VIII. *Petrographical Notes on the Products of the Eruptions of May*, 1902, *at the Soufrière in St. Vincent.*

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[PLATES 26–27.]

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THE rocks collected during our visit to the West Indies, in 1902, included specimens of the ashes, ejected blocks, &c., cast out by the eruptions of May, and of such lavas, belonging to previous eruptions of the Soufrière and the extinct volcanoes of the south part of the island, as were in good preservation and easily accessible from our line of route. We are also indebted to Mr. MACDONALD, Mr. DARRELL, and other inhabitants of St. Vincent, and to Sir DANIEL MORRIS and the officers of the Imperial Agricultural Department for the West Indies acting under him (more particularly to Mr. HENRY POWELL, Curator of the Botanic Station, St. Vincent), for specimens sent us after our departure for England. Professor LACROIX has very kindly furnished us with specimens of the older rocks of St. Vincent, which he collected during his visit, and of an ejected block containing cordierite, which he found on the edge of the crater in January, 1903.

The Ejecta of the Eruptions of May, 1902.

Among the materials ejected during May, 1902, there were not only ashes and sand, with volcanic bombs which were derived from the active magma within the crater, but also large quantities of the older rocks of the mountain which had been torn from the walls of the crater and were mingled with the new ashes. The difficulties of collecting from the deposits of hot sand laid down by the avalanche were considerable, as the principal stream sections of the new materials were too hot and too unstable to be approached. Fragments lying on the surface of the avalanche evidently belonged to the most recent stages of the volcanic activity. The deeper parts of the new deposit were usually inaccessible, but where the secondary steam explosions had built small cones on the rivulets it was easy to collect blocks that had been projected from the interior of the beds of hot ash. These form the major part of the ejected blocks of 1902 contained in our collections.

The ashes and sand gathered in Barbados, Kingstown, Chateaubelair, and other localities during May, 1902, and at subsequent times can, of course, be assigned at once to their respective eruptions, and, with the large semi-vitreous bombs scattered over the surface of cultivated grounds on both the windward and leeward sides of the island, may be taken as satisfactory evidence of the nature of the new magma within the crater. It seems clear, however, that some of the previous eruptions produced bombs not essentially differing from those of 1902, and these can only be distinguished by the traces of decomposition they sometimes show, or by the positions in which they are found.

Volcanic Sand and Dust.

As stated in the first part of this report, fine sand and dust formed the greater part of the hot avalanche, and were the only materials transported to a considerable distance. The Barbados dust has been described by several writers,* and is now well known to most of those who are interested in volcanoes. We have also examined specimens from Kingstown, Calliaqua, and other localities in the south part of St. Vincent, and from Wallibu, Georgetown, and the southern flanks of the Soufrière. These have a great similarity in general character, though they may not be of

* Flett, John S., "Note on a Preliminary Examination of the Dust that fell in Barbados after the Eruption in St. Vincent" 'Quart. Jour. Geol. Soc.,' vol. 58, p. 368 (1902). Falconer, John D., "Volcanic Dust from the West Indies," 'Nature,' vol. 66, p. 132 (1902). Porter, T. C., "Volcanic Dust from the West Indies," 'Nature,' vol. 66, p. 131 (1902). Klein, C., "Ueber die am 7. Mai 1902 vom Vulkan Soufrière auf St. Vincent ausgeworfene vulkanische Asche," 'Sitzb. Berlin. Akad.,' 1902, p. 992. Diller, J. S., "Volcanic Rocks of Martinique and St. Vincent," 'National Geographic Magazine,' vol. XIII., p. 285 (1902). Smith, Longfield, "Volcanic Eruptions in the West Indies," 'West Indian Bulletin,' vol. III., p. 271 (1902).

absolutely identical origin. Those that were carried to some distance were emitted from the crater during the height of the paroxysm of the afternoon of May 7th. Those gathered near the Soufrière may have been mixed with materials emitted at a subsequent time, either during the first or second eruption (May 7th and 18th, 1902). Sand from the Soufrière contains, as might be expected, a larger number of fine lapilli; the Barbados dust consists mainly of single crystals, or fragments of crystals, with small grains of more or less vitreous character. But the same ingredients occur in all the dusts in very much the same proportions. There are slight differences in the relative abundance of the component minerals which can be traced very clearly in the chemical analyses of samples from different localities (see p. 311), but these differences are not great.

Sir Daniel Morris has sent us samples of the Barbados dust-fall of May 7th and 8th, 1902, collected at different hours. These show that the material which fell during the later hours was finer grained and rather more pale coloured than that which fell earlier. It is to be expected that as the dust cloud was at a great height the coarser and heavier minerals would first subside. Fragments of broken felspar crystals and of glass are distinctly more common in the later part of the dust-fall and account for its paler colour.

The most striking feature of these dusts is the large proportion of crystalline minerals they contain, and this led us to bring forward the hypothesis that the magma, "or at least the upper part of it which gave rise to the great black cloud, was to a large extent crystallised, contained comparatively little fluid matter, and was accordingly near the temperature of consolidation, or may even in part have solidified already" (Report, Part I., p. 523). This hypothesis received the most unexpected confirmation at a slightly later period when it was announced that the magma in Pelée was being extruded as a solid vertical column or obelisk which attained at one time a height of 900 feet.

Of the minerals of these dusts the most abundant is plagioclase felspar. Its crystals are often broken, but the smaller may be perfect, especially when they have an adherent pellicle of glass. Optical and specific gravity tests, especially the extinctions of cleavage flakes, show that they range from labradorite to basic bytownite (An 50 per cent. to An 84 per cent.). They are full of glass enclosures, often of regular shape, with fixed bubbles. Zonal structure is very common in them; in fact, they present similar characters to those of the phenocrysts in the bombs, to be described later. The commonest faces are 001, 010, 110, $1\bar{1}0$, $10\bar{1}$, $20\bar{1}$. The augite is pale brownish-green, very slightly pleochroic in thick grains. Good crystals are rare and show 100, 010, 110, 111. The extinction angle $Z : c$ is about 45 degrees. Hypersthene is always present in considerable amount and often its crystals are very perfect. Their faces are 100, 010, 110, and probably 111. Frequently the crystals are broken across, along planes of fracture perpendicular to the prism axis; they then show squarish octagonal outlines with the pinacoids larger than the prism faces.

The pleochroism is strong and is of the usual character. The optic axial angle (negative) is large (2E over 120 degrees, 2V over 60 degrees). Glass enclosures and grains of magnetite are common in the pyroxenes. Olivine occurs in small grains; perfect crystals are not found, but only splinters which often show a conchoidal fracture. It is colourless or pale brown (perhaps from oxidation in presence of hydrochloric acid gas and air), and its presence is easily confirmed by treating the powder with strong cold acid when it is covered with a film of gelatinous silica, even before the basic felspars are attacked. Hornblende, as reported by FALCONER and KLEIN,* is found occasionally. So far as we have seen it is always brownish-green and occurs only in irregular fragments. Most of the iron oxide is titaniferous magnetite in small rounded grains; pyrites, apatite, and possibly zircon are also present.

Non-crystalline or glassy material occurs in all the dusts, though less abundant than the crystals. It is partly in minute fragments, partly in thin films surrounding the crystals, and partly in the form of small, rounded vesicular lapilli. The steam cavities which abound in it are empty. Between crossed nicols some of these lapilli contain small crystals evidently belonging to the second generation, showing that crystallisation was preceding in this portion of the rock as it ascended in the crater. Much of the glass, however, is perfectly vitreous, and this portion was probably liquid at the moment of projection. Occasionally the glass has been drawn out into threads while still in a viscous state. The lapilli, however, are not highly pumiceous and the splinters do not have those arc-shaped, concave outlines which are found in shattered pumiceous glasses (*e.g.*, those emitted by Krakatoa in 1883).†

In the first part of this report we have stated our belief that the magma of the Soufrière, though in large part crystallised, was not entirely solid at the moment when it was shattered into dust and the great black cloud emerged from the crater. Professor LACROIX‡ has found that the later *nuées ardentes* or Peléean clouds of Montagne Pelée were produced by the disruption of a solidified magma. But the facts of the eruption of May 7th in St. Vincent, as given by us in the first part of this report, are sufficient to prove that the magma was a semiliquid mass as it ascended in the crater. The crater lake was at its usual level at 11 a.m. on Tuesday (May 7th); at midday on Wednesday the lake was discharged by overflowing the southern lip of the crater. Thus in 24 hours it had risen about 1000 feet, or 40 feet per hour. Yet, according to the evidence of all who knew it before and have seen it since, the interior of the crater was not greatly modified and many of its old features were recognisable after the eruption. Only a plastic, semiliquid mass could have risen so rapidly and could have been ejected with so little disturbance and so little permanent alteration of the topography of the interior of the crater. The great rock column

* *Loc. cit.*

† SYMONS, G. J., 'The Eruption of Krakatoa and subsequent Phenomena,' Plate 4 (1888).

‡ 'Montagne Pelée,' pp. 206, 208, 383.

which rose from the crater of Pelée in the latter part of 1902 proves that the magma, once solid, is not highly explosive.

The Bombs.

The slaggy black bombs, which were abundant especially on the surface of the new ash deposits in the valleys of the Wallibu and the Rabaka Dry River, all consist of hyalopilitic hypersthene andesite usually containing accessory olivine and sometimes hornblende. They are highly vesicular throughout (Plate 26, fig. 4). A description of their general appearance has been given in the first part of this report. The felspars are the most conspicuous minerals in the hand specimens, some of the larger phenocrysts being more than a third of an inch in length. The pyroxene and olivine formed smaller crystals easily visible without the aid of a lens. The olivine is yellow-green in colour; the matrix is dark grey to black.

The abundant porphyritic felspars are always much zoned, the centres consisting of irregular highly corroded remnants of very basic plagioclase. Around these are successive deposits of felspar varying in composition, more basic and more acid bands often alternating repeatedly. The margins are more acid and more uniform in composition, and are often bounded by good crystalline faces similar to those found in the felspars of the dusts. Albite and Carlsbad twinning are almost universally present, and pericline twinning very frequently. Baveno twins occur, but are rare. Glass cavities with bubbles abound in the felspars, and often have a zonal distribution.

Owing to their perfect freshness these felspars are easily determined by modern optical methods; their specific gravities are not to be relied on because of the complex zoning and the glass enclosures, but fragments from the interior of a large phenocryst sank in a liquid at 2·745 (temperature, 2° C.), indicating 85 per cent. of anorthite in the felspar. The method of determination adopted wherever possible was the measurement of conjugate angles of extinction in Carlsbad-albite twins cut perpendicular to the zone of symmetry of albite twinning. The stereograms of ROSENBUSCH* were used, which differ somewhat in the basic end of the plagioclase series from those of MICHEL LÉVY. Consequently the proportions of anorthite in the felspar are slightly lower than those given by Professor LACROIX, who employed MICHEL LÉVY'S diagrams, but the results accord closely if we allow for this. The values given by Professor BECKE in his recent papers on the optical orientation of the plagioclases were also used wherever possible. Determinations by the position of equal illumination in zoned sections, perpendicular to the plane of symmetry of albite twins, proved useful as confirmatory evidence, though not so valuable as conjugate extinctions. Sections perpendicular to the bisectrices were not frequently made use of, as often

* ROSENBUSCH, H., "Mikroskopische Physiographie," Band I., Heft 2 (1905). MICHEL LÉVY, A., "Étude sur la Détermination des Feldspaths" (1894, 1896, 1904). BECKE, F., "Die optischen Eigenschaften der Plagioklase," 'Tschermak's Min.-Pet. Mittheil.,' vol. xxv., p. 1 (1906).

much time is required to find satisfactory ones. The optical sign in convergent light is easily observed and often valuable. The microlites of the groundmass were determined by their refractive index as measured against oils and Canada balsam, their maximum extinctions in sections from the zone 001,010 (longitudinal sections), and their extinctions in sections perpendicular to this zone.

