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MINERALOGICAL AND CHEMICAL STUDY OF DACITE
FROM QUILOTOA VOLCANO IN ECUADOR

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Abstract. The paper deals with the results of mineralogical and chemical study of dacite — the main rock type forming Quilotoa volcano in the West Cordillera of the Ecuadorian Andes. Phenocrysts of hornblende, biotite and plagioclase were separated and examined, particular attention being paid to glomerophyres of the latter mineral. No matter of comparatively easy accessibility of this volcano, its products were not yet studied in detail.

INTRODUCTION

Quilotoa (3981 m) is one of the eight active volcanoes in Ecuador. It is situated within the West Cordillera ($0^{\circ}52'$ S, $78^{\circ}55'$ W) and the products of its activity are overlying Cretaceous volcanites, Upper Cretaceous-Paleocene sedimentary rocks and Quaternary fluviatile deposits (Fig. 1). It consists of a broad truncated cone with explosive caldera, ca. 3 km in diameter. Its internal part is filled with crater lake ca. 2 km in diameter, from the bottom of which H_2S and CO_2 are evolving. The mineralization of water is nearly 7 g per litre and its temperature is by 5 to $10^{\circ}C$ higher than the average annual of the environment. Hot springs are active at the eastern foot of the slope, accompanied by exhalations.

Actually Quilotoa is in a state of dormancy. In historic times a powerful eruption of 1660 is noted when ashes were deposited up to Quito. Lesser eruptions and changes in crater lake level were observed in 1725, 1740 and 1759. No lava flows were observed. It is supposed that earlier explosive activity of this volcano was accompanied by lahars.

Volcanic cone consists mainly of dacitic lavas, pumiceous tuffs and subordinate andesites. These products were not yet studied in detail.

General geological investigations of Quilotoa were carried out mainly at the end of XIXth and the first decade of XXth century. The results

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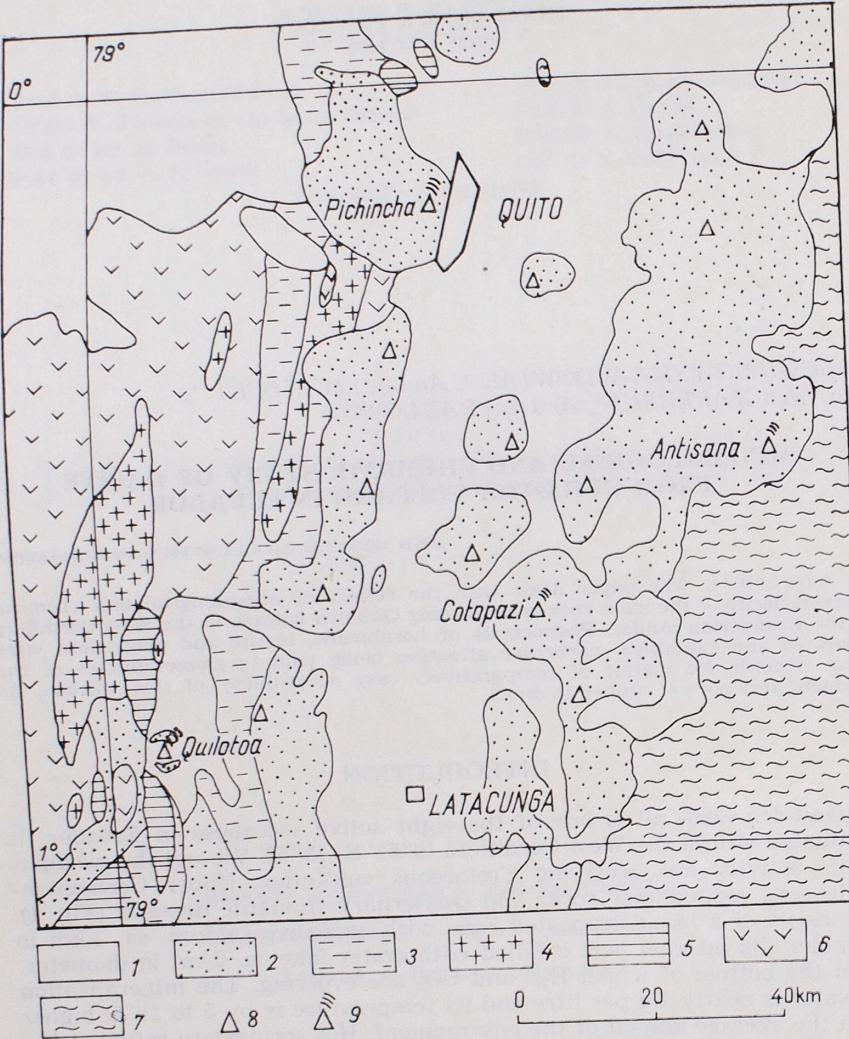


Fig. 1. Geological sketch of the region of Quilotoa volcano
(after Mapa Geológico del Ecuador, 1969)

1-2: Pliocene-Quaternary: 1 — deluvial deposits, moraines, fluvial and lacustrine sediments, 2 — volcanic rocks; 3: Paleocene: red shales and conglomerates; 4-5: Upper Cretaceous-Paleocene: 4 — granites and diorites, 5 — flysch deposits; 6: Cretaceous: Cretaceous metamorphic rocks; 7: Faintly visible Paleozoic: metamorphic rocks; 8: extinct volcanoes; 9: active volcanoes

were summarized by Hantke and Parodi (1966), and Sauer (1971), and the data presented here are due just to these authors.

Samples were collected within internal part of caldera, approximately 50 m below its southern margin, during a short reconnaissance carried out by the members of Czechoslovak-Polish Expedition "Cotopaxi 72". Brittle

rocks of grey dacite, locally grading into more compact, silicified variety, are exposed on a steep slope, being covered with pyroclastic material and slope debris. Of these rocks, the unaltered one was examined more in detail.

Rock samples were collected by A. Paulo, who is the author of geological part and examined mafic and opaque minerals. General microscope investigations and X-ray and infrared spectroscopic studies of feldspars were carried out by A. Manecki, while detailed examination of plagioclasic glomerophyres are due to Z. Gurowska. Chemical analyses of rocks and minerals, recalculations and comparison with other data were carried out by W. Narębski, whereas trace element determinations — by N. Bakun-Czubarow and Z. Wichrowski.

METHODS OF INVESTIGATIONS

Examinations of rocks and minerals in question were carried out by means of microscopic, X-ray, infrared spectroscopic, chemical and emission spectrographic methods.

Microscopic observations were carried out both in thin and polished sections. Detailed study of glomerophytic plagioclase phenocrysts was made using universal stage. Refractive indices were determined in powdered specimens using immersion method. Birefringence was measured by means of Berek-Ehringhaus compensator.

