Petrology of the Galapagos Islands

By

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INTRODUCTION

Petrological descriptions of rocks from the Galapagos Islands are given in papers by Rosenbusch (50)*, Gooch (33), Merrill (40), Lacroix (39), and Washington and Keyes (62), and some old analyses of palagonite tuffs are presented by Bunsen (9). Rosenbusch (50) describes a palagonite tuff from James Island, but this paper is really concerned with rocks from the Kaiserstuhl. Merrill (40) describes a basalt from Chatham Island and other rocks from the neighboring Malepelo and Cocos islands collected by the Albatross Expedition. The paper by Gooch (33), entirely devoted to the Galapagos Islands, describes basaltic lavas and scoriae, pumice with orthoclase crystals from Indefatigable and Abingdon islands, and an olivine bronzite bomb from Charles Island. Lacroix (39, pp. 67-69) summarizes all that was at the time known about the constitution of the Galapagos Islands and adds two short descriptions with analyses of a felspar-rich and an olivine-rich basalt sent him by Chubb as representing the two dominant types of lava developed in the archipelago. Washington and Keyes (62) describe and give analyses of an andesine basalt and a palagonite tuff brought back by Beebe from Eden Islet.

The rocks described in this paper were collected by Darwin during the voyage of the *Beagle* in 1835 and by Chubb during the St. George Expedition in 1924. They include lavas, gabbroic xenoliths, tuffs, and ejected fragments from tuffs and agglomerates. Between the two collections, the main islands are fairly well represented. The bulk of Darwin's specimens are in the Beagle Collection, now in the Sedwick Museum, Cambridge. A few are in the Geological Survey Museum, London. In the petrological descriptions which follow, Nos. 3220-3289 refer to specimens from the Beagle Collection in the Sedgwick Museum, Cambridge; Nos. 323-467 refer to specimens collected by Chubb, a set of which will be deposited in the British Museum, London, and another in Bernice P. Bishop Museum, Honolulu; Nos. F3146-F3154 refer to slides of specimens belonging to the Geological Survey Museum, London.

* Numbers in parentheses refer to Literature Cited, pp. 65-67.

As many of the specimens from different islands of the Galapagos Archipelago are very similar, it will be most convenient to describe them according to rock types and afterwards to give a summary showing where these are developed.

LAVAS

The lavas of the Galapagos Islands are almost all basaltic, but they include a trachyte, an oligoclase andesite, and a spilite [F 3153]. This is, as far as the writer is aware, the only recorded spilite from an island in the Pacific; but as the specimen was collected nearly a century ago, it may easily have been incorrectly labeled.

TRACHYTE

The soda trachyte [3268] from James Island is compact, greenish-grey, with a few small crystals of felspar visible to the naked eye. A thin section shows abundant phenocrysts of felspar, a few of augite, and also occasionally hornblende, olivine and magnetite set in a trachytic groundmass.

The felspar phenocrysts form about 8 per cent of the rock and generally contain inclusions of augite and have rounded outlines, but a few are lath-like in section. They often show patchy extinction, zoning, and also twinning according to Carlsbad, Albite, and sometimes other laws. The twinning tends to be irregularly developed, but symmetrical extinction angles of about 4 and 7 degrees were obtained in one example of combined Carlsbad and Albite twinning. Most of the crystals are negative with a fairly large 2V, but a few have a large positive 2V. Determination of refractive indices by immersion method gave 1.545 for the highest and 1.523 for the lowest. The highest index is greater than $\gamma = 1.541$ for a potash-oligoclase ($Or_{18}Ab_{64}An_{18}$) from Erebus, and the lowest rather below $\alpha = 1.526$ for an anorthoclase ($Or_{27}Ab_{63}An_{10}$) from Kenya recorded by Mountain (42, p. 336). As there is no evidence that two separate felspars are present, these data are taken to indicate a felspar whose composition has changed during crystallization from potash-oligoclase to anorthoclase. The approximate average composition of the total felspar present in the rock as calculated from the norm is $Or_{23}Ab_{72}An_{5}$. Since the lowest refractive index of the groundmass felspar is the same as that of the phenocrysts, the average composition of the phenocrysts must be more calcic than $Or_{23}Ab_{72}An_{5}$, and is probably potash-oligoclase rather than anorthoclase.

The augite phenocrysts are smaller, rounded, and pale green with a strong dispersion and an extinction angle of 45 degrees. They have a narrow darker border where $Z \wedge C$ rises to 52 degrees, and are not therefore appreciably alkaline.

The rare hornblende phenocrysts are of two distinct varieties. The most abundant has an extinction angle $Z \wedge C = 15°$, and shows very strong dispersion and unusual pleochroism with X = brownish-yellow, Y = violet, Z = deep blue-green, $Z > Y > X$; and has the following approximate refractive indices $\alpha = 1.664$, $\beta = 1.685$, $\gamma = 1.688$. It appears to be allied to hastingsite, but the pleochroism is somewhat different. There are only a few fragments of the other hornblende which are deep brown and translucent and show some pleochroism. They are identical with identifiable cossyrite occurring in the groundmass.

The olivine phenocrysts are yellowish and markedly negative with high double refraction and are evidently near fayalite in composition.

The groundmass has a trachytic texture, and is composed [illegible]ely of laths of anorthoclase which show faint Albite and Carlsbad twinning. Green, pleochroic, strongly-zoned, aegirine-augite ($X \wedge C = 35°-5°$), and both types of hornblende found as phenocrysts occur in raggy interstitial patches. The brown hornblende is intensely pleochroic with X = pale brown, Y = golden brown, Z = deep purplish brown, opaque except in very thin flakes, $Z > Y > X$, and $Z \wedge C$ about 35°. It is, therefore, referred to cossyrite. There is in addition a very small quantity of magnetite sprinkled through the slice. Neither nepheline nor quartz was detected, but the latter is present in the norm to the extent of 1.69 per cent.

An analysis of this trachyte (Table 4, no. 1) shows an unusually high percentage of alkalies with rather more than twice as much soda as potash. Analyses of similar rocks that contain about the same percentages of alkalies show rather more Al_2O_3 and less total iron, with the result that they contain a much smaller proportion of femic minerals. The mode of the trachyte does not show much relation to the norm owing to the presence of alkaline hornblendes and aegirine augite.