The most basic cores of the porphyritic felspars contain about 85 per cent. of anorthite; a great part of the crystal yields extinctions almost identical with those given by ROSENBUSCH for bytownite (with 75 per cent. of anorthite). The outer margin is more acid than this, having usually about 50 per cent. anorthite, while the external borders may have as low as 40 per cent. A single crystal may thus have zones which vary from the composition of bytownite-anorthite to that of andesine. The groundmass felspars are usually long and narrow, often branched or hollow at their ends, and with few glass enclosures. They belong to andesine, having usually 40 to 35 per cent. of anorthite.

The augite is pale green or greenish brown, and is free from zonal and hour-glass structures. Many of the crystals are idiomorphic, but others have irregular outlines, as if corroded. Repeated twinning on the orthopinacoid may occur. Transverse sections often show good outlines with the pinacoid faces as large or larger than the prisms. The extinction angle $Z : c$ is 45 or 46 degrees, and the axial angle 2E is 110 degrees. The hypersthene is usually idiomorphic, its prisms being four or five times as long as broad. It has eight-sided cross-sections, with the prism faces small, while the pinacoids are large. It is optically negative with axial angle 2V over 60 degrees and the usual pleochroism of this mineral in andesitic rocks :—$Z = c$ green, $Y = b$ reddish brown, $X = a$ paler reddish brown. Parallel growths of augite and hypersthene occur, the augite being external. Both these minerals frequently contain enclosures of glass and magnetite.

Olivine is not always present, but it occurs in more than one-half of the microscopic sections of these bombs. It is never very abundant, and may be regarded as an accessory mineral. In most cases its grains are rounded, though occasionally they present crystalline outlines. Evidently the mineral has suffered corrosion in the period which preceded the eruption, and this accounts for its rounded shapes and the frequency with which it is surrounded by borders of granular hypersthene. The formation of hypersthene in andesites of this sort by corrosion of olivine has been described by many writers, *e.g.*, in the rocks of Martinique. Many of the crystals, however, have no such border, probably because the movements of the still liquid matrix, during the rise of the magma, swept away the hypersthene grains from around the olivine. The two minerals are never in regular parallel growth, and the hypersthene grains have no constant orientation with reference to one another. Agglomerations of hypersthene also occur which probably occupy the place of a former olivine crystal (Plate 26, figs. 1 and 2). It may be mentioned that another feature of these rocks, which is very constant, is the presence of glomero-porphyritic groups of

augite, hypersthene, plagioclase and magnetite, very often consisting of granular or imperfect crystals closely packed together.

Dark greenish-brown hornblende is not often seen in sections of these bombs. It is always irregular in shape and corroded; the other ingredients are iron oxides (titaniferous magnetite), pyrites and apatite.

The groundmass is of the hyalopilitic type, consisting of felspar and augite microlites, with magnetite embedded in a dark brown glass. The felspars are mainly andesine, as stated above. The pyroxene is often in long narrow prisms. Hypersthene has been recorded in the groundmass of many of the Martinique rocks, but in St. Vincent, where the microlites are large enough to react clearly on polarised light, they have mostly an oblique extinction, and cross-sections may show twinning on a pinacoidal face; hence they belong to augite. The iron oxides form small octahedra. The glassy base varies somewhat in abundance, and is occasionally nearly free from crystals of the second generation. These rocks are always vesicular, and their steam cavities are empty.

A number of excellent analyses of the dust and bombs of the eruption of the Soufrière in May, 1902, have appeared. Of these we select the following as the most complete. The great similarity is at once apparent. The first analysis probably represents most closely the composition of the magma in the later stages of the eruption. The second analysis contains an abnormally high percentage of water, which leads us to suspect that the specimen was not a recent bomb, but an old and somewhat weathered one. No other analysis of the recent products of the Soufrière or Pelée shows so much combined water, except one which Professor LACROIX* suspects for precisely the same reason. Analysis IV. of the dust that fell at Chelston, Barbados, has been criticised by Dr. HILLEBRAND,† who doubts whether nickel and cobalt are present in these rocks. Repeated tests, however, both in the laboratory of the Geological Survey of Great Britain and by other analysts to whom samples were sent, confirm the substantial accuracy of the analysis in this respect, though the amount of cobalt and nickel may be very slightly over-estimated. The curious feature of this analysis is that it proves the Barbados dust to contain less silica and alkalies and more magnesia, lime and iron oxide than the average magma of the eruption. In other words, the glass and acid felspars were not deposited in Barbados in normal amount, but were swept past it by the anti-trade wind. Analyses V. and VI. of ash collected 150 miles further away show, as might be expected, exactly the converse. This brings out clearly the sifting action of air currents on clouds of volcanic dust.

Professor LACROIX‡ has computed that PISANI'S analysis shows that the rock, if completely crystallised, would have yielded:—

* 'La Montagne Pelée,' p. 527.

† 'National Geog. Mag.,' XIII., p. 299, 1902.

‡ 'La Montagne Pelée,' p. 599.

Quartz		9·00
Felspars:—Orthoclase		5·00
	Albite	30·39
	Anorthite	32·15
Pyroxenes		17·98
Magnetite		4·41
Ilmenite		1·52
Apatite		0·34
H_2O		0·34

	I.	II.	III.	IV.	V.	VI.
SiO_2	56·71	55·08	55·64	52·81	57·62	57·75
TiO_2	0·77	0·80	0·98	0·95	0·87	0·70
Al_2O_3	18·80	18·00	18·21	18·79	19·76	17·70
Fe_2O_3	3·12	2·46	3·63	3·28	3·43	2·84
FeO	5·35	4·57	4·83	4·58	3·90	2·73
MnO	—	0·21	0·19	0·28	0·08	—
CoNiO	—	—	—	0·07	—	—
MgO	3·62	3·34	3·48	5·19	1·82	3·51
CaO	8·06	7·74	8·10	9·58	6·25	8·11
BaO	—	—	0·03	—	—	—
Na_2O	3·65	3·45	3·55	3·23	3·79	5·03
K_2O	0·77	0·65	0·58	0·60	0·71	0·94
H_2O	0·11	2·05	0·74	0·37	0·90	1·00
H_2O	—	—	—	—	—	—
P_2O_5	0·08	0·17	0·11	0·15	0·17	tr.
S	—	—	0·04	—	0·11	—
SO_3	—	0·24	—	0·33	—	—
Fe_7S_8	—	0·91	—	—	—	—
Cl	—	—	—	0·14	—	—
	100·95	99·67	100·15	100·35	100·08	100·31

I. Vitreous bomb from the Soufrière (anal. PISANI, cited from LACROIX, 'Montagne Pelée,' p. 598).

II. Lapilli collected at Langley Park, St. Vincent (anal. SCHMELCK, 'Chem. Zeit.,' XXVII., 1903, p. 34).

III. Pumice from St. Vincent collected by Lieutenant PENNY (anal. STEIGER, 'National Geog. Mag.,' XIII., p. 291, 1902).

IV. Dust that fell in Barbados May 8th, 1902 (anal. POLLARD, 'Quart. Jour. Geol. Soc.,' LVIII., p. 368, 1902).

V. Dust that fell on the ship "Coya," 250 miles W.S.W. of St. Vincent (anal. STEIGER, 'National Geog. Mag.,' XIII., p. 291, 1902). (Contains also 0·29 SO_3, 0·20 CaO, 0·08 Na_2O, soluble.)

VI. Lapilli collected at Langley Park, St. Vincent (anal. SCHMELCK, 'Chem. Zeit.,' XXVII., 1903, p. 34).

Old Bombs.

Among the materials washed down by the rivers on both sides of the island were many lapilli and small vesicular bombs, which closely resembled those of the recent eruption, but had a weathered appearance. On section these proved to be hyalopi-

litic hypersthene andesites very similar to those above described. Probably they were washed out of the ash beds deposited by the eruptions of 1812 and 1718, or even at an earlier date.

Blocks of Older Andesites.

These were easily distinguished from the new bombs by their angular outlines (due to fracture), their less vesicular character, and the traces of weathering or fumarole action they often exhibit. Many of them were 2 feet in diameter, while some were 5 feet long and 4 feet thick. Of these rocks the greater part were hyalopilitic hypersthene andesites with accessory olivine, and differ little from the new bombs of 1902, except in their more solid texture and the general absence of steam cavities. Their groundmass is more crystalline, as a rule, than that of the bombs, owing to their having cooled more slowly, but there is considerable variation in this respect, as some contain much brown glass, while others show very little of it. Many of them are very fresh, and must have been derived from the solidified magma of previous eruptions which occupied the passages leading to the base of the crater, or formed its floor. When the vitreous base is abundant, these rocks have a dark lustrous appearance; when the groundmass is more crystalline they are more grey in colour. All carry phenocrysts of plagioclase, augite, and hypersthene; olivine appears in most of them, and is often surrounded by hypersthene; hornblende is rare. The olivine may contain small dark brown octahedra of chromite or picotite. The hypersthene, when the groundmass is well crystallised, may have narrow borders of augite due to corrosion during the last stages of solidification.

A few of these rocks contain as much olivine as hypersthene, and may be classified as hypersthene basalts (Plate 27, fig. 5). The great resemblance which these old andesites and old bombs present to the new products of the magma of 1902 proves that there has been little change in the nature of the materials emitted by the Soufrière for a very considerable period.

An interesting structural variation presented by some of these andesites is flow-brecciation. In a few of them, although the rocks appear perfectly massive in the band specimens, the porphyritic crystals are broken to fragments (Plate 26, fig. 8). This is especially noticeable in the zoned felspars, as the banding does not then continue round the whole crystal, but stops abruptly at the broken edges. These rocks have a rather crystalline matrix, never a glassy one, and are not vesicular. They show no flow banding, but in the groundmass there are patches of different structure which look almost like enclosed fragments. It is clear that the brecciation took place before the rock was entirely solid, as later deposits have gathered on the broken faces of some of the larger felspars, forming thin continuous marginal zones. At the same time there can be no doubt that the matrix was already partly solid, as the brecciation affects it also. On Montagne Pelée* brecciated rocks are common, and

* 'La Montagne Pelée,' pp. 513, 514 (1904).

have arisen in several different ways. On the Soufrière they are rare, and as they occur only in scattered blocks among the ashes, there is nothing to indicate in what manner they have originated.

The alterations which the ejected blocks of former lavas have experienced are due to weathering, to fumarole action and propylitisation, and to contact action.

The weathered blocks show changes of a familiar type. Their olivine is replaced by serpentine and carbonates; their hypersthene by bastite; the felspars become cloudy with kaolin and carbonates. In the groundmass the glass is devitrified and stained with limonite and chlorite.

In some cases the groundmass has been replaced extensively by silica. This may be brownish chalcedony showing spherulitic structure, almost the same in appearance as a spherulitic glass, but harder than steel when tested with a knife. The fibres of the spherulites have positive elongation. More common is quartz in small irregular patches replacing the glassy base and enclosing microlites of felspar. This gives these rocks a secondary micropoikilitic structure.