X-ray studies were carried out using TUR-M-61 diffractometer by applying $\text{CoK}\alpha$ and $\text{CuK}\alpha$ radiations, time constant — 4, compensation — 15, GM counter scanning speed 15' per min, recording chart speed 600 mm per hour. Powdered samples were placed in glass cuvettes 20 mm in diameter. Quartz standards were used for calibration of reflections. Basal reflection pattern of biotite was recorded by examining samples oriented by sedimentation, whereby DRON-1 diffractometer with scintillation counter and $\text{CuK}\alpha$ radiation were used.

Infrared absorption investigations were carried out by means of infrared UR-10. C. Zeiss spectrophotometer in the range $400-1400 \text{ cm}^{-1}$. Samples were prepared as KBr disks.

Chemical analysis. Major elements were determined after fusing with soda and subsequent separation of silica by evaporation with HCl and of sesquioxides from divalent elements by precipitation with urotropine. Silica was estimated gravimetrically, while in the solutions thus obtained alumina, total iron, calcium and magnesium were determined by complexometric titration, whereas titanium, phosphorus and manganese using photocolorimetric methods (Narębski 1962). Ferrous iron was estimated by Jacob's procedure and titration with dichromate. Alkali metals were determined by flame photometry after decomposing the sample in $\text{HF} + \text{H}_2\text{SO}_4$ mixture. These solutions were also used for control estimations of Al, Fe, Ca and Mg. Because of low amount of the material separated, analyses of minerals were carried out in solutions obtained for alkali determination and using semi-micro complexometric and oxidimetric titrations with very diluted reagent solutions.

Trace element content was determined by spectrochemical method using DSF-13 grating spectrograph.

Table 1

GENERAL PETROGRAPHIC DESCRIPTION

Typical dacite of Quilotoa volcano represents a phorphyric rock displaying unoriented and locally fluidal structure (Phot. 1). It contains numerous plagioclase phenocrysts, up to 10 mm in size, and smaller porphyrocrysts of amphibole, biotite and, sporadically, quartz. Hypocrystalline groundmass is light grey in colour. It consists of isotropic glass matrix embedding numerous plagioclase microlites and low amounts of amphibole, biotite, apatite, pyroxene and opaque mineral grains.

As follows from X-ray data (Fig. 2), plagioclases of the groundmass display similar chemical composition as those of the phenocrysts, whereby a broadening of reflexions indicates more high-temperature character of the formers. Distinct increase of background in the low-angle range of the X-ray pattern is due to the presence of glass.

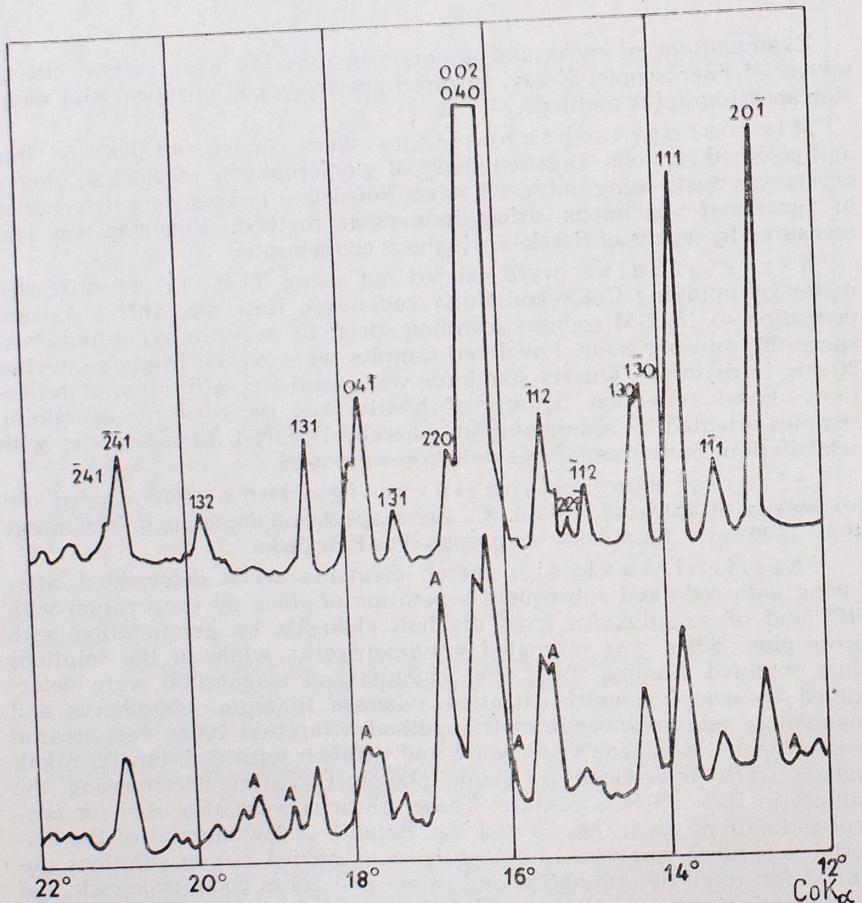


Fig. 2. X-ray diffractometer patterns of unaltered dacite:
a — plagioclase phenocrysts, b — groundmass, A — amphibole reflections

Chemical and normative mineral composition of dacite from Quilotoa

Component	Weight percents	Cation percents	Rittmann norms	Niggli parameters
SiO ₂	65.4	61.7	Quartz	18.0
TiO ₂	0.41	0.3	Sanidine	11.5
Al ₂ O ₃	14.5	16.1	Plagioclase	57.1
Fe ₂ O ₃	2.43	1.7		
FeO	1.72	1.4		
MnO	0.088	—	Clinopyroxene	9.8
MgO	2.22	3.1	Magnetite	2.2
CaO	3.88	4.0	Ilmenite	0.6
Na ₂ O	4.97	9.1	Apatite	0.8
K ₂ O	1.91	2.3		
P ₂ O ₅	0.36	0.3		
H ₂ O	2.05	—		
Total	99.94	100.—	Colour index	13.4
Trace elements (ppm)				
V	107	Sr	450	P — 66
Cr	22	Ba	440	A — 13
Ni	12	Rb	36	Q — 21
Co	12	Li	48	
Rb : Sr = 0.08				
$\text{Fe}_2\text{O}_3 / \text{FeO} = 1.42$				

Table 2

Chemical analyses and calculated average composition of plagioclase glomerophyres from unaltered (1) and silicified (2) dacite

Chemical composition		
Component	1	2
SiO ₂	(61.0)	(57.5)
Al ₂ O ₃	24.5	23.7
CaO	6.7	6.4
Na ₂ O	7.9	7.0
K ₂ O	0.4	0.6

Mineral composition		
Component	1	2
Anorthite	31	32
Albite	67	64
Orthoclase	2	4

Note: in brackets — calculated contents of oxides

Silicified variety of dacite occurs at Quilotoa in subordinate amounts.