Table 4. Analyses of Trachytes

	1	2	3	4	5	Norm of 1		Mode of 1	
SiO_2	61.90	61.69	63.43	63.84	62.17	Q	1.69	Phenocrysts	
Al_2O_3	16.75	17.33	18.64	18.46	18.58	Or	19.24	Felspar	8.3
Fe_2O_3	2.27	5.30	2.78	1.54	2.15	Ab	58.94	Augite	1.0
FeO	4.83	0.07	1.02	1.79	1.05	An	4.14	Hornblende	0.2
MgO	0.57	0.16	1.38	0.78	0.73	Di	5.93	Olivine	0.1
CaO	2.30	1.05	1.68	2.45	1.57	Hy	5.31	Groundmass	
Na_2O	7.20	7.47	6.77	7.25	7.56	Mt	3.29	Felspar	67.4
K_2O	3.25	3.47	3.82	3.08	3.88	Il	0.47	Aegirine Augite	8.6
H_2O+	0.20	1.93	0.24	0.39	1.63	Pyr	0.14	Cossyrite	9.0
H_2O-	0.10	0.42		0.10	0.07	Ap	1.64	"Green" hornblende	5.5
TiO_2	0.25	0.67	0.28	none	tr.				100.1
ZrO_2	n.d.	0.16	n.d.	n.d.	n.d.				
P_2O_5	0.07	0.05	0.18	0.24	0.11				
Cl	n.d.	n.d.	0.04	n.d.	n.d.				
S	0.08	n.d.	0.01	n.d.	n.d.				
MnO	0.30	0.21	0.09	none	tr.				
BaO	n.d.	0.07	n.d.	n.d.	n.d.				
	100.07	100.10	100.36	99.92	99.50				

1. Soda trachyte [3268] James Island, Galapagos, analyzed by Herdsman.
2. Anorthoclase trachyte, Launiupoko Hill, Kukui, Maui, analyzed by Steiger (17a).
3. Trachyte, Mas-a-fuera, Juan Fernandez, analyzed by Sahlbom (47, p. 283).
4. Biotite-b[illegible]g alkali trachyte, Gough Island, analyzed by Herdsman (54a).
5. Acmite trachyte, North Crazy Mountains, Montana, analyzed by Melville (70).

Oligoclase Andesite

The oligoclase andesite [3267] from James Island is a fine-grained, bluish-grey, occasionally slightly scoriaceous lava containing a few fragmentary phenocrysts of felspar which are probably labradorite. It appears to be very similar to oligoclase andesites from the island of Hawaii (61) and from Maui (63).

The rock contains also abundant microphenocrysts of oligoclase (about $Ab_{72}An_{28}$), less plentiful prisms of pale green augite ($Z \wedge C = 47°$), a few of dark golden-brown hornblende ($Z \wedge C = 15°$), and rare negative olivine which does not appear to be rich in the fayalite molecule. The groundmass is trachytic, and varies in grain-size as though a first-formed fine-grained crust had been reincorporated in the lava. It consists mainly of oligoclase laths (about $Ab_{75}An_{25}$), abundant magnetite granules, short needles of augite, and sometimes a few stumpy prisms of brown hornblende. A slightly brownish glassy residuum with a refractive index near that of Canada balsam can be recognized in places.

Basalts

The basaltic lavas of the Galapagos Islands include a few rocks classed as andesites on account of their felspar composition which are in other respects very similar to the basalts. They are almost all porphyritic, and tend to be rich in either felspar or olivine phenocrysts, though the olivines are never sufficiently abundant for the rock to be termed an oceanite. None of them show true alkalinity; but analcime occurs occasionally as interstitial material where there has been considerable alteration of the olivine present, and is sometimes accompanied by the development of a yellow pyroxene and hematite.

BASALTS WITH OLIVINE PHENOCRYSTS ONLY

Porphyritic olivine basalt forms a large flow entering James Bay, James Island. A specimen [346] taken from 12 feet below the surface of the flow is grey, rather porous, and friable with small pale green olivine phenocrysts which form about 20 per cent of the rock. In thin section these are colorless, rounded, and somewhat shattered, and contain abundant inclusions of small brown picotite octahedra. They are enclosed in a groundmass of labradorite laths ($Ab_{35}An_{65}$-$Ab_{39}An_{61}$), smaller olivine granules, ophitic plates of purplish augite, and interstitial iron ore. The doleritic basalt described by Lacroix (39, p. 68) comes from the same part of the flow and shows the same features. The analysis of this rock and of two closely similar Hawaiian basalts is quoted in Table 5. A rock [3280] collected by

Darwin from James Island is so similar to No. 346 that it probably comes from the same flow, and another [415] from Charles Island is almost identical.

Table 5. Analyses of Olivine Basalt

	1	2	3	Norms	1	2	3
SiO_2	46.72	46.76	47.72	Or	1.78	3.89	3.89
Al_2O_3	14.10	13.78	15.44	Ab	15.46	15.72	19.39
Fe_2O_3	2.14	1.26	0.23	An	28.00	19.46	29.75
FeO	9.63	10.43	9.52	Ne	....	7.95	....
MgO	11.64	11.07	11.31	Di	18.28	25.00	16.19
CaO	10.92	10.54	10.23	Hy	11.58	....	2.72
Na_2O	1.83	3.59	2.31	Ol	15.88	22.02	22.37
K_2O	0.30	0.64	0.63	Mt	3.11	1.86	0.23
H_2O+	0.20	0.10	0.46	Il	3.72	3.95	3.50
H_2O-	0.21	0.10	0.05	Ap	0.81	0.67	0.34
TiO_2	1.96	2.12	1.81				
P_2O_5	0.34	0.32	0.15				
MnO	0.14	0.08	0.16				
	100.13	100.79	100.02				

1. Doleritic basalt [346] James Island, Galapagos, analyzed by Raoult (39, p. 69).
2. Olivine basalt, block from pit crater summit of Hualalai, Hawaii, analyzed by Washington (61, p. 102).
3. Olivine basalt, Iao valley, Kukui volcano, Maui, analyzed by Keyes (63, p. 203).

A specimen [323] from the actual surface of the same flow from which No. 346 was taken differs in having a groundmass that contains abundant dark-brown opaque glass enclosing small olivine granules and laths of labradorite which show great variation in size. The smaller laths are thinner than the section, and are surrounded by crystallites, giving them a tufted appearance. At the actual surface the glassy base is pale yellow, transparent, and contains bundles of dark-brown crystallites. It passes rapidly into the more normal opaque glass by increase in the brown crystallite material. Similar basalts with olivine phenocrysts and vitreous bases are found on Indefatigable Island [375, 387, 410], James Island [3281] and Chatham Island [F 3146]. With the exception of No. 387 they all have a smaller proportion of glass and contain a more thoroughly crystalline residuum in which augite crystallites and magnetite granules can be identified as well as feldspar and olivine. This type of groundmass is also found in a basalt from Chatham [3234] which contains phenocrysts of labradorite in addition to olivine, an aphanitic basalt scoria from Bindloes [3286], and a microporphyritic olivine basalt lapilli [377] from a small crater on Indefatigable Island whose olivine is largely replaced by orange-brown iddingsite.