In small cavities in many of these ejected blocks, scales of tridymite are found, and Professor LACROIX has observed cristobalite also in some of them.* It has been pointed out by WEINSCHENK† that tridymite is a fumarole deposit, and indicates that the rocks have been subjected for some time, in the solid condition, to the action of steam at a high temperature. In St. Vincent, as in Martinique, it does not occur in the new bombs of the first eruptions of 1902. Professor LACROIX‡ has made some very interesting observations on its development in the ejecta of Pelée. It began to appear in the vesicular andesites during the winter 1902–03, that is to say, six or eight months after the eruptions had begun. In the materials cast out in 1904, after the dome had stood for some time, tridymite was abundant. It appeared in the enclosed blocks before it was found in the new lava itself.

Rocks of propylite type are also found among the ejected blocks. They are grey or greenish grey masses in which the felspars are often decomposed along certain zones or at their centres, but elsewhere fresh. In these rocks pyrite is common and indicates the operation of sulphurous gases from fumaroles. Chlorite and epidote replace the augite, the hypersthene often yields a pale coloured fibrous mineral with strong double refraction, perhaps iddingsite or a secondary mica. Quartz occurs in some of these rocks; carbonates are scarce. The igneous structures may be perfectly retained, even when the original minerals have entirely disappeared; the whole mass between crossed nicols is nearly isotropic, and apparently consists mainly of kaolin and limonite, but the outlines of all the porphyritic crystals are clearly visible in ordinary light.

The ultimate stages of fumarole decomposition are not well illustrated in

* 'La Montagne Pelée,' p. 593, 1904.

† 'Die gesteinsbildenden Mineralien,' Edit. I., p. 76, 1901.

‡ *Ibid.*, p. 519.

St. Vincent, as since 1812 the Soufrière crater was occupied by a lake of water and the escape of steam did not take place on a large scale. In Dominica and St. Lucia there are many "Soufrières" discharging sulphurous gases. The crater of Pelée contained a "Soufrière" of this kind, and Professor LACROIX has given a full account of the products of fumarole action in Martinique.

It is rather a remarkable fact that of all the specimens which we collected of older andesitic rocks ejected during the 1902 eruptions only one shows contact alteration. The fresher specimens could not be expected to suffer much change by being again raised to the temperature at which they consolidated. With the weathered rocks it is different, for their secondary minerals would certainly be modified had they been enveloped in the new incandescent lava. Hence we may infer that the ejected blocks above described were mainly the materials which plugged the orifice of the volcano and were cleared out by the rise of the magma.

The specimen which does show contact alteration is a fine grained, dark coloured and banded rock. It consists essentially of dark brown biotite in small scales, rounded or nearly idiomorphic when enclosed in the felspars; hypersthene in minute pleochroic grains; a little augite of similar habit, iron oxides and granular, usually untwinned felspar. The latter is andesine and labradorite; the whole rock has typical hornfels or "pflaster" structure and is indistinctly spotted. Its composition shows that it is igneous, and there can be little doubt that it was originally a fine banded andesitic tuff. In one part the specimen shows larger phenocrysts of bytownite-labradorite felspar, with aggregates of hypersthene and augite (chondritic groups) replacing porphyritic pyroxene. These lie in a fine matrix rich in biotite like that above described. This portion of the specimen seems to be a fragment of andesite in the tuff. The rock is crossed by little veins filled with recrystallised hypersthene. It presents many points of resemblance to the contact-altered andesites of the Cheviots and of Lorne.

Quartz Andesites.

In the ash beds of the 1902 eruptions there are a limited number of andesitic rocks which present some remarkable characters which seem to indicate that they have undergone alteration of an unusual type. These rocks are milky white or pale grey, often with dark patches which represent the ferro-magnesian minerals. Many of them are brecciform; in fact, they look like whitened or bleached tuffs. It is difficult to prepare microscopic sections of them, as they fall to pieces when being mounted.

Under the microscope they prove to be full of quartz which occurs only in the matrix and not as phenocrysts (Plate 26, fig. 5). The original basic felspars of the andesites remain, though small grains of quartz may form along their margins. These felspars often show intense zoning and have much the same characters as those of the andesites and hypersthene basalts. The primary olivine, augite, hypersthene,

and hornblende have more or less completely vanished. In their place we have aggregates of dark brown biotite, pale green augite, and hypersthene in small grains which may have parallel orientation, so that they build up skeleton crystals the interstices of which are filled with quartz and felspar. These aggregates do not form good pseudomorphs, and the minerals they represent cannot be identified by their outlines. They are strikingly different, however, from the idiomorphic plagioclase crystals. The process of alteration can be seen in certain large crystals of brown hornblende which are rather common in these slides. The amphibole is reduced to a series of irregular patches (Plate 26, fig. 3), which can be recognised as having belonged to one crystal from their parallel orientation and simultaneous extinctions. The interspaces are filled up by granules of hypersthene and scales of dark brown biotite. These are the only rocks from St. Vincent with the exception of the norites and andesite-hornfelses in which biotite has been observed. In these secondary aggregates pale green augite occurs also, so similar to the hypersthene in colour and mode of growth that it can hardly be distinguished except by its optically positive character and its lack of pleochroism. The hypersthene has a large apparent axial angle, though it is pale green, and is always optically negative. Very little iron oxide occurs in these aggregates.

The groundmass consists of quartz, felspars, hypersthene, tridymite and an isotropic material. The quartz may be in irregular grains; very often, however, it is in perfectly formed double pyramids which, when the matrix is dissolved away, are beautifully sharp. It contains few enclosures, mostly tridymite. The felspars are of many kinds; some are highly zonal and consist mainly of labradorite at their centres with margins of andesine; there are also irregular plates of untwinned alkali felspar which are covered with scales of tridymite. Hypersthene appears in the groundmass as grains and as perfect minute prisms of the usual shape. Iron oxides are practically absent. An isotropic material surrounds and separates all the crystalline minerals of the groundmass in very thin colourless or yellow films. It is dissolved by boiling with caustic potash for some time, and this suggests that it may be a form of colloid silica, but its refractive index is 1·484, but varies slightly, and no kind of opal is known which has so strong refringence. It has also very nearly the same index of refraction as the more acid varieties of andesitic glass which were examined by Professor LACROIX* in Martinique.

It is clear that these rocks have undergone alteration. Their pale colour shows that they contain but little iron; the great abundance of quartz in many of them leads us to suspect that there has been an introduction of silica. The transformation of the hornblende might be ascribed to fusion, or to contact alteration. That the changes have taken place at a high temperature is clear from the occurrence of veins of pyroxene traversing the groundmass, and filling cracks in porphyritic felspar. This shows that after the rock had consolidated there was a formation of augite. They

* *Op. cit.* p. 511.

have at the same time very little in common with the rocks which have been weathered under atmospheric conditions, or with the propylites. It seems probable that steam, acting at high temperatures and pressures, was the modifying agency. Perhaps these rocks lined fissures beneath the crater through which gases ascended after the eruptions of 1812 and 1718.

In St. Vincent quartz-bearing andesites are rare; in Martinique, where the magma was more acid and the volcanic activity more continuous, they are common. Professor LACROIX has some very interesting notes on these rocks. They did not appear at the first eruptions; but in 1904 the materials produced by the rupture of the dome were full of quartz. He concludes that it arose in those rocks which were situated beneath the surface of the dome, and were affected for a long period by steam emitted from the magma.*

Cordierite Andesites.

Six months after we left St. Vincent Professor LACROIX found two specimens of cordierite-bearing rocks on the Soufrière, one an andesite, the other a variety of quartzite. In our collection there are no cordierite-bearing rocks; probably they were not emitted by the first eruptions; if they were, they must have been very scarce. At Martinique, quartz andesites and cordierite andesites were not obtained till the volcano had been in activity for some months. Some of these rocks seem to bear a close relationship to the quartz andesites above described, but for particulars regarding them we may refer to Professor LACROIX's monograph on Montagne Pelée (p. 597).

Anorthite-Olivine Blocks.

Many crystalline masses, consisting mainly of anorthite and olivine, with augite, hypersthene, and hornblende, occurred among the new ash deposits. They were mostly in a perfectly fresh condition; some, however, must belong to previous eruptions, as their minerals show decomposition. In St. Vincent, several people showed us similar blocks which had been picked up on the Soufrière before 1902; we also saw these blocks in the older tuffs and lavas of the mountain. They occur also in Martinique, St. Kitts, and other islands of the Antilles.

They present a great diversity of appearance in the hand specimens. All are rich in felspar, which is usually milky white rather than glassy and transparent. Olivine in rounded, greenish yellow, or brownish grains, is the next mineral in abundance, and then augite in black crystals which are pale green in thin sections. Dark elongated prisms of hornblende are common in some of these rocks. Of the ferro-magnesian minerals hypersthene is the least frequent.

They have usually the appearance of granular crystalline rocks, the grains ranging in size from half-an-inch downwards. Some contain larger crystals, which give them

* *Op. cit.*, p. 521.

a porphyritic appearance; others have finer grained bands, which may possibly be veins. We obtained also some blocks rich in long bladed crystals of hornblende (over an inch in length). These are arranged parallel to one another, giving the rock a coarsely gneissose character; or it might be compared to a comby vein with prismatic crystals perpendicular to the boundary walls. There is little olivine in these specimens. Others have a drusy structure with small cavities lined by the terminations of idiomorphic crystals. None of the masses was of large size; specimens over a foot in diameter were scarce. On the other hand, many of the fragments which lay near one another on the ashes were very much alike, as if they were parts of a large block which had been shattered on striking the ground. The great variety in the appearance of these blocks indicates that if they come from a single rock mass situated beneath the volcano, that mass must be very heterogeneous. These blocks were all exceedingly friable, and fell to powder when struck with the hammer, so that thin chips could not be detached from them, a property which will be explained when their microscopic characters are described.

In thin sections none of the minerals have definite crystalline form. The olivine is rounded and often much cracked. The augite is pale green and not dichroic. Its extinction angle $Z : c$ is 45 degrees; the optic axial angle 112 degrees. Twinning on 100, simple or repeated, is common. The hypersthene has the usual pleochroism, not very intense: its axial angle 2V is over 60 degrees. The felspar, which is the most abundant constituent, very seldom is zoned. Pericline and albite twinning are both frequent; Carlsbad twins are few. Conjugate extinctions in sections of Carlsbad-albite twins indicate a high percentage of anorthite (85 to 90 per cent.). In convergent light the sections are negative. The specific gravity of the powdered felspar is on an average 2·75. The refractive index and double refraction are both very high. The hornblende is brownish green, fairly deep in colour, and is often in parallel growth with the augite, the two minerals having their prism axes and zones of symmetry parallel. Sometimes the amphibole surrounds the pyroxene; at other times they are intergrown. The pleochroism of the amphibole is X yellow, Y yellow green, Z darker brownish green. $Z : c$ about 13 degrees in sections showing vertical emergence of the optic normal. $Y = b$.

All the minerals contain small glass cavities with a fixed bubble; they may also show large enclosures of brown glass. Some of the cavities seem to be empty. Fluid enclosures with mobile bubbles, though they might be expected to occur, were not seen. None of the minerals, though the rocks have plutonic structure, have the dark platy enclosures which produce schiller. As a rule there is no definite zonal or crystallographic arrangement of the glass cavities.