This is a porphyryaceous rock, exhibiting unoriented structure and being cut by quartz veinlets. Phenocrysts are represented mainly by plagioclases (Phot. 2) and lower amounts of biotite and quartz. Plagioclase and quartz are strongly fractured and slightly corroded, whereby fissures are micatrized with fine-granular quartz. As follows from the results of microscope, X-ray and chemical examinations (Tab. 2), plagioclases of both varieties of dacite are very similar. The groundmass is holocrystalline and unevenly grained (Phot. 3). It consists essentially of quartz, accompanied by randomly dispersed small biotite flakes, plagioclase grains, opaque minerals and sporadic apatite crystals. Moreover, the rock in question contains coarser biotite-magnetite and biotite-quartz-magnetite aggregates resembling amphibole grains in shape.

DESCRIPTION OF MINERALS

Plagioclase

Plagioclases contained in dacite of Quilotoa belong to two generations. The younger is represented by very fine microlites of the groundmass whereas older phenocrysts are up to 10 mm in size. Plagioclase grains of both generations are euhedral and generally show no traces of post-magmatic or secondary alterations. Only some phenocrysts are fractured and exhibit mechanical defects. Magmatic corrosion phenomena are very scarce (Phot. 4).

Larger phenocrysts are represented by glomerophytic grains, resulted from intergrowths of several or even of a dozen of individual grains. The latter, in turn, consist of subindividuals displaying Albite and Pericline or, less frequently, triadic Albite-Carlsbad-Roc Tourné twinning. Plagioclase glomerophyre, presented in Fig. 3a, consists of 9 individuals A, B, C, D, E, F, G, H and I, of which A, B, C, D, and E, similarly as F, G, H, and I show parallel intergrowths. The orientation of subindividuals in both these groups can be presented as follows:

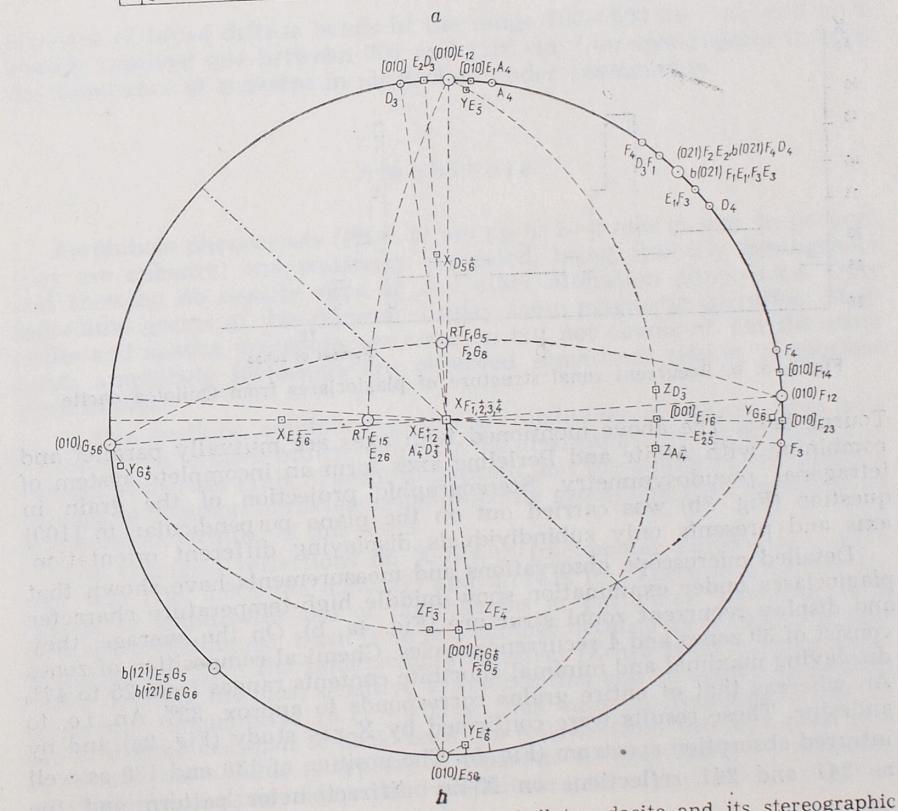
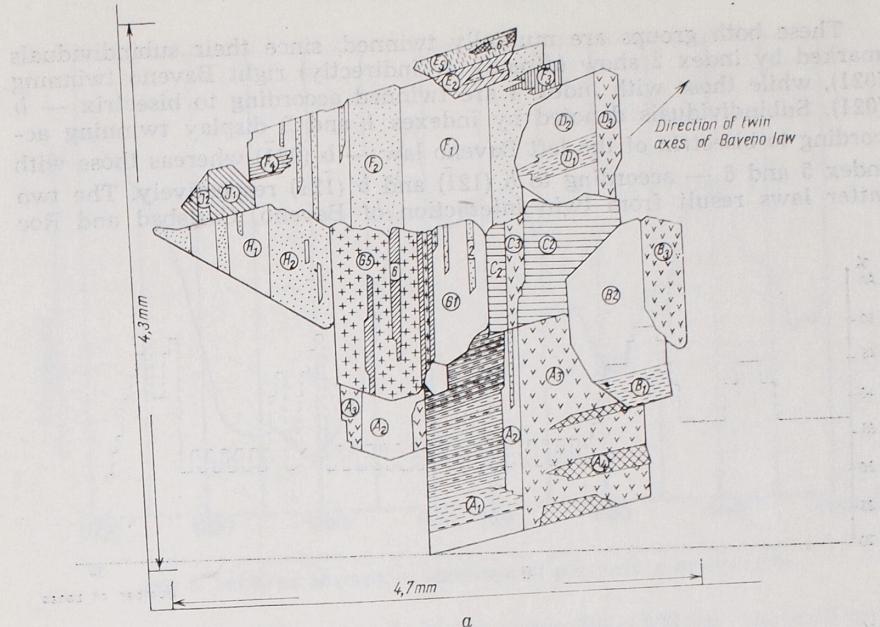
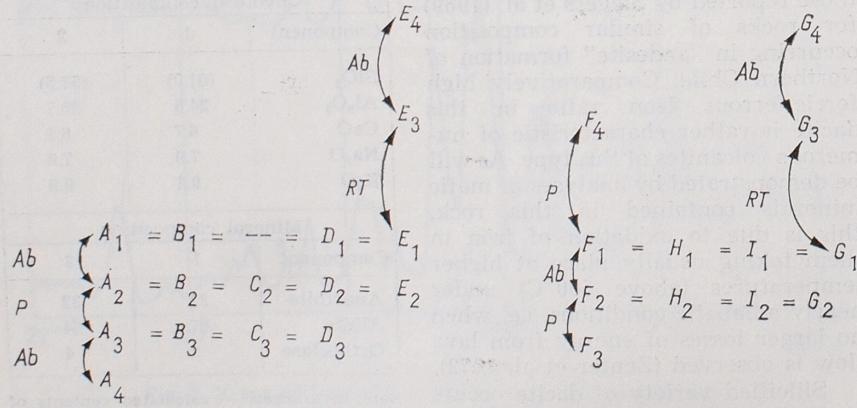