There is a rather larger proportion of olivine phenocrysts (20-25 per cent) in No. 425 from Charles Island than in No. 346, but the actual crystals are generally smaller. They show evidence of magmatic resorption, and some alteration resulting in the formation of a narrow dense marginal zone of magnetite, and a reddish pleochroic interior due to the presence of parallel-orientated dustlike inclusions which may be iddingsite. The groundmass consists of labradorite laths ($Ab_{30}An_{70}$-$Ab_{38}An_{62}$), prisms of colorless augite ($Z \wedge C = 48°$), locally altered to a pale yellow variety with $Z \wedge C = 60°$ around some of the vesicles. Another specimen [F 3150] from Charles Island is identical with the altered portions of No. 425, and may easily have come from another part of the same flow.

A similar yellow augite, which is generally more strongly colored, but still has an extinction angle $Z \wedge C$ of about 60 degrees is common in specimens showing alteration, but is only an important mineral in a few specimens, for example No. 3287 (Tower Island) and No. 3278 (James Island). In the Tower Island specimen it occurs in granules almost to the exclusion of the common pale green augite. It is markedly positive, has strong double refraction, dispersion, and a mean refractive index about 1.71. Similar alteration of augite in basaltic rocks is recorded from Rapa by Smith and Chubb (55, p. 328), and was found to be identical by comparison of slides; and also from Tahiti by Lacroix (38) and from Vesuvius by Lacroix (37) and by Cesaro (10). Lacroix (37, p. 194) quotes two analyses given by Freundenberg (31, p. 264) of a grey-green augite and a yellow variety replacing it which show clearly that the change in color is largely due to the complete oxidation of the iron, stating that the extinction angle changes from 30 to 70 degrees. He has probably taken this value from a zoned aegirine-augite described earlier in the same paper (31, p. 249), as Freundenberg says quite clearly that there is no accompanying change in optical properties. Hence no conclusion can be reached regarding the composition of this yellow pyroxene, but it is certainly not an aegirine-augite.

Olivine phenocrysts are much less plentiful in the remaining basalts in which olivine phenocrysts are dominant, and they generally show some alteration which may be pneumatolytic, as the rest of the minerals are perfectly fresh.

In two light-grey and compact basalts from Chatham Island [F 3149, F 3152] which contain a few spherical vesicles, lined with transparent minerals in No. F 3152, the olivine phenocrysts appear brownish and dull in hand specimens. Thin sections show that this is due to a narrow margin of yellow iddingsite replacing the olivine which contains unusually large picotite inclusions. There are also occasional relics of bytownite phenocrysts, especially in No. F 3152. The groundmass contains labradorite laths (about $Ab_{34}An_{66}$), granules of faintly greenish augite, some olivine almost entirely replaced by iddingsite, magnetite, a little residual brown glass in No. F 3149, and calcite and analcime as interstitial material and vesicle linings in No. F 3152. The same type of alteration is shown by olivine with a prismatic habit in a microporphyritic basalt also from Chatham Island [F 3151].

Another porphyritic basalt [3235] from Chatham Island contains abundant small red olivine phenocrysts, whose color is the result of partial alteration to an iddingsite which is deep orange-red in thin section. There are in addition some microphenocrysts of medium labradorite. These are enclosed in a groundmass of more acid labradorite, slightly green-brown granular or prismatic augite, smaller grains of almost completely altered olivine, magnetite, and in places calcite and dirty isotropic material.

A somewhat similar, but less highly porphyritic rock [317] is found on Charles Island. The olivine is marginally altered to a dusty red iddingsite or hematite and forms phenocrysts which are generally too small to be visible in the hand-specimen. There are also a few microphenocrysts of colorless augite, some picotite, and in one section a green, partially resorbed fragment of hercynite. The groundmass contains abundant hematite, probably formed from original magnetite, which gives the rock a red color.

BASALTS WITH DOMINANT FELSPAR PHENOCRYSTS

The scoriaceous basal lavas from the Tagus Cove area on Albemarle Island have abundant phenocrysts of bytownite ($Ab_{10}An_{90}$–$Ab_{15}An_{85}$). These are generally much shattered and contain inclusions of brown opaque glass along their cleavage planes. In No. 458 they are about 5 mm. long, form nearly 30 per cent of the rock, and are associated with rare smaller phenocrysts of augite and olivine. They are enclosed in a groundmass of felspar laths ($Ab_{42}An_{58}$–$Ab_{53}An_{47}$), granules of colorless augite, rare olivine, much magnetite, and a little residual brown glass. The specimen described by Lacroix (12, p. 68) as a "basalte porphyritique à plagioclase" comes from the same locality and differs only in a slight and unimportant manner from No. 458. The analysis (Table 6, no. 1) shows a high percentage of CaO and Al_2O_3 owing to the abundance of bytownite phenocrysts, and the norm a little quartz. There are very few analyzed basalts which contain as much CaO and Al_2O_3. The nearest is from Reunion and is also given in Table 6.

Table 6. Basalts with Felspar Phenocrysts

	1	2	3	4	5	6	7	8
SiO_2	47.80	48.65	46.27	45.55	48.24	48.04	48.10	48.68
Al_2O_3	18.31	17.50	18.43	18.25	15.82	15.35	15.90	15.70
Fe_2O_3	1.47	0.25	3.98	7.28	0.78	5.72	1.93	1.81
FeO	8.20	9.75	8.22	5.01	9.84	7.67	10.28	9.75
MgO	4.89	6.61	3.75	6.00	5.84	5.77	6.28	6.08
CaO	13.00	11.85	12.33	10.20	9.84	10.13	11.60	11.64
Na_2O	2.48	2.15	2.58	3.18	3.63	3.26	2.68	2.32
K_2O	0.57	0.38	0.96	0.85	0.64	0.79	0.30	0.88
H_2O+	0.31	tr.	n.d.	0.95	0.72	0.27	0.40 }	0.10
H_2O-	0.11	0.10	n.d.	0.25	0.11	0.04	0.10 }	
TiO_2	2.40	2.10	2.98	1.80	3.88	3.13	1.90	2.68
P_2O_5	0.41	0.21	0.33	0.23	0.16	0.33	0.23	0.46
S	n.d.	tr.	n.d.	tr.	n.d.	n.d.	tr.	n.d.
MnO	0.14	0.25	n.d.	0.30	0.20	0.10	0.29	n.d.
	100.09	99.80	99.83	99.85	99.70	100.62	99.99	100.10
Norms								
Q	3.75	....	....	....	....	....	....	....
Or	3.39	2.22	5.56	5.00	3.89	4.45	1.67	5.00
Ab	20.96	17.81	22.01	25.64	29.87	27.77	23.06	19.39
An	37.09	40.03	35.86	32.52	25.02	24.74	30.30	30.02
Ne	....	....	....	0.85	0.28	....	....	....
Di	20.35	14.87	19.10	13.45	18.67	18.65	20.02	20.56
Hy	11.46	13.44	0.43	....	....	8.91	5.44	13.97
Ol	....	7.66	4.73	6.50	11.98	0.76	10.28	2.28
Mt	2.14	0.23	5.80	10.68	1.16	8.35	2.78	2.55
Il	4.56	3.96	5.62	3.50	7.45	5.93	3.65	5.17
Ap	0.97	0.34	0.67	0.34	0.34	0.67	0.34	1.01

