64. The value of the alkali-lime index is 48.2 to 51.7.

The basalts of Patagonia are undersaturated in silica. Therefore, normative quartz is absent, while normative nepheline is always present, ranging in amount from 4.97 to 14.81. Normative olivine is present in all the rocks.

In MFA diagram (Fig. 5) the basalts of Patagonia are plotted in the area with $Fe_2O_3 + FeO$ always less than 50%. The majority of the rocks are plotted in the field of 25–30 % Na_2O+K_2O. The total alkalis versus SiO_2 diagram for the Patagonian basalts have higher alkali contents than the variation curves of the average alkalic rock series of the Circum Japan Sea Region. From these results, it has been concluded that the parental magma of the volcanic zone in Patagonia is rich in Na_2O.

From these facts, it is estimated that the parental magma of the Patagonian plateau basalts belongs to the alkali basalt magma, and that the rocks from the Patagonian plateau are the products of normal differentiation. In this trend rocks of IIIb type appeared at first, followed by the rocks of IVb type. This series represents the evolution of alkali rock series.

The basalts of Patagonia do not agree well with those of the groups of shield volcanoes (Deccan, Montana and Manchuria) in chemical characters. On the contrary, there are cases when alkali basalts of island arc and volcanic islands (Jan-Mayaen, Cape-Verde, Camary, Hawaii...) agree better with those of the groups of shield volcanoes.

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