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CRYSTAL CAVITIES IN LAVAS FROM THE HAWAIIAN ISLANDS

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I. INTRODUCTION AND ACKNOWLEDGMENTS

The existence of veins containing good crystals of nephelite, augite and zeolites in a nephelite-melilite basalt exposed in a quarry near Honolulu has been known since 1900, when C. H. Hitchcock

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published his account of the geology of the island of Oahu. The same veins were mentioned by Whitman Cross (1915) but no detailed study of them was undertaken until 1930 when Professor Eakle upon his retirement to Honolulu made full collections of material from the crystal cavities not only of this locality but also of several others in the Hawaiian islands. At the time of his death in 1932, Professor Eakle was engaged in investigating these collections at the University of Hawaii, and it is to this work that he referred in a letter which has recently appeared in a memorial of his life written by C. Palache (1932). Professor Eakle had completed a number of chemical analyses, and had published a preliminary note on his work (1931).

The collections were acquired by Professor Palache for the Department of Mineralogy and Petrography of Harvard University, where at his suggestion the present author undertook to complete the study begun by Professor Eakle by determining the optical constants of both analyzed and unanalyzed minerals, and investigating the paragenesis and mode of origin of the minerals. Professor Eakle's notes were made available to the author and certain of his new analyses are included in the present account.

The author wishes to express his gratitude to Professor Palache for allowing him the opportunity of carrying this work to its conclusion, and also for helpful criticism and advice throughout the work. He also wishes to thank Professor E. S. Larsen, Jr. for discussing with him some of the optical determinations, and Dr. M. A. Peacock who was kind enough to make goniometric measurements on several crystals in order to confirm their identity. Unfortunately most of the crystals in the cavities did not prove amenable to goniometric treatment, either owing to corrosion or, in the case of the zeolites, because of the excessive development of vicinal faces. The author is also grateful to Professor L. C. Graton for allowing him to have polished surfaces of opaque minerals made by his special process.

Three principal localities are represented in the collection:

Moiliili quarry, referred to above. This lies within the city limits of Honolulu about one half mile east of the University of Hawaii grounds. The rock is quarried by the Honolulu Construction Company for use as road material.

The Alexander Dam which was being constructed for the McBryde Sugar Company on the island of Kauai.

The Lanakai hills, near Kailua, western Hawaii. Some of the specimens from this district are labelled "near railroad station, Kailua."

Several minor localities will also receive brief mention.

II. MOILIILI QUARRY, HONOLULU

Petrography of Nephelite-Melilite Basalt

The lava exposed in Moiliili quarry was first collected by C. H. Hitchcock and identified by G. P. Merrill (1900) as a nephelite-melilite basalt. Whitman Cross (1915) has described its petrography, and his account contains the following analysis and norm:

Analysis	
SiO_2	36.34
Al_2O_3	10.14
Fe_2O_3	6.53
FeO	10.66
MgO	10.68
CaO	13.10
Na_2O	4.54
K_2O	1.78
H_2O-	1.00
H_2O+	1.00
TiO_2	2.87
CO_2	0.15
P_2O_5	1.02
S	0.04
MnO	0.20
	100.05

Norm	
Leucite	8.28
Nephelite	21.02
Anorthite	1.67
Diopside	17.39
Olivine	20.23
Akermanite	11.95
Magnetite	9.51
Ilmenite	5.47
Apatite	2.35
	97.87
H_2O	2.00
Calcite	0.31
	100.18

In the hand specimen the rock is greyish brown in color and appears to be holocrystalline, without recognizable phenocrysts. The microscope reveals that the rock has a microporphyritic texture, with phenocrysts of olivine in a holocrystalline ground mass consisting of granular augite, nephelite, melilite and magnetite. The olivine phenocrysts show reaction rims of pyroxene, but apart from this the minerals are remarkably fresh, both distant from and near the cavities. The average size of the phenocrysts is about 0.75 mm., while the groundmass has an average grain of about 0.15 mm., the ragged augite crystals of the groundmass generally exceeding this figure. Apatite is present as an accessory mineral in the rock, in minor amounts only.