1. Plagioclase basalt [458], Tagus Cove, Albemarle Island, analyzed by Raoult (39, p. 69).
2. Porphyritic olivine basalt [463], Narborough Island, analyzed by Herdsman.
3. Plagioclase basalt, Etang Salé, Reunion Island, analyzed by Boiteau, (39a, p. 544).
4. Olivine andesite [3239], Chatham Island, analyzed by Herdsman.
5. Andesine basalt, Eden Islet, Galapagos Islands, analyzed by Keyes (62, p. 539).
6. Andesine basalt, Hualalai, Hawaii, analyzed by Washington (61, p. 104).
7. Olivine andesite [433-B], ejected fragment, Albemarle Island, analyzed by Herdsman.
8. Basalt, Reunion Island, analyzed by Boiteau (39 b, p. 253).

Darwin's specimens Nos. 3247 and 3248 are macroscopically identical with No. 458 described above, and may come from the same flow. The groundmass in No. 3247 is coarser, probably as the result of slower cooling. A specimen [443] from a very rugged flow on the other side of Tagus crater

I did not note this as a rock

is less scoriaceous. The individual crystals are larger and bytownite phenocrysts more abundant (35 per cent). It overlies a smooth flow [442] containing smaller but much more plentiful phenocrysts (50 per cent) than any of the other bytownite-bearing basalts, and an appreciable proportion of these are augite and olivine. No. 3289 from Abingdon Island is superficially somewhat similar to No. 443, but contains about 50 per cent of felspar phenocrysts which are less basic ($Ab_{18}An_{82}$–$Ab_{25}An_{75}$), and it has a coarser groundmass with a good deal of olivine largely altered to a yellow serpentinous mineral.

The felspar phenocrysts in a basalt [3265] from James Island are basic labradorite ($Ab_{21}An_{79}$–$Ab_{40}An_{60}$) and much smaller than those in any of the above basalts. They show the usual shattering and invasion by the magma and also marked zoning, especially in the outer portions of the crystals, which is often parallel to their present irregular margins. There are also a few rounded phenocrysts of pale-greenish augite and colorless olivine, generally partially replaced by an orange-yellow iddingsite; and a second generation of microphenocrysts of felspar, olivine, and augite which in places form aggregates and grade into a groundmass of the same minerals with magnetite and interstitial brown glass. Another specimen [3266] from James Island differs from the foregoing chiefly in containing only a few phenocrysts of the first generation and having none of augite, but a larger proportion of olivine.

A basalt [463] from Narborough Island is only slightly porphyritic. The felspar phenocrysts ($Ab_{14}An_{86}$–$Ab_{30}An_{70}$) are small, strongly zoned, especially near their margins, and some of them occur in aggregates with olivine. The groundmass is moderately coarse and consists of felspar laths ($Ab_{40}An_{60}$), pale-greenish granular augite, some rather larger colorless olivine granules, iron ore, which is mainly magnetite, and a little residual brown glass. This specimen contains fewer bytownite phenocrysts and more olivine than No. 458, and these differences are reflected in the analysis (Table 6, no. 2). Another basalt [467] from Narborough Island is very similar but contains additional augite phenocrysts. The groundmass felspar is more acid ($Ab_{45}An_{55}$) than in No. 463, and the olivine shows considerable alteration. A few yellow augites replace the normal greenish variety.

The remaining basalts with dominant felspar phenocrysts come from James Island. They contain phenocrysts of olivine and augite in addition to felspar, much of which is strongly zoned, and show more or less extensive alteration of the olivine and replacement of the normal augite by a yellow variety. In No. 3278 the felspar phenocrysts are basic labradorite ($Ab_{28}An_{72}$–$Ab_{35}An_{65}$) and show great variation in size and marked resorption by the magma. The olivine phenocrysts are entirely replaced by magnetite with a little hematite and iddingsite. In the early stages of replacement the altera-

arrive up from Abingdon!

tion products are concentrated along possible cleavage directions. The augite phenocrysts are colorless with a narrow rim of yellow pyroxene which is also devloped as small prisms throughout the groundmass, where it is greatly in excess of the normal augite. It is there associated with labradorite laths and hematite which appears to be derived from original magnetite and olivine. The alteration has been less extensive in No. 370, where iddingsite is a more abundant alteration product of the olivine, and hematite and yellow pyroxene are confined to definite areas in the groundmass, which is finer grained and somewhat obscured by brown glass. No. 3269 is less altered and shows practically no yellow pyroxene.

NON-PORPHYRITIC BASALTIC ROCKS

An olivine basalt or dolerite [F 3154] from Dalrymple rock, Chatham Island is a very coarse-grained rock, and may represent a volcanic neck filling a tuff cone which has since been denuded away.

It is composed of labradorite laths ($Ab_{30}An_{70}$-$Ab_{45}An_{55}$) about 0.8 mm. long, grains of olivine showing slight alteration, smaller colorless granular prisms of augite which often form aggregates around the olivine, irregular patches of magnetite, abundant needles of apatite, rare interstitial analcime and much yellow powdery material which is visible in the hand specimen. This is made up of minute greenish-yellow or brown scales which sometimes form darker fringes around the other minerals and occasionally surround cavities which may be filled with chabazite. It is probably crystalline chlorophaeite, and its mode of occurrence suggests that it represents an original interstitial glassy residue.

An olivine andesite [3239] from Chatham Island is not as coarse-grained as No. F 3154.

It is formed largely of felspar laths ($Ab_{51}An_{49}$-$Ab_{52}An_{48}$) which show considerable variation in size, granular prisms of pale greenish-brown augite and colorless olivine showing slight marginal alteration, much magnetite, and in places apatite and very occasionally a little analcime. The analysis of this specimen (Table 6, no. 4) shows high Al_2O_3 and CaO, and also Fe_2O_3, which is probably the result of partial alteration of the olivine. The normal felspar is much more calcic than the modal, suggesting that the augite is aluminous.