In structure these rocks resemble gabbros and troctolites (Plate 27, figs. 1 and 2). The felspar has partly crystallised after the augite, and may be enclosed in it, but is never enveloped by olivine, which has probably been the earliest of the silicates.

The rocks consist generally of nearly equidimensional grains, fitting together in a

perfect mosaic. If regarded as true plutonic rocks they may be classified as gabbros, troctolites, anorthosites, &c. (or seeing that their felspar is anorthite, as allivalites, harrisites, &c.). They have evidently formed under plutonic conditions. Hornblende and olivine are frequent in them, but these minerals are unstable at the levels to which the magma ascends before effusion, and are gradually dissolved. Professor LACROIX has described and figured* fused crystals of hornblende in nodules of this sort from St. Vincent, but we have not met with any in our specimens, where these minerals are always perfectly clear and sound. The felspars of these rocks resemble those of the early central portions of the phenocrysts of the lavas, though somewhat more rich in lime and containing more enclosures. The absence of outer zones of bytownite and labradorite shows that these felspars ceased growing at great depths. All the minerals, however, are like those met with, under certain conditions, in the lavas; hence there can be no doubt that these crystalline rocks are from the same magma, but they have formed at great depths and are more basic in character than the rocks erupted at the surface.

A very interesting structural feature of these rocks is that their minerals are not in perfect contact with one another, but are separated by the thinnest possible films of brown glass (Plate 27, fig. 1). The vitreous material even passes into the cracks and cleavages of the felspars. It seems to enter the original cavities and enlarge them by corroding the surrounding mineral. This glass contains usually only small dusty grains of black magnetite. Near the edges of the specimens the finest veins unite to form thicker ones, which sometimes contain microlites of andesine and labradorite; the glass is consequently similar to that of the hyalopilitic andesite matrix. This makes it probable that the glass veins are an injection of that portion of the magma which was liquid at the time of the eruption; it explains also the absence of zones surrounding the anorthite and intermediate in composition between it and the andesine of the glass. The very friable character of the nodules arises from the presence of these films of brittle glass separating the crystals.

The subjoined analyses show the composition of two crystalline blocks collected in St. Vincent by Professor LACROIX. The second indicates the great abundance of anorthite in some of them; compared with the first, it proves a considerable range in composition in these blocks, though both of them are highly basic. The other three analyses are of anorthite, hypersthene, and hornblende, in a similar block from St. Kitts. Dr. FELS's paper contains also particulars of the crystallographic and optical properties of these minerals. Analysis III. is interesting as proving that the felspar is not absolutely pure anorthite, but corresponds to Ab $12\frac{1}{2}$, An $87\frac{1}{2}$. The felspar of Professor LACROIX's rock must be rather more basic than this. The St. Kitts hypersthene contains 18 per cent. of iron oxides; a sample of hypersthene separated from the rocks of Martinique contained 27·7 per cent.† of iron oxides; if we

* *Op. cit.*, Plate 26, fig. 6, and p. 542.

† LACROIX, A., *op. cit.*, p. 506.

judge by the optic axial angle, which in this group of minerals varies with the percentage of iron present, the St. Vincent hypersthene is not quite so ferriferous as that of Martinique.

	I.	II.	III.	IV.	V.
SiO_2	47·15	45·0	44·17	50·54	43·26
TiO_2	0·90	0·3	—	—	0·29
Al_2O_3	22·30	32·5	35·06	3·94	13·15
Fe_2O_3	2·22	0·2	—	0·90	2·27
FeO	6·93	3·0	0·58	17·08	10·50
MgO	5·15	0·7	0·57	25·71	15·06
CaO	12·30	17·1	18·84	1·82	12·11
Na_2O	1·81	0·8	1·21	0·79	3·49
K_2O	0·35	0·2	0·43	0·55	0·57
P_2O_5	0·19	—	—	—	—
H_2O	1·00	—	0·59	—	0·21
	100·20	100·8	101·45	101·33	100·91

I. Dioritic enclosure (anorthite-hornblende rock) Chateaubelair (anal. PISANI, cited from LACROIX, 'La Montagne Pelée,' p. 598).

II. Troctolitic enclosure (anorthite-olivine rock), St. Vincent (anal. ARSANDAUX, *ibid.*, p. 598).

III. Anorthite from an anorthite-olivine block from St. Kitts (anal. FELS, 'Zeits. Kryst.,' XXXVII., p. 459, 1903).

IV. Hypersthene from an anorthite-olivine block from St. Kitts (*ibid.*).

V. Hornblende from an anorthite-olivine block from St. Kitts (*ibid.*).

Norites, Quartz-Norites (Andes-Norites).

These are less common than the anorthite-olivine blocks, but are of interest because they represent a type known also in Martinique and some of the other islands and of wide distribution among the volcanoes of the Andean or Pacific facies.* They consist of plagioclase, augite, and hypersthene, and are rather fine grained and holocrystalline, or contain a little glass. Larger phenocrysts of plagioclase may occur, but are scarce. Their felspars, in contrast to those of the anorthite-olivine blocks, are invariably much zoned and are often idiomorphic. They show Carlsbad, albite and pericline twinning in great perfection. The centres of different crystals proved to contain 80, 75, and 60 per cent. of anorthite; bytownite is evidently the prevailing type. These centres are corroded and surrounded by more acid zones succeeding one another in great numbers; more and less acid bands may alternate repeatedly. The margins are often andesine with 35 per cent. anorthite, but oligoclase (20 per cent.

* ROSENBUSCH, H., 'Mikroskopische Physiographie,' B. II., p. 292 (1907); HÖGBOM, A. G., "Zur Petrographie der Kleinen Antillen," 'Bull. Geol. Inst. Upsala,' vol. vi., p. 214 (1905).

anorthite) forms the outer borders of some crystals. Glass cavities are frequent (Plate 27, fig. 3). In all their features these felspars resemble the phenocrysts of the andesites.

Augite and hypersthene are about equally common, the former sometimes euhedral, but often anhedral; the latter always occurs in long prisms similar in shape to those of the lavas. The augite has a green colour and simple or repeated twinning on 100. The hypersthene is pleochroic in the usual tints; one section gave an optic axial angle $2E = 132$ degrees (which corresponds to $2V = 65$ degrees). Parallel growths between the pyroxenes occur as in the andesites; they also contain glass enclosures. A few scales of dark brown biotite are sometimes present. Olivine occurs in several of these norites, but is scarce and is always surrounded by corrosion borders of hypersthene (Plate 26, fig. 1). The other ingredients are magnetite and apatite.

In all these rocks there are traces of a matrix between the larger crystals, though this is not abundant. In some it is felspathic and consists of small imperfect crystals of andesine. In others it is a brown glass, very scanty in amount. This glass resembles that of the enclosures and does not seem to be a later injection, as in the anorthite-olivine nodules. Most of these rocks, however, contain a small amount of micropegmatite (Plate 26, fig. 7), which serves as a groundmass and forms aureoles around the felspars. The latter then have borders of oligoclase; the felspar of the micropegmatite is untwinned alkali felspar with lower refractive indices than those of the quartz.

These rocks approach closely in composition and in the peculiarities of their minerals to the effusive andesites and differ greatly from the anorthite-olivine nodules. The scarcity of olivine, the zonal structure of the felspars, and the presence of glassy base in some of them proves that they crystallised at intermediate depths and pressures. They represent the rocks which would have been produced had the andesitic magma solidified without forcing its way to the surface.

Sedimentary Rocks.

Calc-silicate Hornfelses.—The sedimentary rocks ejected by the eruptions of May, 1902, all occurred in small fragments among the ash and were much contact-altered. The commonest were fine grained, pale green or greyish-green calc-silicate rocks. In all probability they represent sedimentary beds which lie beneath the volcano. The hand specimens are often banded, apparently owing to original bedding; often they are crossed by irregular veins, and they may show spots due to local aggregation of wollastonite, augite, or other minerals. Similar blocks had been thrown out by previous eruptions, and as they are fine grained and tough were used by the Caribs in the manufacture of stone implements.

These rocks contain little carbonates and most have originally been impure siliceous and argillaceous limestones. Some consist mainly of wollastonite, with granular

augite and sphene; in others lime-felspar is common, while a few contain small rounded grains of quartz. The absence of hornblende, garnet, vesuvianite, and epidote is rather striking.

The wollastonite, which is the most important mineral, forms plates, fibres, and irregular blades. Sometimes it shows traces of idiomorphism, being elongated parallel to the *b* axis. Very often its fibres are sub-radiate, or have a tendency to spherulitic or stellate groupings. The augite is dark green, sometimes brownish green, and forms only small grains which rarely exhibit crystalline faces. The felspar, also, is anhedral as a rule. It shows albite twinning, more rarely Carlsbad and pericline twinning, and belongs to the basic end of the plagioclase series, being near anorthite in composition. Quartz is rare and occurs only as rounded grains. Granular sphene is always present, but never well crystallised.

The green veins which traverse these rocks are mainly augite; the white patches consist of wollastonite and felspar, but the rocks show little uniformity in structure or in the shape and size of their component minerals.

Where anorthite is abundant it has a tendency to idiomorphism, and its crystals are frequently bounded in part by good crystalline faces (Plate 27, fig. 4). The matrix is then wollastonite, augite, and smaller grains of felspar. The large felspars enclose wollastonite, augite, and the other minerals of the rock. The porphyritic crystals give rise to a structure somewhat resembling those of igneous rocks. Professor LACROIX has noted the same phenomenon in the calc-silicate hornfelses of St. Vincent.

Quartzites, Baked Sandstones.—We obtained also a few fine-grained contact-altered rocks consisting mainly of quartz. They may have been sandstones or siliceous portions of the underlying sedimentary beds, or perhaps secondary deposits of quartz among the igneous rocks.

Albite Rock.—The most peculiar of these rocks is a small pale-coloured fragment which proved in microscopic section to consist of albite and pleochroic green augite (ægirine augite). In the calc-silicate hornfelses the pyroxene sometimes has a weak pleochroism; in the granular augite of this rock it is quite strong and ranges from yellow to dark green. The albite forms long prisms, not perfectly idiomorphic, but with irregular or indented edges. A little quartz occurs among the felspars. There are no phenocrysts. The origin of this rock is obscure; it is unique in our collections, and no similar ejecta have been found in Martinique. As its pyroxene resembles that of some of the calc-silicate hornfelses, we have placed it with them.

THE OLDER IGNEOUS ROCKS OF ST. VINCENT.

Our collections do not include a large number of specimens of the older igneous rocks of St. Vincent, but they have been supplemented by a series which Professor LACROIX sent us, and these enable us to show what are the main petrographical features of the island. Professor BERGEAT has grouped the rocks which

were collected by Professor SAPPER* as felspar basalts, hypersthene-bearing basalts, basalts, olivine augite andesites, hypersthene andesite, hypersthene augite andesite, and hornblende pyroxene andesite. Professor LACROIX† has classified his specimens as andesites, andesilabradorites and labradorites with augite and hypersthene, and basalts. Recognising that they all belong to one series and are linked together by intermediate types, we shall describe them as hypersthene andesites (with accessory olivine and hornblende), hypersthene basalts (with both olivine and hypersthene) and olivine basalts; this terminology is more in accordance with the nomenclature current in Great Britain.