TABLE I. DETERMINATIVE CRITERIA FOR MOILIILI MINERALS

Name	Optical Character	ω α	β	ϵ γ	Crystal Form	Color, etc.
Nephelite	Uniaxial−	1.542		1.537	Hexagonal, prismatic Elongated parallel to "*c*"	Colorless, greasy lustre
Augite	Biaxial+ 2V near 60°	1.699	1.701	1.721	Flattened parallel to *b*(010) or *a*(100)	Dark green
Melilite	Uniaxial−	1.635		1.631	Tabular, much corroded	Yellowish-brown
Apatite	Uniaxial−	1.637		1.629	Acicular, hexagonal	Colorless
Magnetite	Opaque				Octahedra	Red coating. Strongly magnetic
Phillipsite	Biaxial− 2V mod.	1.493	1.497	1.500	Cruciform penetration twins	Colorless
Chabazite	Anomalous		1.485 (mean)		Rhombohedra, with penetration twins	Colorless to pale yellow
Hydronephelite		α^1 1.491		γ^1 1.499	Fibrous, radiating	White
Allophane	Isotropic		1.49 (mean)		Amorphous or cryptocrystalline crustification; banded	White
Calcite	Uniaxial−	1.670		1.485	Small "dog-tooth" crystals, corroded. Crustifications	White, pink (rarely)

DETERMINATION OF MINERALS IN VEINS AND CAVITIES

Hitchcock (1900) described the veins traversing the basalt in the following words:

"The bluff is traversed by small veins full of nephelite, granular melilite and augite. Either of the minerals may form a layer of crystals, closely crowded together all standing vertically to the plane of occurrence. Veins three inches wide or less abound in these minerals, mixed with a multitude of acicular crystals of kaliophilite." The veins are irregular in form and probably represent shrinkage cracks or lines of cavities in the lava. They are now only partly filled, and it is evident from the open texture of the filling that the minerals have been free to grow in open spaces.

TABLE II. ANALYSES OF MOILIILI MINERALS

	I Nephelite	II Phillipsite	III Chabazite	IV Hydronepehlite
SiO_2	41.27	42.34	47.00	43.31
Al_2O_3	32.38	22.31	21.64	29.92
Fe_2O_3	1.08			
CaO	1.33	3.90	10.13	3.27
Na_2O	16.95	4.26		11.66
K_2O	4.65	6.78		
H_2O		19.70	20.98	12.38
	99.46	99.29	99.75	100.54

Analyst, A. S. Eakle

The accompanying table (Table I) summarizes the criteria used in determining the minerals. This data is here placed upon record so that even if the names here assigned to the minerals prove inapplicable when work such as M. H. Hey of the British Museum is carrying out on the zeolites is completed, the diagnostic criteria for the minerals will still be available. The new analyses of the Moiliili minerals made by Dr. Eakle are contained in Table II.

Several observations must be added to those in the tables. The determination of the magnetite was confirmed by examination of polished surfaces in reflected polarized light. The reddish coating was found to represent a hematitic marginal alteration product, the layer of which is very thin. The rest of the crystals consists wholly of magnetite, and no evidence of the presence of ilmenite was found.

The author is aware that the species hydronephelite is suspect, and that therefore the use of this name is open to objection. Nevertheless, the analysis (IV) shows that the material has a composition too far remote from natrolite to be described under this name, and since the mineral here occurs as a white alteration product of nephelite, just as did the original hydronephelite from Litchfield, Conn., and since it is chemically nearest to this material, it is proposed to retain the name here until this doubtful species has either been established or discredited. There is no indication in the optical properties of the material to suggest that it is not homogeneous, and if, therefore, it is a mixture of natrolite and diaspore as St. J. Thugutt (1932) has suggested, then these minerals must be in solid solution in one another. M. H. Hey (1932) states that he intends to thoroughly investigate this species in the near future; the examination of the Moiliili material was not therefore carried beyond the stage indicated by the data here recorded. Should the mineral prove to be a mixture, it is still possible that the term hydronephelite might usefully be retained for hydrous alteration products of nephelite of this type.