The andesine basalt from Eden islet described by Washington and Keyes (62, p. 539) has felspar of about the same composition as that in No. 3239, and would according to the terminology adopted in this paper be classed as an andesite. It differs, however, in containing a titaniferous augite, and the analysis consequently shows a higher percentage of TiO_2 than No. 3239 (Table 6).

A porphyritic olivine andesite [3279] from James Island also contains felspar laths of about the same composition as No. 3239, but differs in the presence of a few large, slightly altered olivine phenocrysts, and in having ophitic augite which is strongly zoned and passes locally to a yellow variety.

GABBROIC XENOLITHS

Gabbroic xenoliths were collected by Darwin from the lavas and scoriae of a small cone at Freshwater Bay, James Island, and described by him in some detail (25, p. 110-112). He refers to the felspar as albite because of the cleavage angle.

The specimens have a burned appearance and tend to be very friable. They all consist of much-shattered glassy felspar, black iridescent augite, duller reddish olivine, and in places interstitial red earthy material, but show some variation in grain-size and proportion of the different minerals.

No. 3273 contains zoned felspar laths ($Ab_{29}An_{71}$-$Ab_{39}An_{61}$) about 7 mm. long which made up about half the bulk of the rock, pale brownish-green ophitic augite, colorless olivine granules containing about 29 per cent of fayalite and showing much alteration to a red-brown pleochroic, fibrous or dusty material which is probably iddingsite, and a little deep red interstitial glass with occasional crystallites. The composition of the felspar and the olivine is about the same in the other xenoliths. No. 3270 contains more and olivine. This is especially true of No. 3271, which is a eucrite rather than a gabbro. augite and less felspar than No. 3273, whereas No. 3271 and No. 3272 have more felspar

Darwin (25, pp. 111-112) suggests that the xenolithic material is responsible for the phenocrysts in the lava flows from this small crater, but determination of the composition of the felspar ($Ab_{40}An_{60}$–$Ab_{60}An_{40}$) and the olivine (18 per cent fayalite) phenocrysts in the basalt matrix does not bear this out.

FRAGMENTS FROM TUFFS AND AGGLOMERATES

The tuffs and agglomerates from craters in the neighborhood of Tagus Cove, Albemarle Island, include many fragments most of which are angular, dark grey and aphanitic, though some are slightly vesicular, and a few porphyritic. In addition there are a few coarse-grained ultrabasic nodules.

The aphanitic fragments (border-line andesites and basalts) show in thin sections considerable range in grain size, but close similarity in composition and in the proportions of the various minerals present. They consist of basic andesine or acid labradorite felspar laths, pale green or greenish-brown granular augite, iron ore (largely magnetite) a small quantity of brown interstitial glass, and olivine which is only distinguishable from the augite in the coarser specimens.

A typical example [433B] of the fine-grained fragments contains andesine laths ($Ab_{52}An_{48}$), greenish brown augite, a little olivine, magnetite, and some interstitial glass. As shown by the analysis (Table 6, no. 7), its chemical composition is nearer that of the basalt from Narborough Island (Table 6, no. 2) than any of the other analyzed Galapagos specimens. But calculations show th[illegible] could not be derived from the porphyritic varieties (Table 6, nos. 1 and 2) by the removal of bytownite phenocrysts. An analysis of a basalt (Table 6, no. 3) from Reunion Island is given for comparison.

The porphyritic fragments have groundmasses similar to the aphanitic fragments, but owing to the prsence of phenocrysts of bytownite are all basalts. They range from very slightly porphyritic with occasional phenocrysts of bytownite (about $Ab_{10}An_{90}$–$Ab_{15}An_{85}$) to highly porphyritic with phenocrysts of olivine and augite in addition but subordinate to bytownite.

The ultrabasic fragments consist of crystals of basic bytownite (about $Ab_{10}An_{90}$–$An_{15}An_{85}$), faintly brownish-green augite which is generally ophitic, colorless olivine, and interstitial pale brown glass in varying proportions.

Bytownite is most abundant in No. 461 A, where it forms about 85 per cent of the bulk of the rock and occurs as slightly rounded crystals about 5 mm. or 10 mm. long containing inclusions of brown glass identical with that occurring interstitially except for the presence in the latter of darker crystallite aggregates. The refractive index (1.608) of this glass is equal to that of the sideromelan in some of the tuffs which are of about the same age. Augite and olivine are present in addition, but neither is important. There is sufficient glass in this specimen for it to resemble a highly porphyritic pitchstone. Both bytownite and glass are much less abundant in the other ultrabasic fragments, which therefore have a granular gabbroic appearance. Also the felspar crystals are smaller and show great variation in size, especially in No. 450 C; and the augite forms large ophitic plates, one occupying the whole of a slide of No. 451 B.

The same minerals are present in No. 434 B, which is comparatively fine-grained and has a different appearance in thin section. The bytownite forms well-defined laths, whereas the augite and olivine are both granular and tend to occur in aggregates. The small quantity of residual glass shows streaky variations in color, and has a refractive index which ranges between about 1.590 and 1.630.

The identity of the included and interstitial glass in these ultrabasic fragments suggests that they represent aggregates formed by crystal sinking near the bottom of the magma-reservoir which were occasionally brought up at explosions with the more abundant non-porphyritic and porphyritic fragments from higher levels which had crystallized completely prior to ejection.

TUFFS

The tuff specimens from Chatham, James Island, Tagus Cove, Albemarle Island, and from Eden Islet are all basic. They are composed largely of sideromelan fragments showing all degrees of palagonitization and are in many respects very similar to tuffs from Iceland described by Peacock (44). It will convenient to adopt Peacock's classification, with a slight modification, and divide the tuffs into unaltered sideromelan tuffs, slightly altered palagonite tuffs, and highly altered palagonite tuffs, including specimens which would be called "palagonite rocks" by Peacock (44, p. 54) because they differ from the other highly palagonitized tuffs only in size and proximity of the fragments.

All tuffs from one island show, however, certain common features regardless of palagonitzation. The tuffs from Eden Islet and Chatham Island have fragments of olivine with picotite inclusions, and also a few basalt fragments which are generally trachylitic. The Albemarle Island tuffs on the other hand are characterized by abundant crystal fragments of bytownite ($Ab_{10}An_{90}$–$Ab_{15}An_{85}$), olivine, and augite in this order of abundance, and also a large variety of basalt fragments. The tuffs from James Island occupy an intermediate position.