The *hypersthene andesites*, except that they are more or less decomposed, bear a strong resemblance to those ejected by the Soufrière during 1902. They are all porphyritic, the minerals of the first generation being plagioclase, augite, and hypersthene, while the groundmass consists of augite, plagioclase, and iron oxides. Magnetite and apatite are constantly present; hornblende occurs in a few specimens, as in the recent bombs of the Soufrière. Olivine is more common, and is often surrounded by a resorption border of hypersthene. Small nodules or glomero-porphyritic groups of hypersthene are common in these rocks, and represent the final stages of resorption of olivine (Plate 26, fig. 2). They often contain branching growths of magnetite at their centres, showing that part of the iron oxides was rejected in the transmutation from olivine to hypersthene. The hypersthene is usually idiomorphic, but when the matrix is comparatively well crystallised, a zone of augite surrounds it, and has probably formed by corrosion of the hypersthene during the last stages of crystallisation of the groundmass. The porphyritic felspars are much zoned, consisting of bytownite (80 per cent. anorthite) at their centres, while their margins are acid labradorite and andesine. The groundmass felspars are andesine (about 40 per cent. An), and occur as small elongated laths; the augite of the second generation is granular and usually anhedral. Most of these rocks contain little glassy base, and are far less rich in this substance than the recent bombs of the Soufrière, but had the latter cooled slowly as in a lava flow, they would have very much the same structure as many of the older andesites.

As indicated by the ejected blocks of the 1902 eruption, there is much hypersthene andesite in the Soufrière, though hypersthene basalts occur there also, and Professor BERGEAT‡ mentions two olivine basalts from the Black Ridge on the mountain. Hypersthene andesites are exposed at Morne Ronde, Larikai, and Baleine, and occur also at Cumberland, north of Chateaubelair.

The *hypersthene basalts* are richer in olivine than the hypersthene andesites, but contain less hypersthene (Plate 27, fig. 5). They may be defined as consisting of plagioclase, augite, olivine and hypersthene, with the last two minerals in nearly

* KARL SAPPER, 'In den Vulkangebieten Mittelamerikas und Westindiens,' p. 194 (1905).

† *Op. cit.*, p. 592.

‡ In KARL SAPPER, 'In den Vulkangebieten Mittelamerikas und Westindiens,' p. 194 (1905).

equal proportions. The olivine shows resorption with formation of hypersthene; the latter is often partly replaced by augite. The porphyritic structure of the andesites is repeated in this group. The large felspars are highly zonal, and have centres of bytownite (75 to 85 per cent. anorthite), while the margins are labradorite (about 50 per cent. anorthite). There is rarely much glass in the matrix of these rocks, and in this respect they show affinities to the basalts. Hypersthene basalts occur in small numbers among the ejected blocks of the Soufrière, and are found also at Chateaubelair, Cumberland, Buccament, and other portions of the island. According to Professor BERGEAT the Somma of the Soufrière contains rocks of this type.

The *olivine basalts* consist of plagioclase, augite, and olivine. Hypersthene is rare or absent and hornblende is not known to occur in them. Coarsely porphyritic and finely porphyritic types occur. Some carry large phenocrysts of felspar; others contain only porphyritic augite and olivine. Many of the latter group are very rich in olivine (Plate 27, fig. 6), which acquires a rusty brown colour as it weathers and ultimately passes into serpentine. The large felspar phenocrysts are much zoned, though not so markedly as those of the andesites. Their centres are similar to those of the felspars in the hypersthene basalts; the borders are labradorite and in the groundmass the small elongated microliths have labradorite centres with outer zones of andesine. Olivine may occur as small crystals of the second generation in the groundmass. The augite is less green and more brown in colour than in the andesites. Traces of a vitreous base are to be seen in some basalts near Cumberland, but this is not common. Tridymite may occur in cracks and cavities in the groundmass.

Basalts have been described from Chateaubelair Point by Professor LACROIX. He compares them with the rock of Ramiers Island in Martinique. Professor BERGEAT identified specimens from Buccament and the Soufrière. They occur also at Barroualee, Cumberland, Calliaqua, and Kingstown. Many of the largest lava flows appear to belong to this group.

Two analyses (cited from Professor LACROIX) are given below, one of a hypersthene basalt, the other of an olivine basalt from St. Vincent. They show very well the decrease in silica and the alkalies, accompanied by an increase in lime and still greater increase in magnesia, which are to be expected from the mineralogical constitution of these rocks. Compared with the analyses of recent bombs, already given, they prove that the hyalopilitic hypersthene andesites recently erupted are the most acid lavas known to occur in the island.

The petrography of St. Vincent, so far as is known, is less varied than that of Martinique, Grenada, and Dominica. Hornblende andesites, dacites, trachytes, and rhyolites apparently do not occur, and there is no evidence that plutonic rocks are anywhere exposed at the surface. The absence of the more acid types which are found in Martinique and Dominica is the most striking feature of the petrography.

	I.	II.
SiO_2	53·51	48·71
TiO_2	1·06	1·08
Al_2O_3	18·90	18·40
Fe_2O_3	3·37	3·70
FeO	5·70	5·33
MgO	4·38	10·30
CaO	9·15	10·11
Na_2O	3·13	2·34
K_2O	0·51	0·43
P_2O_5	tr.	0·06
H_2O	0·12	0·25
	99·79	100·71

I. Hypersthene basalt (*labradorite à hypersthène*) from the Somma of the Soufrière (anal. PISANI).*
II. Olivine basalt from Chateaubelair Point (anal. PISANI).*

All the rocks are basic types of andesite and basalts. Hypersthene and olivine are the characteristic minerals with highly zonal crystals of plagioclase.

During the recent eruptions in Martinique and St. Vincent, in spite of all variations the more basic character of the ejecta in the southern island has been maintained throughout. Perhaps for this reason the outbursts have been fewer and less spasmodic; other consequences are the comparative scarcity of pumice, the absence of bread-crust bombs which were partly solid when they struck the ground, and the non-appearance of quartz in the new St. Vincent andesites. After the emergence of the dome in the crater of Pelée, many of the ejected blocks had a quartzose groundmass.

The greater viscosity of the magma in Martinique led to the extrusion of the lava as a high pillar which rose from the crater. No counterpart of this is known on the Soufrière, where the floor of the crater is now almost exactly at the same level as before the 1902 eruptions. The more basic character of the rocks of the Soufrière probably accounts also for the greater abundance of anorthite-olivine blocks.

In spite of these differences there is a great similarity between the products of the eruptions in Martinique and St. Vincent. Representatives of every type of rock described here† have been obtained by the French geologists from the active or extinct volcanoes of Martinique.

The material of the eruption of 1902 is the most acid which has been found in St. Vincent, where also hypersthene andesites are most common in the Soufrière at the north end of the island. For a prolonged period this volcano has erupted only andesitic materials. In its earlier stages, when flows of lava were more common,

* LACROIX, A., 'La Montagne Pelée,' p. 598.
† With the exception of the albite rock described on p. 322

hypersthene basalts were emitted. The latest eruptions have been entirely of the spasmodic type, the effusive having given place to the explosive phase. This may not be without significance, especially seeing that most of the great explosive outbursts of recent years, Krakatoa, Bandaisan, Tarawera, Santa Maria, &c., have been produced by andesitic magmas. This may be explained by supposing that a magma of this nature retains its steam in solution till it is on the point of solidification, and then releases it suddenly with great violence.

The Dusts that fell in Barbados in 1812, October 1902, and March, 1903.

By the kindness of Sir Daniel Morris and of the Rev. N. B. Watson, vicar of St. Martin's, Barbados, we have received specimens of all the dust-falls of volcanic ash from St. Vincent, which are known to have taken place at Barbados. Their dates are May 1, 1812, May 7, 1902, October 16, 1902, and March 22, 1903. All consist of the same minerals and have very much the same appearance. They differ slightly in colour and in coarseness. The dust of 1812 is distinctly paler brown than that of May 7, 1902, and that of March 22, 1903, is rather darker. The dust of October 16, 1902, is very fine and of a grey colour, resembling in this respect the finer dusts from Montagne Pelée in Martinique. It is the lightest coloured of all the Soufrière dusts which have fallen in Barbados.

Samples of these dusts were passed through sieves having 30, 60, and 90 meshes to the inch. This gives a rough test of the size of the component grains. The meshes of these sieves were measured under the microscope and proved to have the average diameters stated in the last column of the table.

Meshes to 1 inch.	1812.	May 7, 1902.	October 16, 1902.	March 22, 1903.	
	per cent.	per cent.	per cent.	per cent.	mm.
30 retains . . .	0·17	0	—	0·0	>0·73
60 „ . . .	11·76	5	—	0·1	>0·31
90 „ . . .	7·97	26	1·8	0·2	>0·19
90 passes . . .	80·10	69	98·2	99·7	—

These show that the 1812 dust contained most coarse particles. Many of these were small vesicular pieces of pumice, very light, and hence likely to be transported to a great distance. The dust of May, 1902, is coarser than any other Barbados dust of the recent eruptions, probably because it had been projected into the air with greater violence and to a greater height; hence, when the cloud passed eastwards over Barbados, it still retained a larger proportion of the coarser particles.

The minerals of these dusts are the same as those of the May eruptions of 1902. All contain plagioclase felspars, augite, hypersthene, and olivine. Hornblende was seen only in the dust of May, 1902. Glassy material, more or less devitrified by

crystallisation, magnetite and apatite also are present in all the samples. There are, however, points by which these dusts can be distinguished from one another. The 1812 dust is by far the richest in brown glass,* often very free from microlites; it occurs largely as minute rounded spongy lapilli. The dust of October, 1902, which is very fine and pale coloured, is also rich in glass, which occurs as minute broken splinters. In this dust also broken felspars are very common, which circumstance

ANALYSES of Volcanic Dusts from St. Vincent, which fell in Barbados.

	I.	II.	III.
SiO_2	52·81	50·722	51·523
TiO_2	0·95	1·150	1·000
Al_2O_3	18·79	12·550	21·648
Fe_2O_3	3·28	9·484	} 6·372
FeO	4·58	4·676	}
MnO	0·28	0·450	—
(CoNi) O	0·07	—	—
CaO	9·58	10·100	10·000
MgO	5·19	5·911	4·716
K_2O	0·60	0·531	0·675
Na_2O	3·23	3·451	3·551
P_2O_5	0·15	0·192	0·141
SO_3	0·33	0·108	0·124
Cl	0·14	—	—
$H_2O - 105°$ C.	0·20	0·130	0·190
$H_2O + 105°$ C.	0·17	0·545	0·060
	100·35	100·000	100·000

I. Dust that fell on Barbados, May 7 and 8, 1902 (anal. Dr. W. POLLARD, 'Quart. Journ. Geol. Soc.,' LVIII., p. 369, 1902).

II. Dust that fell on Barbados, March 22, 1903 (anal. Professor D'ALBUQUERQUE, 'West Indian Bulletin,' vol. IV., p. 98, 1903).

III. Dust that fell on Barbados, May 7 and 8, 1902 (anal. Professor D'ALBUQUERQUE, 'West Indian Bulletin,' vol. III., p. 283, 1902).

probably accounts for the greyish colour of the samples. Olivine is comparatively infrequent. The dust of March, 1903,† is also fine grained, but is very dark in colour, being deep brown. This dust contains more olivine than any other of the specimens examined, and its crystals are often coated with very dark films of glass. Professor LONGFIELD SMITH‡§ has noted that this dust is richer in ferromagnesian

* PRIOR, T. G., 'Quart. Journ. Geol. Soc.,' LVIII., p. 370 (1902).