Fig. 3. a, b. Plagioclasic glomerophyre from Quilotoa dacite and its stereographic projection || [100]

These both groups are mutually twinned, since their subindividuals marked by index 2 show (directly or indirectly) right Baveno twinning — b (021), while those with index 4 are twinned according to bisectrix — b (021). Subindividuals denoted by indexes 1 and 3 display twinning according to bisectrix of the left Baveno law — b (021) whereas those with index 5 and 6 — according to b (121) and b (121) respectively. The two latter laws result from twin interaction of Baveno, Carlsbad and Roc

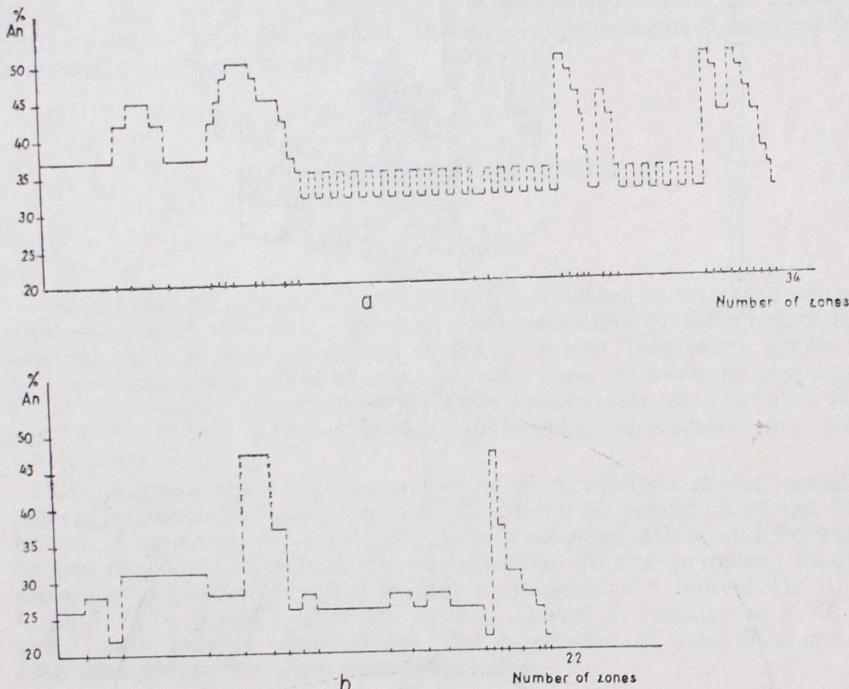


Fig. 4. a, b. Recurrent zonal structure of plagioclases from Quilotoa dacite

Tourné laws. The above mentioned twin axes are mutually parallel and combining with Albite and Pericline axes form an incomplete system of tetragonal pseudosymmetry. Stereographic projection of the grain in question (Fig. 3b) was carried out on the plane perpendicular to [100] axis and presents only subindividuals displaying different orientation.

Detailed microscope observations and measurements have shown that plagioclases under examination show middle high-temperature character and display recurrent zonal structure (Fig. 4a, b). On the average, they consist of 30 zones and 4 recurrence cycles. Chemical composition of zones displaying maximal and minimal anorthite contents ranges from 25 to 47% An whereas that of entire grains corresponds to approx. 33% An, i.e. to andesine. These results were confirmed by X-ray study (Fig. 2a) and by infrared absorption spectrum (Fig. 5). The position of 130 and 130 as well as 241 and 241 reflections on X-ray diffractometer pattern and the

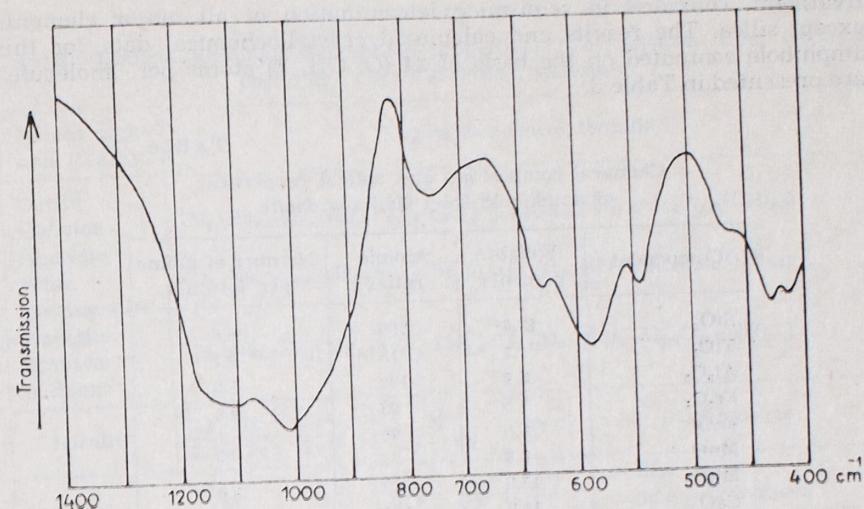


Fig. 5. Infrared absorption spectrum of plagioclase phenocrysts

presence of broad diffuse bands in the range 700—800 cm^{-1} as well as of weakly resolved one between 900 and 1200 cm^{-1} on spectrogram indicate the dominance of andesine in plagioclase under examination.

Amphibole

Amphibole phenocrysts (Phot. 5) are up to 2—5 mm in size. In general, they are euhedral and positively elongated, being optically homogenous and showing no opaque rims or any other alteration phenomena. Only individual grains of this mineral display some magmatic corrosion. Magnetite and apatite inclusions are common but not abundant. On the other hand, amphibole inclusions are observed sometimes within plagioclase phenocrysts.

In thin sections, amphibole grains are distinctly pleochroic from pale yellow-green to olive-brown, whereby the absorption scheme is $\beta \geqslant \gamma > \alpha$. Optical properties (Tab. 3) seem to indicate that the amphibole in question belongs to common hornblende-lamprobolite group and may represent an intermediate member of this series.