Sideromelan Tuffs

Sideromelan tuffs are recorded from James and Albemarle islands. They are green or yellowish-brown in color, and tend to be friable. Some [3276, 372, James Island] are completely unconsolidated; others [453, Albemarle Island] are held together by fine volcanic dust which gives a comparatively strong cement when it is altered as the result of weathering or incipient palagonitization [3277, James Island].

Specimen No. 453 (Albemarle Island) is a typical fine-grained, greenish-brown, fairly compact tuff consisting principally of sideromelan fragments which are pale greenish-brown in thin section and have a refractive index of 1.606. The majority are small (0.5 mm. in diameter) and show ash structure, but a few are larger and vesicular, containing in places crystallite aggregates which give the glass a mottled appearance. There are also many small fragments of felspar, most of them partially embedded in the sideromelan, and a few of olivine, augite, and basalt, which is generally tachylitic. Interstitially there is a much darker brown material which is probably fine volcanic dust.

The other sideromelan tuffs show some difference in the proportion of the various constituents and some very slight marginal alteration of the sideromelan fragments. For example, No. 3277 (James Island) contains fewer crystals but more plentiful basalt fragments, some of which are holocrystalline. It consists principally of large, highly vesicular sideromelan fragments which have a very narrow marginal zone of fine black banding, in places associated with a yellow coloration as noted by Peacock (44, p. 59). The interstitial dust is yellowish. No. 445 (Albemarle Island) differs from Nos. 453 and 3277 in being composed largely of crystal fragments, and is a crystal-vitric tuff whose composition suggests that it is the explosive equivalent of a basalt with bytownite and olivine phenocrysts such as No. 442 (Albemarle Island).

Nos. 3249, 3250, and 435 (Albemarle Island) are less consolidated and coarser-grained than No. 453. They also contain more abundant and much more varied basalt fragments and pisolitic nodules which are almost all spherical and about 5 to 10 mm. in diameter. These have a thin compact outer shell, composed of the smallest sideromelan fragments and dust, which gives a sr ior resistance to weathering and surrounds an interior differing from the tuff matrix only in the absence of the largest fragments. As in No. 3277 there is incipient marginal alteration of the fragments, especially of those forming the outer coats of the pisolites in No. 435.

Such pisolites are formed either by the condensation of water in an ash cloud giving balls of mud (32), as took place during the 1906 eruption of Vesuvius (45), or by gentle rain falling on heated ash, as was observed by Lacroix (36) at Mt. Pelée after the main eruption in 1902. They are also recorded from the Philippine Islands by Pratt (46), from Hawaii by Frielaender (32), from the Brisbane tuff by Richards and Bryan (48), and from the Pentlands by Johnston-Lavis (35). These authors regard the pisolites as mud-balls which formed from ash clouds, but in the absence of any evidence that mud fell on Albemarle Island, the pisolites there were probably formed as at Mt. Pelée.

Slightly Altered Palagonite Tuffs

Some palagonite tuffs from Chatham, Albemarle, and Eden islands are slightly compacted and show a good deal of variation in appearance, though all are brownish in color and similar in thin section, with the exception of Nos. 447 and 449 (Albemarle Island) which are crystal-vitric tuffs and differ from No. 445 only in the marginal palagonitization of the sideromelan fragments.

The fresh sideromelan shows exactly the same features as in the unaltered tuffs, but in the Chatham Island specimens its refractive index is only about 1.590 and it often encloses olivine crystals which may show fantastic resorption and are in places associated with picolite octahedra and small labradorite laths.

The palagonite is bright yellow in thin section and forms borders about 0.02-0.04 mm. wide replacing the sideromelan with a well-defined undulose inner margin and in places stringers pushing out into the unaltered glass. In No. 3224 (Chatham Island) the palagonite is traversed by fine black bands parallel to the original outline of the fragment and concentrated against the unaltered sideromelan. Apart from the absence of change in color, this is closely similar to the palagonite described by Peacock (44, p. 60). Black bands are more marked in No. 3223 (Chatham Island), where they are concentrated in definite zones separating palagonite of slightly different shades of yellow; but they are hardly developed in the Eden islet specimens [406, 407, 409].

In all the specimens described above the palagonite has a variable refractive index which lies between 1.480 and 1.535. It is isotropic, except at the extreme outer margin, where it may show faint double refraction, and in most specimens is followed by a thin band of zeolitic material.

True cement is generally lacking, the smallest completely altered fragments playing an important part in holding the rock together. A little interstitial granular zeolite is sometimes present, and calcite which is locally important in No. 406 (Eden Islet). The areas where the calcite is developed are grey in color and stand out on weathering. In No. 407 (Eden Islet) a colorless chlorite occurs interstitially with calcite, and the sideromelan fragments are fairly far apart, so that the rock has a speckled brown and white appearance.

Highly Altered Palagonite Tuffs

The highly altered palagonite tuffs from Chatham, Eden, James, and Albemarle islands are even more varied in appearance than the slightly altered tuffs, and only some of the specimens from Chatham Island [3220-3222] and Eden Islet [393] agree superficially with Von Waltershausen's "Palagonitfels" (44, p. 54). They are brown, compact, and have a resinous luster and conchoidal fracture. In the hand specimen a few olivine fragments and vitreous particles are visible.

The palagonite in No. 3222 (Chatham Island) is bright yellow, transparent, and isotropic in thin section, and has a refractive index of about 1.530. It has replaced all but the cores of the largest sideromelan fragments, the included crystals of olivine, felspar, and spinel, and the few brown crystallite bands. The outlines of the original sideromelan fragments are perfectly preserved, and the interstitial spaces and vesicles are filled with chlorite and zeolites. There is generally a very narrow fringe of indeterminable fibrous zeolite around the palagonitized fragments. In places this fringe is followed by a wider fringe of pale green chlorite, and the residual space is occupied by squarish granules which are probably phillipsite.

The palagonite in the Eden islet specimen [393] has a higher average refractive index (1.580) and is a deeper but more variable yellow color. It is turbid in places, and may then show faint double refraction.

The palagonite tuff described by Washington and Keyes (62, p. 540) is almost identical, though the term "glass" is used instead of "palagonite" in the description. Its analysis (Table 7, no. 9), when calculated on a water-free basis, is, apart from the oxidation of the iron, closely similar to analyses of basalts from Albemarle and Narborough islands (Table 7, nos. 2 and 3).

The lowest portions of Eden Islet are formed principally of brown palagonite rock similar to that described above, but in places a rather different type is developed [403]. This also has a resinous luster, but it is less pronounced. The rock is red in color and the individual fragments larger and not as closely packed as in No. 393, so that white interstitial material is visible in places.