† BONNEY, T. G., "Notes on March Dust from the Soufrière," 'Nature,' vol. 67, p. 584 (1903).

‡ SMITH, LONGFIELD, "Volcanic Eruptions in the West Indies," 'West Indian Bulletin,' vol. III., p. 271, 1902).

§ Anon., "Notes on fall of Volcanic Dust at Barbados, March 22, 1903," 'West Indian Bulletin,' vol. IV., p. 91 (1903).

minerals than any of the others, and that augite is the predominant pyroxene. If we compare the analyses given below, it is clear that the 1903 dust is more like a hypersthene basalt in composition. The May dust of 1902 resembles a hypersthene andesite. Yet as the 1903 eruption was a small one compared with that of May, 1902, it might have been expected that a larger proportion of the heavy particles would have subsided before the cloud reached Barbados. From this it seems clear that there was a slight change in the composition of the magma erupted by the Soufrière during the 12 months for which it had been in activity, and that the last emissions were more basic than the earlier. As Professor D'ALBUQUERQUE's analysis is not stated in exactly the same way as Dr. POLLARD's, we give also the results of his examination of the dust of May 7 and 8, 1902, for comparison; it shows the more acid character of the latter clearly.

APPENDIX.

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DESCRIPTION OF PLATES.

PLATE 26.

Fig. 1. *Norite*, Wallibu, St. Vincent (polarised light, magnified 55 diameters).

Shows a crystal of olivine surrounded by a corrosion border of hypersthene.

Fig. 2. *Hypersthene basalt*, Calliaqua, St. Vincent (magnified 24 diameters).

A hypersthene cluster full of spongy magnetite, the product of the resorption of olivine.

Fig. 3. *Quartz andesite*, Soufrière, St. Vincent (magnified 47 diameters).

Part of a large crystal of hornblende which is being replaced by hypersthene, biotite and felspar. The scaly biotite is very dark; the hypersthene and felspar are pale coloured. The hornblende (dark) occurs only as islands surrounded by the other minerals.

Fig. 4. *Bomb* (*hypersthene andesite*) of the May eruptions, 1902, Wallibu, St. Vincent (magnified 36 diameters).

The photograph shows phenocrysts of augite, hypersthene, and plagioclase felspar in a vesicular, semi-vitreous groundmass.

Fig. 5. *Quartz andesite*, Soufrière, St. Vincent (magnified 47 diameters; polarised light).

Highly zoned phenocrysts of plagioclase felspar lie in a matrix full of small brightly polarising grains of quartz.

Fig. 6. *Hypersthene andesite*, Soufrière, St. Vincent (magnified 24 diameters; polarised light).

Below the centre of the photograph there is an idiomorphic cross-section of hypersthene so placed that it is extinguished; around it there is a narrow border composed of granular augite.

Fig. 7. *Quartz norite*, Soufrière, St. Vincent (magnified 55 diameters; polarised light).

The minerals represented are pyroxene and plagioclase felspar. The spaces between them are occupied by micropegmatite.

Fig. 8. *Hypersthene andesite*, Soufrière, St. Vincent (magnified 48 diameters; polarised light).

All the phenocrysts are broken and have very irregular forms. This is an instance of brecciform structure in the andesites.

PLATE 27.

Fig. 1. *Anorthite-olivine block*, Rabaka Dry River, St. Vincent (magnified 26 diameters).

The crystals shown in the photograph are mainly anorthite, with a few grains of olivine. None are euhedral; thin films of dark glass separate the minerals and pass along their fissures and cleavages. The anorthite shows many enclosures, irregularly arranged.

Fig. 2. *Anorthite-olivine block* (magnified 26 diameters).

The photograph, taken with crossed nicols, shows the polysynthetic twinning of the anorthite, interrupted along lines of fracture, the optically simple olivine and the dark threads of glass between the crystals.

Fig. 3. *Norite* (*andes-norite*), Wallibu, St. Vincent (magnified 23 diameters).

This rock consists of nearly idiomorphic felspars, with many glass enclosures, augite, hypersthene, and iron oxide. Between the crystals there is a small amount of glassy base.

Fig. 4. *Calc-silicate hornfels*, Dry River, Lot 14, St. Vincent (magnified 33 diameters).

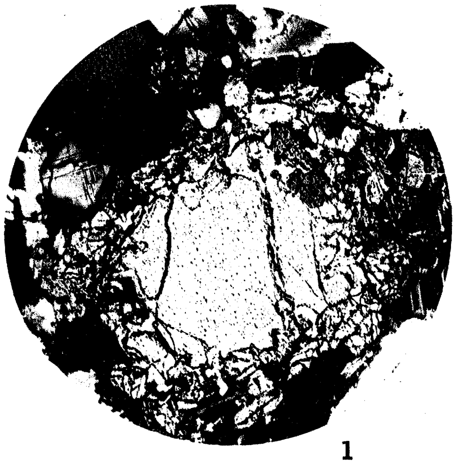
The fine grained matrix consists of granular augite, wollastonite, sphene, and felspar. The large anorthites show traces of idiomorphism, giving the rock a porphyroblastic structure; they contain many enclosures of wollastonite, augite, &c.

Fig. 5. *Hypersthene basalt*, River Bed, Lot 14, St. Vincent (magnified 14 diameters).

The olivine of this rock is weathered to serpentine and is represented in the photograph by dark patches. Hypersthene (idiomorphic) is seen below the centre to the left. The other porphyritic crystals are augite and plagioclase felspar.

Fig. 6. *Olivine basalt*, Richmond Point, St. Vincent (magnified 14 diameters).

This rock contains many small phenocrysts of olivine (partly decomposed), felspar, and augite in a finely crystalline groundmass.



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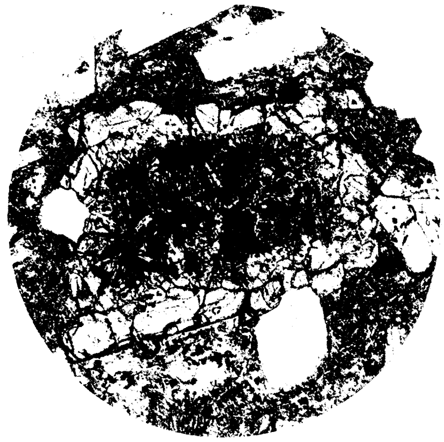

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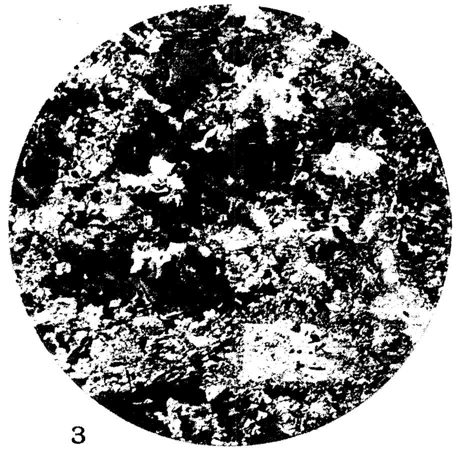

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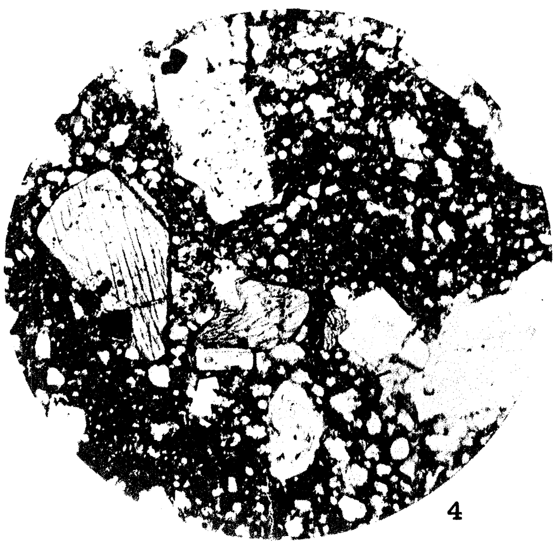

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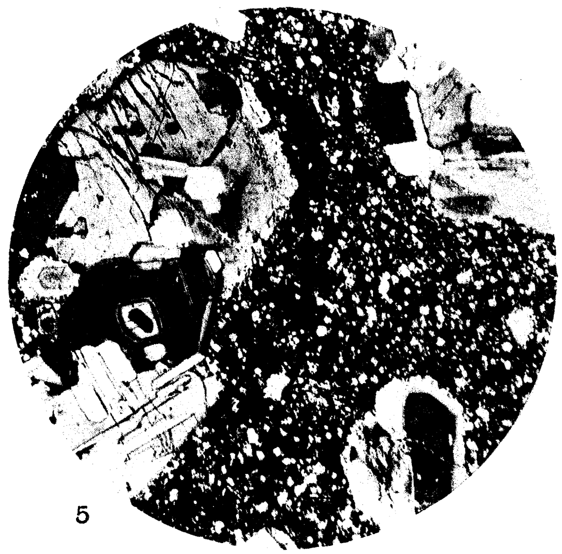

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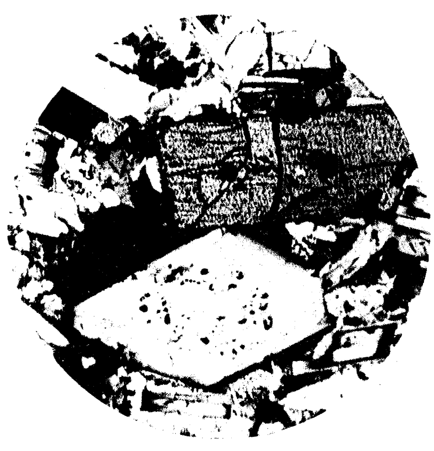

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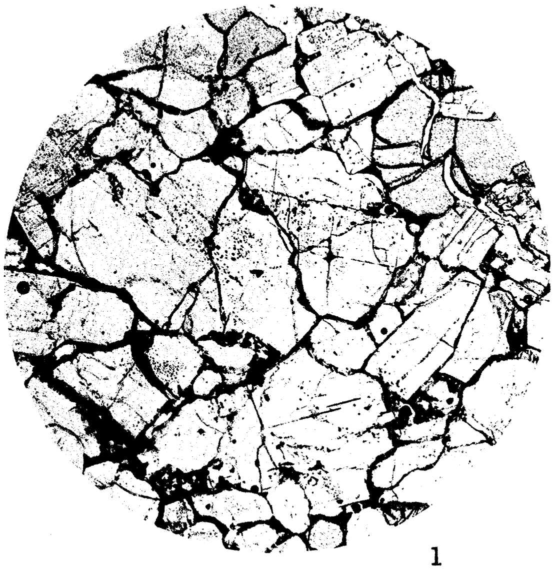

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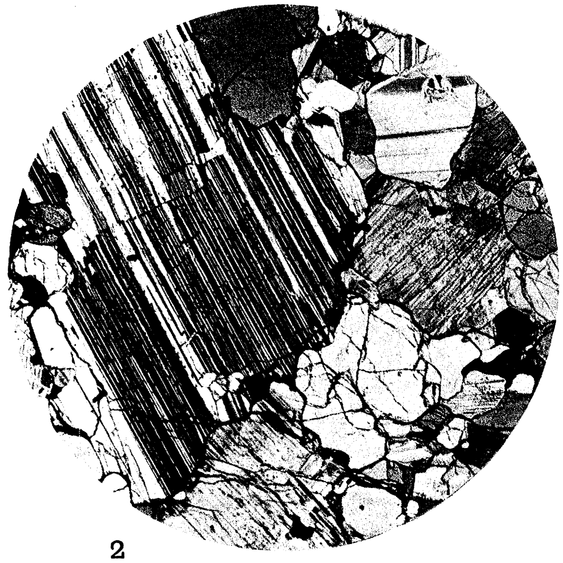