Allophane occurs as an amorphous or cryptocrystalline "metacolloidal" coating, exhibiting delicate banding on the microscopic scale. There was insufficient material in the Moiliili collection to make possible an analysis, but optically identical material from Alexander Dam has been analyzed. It should be noted that the refractive index indicates that the material is not amorphous silica, and the coatings have not the appearance of opaline silica.

A note must also be added concerning the analysis of phillipsite (II). Dr. Eakle's original analysis showed some 11.0% of Na_2O and no K_2O. Since it was evident from a morphological study that the mineral was phillipsite, it was decided to have the alkalis re-examined in order to check the correctness of this large divergence from the normal composition of phillipsite. The material used was some phillipsite remaining from Dr. Eakle's analysis; determination of alkalis in this by Mr. F. A. Gonyer showed Na_2O 4.26%, K_2O 6.78%. These figures have therefore been inserted in the analysis in the place of the original figures for alkalis.

PARAGENESIS

Study of the order of deposition of the minerals has revealed a surprisingly consistent succession of events in the filling of the veins and cavities. The sequence is summarized in Table III.

TABLE III. PARAGENESIS OF MINERALS, MOILIILI QUARRY AND ALEXANDER DAM

MOILIILI

	Phenocrysts	Groundmass	Pegmatitoid phase	Metacolloid phase	Zeolitic phase	
Olivine	—	Alteration to pyroxene				
Augite		—	—			Alteration to hydronephelite
Nephelite		—	—			
Melilite		—	—			
Apatite		—	—			
Magnetite		—	—			
Allophane				—		
Chabazite					—	
Phillipsite					—	
Hydronephelite						—
Calcite				—	—	—

ALEXANDER DAM

Olivine	—	—	—			
Augite		—	—			
Nephelite		—	—			Alteration to hydronephelite
Magnetite		—				
Allophane				—		
Stilbite					—	
Gismondite					—	
Hydronephelite						—
Aragonite				—	—	—

Pegmatitoid phase. The term "*pegmatitoid*" is used to cover the segregations of pyrogene minerals which whenever they are present form the earliest fillings in the cavities. Though such segregations have long been recognized, they have had no proper name until A. Lacroix applied this term to them in 1928. It is interesting to note that the examples described by him are similar to those described here in that they occur in association with nepheline-bearing rocks. The term "pegmatitoid" is the equivalent of the term "segregation-vein" as used by the Mull authors (1924).

The term is an appropriate one because it suggests an analogy

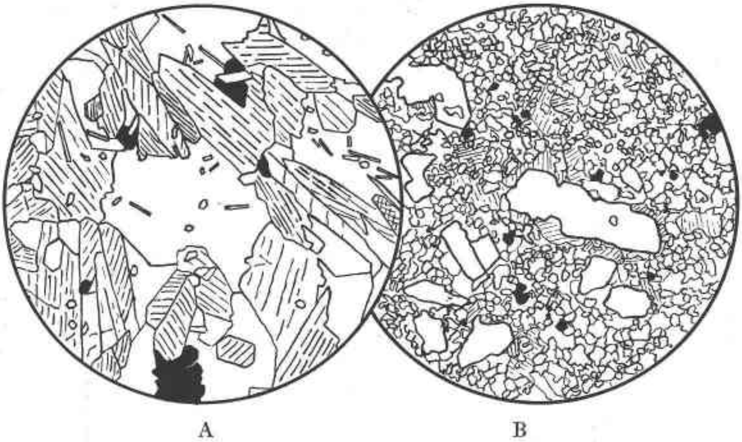


FIG. 1. Camera Lucida drawings illustrating the contrast in texture between the nephelite-melilite basalt of Moiliili quarry and its pegmatitoid phase.