The palagonite is orange in thin section and some of it shows slight zonal variations in color. Its refractive index may be as high as 1.630, though that of the unaltered brownish sideromelan is only 1.603. This is probably due to the absorption of ferric oxide from extraneous solutions. The larger fragments contain more unaltered sideromelan than in No. 393; and, when crystallites are present, show very clearly their resistance to palagonitization. Chlorite again forms fringes to the vesicles and margins of the frag ts, and there is interstitial calcite and finely granular zeolitic material.

Orange palagonite which also has a high refractive index lying partially above that of the unaltered sideromelan is found in some tuffs from James Island. The specimens studied [3282, 3283] show complete palagonitization of all but the largest sideromelan fragments, but have neither a resinous luster nor conchoidal fracture. This is partly due to the greater abundance of interstitial material, and also probably in No. 3283 to slight crystallization of the palagonite.

A light drab-colored compact tuff [459] from Albemarle Island has a very slight resinous luster. It contains abundant basalt and crystal fragments, especially in one band, and also dark spherical bodies.

In thin section these are seen to be pisolites whose interiors have not been palagonitized, except when their fine-grained outer shells have been fractured. The palagonite is very pale in color, but has a high average refractive index (1.585). The tuff agrees closely in original composition with the pisolitic sideromelan tuffs [3249, 453], but owing to palagonitization the matrix is as hard as the pisolites, and fractures pass through these without interruption.

In a group of tuffs from Chatham Island [3226, 3236-3238] the specimens are compact and pale brown and tend to have a platy fracture, but no resinous luster.

Under a lens the coarser-grained specimens, for example, No. 3226, appear to consist of pale yellowish fragments, some of which are cellular and surrounded by darker brown borders with white interstitial crystalline material. A few of the yellow areas enclose black vesicular sideromelan. Thin sections show that the yellow and brown substances are both palagonite, and the interstitial crystalline material zeolites, calcite, and pale green chlorite. The yellow palagonite is generally clear and transparent, but some of it is traversed by faint black zonary lines which form a marked band against the unaltered sideromelan. The darker palagonite completely replaces the smallest fragments and is sharply separated from the yellow in the larger. It is orange brown in thin section. Some of it is crowded with black zonary bands, and some is turbid and may show double refraction.

The palagonite shows extensive crystallization in only one specimen [3225, Chatham Island]. In thin section it varies in color from yellowish-green to bright orange, and is generally turbid and doubly refracting with spherulitic or fibrous crystallization between crossed nichols, though the fibers are too small to be identified in ordinary light.

The tuffs from the Galapagos Islands differ from the Iceland tuffs in the absence of palagonite cement and the greater rarity of fibro-palagonite. The chlorite and zeolites have clearly been deposited from traveling solutions and have not been formed at the expense of the neighboring palagonite, as in some of the Iceland rocks.

Peacock (44, pp. 67-69) has shown that palagonite is a hydration-oxidation product of transparent basalt glass formed by the action of glacial, marine, or magmatic waters. The low elevation of the tuff craters in the Galapagos suggests that sea water was the main agent of palagonitization, but the only evidence in favor of uplift is the presence of a few marine shells noted by Darwin (25, p. 115) and by Wolf (68, p. 250).

SUMMARY OF ROCK TYPES AND ANALYSES

The following list records the types of rocks so far reported from the different islands of the Galapagos Archipelago. Those not represented in Darwin's or Chubb's collections are credited to the author who described them. All the available analyses except that of the palagonite by Bunsen (9) are grouped in Table 7.

Abingdon:	Basalt with abundant felspar phenocrysts
	Vitreous basalt scoriae (Gooch)
	Pumice with orthoclase (Gooch)
Albemarle:	Basalt with abundant bytownite phenocrysts
	Ejected basaltic and ultrabasic fragments
	Sideromelan and palagonite tuffs, some with pisolites
Bindloes:	Vitreous basalt scoriae
	Basalt with felspar phenocrysts (Gooch)
	Basalt scoriae (Gooch)
Charles:	Basalt with olivine only phenocryst
	Amygdaloidal basalt (Gooch)
	Basalt scoriae (Gooch)
	Olivine bronzite lapilli (Gooch)
Chatham:	Basalts with dominant felspar phenocrysts
	Basalts with olivine only phenocryst
	Olivine basalt or dolerite
	Olivine andesite
	? Spilite
	Olivine basalt (Merrill)
	Palagonite tuffs and palagonite rock
Hood:	Basalts (Gooch)
Indefatigable:	Basalt with olivine only phenocryst
(including)	Andesine basalt (Washington and Keyes)
Eden)	Pumice with orthoclase (Gooch)
	Palagonite tuffs with palagonite rock
James:	Basalts with olivine only phenocryst
	Basalts with felspar dominant phenocryst
	Aphanitic basalt
	Porphyritic olivine andesite
	Oligoclase andesite
	Soda trachyte
	Gabbroic xenoliths
	Sideromelan and palagonite tuffs
Narborough:	Basalts with few felspar phenocrysts
Tower:	Basalts (Gooch)

Table 7. Analyses of Rocks from Galapagos Islands

	1	2	3	4	5	6	7	8	9
SiO_2	61.90	46.72	47.80	48.65	45.55	48.10	48.24	38.13	47.75
Al_2O_3	16.75	14.10	18.31	17.50	18.25	15.90	15.82	14.64	18.34
Fe_2O_3	2.27	2.14	1.47	0.25	7.28	1.93	0.78	7.93	9.94
FeO	4.83	9.63	8.20	9.75	5.01	10.28	9.84	0.87	1.09
MgO	0.57	11.64	4.89	6.61	6.00	6.28	5.84	3.84	4.78
CaO	2.30	10.92	13.00	11.85	10.20	11.60	9.84	8.97	11.25
Na_2O	7.20	1.83	2.48	2.15	3.18	2.68	3.63	2.67	3.34
K_2O	3.25	0.30	0.57	0.38	0.85	0.30	0.64	0.15	0.19
H_2O+	0.20	0.20	0.31	tr.	0.95	0.40	0.72	12.34	....
H_2O-	0.10	0.21	0.11	0.10	0.25	0.10	0.11	8.41	....
TiO_2	0.25	1.96	2.40	2.10	1.80	1.90	3.88	2.50	3.12
P_2O_5	0.07	0.34	0.41	0.21	0.23	0.23	0.16	0.01	0.01
S	0.08	n.d.	n.d.	tr.	tr.	tr.	n.d.	n.d.	....
MnO	0.30	0.14	0.14	0.25	0.30	0.29	0.20	0.15	0.19
	100.07	100.13	100.09	99.80	99.85	99.99	99.70	100.61	100.00

1. Soda trachyte [3268], James Island, analyzed by Herdsman.
2. Doleritic basalt [346], James Island, analyzed by Raoult (39, p. 69).
3. Plagioclase basalt [458], Tagus Cove, Albemarle Island, analyzed by Raoult (39, p. 69).
4. Porphyritic olivine basalt [463], Narborough Island, analyzed by Herdsman.
5. Olivine andesite [3239], Chatham Island, analyzed by Herdsman.
6. Andesite [433 B], ejected fragment, Albemarle Island, analyzed by Herdsman.
7. Andesine basalt, Eden Islet, analyzed by Keyes (62, p. 538).
8. Palagonite tuff, Eden Islet, analyzed by Keyes (62, p. 541).
9. The same as No. 8, but calculated to 100.00 as free from H_2O.