The strongest reflections on X-ray diffractometer pattern are: 3.115 (10), 8.42 (10), 2.801 (8), 3.273 (7) and 2.714 Å (6). These d_{hkl} values are typical of amphiboles and of hornblendes in particular. However, it is difficult to distinguish them from one another because quite different substitutions can give the same structural effect (Ernst 1968). Lattice parameter b , being the most sensitive to composition and computed from $\text{O}_\text{K}\text{O}$ reflections, amounts to 18.11 ± 0.03 Å. This value corresponds rather to calcic amphiboles than to sodic ones. As follows from the data presented by Ernst, this b value is typical of synthetic Al-poor $\text{Mg}-\text{Fe}^{2+}$ members. Chemical analysis of separated amphibole grains, purified by magnetic

Table 4

Crystalllochemical formulae and optical properties of hornblendes from Quilotoa dacite and from Carpathian andesites

treatment, consisted in semi-microdetermination of all major elements except silica. The results and calculated crystallochemical data for this amphibole computed on the basis of 24 (O, OH, F) atoms per "molecule" are presented in Table 3.

Table 3

Chemical composition and optical properties of amphibole from Quilotoa dacite

Component	Weight percents	Atomic ratios	Number of atoms per formula
SiO ₂	45.0*	750	6.6
TiO ₂	1.2	15	0.1
Al ₂ O ₃	8.8	172	1.5
Fe ₂ O ₃	7.5	93	0.8
FeO	6.8	95	
MnO	0.3	4	0.9
MgO	13.8	342	3.0
CaO	11.0	196	1.7
Na ₂ O	1.4	46	0.4
K ₂ O	0.9	20	0.2
$\frac{\text{Mg} \cdot 100}{\text{Mg} + \text{Fe}} = 65$		$\frac{\text{Fe}_2\text{O}_3}{\text{FeO}} = 1.13$	

Refractive indices: $n_{\gamma} = 1.690 \pm 0.002$
 $n_a = 1.658 \pm 0.002$

$z/\gamma = 12-15^\circ$

Pleochroism: γ — olive brown
 a — pale yellow green

* deduced by comparison with very similar hornblende C 2017 from Alboroto quartz latite (Larsen et al. 1937)

As follows from these data, the most peculiar chemical properties of this amphibole are: relatively high degree of oxidation of iron and its distinctly magnesian character, rather contrasting with dacitic nature of its parent rock.

When compared with numerous available chemical analyses of amphiboles from metamorphic and plutonic rocks, there are very few data on the composition of these minerals from volcanites. In general, amphiboles occurring in them, because of high ferric:ferrous iron ration are called oxyhornblendes or lamprobolites (Deer et al. 1963). However, the vast majority of analyses of these amphiboles displays distinctly higher iron oxidation as in the case of this mineral from Quilotoa dacite and, consequently, different optical properties, though all these hornblendes, even if occurring in acid rocks, are rather magnesian in character too.

Hornblendes, displaying similar $\text{Fe}^{3+} : \text{Fe}^{2+}$ ratios, were reported to occur in andesites of the Pieniny Mts. in the Polish Carpathians (Małkowski 1921) and of the Transcarpathian region (Piekun 1951) (Tab. 4). It can be concluded that the amphiboles under consideration represent an

Parent rock and locality	Crystalllochemical formula				
	$\text{Ca}_{1.7}\text{Na}_{0.4}\text{K}_{0.2}(\text{Mg}_{3.0}\text{Fe}_{0.9}^{2+}\text{Fe}_{0.8}^{3+}\text{Ti}_{0.1}\text{Al}_{0.1})[\text{Si}_{6.6}\text{Al}_{1.4}\text{O}_{22.0}(\text{OH})_{2.0}]$				
Dacite Quilotoa	$\text{Ca}_{2.1}\text{Na}_{0.6}\text{K}_{0.2}(\text{Mg}_{3.1}\text{Fe}_{0.7}^{2+}\text{Fe}_{0.7}^{3+}\text{Ti}_{0.2}\text{Al}_{0.4})[\text{Si}_{6.1}\text{Al}_{1.9}\text{O}_{22.6}(\text{OH})_{1.1}]$				
Andesite Wżar, Pieniny Mts.	$\text{Ca}_{1.9}\text{Na}_{0.5}\text{K}_{0.1}(\text{Mg}_{2.9}\text{Fe}_{0.8}^{2+}\text{Fe}_{0.8}^{3+}\text{Ti}_{0.4}\text{Al}_{0.3})[\text{Si}_{6.0}\text{Al}_{2.0}\text{O}_{22.6}(\text{OH})_{1.1}]$				
Locality	Pleochroisme				
	$\frac{\text{Mg} \cdot 100}{\text{Mg} + \text{Fe}}$	$\frac{\text{Fe}^{3+}}{\text{Fe}^{2+}}$	n_{γ}	z/γ	
Quilotoa	65	1.1	1.69 0.03	$12-15^\circ$	γ — olive brown a — pale yellow-green
Wżar	70	1.1	no data	12°	γ — greenish yellow a — yellow brown
Transcar- pathians	64	1.0	1.69 0.02	15°	γ — greenish β — yellowish brown a — yellow

intermediate stage of oxidation of common hornblende and, because of some specific physical properties, may be provisionally called semi-oxy-hornblendes.

Biotite

Biotite phenocrysts are up to 5 mm in size. This mineral forms euhedral, pseudohexagonal, optically homogeneous plates containing individual apatite and ore mineral inclusions. Biotite is megascopically black and in thin section displays distinct pleochroism from pale yellowish-green to dark brown. Its optical properties are given in Table 5. Refractive indices are characteristic rather of iron-rich members. However, it was not possible to apply Winchell's (1951) diagram for interpreting its composition since it does not take into account strong influence of Fe^{3+} and Ti contents on refractive index which is almost twice stronger than that of Fe^{2+} (Heinrich 1946).

The unit cell parameters calculated from X-ray powder data ($a_0 = 5.26$, $b_0 = 9.25$, and $c \cdot \sin \beta = 10.06 \text{ \AA}$) correspond to typical biotites but do not allow to interpret its composition. However, as it was found by Brown (1955) and other authors, the intensities ratios of 001 reflections in micas are sensitive to isomorphous substitutions and general amounts of atoms in their octahedral positions. In the biotite under examination these ratios were found to be as follows:

$$\frac{I_{004}}{I_{005}} = 0.554 \text{ and } \frac{I_{004} + I_{006}}{I_{005}} = 1.07-1.08$$

According to Gower's diagram (1957) the former indicates that only 26% of octahedral sites is occupied by Fe and Ti but this value should be considered as approximate since Cu radiation instead of Fe one was used in this experiment. According to Franzini and Schiaffino (1965) the value of

this is particularly similar to those reported by Zenter et al. (1972) to occur in Neogene andesite-dacite lava flows of the Zangezur ridge in the Little Caucasus (Tab. 6). Crystalliochemical formula of the biotite from Quilotoa dacite was calculated on the basis of 2 (K, Na, Ca) atoms per "molecule" and subsequent balancing of positive and negative charges.