A. Pegmatitoid phase. White areas, nephelite; augite crystals shaded to show cleavage; black areas, magnetite; needles are apatite.

B. The parent lava. Olivine phenocrysts (white) in groundmass of augite (showing cleavage), nephelite and melilite. Black areas are magnetite.

with the pegmatites associated with plutonic rocks. In the case of Moiliili the mineral composition of the pegmatitoid is qualitatively the same as that of the groundmass; there is, however, a great difference in grain size, as Table IV and the camera lucida drawings show.

TABLE IV. CONTRAST IN GRAIN SIZE BETWEEN GROUNDMASS OF THE PARENT LAVA AND THE PEGMATITOID

	Greatest average dimensions of minerals in mm.	
	Groundmass	*Pegmatitoid*
Augite (ragged)	0.5	3.0
Nephelite	0.1	2.0
Melilite	0.15	2.0
Magnetite	0.1	1.0
Apatite	0.1	3.0

Quantitatively, there is a very significant difference between the mineral composition of the lava and the pegmatitoid; for while apatite is only rarely seen in the thin sections of the lava, it is very abundant in the coarse segregations. This difference will be further discussed in a later section.

Metacolloid phase. Following the deposition of the pyrogene minerals, a white coating of allophane was deposited on them. This is interesting mainly because it definitely preceded the crystallization of the zeolites. This white incrustation never covers the zeolitic minerals, whereas they are frequently seen to rest upon it. It is not, however, invariably present between the pegmatitoid and zeolitic phases.

Zeolitic phase. The zeolites, together with some carbonate material, constitute the last stage in the succession. No alteration of the pyrogene minerals is associated with the deposition of chabazite and phillipsite, but on the other hand, alteration amounting almost to complete pseudomorphous replacement of nephelite has occurred wherever hydronephelite is found.

III. ALEXANDER DAM EXCAVATION, KAUAI

Petrography of Ankaratrite

The rock in which the crystal cavities occur was collected from material excavated during the building of the Alexander Dam, on the island of Kauai. It is a melanocratic basaltic type, and is black in the hand specimen. The grain is fine. The texture is microporphyritic, with idiomorphic phenocrysts of olivine in a holocystalline groundmass composed of granular olivine, augite laths, magnetite, and nephelite, the amount of the last named constituent being very small. These characteristics show that the rock is an ankaratrite, a type apparently new to Hawaii, though the nearly-related limburgites have been abundantly found in the province (cf. Washington, 1923). N. E. A. Hinds (1925) has described several occurrences of nephelite basalt on Kauai, and the ankaratrite may be regarded as intermediate between the limburgite and nephelite basalt. No analysis is at present available.

Determination of Minerals in Cavities

The mineralogy of the cavity fillings in the ankaratrite has much in common with that of the Moiliili rock, and is summarized in Table V.

Crystals of augite are rare in these cavities, whereas olivine is comparatively abundant. Unfortunately the olivine is too much etched to be suitable for crystallographic study. No unaltered nephelite remains, though the hexagonal prismatic crystals are beautifully preserved as pseudomorphs in hydronephelite.

Table V. Determinative Criteria for Alexander Dam Minerals

Name	Optical Character	ω α	β	ϵ γ	Crystal form	Color, etc.
Olivine	Biaxial+ 2V 90°	1.663	1.680	1.701	Deeply etched	Dark green
Augite	Biaxial+ 2V mod.		1.69 (mean)		Flattened parallel to *a*(100) which is the best developed face	Green; very intense absorption color
Nephelite	Pseudomorphs in hydronephelite				Hexagonal prismatic form	
Stilbite	Biaxial− 2V mod.	1.495	1.498	1.501	Typical twins, show hour-glass structure. *m*(110), *c*(001), and *b*(010)	Colorless
Gismondite	Biaxial−	1.538	1.543	1.548	Pseudotetragonal. Characteristic pyramidal form with rough faces	Colorless
Hydronephelite		α' 1.491		γ' 1.500	Fibrous	White
Allophane	Isotropic		1.49 (mean)		Amorphous incrustations	White
Aragonite	Biaxial−	1.683	1.680	1.537	Botryoidal masses	White