AGE RELATIONS

In an attempt to determine the age relations of the Galapagos rocks, the compositions of the felspar and olivine phenocrysts in the porphyritic rocks, deduced from refractive index tables given by Winchell (66), were plotted against each other (see fig. 9). In rocks where the only phenocrysts are olivine, the composition of the groundmass felspar was plotted against that of the total olivine. Data from non-porphyritic rocks and tuffs, which contain both olivine and felspar, were also used. In the graph the average compositions are plotted, except for rocks in which the felspar shows a range of more than 12 per cent anorthite or the olivine 5 per cent fayalite, when the range is shown by a dotted line. In order to avoid confusion, the tuffs from James and Albemarle islands are each represented by a single point, which is the average of several closely similar determinations.

The points indicate one main line of differentiation (Series I) and a definite subsidiary line where the olivine is enriched in fayalite (Series II).

As a basalt magma cools and crystallizes, the felspar crystals which it contains become more acid and the olivine richer in fayalite. Thus the composition of felspar phenocrysts in lavas erupted at intervals from a cooling and partially crystalline basalt magma will become increasingly acid as the process continues. Hence the right-hand ends of the two curves (fig. 9) represent the oldest lavas. Xenoliths from the acid end of Series II are inclosed in basalt containing felspar phenocrysts showing a long range in composition from near the acid end of Curve I. Thus the basalts of Series II must be older than some of the lavas of Series I, but may in part be contemporaneous.

The sequence of events therefore appears to be the ejection of tuffs at Albemarle, James, and probably other islands which cannot be represented on the graph, followed by basalts with abundant bytownite phenocrysts at

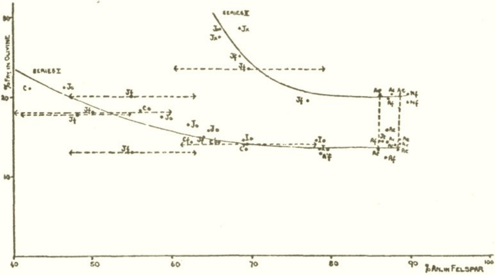

FIGURE 9.—Graph showing relationships of the rocks of the Galapagos Islands, symbols to be interpreted as follows: *A'*, Abingdon Island; *A*, Albemarle Island; *C'*, Charles Island; *C*, Chatham Island; *I*, Indefatigable Island; *J*, James Island; *N*, Narborough Island; *f*, lavas with dominant felspar phenocrysts; *o*, lavas with dominant olivine phenocrysts; *e*, ejected fragments; *t*, crystals from tuffs; *x*, xenoliths.

Albemarle (which agrees with field evidence) and Abingdon islands. Most of the succeeding basalts (central portion of Curve I) contain only olivine phenocrysts. It is possible that these really belong to another line of differentiation and that the points representing them lie on Curve I by accident, as there are some basalts with felspar phenocrysts which give nearly coincident points. These were followed by basalts at James Island (long range in composition of felspar phenocrysts) containing xenoliths, and finally andesites.

Neither the oligoclase andesite nor the trachyte could be represented on the graph, but the presence in the andesite of olivine which does not appear to be very rich in fayalite suggests that it may be a late member of Series I. The trachyte with its occasional fayalite crystals might be an offshoot of Series II.

SUMMARY AND COMPARISON

The chief petrological characters of the Galapagos Archipelago are the predominance of basaltic material (both lavas and tuffs) on all the islands, the absence of nepheline-bearing rocks, and the rarity of trachyte.

The basaltic rocks are almost all prophyritic with dominant phenocrysts of olivine or basic plagioclase, and they are distinguished by a very low content of K_2O and also high Al_2O_3 and CaO in the felspar-rich varieties (Table 7). These two types of basalt are found together on many Pacific islands (39) and at Ascension Island (22), but only those from Mangareva (Gambier Islands) (39, p. 43-45) and Juan Fernandez Islands (39, p. 65; 47) are also similar as regards chemical composition. Actually some of the Hawaiian basalts have analyses which are nearer to that of the porphyritic olivine basalt from James Island (Table 5), and certain basalts from Reunion Island are chemically closer to the felspathic types (Table 6) than are those of Mangareva and Juan Fernandez.

The analyzed trachyte and andesine basalt as well as the porphyritic olivine basalt can be matched much closer in Hawaii than elsewhere (see Tables 4, 5, 6), but the dominant lavas of Hawaii are olivine basalts, and none resembling the bytownite-bearing basalts of Albemarle Island are developed.

The Juan Fernandez are the only islands on which both types of basalt are found in addition to soda trachyte similar to that occurring in the Galapagos Archipelago (Table 4). Although oceanites and basanitic lavas are also present, the Juan Fernandez Islands are petrologically closer to the Galapagos than are any other islands. Both are situated comparatively near the American coast of the Pacific, but their similarity is not shared by San Felix and San Ambrasio islands (65), or any of the other islands on that side of the Pacific where the lavas are throughout richer in K_2O.

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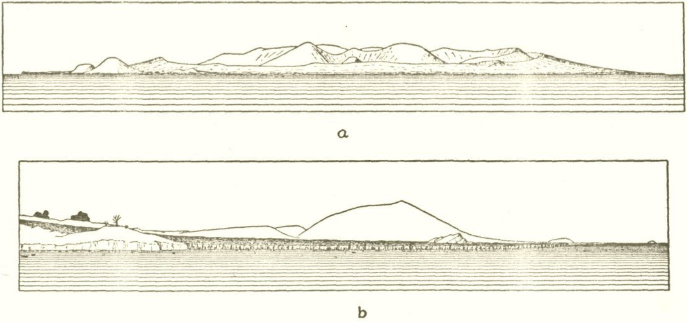

FIGURE 5.—Tuff craters: *a*, sketch of Bindloe Island from the east-northeast, showing a caldera with several tuff craters standing in and around it; *b*, sketch of southern side of James Bay, James Island, showing several tuff craters and a single lava stream that flows down the tuff slopes of the main volcano and spreads out on reaching the sea.