Table 5

Chemical composition and optical properties of biotite from Quilotoa dacite

Component	Weight percents	Atomic proportions
SiO ₂	37.7*	627
TiO ₂	2.8	35
Al ₂ O ₃	13.8	270
Fe ₂ O ₃	8.9	112
FeO	5.5	77
MnO	0.2	3
MgO	14.7	365
CaO	1.4	25
Na ₂ O	1.3	42
K ₂ O	7.4	158

$$\frac{\text{Mg} \cdot 100}{\text{Mg} + \text{Fe}} = 66 \quad \frac{\text{Fe}_2\text{O}_3}{\text{FeO}} = 1.44$$

Refractive indices: $n\gamma = n\beta = 1.660 \pm 0.002$

$$na \approx 1.610$$

Optical axial angle $2V = 5-10^\circ$

Pleochroism: γ — dark brown

a — pale yellowish green

* calculated content

the latter ratio correspond to 1.8 ($\text{Fe}^{2+} + \text{Fe}^{3+} + \text{Mn}$) atoms and 3.9 ($\text{Mg} +$

$+ \text{Al} + \frac{1}{2}\text{Li} + 2\text{Ti}$) atoms per 6 octahedral positions. All these values are fairly concordant with those computed from chemical analyses (Tab. 6). It should be emphasized that the deficiency of ions in octahedral sites is also typical of biotites, contrary to phlogopite members.

By comparing the results of X-ray and optical examinations it is concluded that relatively high refractive index of the biotite in question is most probably due to high amount of ferric iron in it.

Chemical analysis of biotite phenocrysts from unaltered Quilotoa dacite (Tab. 5) has shown that, as regards high ferric: ferrous iron ratio and magnesian nature, the biotite in question has much in common with paragenetic hornblende. It should also be noted that there are very few analytical data on biotites from extrusive rocks (Larsen et al. 1937, Zenter et al. 1972). By comparing chemical and physical properties of various biotites from volcanic rocks it was found that the mineral under examina-

Table 6

Crystalliochemistry and refractive indices of biotites from volcanic rocks

Structural site	Ions	Locality, rock and sample	
		Quilotoa dacite CQ 1	Zangezur ridge (Little Caucasus) andesite-dacite
Interlayer ions	K ⁺	1.4	1.6
	Na ⁺	0.4	0.3
	Ca ²⁺	0.2	0.1
Octahedral positions	Mg ²⁺	3.4	3.6
	Fe ²⁺ + Mn ²⁺	0.7	0.8
	Fe ³⁺	1.0	0.9
	Ti ⁴⁺	0.3	0.5
Tetrahedral positions	Al ³⁺	—	—
	Si ⁴⁺	5.6*)	5.7
Anions	Al ³⁺	2.4	2.3
	O ²⁻ (OH), F	20.0*) 4.0*)	21.7 2.3
$\frac{\text{Fe}_2\text{O}_3}{\text{FeO}}$		1.44	1.1
	$\frac{\text{Mg} \cdot 100}{\text{Mg} + \text{Fe}}$	66	68
Refractive indices	$n\gamma$	1.66	1.645 — 1.660
	na	1.61	1.620

* calculated

As follows from these data, the composition of biotites of extrusive rocks do not fit the fields of their intrusive equivalents (Deer et al. 1963). The minerals in question are distinctly richer in Mg and Ti and display considerably higher degree of oxidation of Fe. This phenomenon is unquestionably due to different conditions of their crystallization when compared with those of the matrix.

Biotites of silicified dacite, occurring both as phenocrysts and in the groundmass, differ only slightly in optical properties and, consequently, in chemical composition, from those examined in detail. In thin section they are deeper green in colour and display slightly lower refractive indices: $n\gamma = 1.645$ for phenocrysts and $n\gamma = 1.64$ for biotites from the groundmass. This would indicate a little higher Mg content and/or lower degree of oxidation of iron in biotites from silicified dacite.

Quartz

Quartz grains occur in subordinate amounts only within phenocrysts, sometimes glomerophytic, being developed in fractured anhedral forms (Phot. 6). No quartz grains were found to occur in the groundmass of unaltered dacite. On the opposite, the groundmass of silicified variety consists mostly of quartz.

Accessory minerals

Accessory mineral assemblage consists of apatite, pyroxene and opaque minerals.

Apatite grains are euhedral in shape and occur both as inclusions within feldspars, amphibole and biotite and as dispersed phase in the groundmass. Small, anhedral pyroxene grains or their aggregates were found but sporadically. Their optical properties are close to those of enstatite.

Magnetite is the main opaque mineral being accompanied by ilmenite and traces of chalcopyrite and haematite. Total content of ores does not exceed 1%. Their grains occur in the groundmass and within amphiboles, being up to 1 mm in size. Magnetite forms isometric, hipidiomorphous and anhedral grains, generally containing no inclusions. Only sporadically there occur microscopic inclusions of chalcopyrite, ilmenite and, at the margins and fractures, of haematite. No subtle exsolution structures, typical of titanomagnetite, were observed when examined using immersion technique and high power objectives.

CONCLUSIONS

As follows from this study, the rock in question is a typical dacite, belonging to calc-alkali series of the northern Andes (Katsui 1972), in accordance with earlier general field and petrographic data.

Plagioclases of glomerophytic phenocrysts and occurring in the groundmass are, on the average, andesine in composition. Intermediate structural state of the formers and recurrent zonal development indicates their sub-volcanic origin. More high-temperature (less ordered) character of plagioclases embedded in partly glassy groundmass suggests violent cooling of magma under superficial conditions. This conclusion is confirmed by relatively high degree of oxidation of iron in both mafic minerals: amphibole and biotite, in which $\text{Fe}^{3+} : \text{Fe}^{2+}$ ratio is approximately 1:1. This fact seems to be rather typical of andesitic and dacitic lavas solidified at the surface which contain phenocrysts formed at greater depths.

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Zofia GUMOWSKA-WDOWIAK, Andrzej MANECKI,
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BADANIA MINERALOGICZNO-CHEMICZNE DACYTU Z WULKANU QUILOTOA W EKWADORZE

Streszczenie

Produkty wulkanu Quilotoa, którego ostatnie erupcje notowano w XVIII wieku, nie były dotąd szczegółowo badane. Główną odmianą skał wylewnych, z których jest zbudowany stożek wulkanu, jest dacyt o strukturze porfirowej, z licznymi, dużymi fenokryształami plagioklazów, amfiboli, biotytu i sporadycznie kwarcu. Skład chemiczny tej skały podano w tabeli 1. Z reguły nie obserwuje się ani w tle skalnym, ani w fenokryształach śladów przeobrażeń pod wpływem procesów pomagmowych lub wietrzeniowych, co ułatwia analizę poszczególnych minerałów skałowych. Niemniej lokalnie stwierdzono objawy intensywnej sylifikacji tła skalnego i zanik amfiboli.