Allophane is more abundant than at Moiliili, and was present in sufficient amount to make possible an analysis (Table VI). In view of the frequency with which "amorphous silica" is described

Table VI. Analysis of Allophane, Alexander Dam

SiO_2	30.2
Al_2O_3	40.3
MgO	1.8
H_2O	27.6
	99.9

Analyst, L. E. Davis, Honolulu

from cavities of the type here under discussion it is perhaps worth while at this point to call attention to the fact that such coatings may not always be silica, but may consist of hydrous silicate material as in the present instance. The magnesia in the analysis may be present as impurities, or as stevensite, which has much the same optical properties as allophane.

PARAGENESIS

The same stages as were recognized at Moiliili occur in the Alexander Dam cavities, and though there are some differences in mineralogy, an essentially similar sequence is plainly recognizable. Again there is a marked difference in texture between parent rock and pegmatitoid. The order of deposition is summarised in Table III.

IV. LANAKAI HILLS, HAWAII

PETROGRAPHY OF BASALT

The Lanakai lava is a brown amygdaloid of exceedingly fine grain and aphanitic aspect, without phenocrysts. The microscope shows that it is non-porphyritic and almost cryptocrystalline. The constituent minerals are labradorite in tiny laths, a monoclinic pyroxene and magnetite. The poecillitic texture is revealed only by the use of the highest power lens, but with this magnification it is evident that the rock contains no glass, but is holocrystalline. Neither quartz nor alkali feldspar were detected, and olivine is entirely absent. The rock is thus a normal basalt. Chloritic alteration extends throughout the whole rock, but is nowhere intense, and patches of what at first sight appear to be glass prove on close examination to consist of chlorite. The alteration shows no relation to the cavities.

DETERMINATION OF MINERALS IN AMYGDULES

The amygdules are widespread through the rock, and have a rudely spherical shape, or may be elongated parallel to one another. The minerals include quartz, zeolites and a green fibrous material probably related to nontronite (Table VII).

Three of the zeolites represented had been analyzed by Dr. Eakle. Epistilbite, which had not been determined in this way, has been confirmed here by goniometric measurements made by Dr.

Peacock. The form proved to be identical within the limits of experimental error with that given for the mineral in Victor Goldschmit's "Atlas der Kristall Formen" and "Winkeltabellen."

TABLE VII. DETERMINATIVE CRITERIA FOR LANAKAI MINERALS

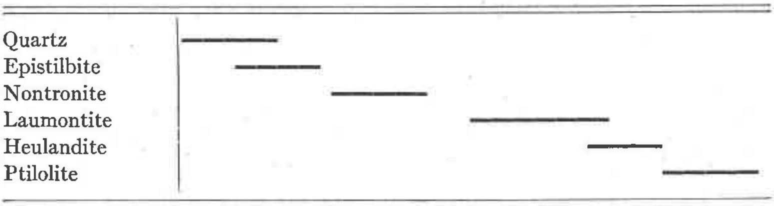
Name	Optical Character	ω α	β	ϵ γ	Crystal form	Color, etc. Max. size
Quartz	Uniaxial+	1.544		1.553	Characteristic. Sometimes doubly terminated	Colorless 2 mm.
Epistilbite	Biaxial− 2V small	1.505	1.515	1.519	Monoclinic twins with *m*(110), *b*(010) and *c*(001)	Colorless 3 mm.
Laumontite	Biaxial− 2V small	1.511	1.518	1.522	Elongated parallel to *m*(110). *c*(001) is poorly developed.	White 10 mm.
Heulandite	Biaxial+ 2V small	1.501	1.504	1.509	*b*(010), *s*($\bar{2}$01), *t*(201), *c*(001). Rhombohedral	Colorless 9 mm.
Ptilolite		α' 1.475		γ' 1.478	Fibrous, woolly. Extinction parallel	White
Nontronite ?	Elongation +		1.56 (mean)		Fibrous	Greenish brown