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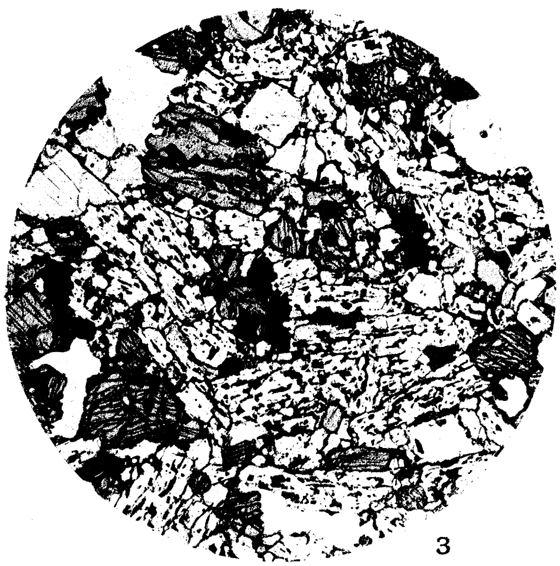

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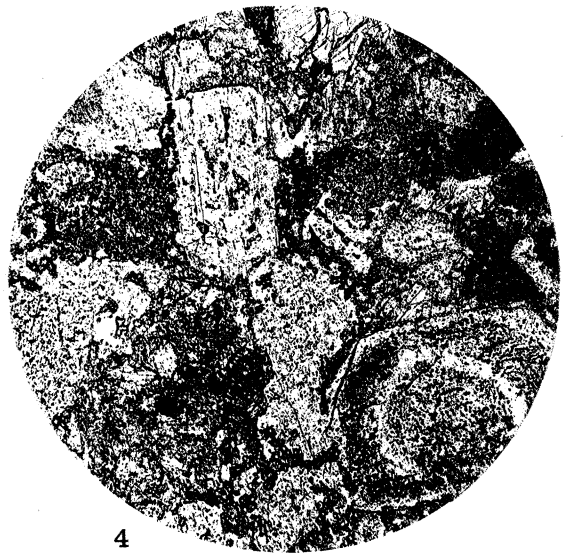

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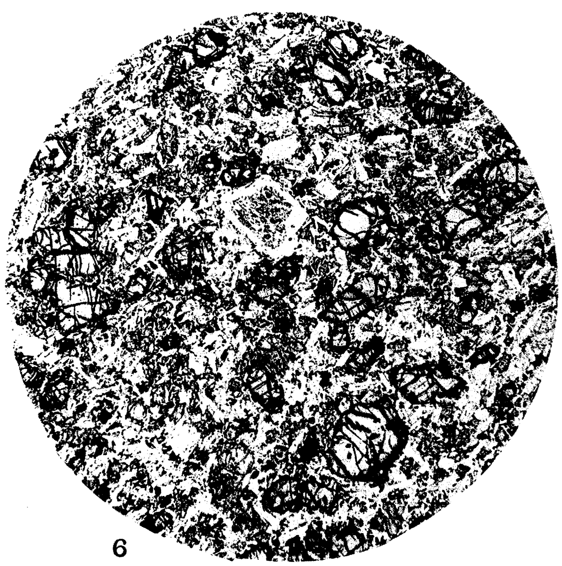

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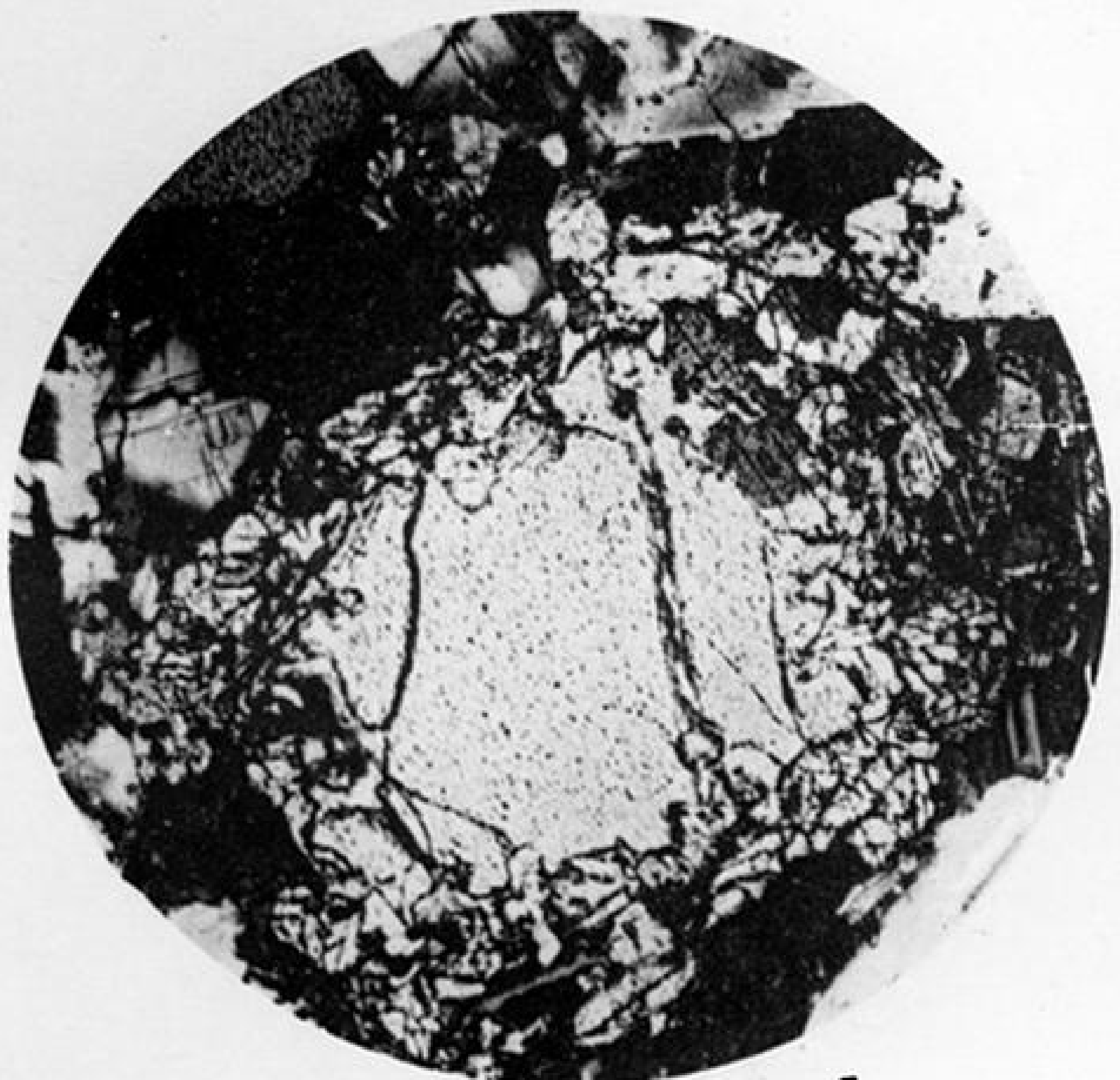

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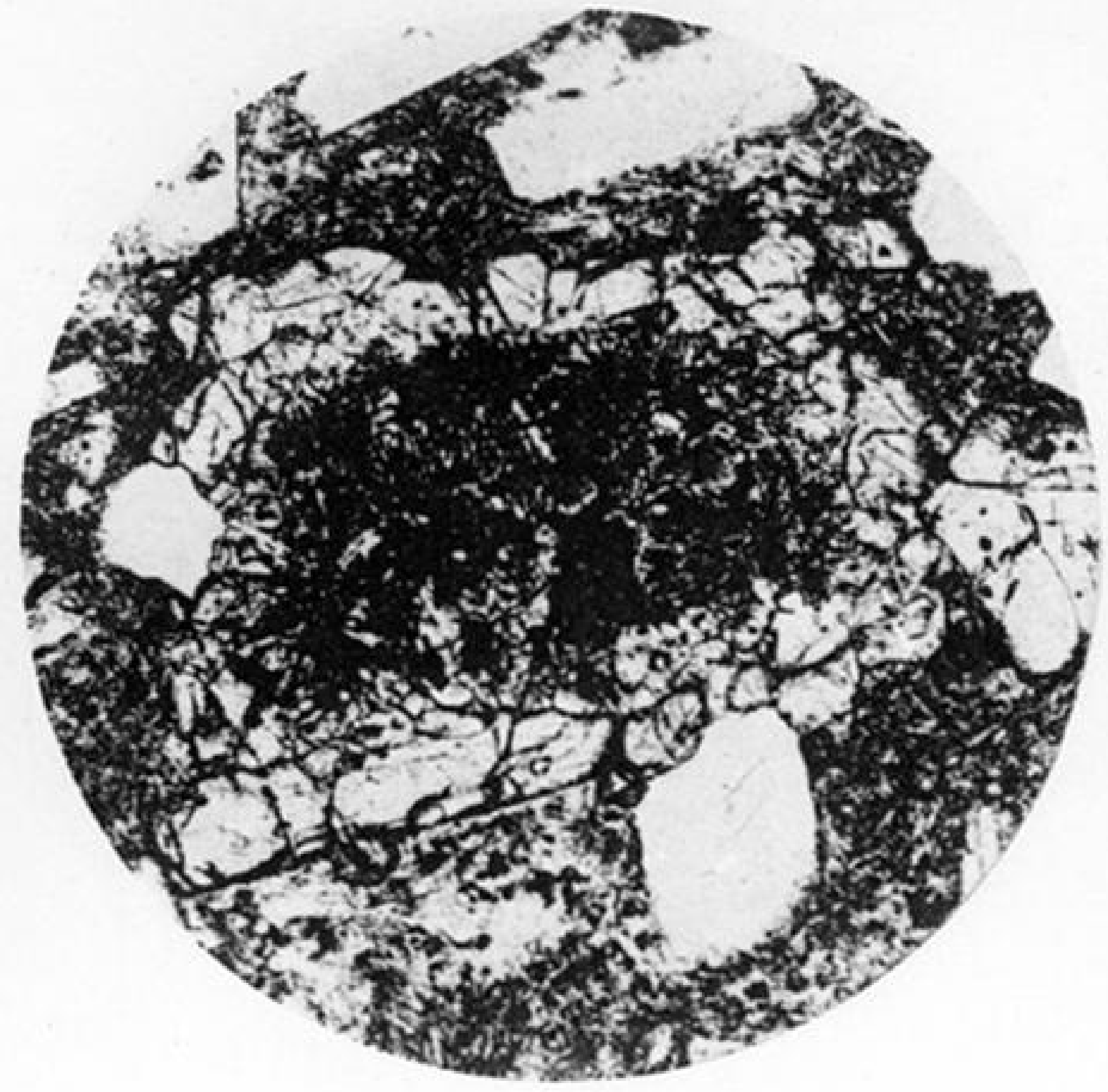