Plagioklazy fenokryształów i tła mają przeważnie skład andezynu, przy wahańach 25—47% An. Fenokryształy mają zwykle charakter glomerowanych, których budowa jest szczegółowo opisana w pracy. Pośredni stan strukturalny i rekurencyjna budowa pasowa wskazują na ich subwulkaniczną genezę. Bardziej wysokotemperaturowy charakter plagioklazów zawartych w częściowo szklistej masie podstawowej sugeruje gwałtowne ochłodzenie magmy w warunkach powierzchniowych.

Amfibol wyróżnia się wysokim stopniem utlenienia żelaza, $\text{Fe}^{3+} : \text{Fe}^{2+} \approx 0.9$, i dużą w porównaniu ze skałą macierzystą zawartością Mg. Skład jego i własności fizyczne (tab. 3) odpowiadają członom przejściowym szeregu hornblendy — oksyhornblendy. Biotyt także cechuje się wysokim stężeniem Fe³⁺:Fe²⁺ ≈ 1.4, a jego skład znacznie odbiega od składu biotytów z intruzywnych odpowiedników dacytu. Jak wynika z przeprowadzonych porównań (tab. 4 i 6) i studiów szerszego, nie dyskutowanego w pracy materialu analitycznego, zjawisko to wydaje się być typowe dla law andezytowych i dacytowych, które zakrzepły na powierzchni i zawierają fenokryształów wczesnej i w odmiennych warunkach utworzonych mineralów.

OBJAŚNIENIA FIGUR

Fig. 1. Położenie wulkanu Quilotoa. Geologia na podstawie Mapa Geologico del Ecuador (1969)

1–2: Pliocen–czwartorzęd: 1 — deluwia, moreny, osady rzeczne i jeziorne, 2 — skały wulkaniczne; 3: Paleocen: czerwone łupki i ziepience; 4–5: Góra kreda — paleocen: granity i dioryty, 6 — flisz; 6: Kreda: skały wulkaniczne z wkladkami osadowymi; 7: Paleozoik?: skały metamorficzne; 8: wulkany wygasłe; 9: wulkany czynne

Fig. 2. Difraktogramy rentgenowskie niezmienionego dacytu:
a — fenokryształy plagioklazów, b — tło skalne. A — refleksy amfibolu

Fig. 3. a, b. Glomerofir plagioklazowy z dacytu Quilotoa i jego rzut stereograficzny || [100]

Fig. 4. a, b. Rekurencyjna budowa pasowa plagioklazów dacytu Quilotoa

Fig. 5. Spektrogram absorpcji w podczerwieni fenokryształów plagioklazowych

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МИНЕРАЛОГО-ХИМИЧЕСКИЕ ИССЛЕДОВАНИЯ ДАЦИТА ВУЛКАНА КИЛОТОА В ЭКВАДОРЕ

Резюме

Продукты деятельности вулкана Килотоа, последние извержения которого проявились в XVIII веке, до сих пор детально не исследованы. Среди эфузивных пород, слагающих вулkaniczny konus, основную роль играет дацит с порfirowej strukturą, с многочисленными крупными fenokristallami plagioklazów, amfibolów, biotita i spodumenu. Химический состав этой породы приведен в таблице 1. Как правило, ни в породообразующей массе, ни в fenokristalлах нет признаков воздействия постмагматических процессов и выветривания, что значительно облегчает анализ отдельных породообразующих минералов. Однако, местами наблюдаются интенсивные проявления силицификации породообразующей массы и распад amfibolów.

Плагиоклазы в fenokristalлах и в породообразующей массе характеризуются преимущественно андезиновым составом с колебанием 25—47% An. Fenokristalły thường имеют вид гломерофиров, строение которых детально описано в работе. Промежуточное структурное состоя-

ние и зональное строение свидетельствуют об их субвулkaniczkim происхождении. Более высокотемпературный характер plagioklazów и присутствие стекла в породообразующей массе, указывают на резкое охлаждение magmy на поверхности.

Амфибол отличается высокой степенью окисления железа (отношение $\text{Fe}^{3+} : \text{Fe}^{2+} \approx 0.9$) и высоким содержанием Mg, в сравнении с материнской породой. По своему составу и физическим свойствам (табл. 3) он соответствует промежуточным членам ряда роговая обманка — базальтическая роговая обманка. Биотит также характеризуется высоким отношением $\text{Fe}^{3+} : \text{Fe}^{2+} \approx 1.4$ и по своему составу значительно отличается от состава биотитов в интрузионных аналогах дацита. Из проведенных сопоставлений (табл. 4 и 6) и более обширного аналитического материала следует, что это явление характерно для андезитовых и дацитовых лав, застывших на поверхности и содержащих фенокристаллы минералов, которые образовались раньше и в других условиях.

ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Схематическая карта района вулкана Килотоа. Геология по Геологической карте Эквадора (1969)

1–2: плиоцен–четвертичные породы: 1 — делювиальные, речные, озерные отложения, морены, 2 — вулканогенные породы; 3 — палеоцен: красные сланцы и конгломераты, 4–5 — верхний мел—палеоцен: 4 — граниты и диориты, 5 — флиш, 6 — мел: вулканогенные породы с прослоями осадочных отложений, 7 — палеозой?: метаморфические породы, 8 — потухшие вулканы, 9 — действующие вулканы

Фиг. 2. Рентгеновские дифрактограммы неизмененного дацита:

a — фенокристаллы plagioklazów, b — породообразующая масса, A — рефлексы амфибola

Фиг. 3. a, b. Плагиоклазовый гломерофир из дацита вулкана Килотоа и его стереографическая проекция || [100]

Фиг. 4. a, b. Рекуррентное зональное строение plagioklazów w dacie wulkanu Kilototoa

Фиг. 5. ИК-спектрограмма поглощения фенокристаллов plagioklaza

PLATE I, (PLANSZA I, ТАБЛИЦА I)

- Phot. 1. Plagioclase phenocryst displaying zonal structure. Unaltered dacite. Crossed nicols. $\times 40$
 Fenokryształ plagioklazu o budowie zonalnej. Niezmieniony dacyt. Nikole skrzyżowane. $\times 40$
 Фенокристалл плагиоклаза с зональным строением. Неизмененный дакит. Николи скрещенные. $\times 40$
- Phot. 2. Fractured plagioclase phenocryst in holocrystalline groundmass. Silicified dacite. Crossed nicols. $\times 40$
 Spękany fenokryształ plagioklazu w holokrystalicznym tle skalnym. Zsylifikowany dacyt. Nikole skrzyżowane. $\times 40$
 Трещиноватый фенокристалл плагиоклаза в голокристаллической породообразующей массе. Силифицированный дакит. Николи скрещенные. $\times 40$