TABLE VIII. ANALYSES OF MINERALS FROM THE LANAKAI HILLS

	I	II	III	IV	V
	Laumontite		Heulandite	Ptilolite	
	Lanakai Hills	Kailua		Lanakai	Kailua
SiO_2	52.34	52.30	57.28	65.56	65.66
Al_2O_3	22.27	23.38	17.76	10.55	10.77
CaO	10.83	10.36	7.18	5.46	5.43
Na_2O			2.95	3.07	3.90
H_2O	14.06	14.26	15.42	15.31	14.40
	99.50	100.30	100.59	99.95	100.18

Analyst, A. S. Eakle

Table IX. Order of Deposition of Lanakai Minerals.



Paragenesis

Table IX summarizes the order of deposition of the minerals. Again there is a surprising constancy in this sequence, and while no single cavity shows the whole succession, no anomalies or reversals of the order were found, although a large number of amygdules were examined. The nontronite occupies a definitely intermediate position and occurs between quartz and epistilbite and the other zeolites. Cavities lined on their walls with nontronite do not contain quartz and epistilbite; cavities with nontronite as the central core contain in addition only these minerals. Many examples of both cases were observed, both in the hand specimen, and under the microscope. When ptilolite occurs, it is always the last mineral to crystallize, and there are many examples of amygdules lined with heulandite and having a woolly central filling of ptilolite. A few cavities showed beautiful examples of colorless heulandite crystals which had grown round radiating acicular laumontite crystals, the laumontite being clearly visible through the heulandite.

V. GENETIC FEATURES

The material from the principal localities having been described, it is now appropriate to consider the bearing of the observations made upon the more general problems of mineral genesis. The investigation has led to the recognition of two distinct groups of minerals in the veins and cavities; an anhydrous group, consisting of pyrogene minerals, similar in composition to the groundmass of the parent lava; and a later group of hydrous silicates.

The Pegmatitoid Stage

Stress has been laid upon the similarity in composition between the groundmass of the enclosing lava, and the coarse segregations of anhydrous silicates because this provides clear evidence of the source of the pyrogene minerals. The constituents of the pegmatitoids were undoubtedly derived from the rock in which they occur. Yet it is clear from their mode of occurrence that the minerals cannot have crystallized until the lava was more or less completely consolidated. Why then should a small residue of the magma have remained uncrystallized until after all the rest had solidified? Presumably this residue was subject to the same temperature-pressure conditions as the rest of the magma. A valuable clue is to be found in the concentration of apatite in the pegmatitoid phase at Moiliili. This indicates a richness in the mineralizers fluorine (the Moiliili apatite is a fluor-apatite) and phosphorus pentoxide. Further, the association of the pegmatitoids with zeolites suggests, as Lacroix (1928) has already pointed out, that the residue of the magma from which they were derived was unusually rich in water.

The analogy between the pegmatitoids and the pegmatites is thus complete. Both result from the crystallization of a volatile-rich rest-magma, and in both cases the grain is coarse because of the conditions induced by the presence of mineralizers. The panidiomorphic texture of the pegmatitoids here described is to be ascribed to their slow rate of crystallization, and to the freedom of the minerals to grow in open spaces. The cavities in which the pegmatitoids occur probably mark the loci of concentration of the residual liquors, perhaps in part in the gaseous state. When the form is more definitely vein-like, segregation into fissures resulting from contraction during the cooling of the lava may have taken place. There should exist some minimum depth below the lava-top, above which pegmatitoids cannot form because too great a freedom for escape of volatiles is possible; but unfortunately no field evidence is at present available to support this contention.