Phot. 1

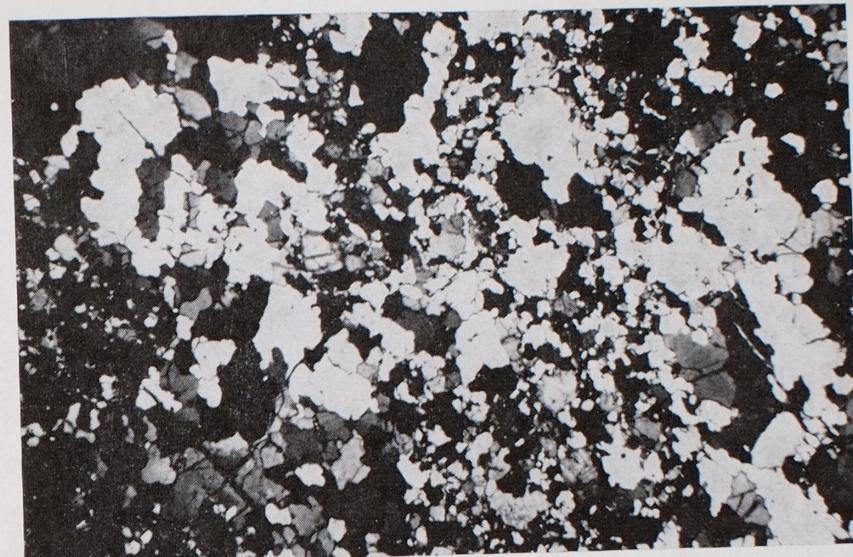


Phot. 2

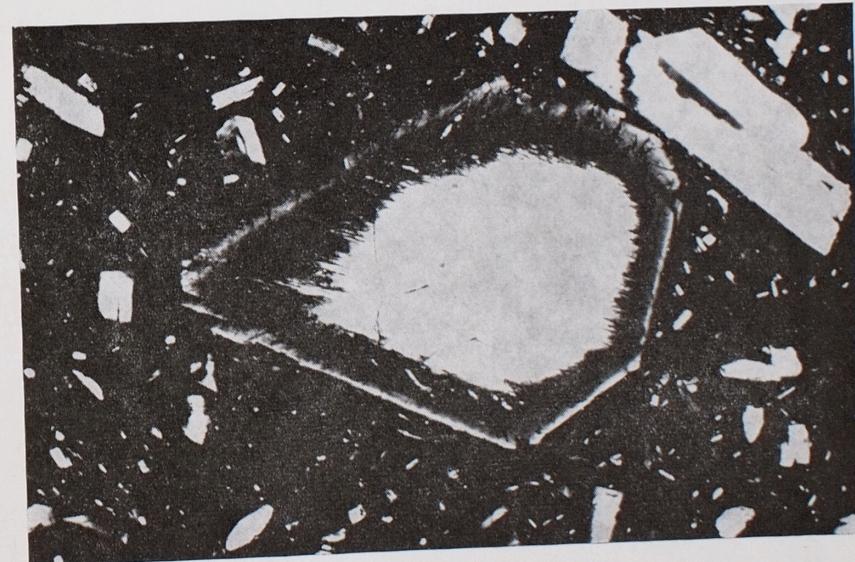
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PLATE II (PLANSZA II, ТАБЛИЦА II)

- Phot. 3. Holocrystalline groundmass consisting essentially of quartz with subordinate plagioclases and biotite. Silicified dacite. Crossed nicols. $\times 40$
 Holokrystaliczne tło skalne, złożone głównie z kwarcu z domieszką plagioklazu i biotytu. Zyslikowany dacyt. Nikole skrzyżowane. $\times 40$
 Голокристаллическая породообразующая масса, сложенная, в основном, кварцем с примесью плагиоклаза и биотита. Силифицированный дакит. Николи скрещенные. $\times 40$
- Phot. 4. Plagioclase phenocryst with margins showing but slight magmatic corrosion and diffused zonal structure. Unaltered dacite. Crossed nicols. $\times 100$
 Fenokryształ plagioklazu o dyfuzyjnej budowie zonalnej, wykazujący słabe oznaki korozji magmowej. Niezmieniony dacyt. Nikole skrzyżowane. $\times 100$
 Фенокристалл плагиоклаза с диффузионным зональным строением, проявляющий слабые признаки магматической коррозии. Неизмененный дакит. Николи скрещенные. $\times 100$



Phot. 3

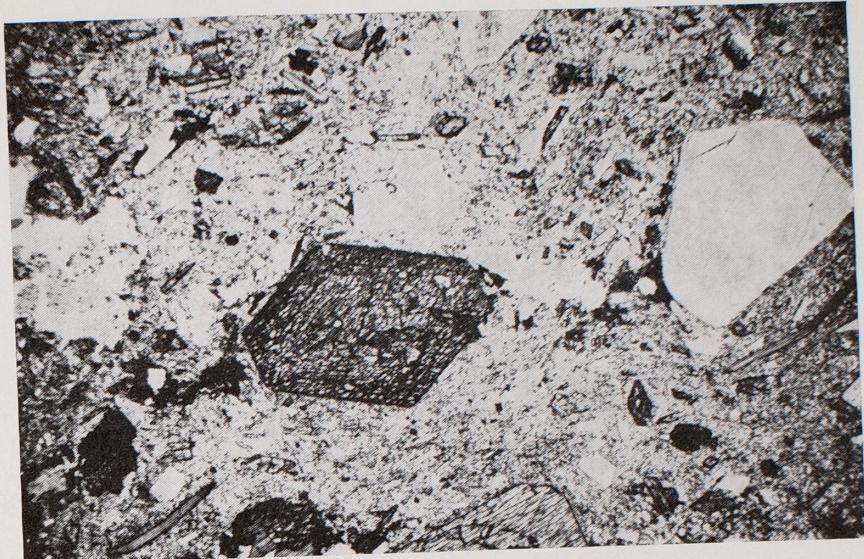


Phot. 4

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PLATE III (PLANSZA III, ТАБЛИЦА III)

- Phot. 5. Euhedral amphibole phenocryst. Unaltered dacite. No analyzer. $\times 40$
 Idiomorficzny prakryształ amfibolu. Niezmieniony dacyt. Bez analizatora.
 $\times 40$
 Идиоморфный фенокристалл амфиболя. Неизмененный дацит. Без анализатора. $\times 40$
- Phot. 6. Quartz grains displaying cracks and mechanical distortions embedded in hypocrystalline groundmass. Unaltered dacite. Crossed nicols. $\times 40$
 Prakryształy kwaretu wykazujące spękania i uszkodzenia mechaniczne otoczone hypokrystalicznym tłem skalnym. Niezmieniony dacyt. Nikole skrzyżowane. $\times 40$
 Фенокристаллы кварца с механическими трещинами и повреждениями, окруженные скрытокристаллической породообразующей массой. Неизмененный дацит. Николи скрещенные. $\times 40$



Phot. 5



Phot. 6

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