Some examples of pegmatitoids other than those here described may be mentioned before concluding this section. An occurrence almost identical with that at Moiliili is represented in a collection made by Professor Palache from the Capo di Bove, near Rome. Here vein-like cavities lined with nephelite, augite, melilite and apatite occur in an alkali-basaltic lava. The richness of the pegmatitoid in apatite is again a noteworthy feature. Segregation veins in olivine basalt on the island of Mull have been described by H. H. Thomas (1924). These contain an early phase composed of coarse augite and feldspar, followed by a later phase with analcite, chlorite, alkali feldspar and natrolite. Lacroix (1928) has described pegmatitoids from Wei t'chang, China; Bora-Bora, Polynesia; and Beaulieu and Rougiers, France. In all these cases, the rôle of water and mineralizers is apparent.

HYDROTHERMAL STAGE

It is suggested that the hydrous silicates are primary products also derived from the magmatic residuum responsible for the pegmatitoids. There are two alternatives to this hypothesis. One is the postulate that the zeolites are secondary products arising from the attack of circulating meteoric waters upon the lava. Since the constancy in the order of deposition of the zeolites cannot be explained upon this hypothesis, and since evidence of such attack is wanting, this mode of origin may be excluded. A second possibility is that the zeolites were introduced by hot solutions from some source outside the lava. There is no evidence, in the form of rock alteration, of the passage of such solutions. The zeolitic stage is therefore believed to result from crystallization from hot solutions which remained from the water-rich magma of the pegmatitoid stage. The phase of hydrous silicates is therefore designated the *hydrothermal* stage.

Some justification for the use of this term is provided by a study of the sequence of hydrous minerals. It was thought at first that the order of deposition of minerals in this phase might be explained on compositional grounds alone, and it was expected that the minerals would show a progressive increase in water-content. Table X shows that there is no such increase. In the Lanakai occurrences, there is a surprising constancy in the water-content; in the other two instances, the water-content actually decreases. While it is recognized that the water content of the zeolites is variable, it is scarcely possible to invoke this variation to account for the failure of the sequence to show increasingly hydrous minerals towards its end. Thus the view is put forward that the control of deposition in sequence was not composition but falling temperature. If this contention is correct, then clearly, hot solutions were involved and this stage is correctly described as hydrothermal.

A final observation must be added. It is an interesting fact in all three sequences that the last mineral to crystallize is a fibrous zeolite, and that fibrous zeolites do not occur earlier in the succession. Possibly the fibrous type crystallizes in preference to the well crystallized type at low temperatures.

Table X. Water Content of Minerals in the Hydrothermal Stage.

Figures in parentheses indicate average figures for the mineral concerned, there being no analysis available for the mineral from this locality

	Moiliili	%H_2O	*Alexander Dam*	%H_2O	*Lanakai Hills*	%H_2O
Early	Allophane	(27)	Allophane	27	Epistilbite	(16)
	Chabazite	20	Stilbite	(17)	Nontronite	(20)
	Phillipsite	19	Gismondite	(25)	Laumontite	15
Late	Hydronephelite	12	Hydronephelite	(12)	Heulandite	14
					Ptilolite	15

VI. OTHER MINERAL OCCURRENCES

A number of less of important localities are represented in the collection made by Professor Eakle; brief descriptions of the minerals found follow here.

Salt Lake Crater. The county rock is an agglomerate. Thin sections show that it consists of lava fragments made up of olivine in a glass base, and shattered crystals of olivine and augite, the whole being cemented together by amorphous material. In cavities, typical laumontite is found, associated in many instances with green nontronitic material, which has preceded the laumontite in time of deposition. The similarity of this type of filling with that found in the Lanakai Hills suite is striking.

Dillinghams Quarry. Here spherical cavities occur in a dark basalt. The sole filling is aragonite, in well developed acicular crystals up to 10 mm. in length.

Halemaumau, Hawaii. The collection includes an explosion block hurled out of Halemaumau in 1924. The rock is grey in color, and contains many cavities. The grain is coarser than is usual with the Hawaiian lavas. Under the microscope, the rock is seen to have a moderately coarse ophitic texture, with labradorite laths and augite crystals. An opaque mineral is present in plates which in section have the same geometrical form as the labradorite. This mineral is evidently an original constituent of the rock. A polished surface showed that it is fairly strongly anisotropic; but the color has not the white quality of hematite; and the mineral is fairly strongly magnetic. It seems likely therefore that this mineral is hematite which is undergoing a transformation to magnetite.

The cavities in the rock contain small white crystals which have proved to be cristobalite, with refractive index 1.485.

VII. SUMMARY

1. The mineralogy of veins, cavity fillings and amygdules in lavas from three localities in the Hawaiian islands is recorded, to-

gether with new analyses of certain of the minerals made by the late Professor A. S. Eakle, who was the collector of the material.

2. In two of these cases, segregations of pyrogene minerals qualitatively similar in mineral composition to the groundmass of their parent lavas were found. These are described as *pegmatitoids,* using the term proposed by Lacroix. It is shown that the late crystallization of these and their coarseness in grain are to be ascribed to crystallization from volatile-rich magmatic residua.

3. In each case a white coating of a hydrous aluminium silicate followed the deposition of the pegmatitoid, but preceded the crystallization of a series of zeolites.

4. An orderly succession of zeolites is described from all three localities. It is suggested that these are primary minerals representing the hydrothermal stage of the lava-magma.

5. Thus just as in the depths of the earth, the magma at the surface upon crystallization tends to produce a "rest-magma," rich in water and volatile components. From this, coarse-grained anhydrous minerals crystallize first, and hydrous silicates follow at a later and therefore cooler stage.

6. A number of less important mineral localities in the islands are also described.

VIII. BIBLIOGRAPHY

Bailey, E. B., Thomas H. H. et aliter, 1924. The Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban: *Mem. Geol. Surv. Scotland,* p. 138.

Cross, Whitman, 1915. The Lavas of Hawaii and their Relations: *Prof. Paper* **88,** *U.S.G.S.* p. 21.

Eakle, A. S., 1931. The minerals of Oahu: *Mid-Pacific Magazine,* October, pp. 341–343.

Hey, M. H., 1932. Studies of the Zeolies. Part III, Natrolite and Melanatrolite *Mineral. Mag.,* **xxiii,** p. 244.

Hinds, N. E. A., 1925. Melilite and Nephelite Basalt in Hawaii: *Jour. Geol.,* **xxxiii,** pp. 526–539.

Hitchcock, C. H., 1900. The Geology of Oahu: *Bull. Geol. Soc. Amer.,* **xi,** p. 47.

Lacroix, A., 1928. Les Pegmatitoides des Roches Volcaniques a facies basaltique: *C. R. Acad. Sci.,* Paris, pp. 321–326.

Merrill, G. P., 1900. Nepheline Melilite Basalt from Oahu, Hawaiian Islands: *Amer. Geologist,* **xxv,** pp. 312–13.

Palache, C., 1932. Memorial of A. S. Eakle: *Bull. Geol. Soc. Amer.,* **xliii,** pp. 46–52.

Thugutt, St. J., 1932. Sur l'epinatrolite, mineral composant l'hydronephelinite: *Archive de mineralogie de la societe des sciences et des lettres de Varsovie,* **vii,** pp. 143–144.

Washington, H. S., 1923. Petrology of the Hawaiian Islands; III. Kilauea and General Petrology of Hawaii: *Amer. Jour. Sci.,* 5th ser., **vi,** pp. 338–367.