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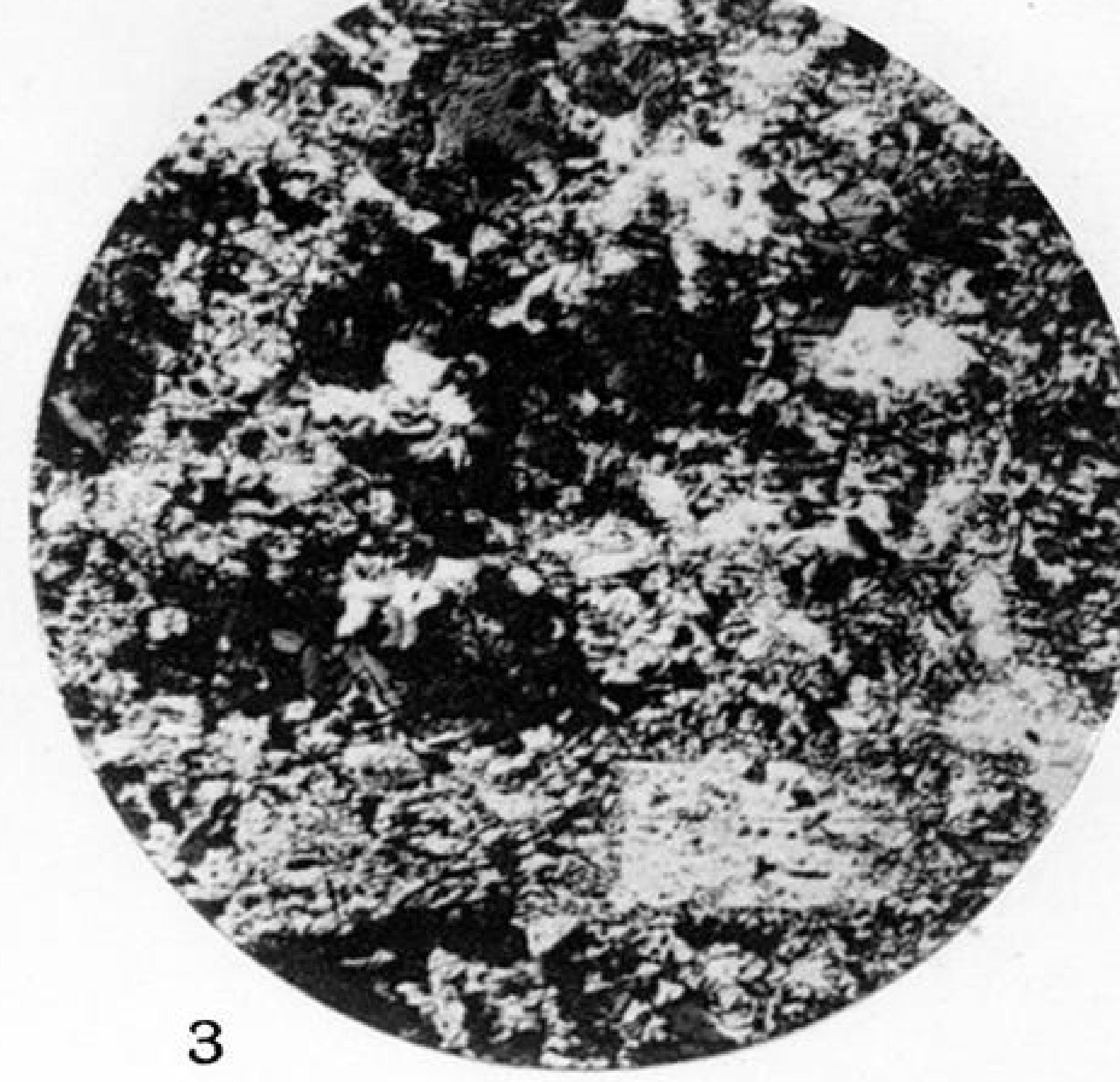

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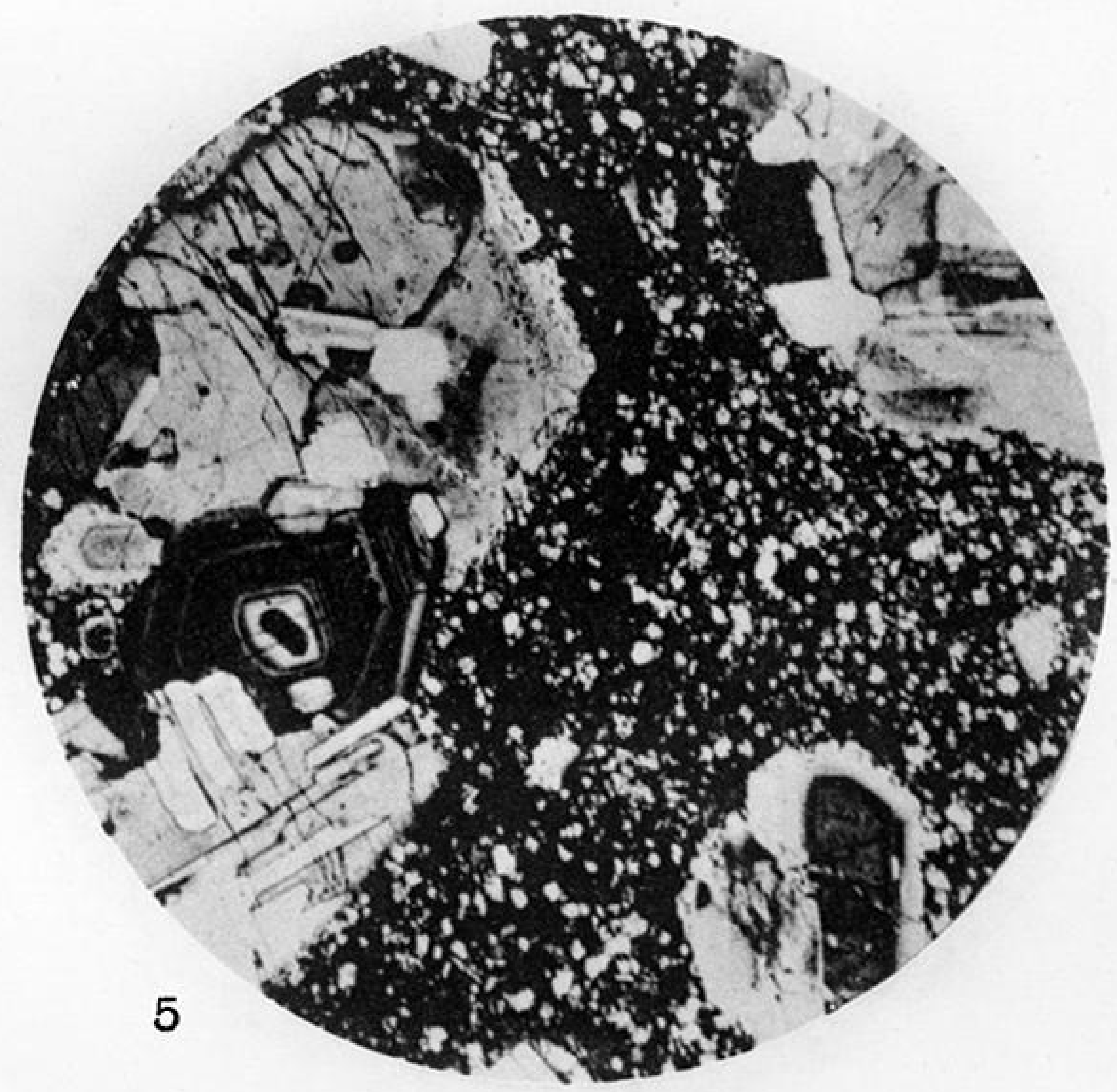

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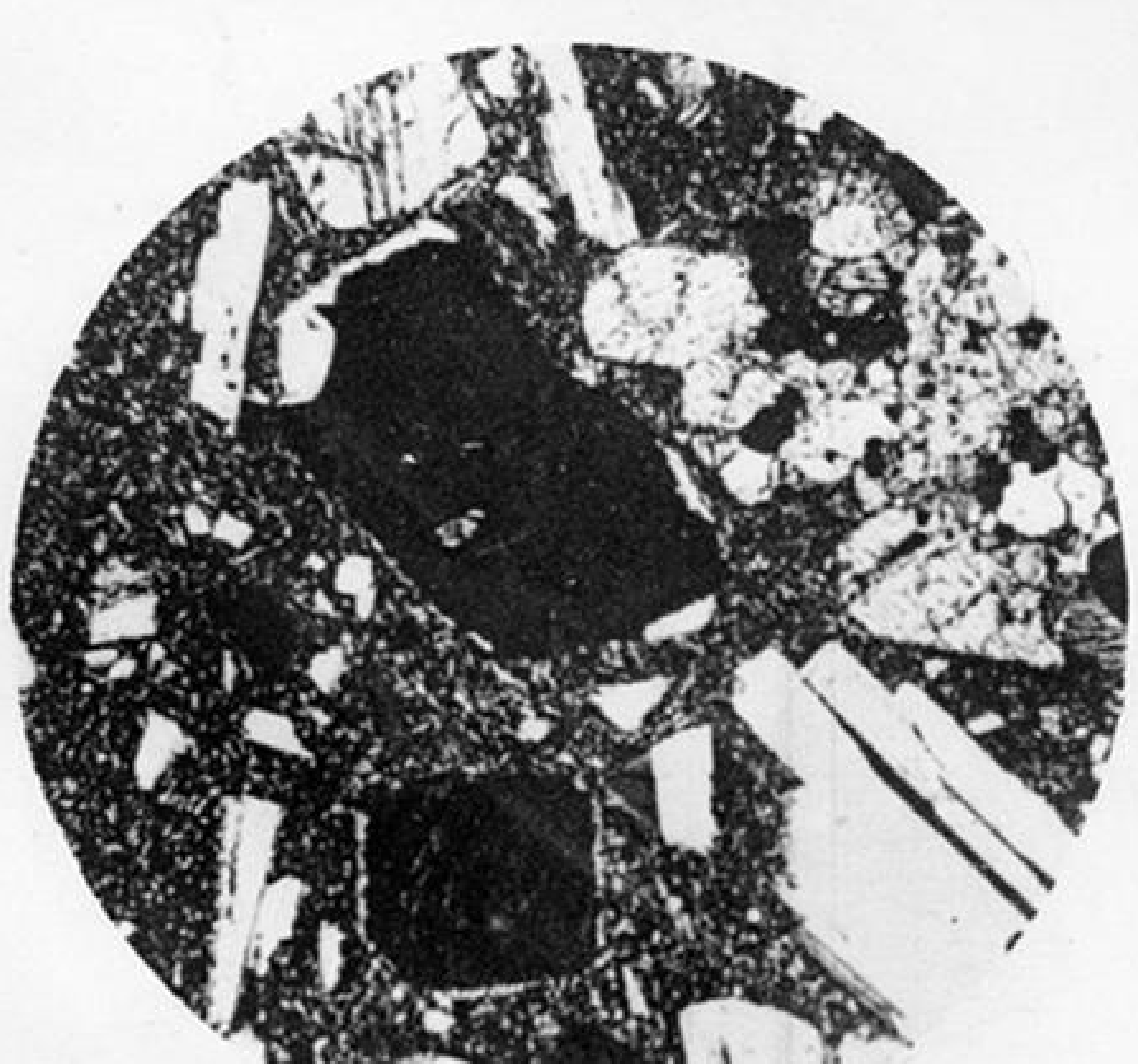

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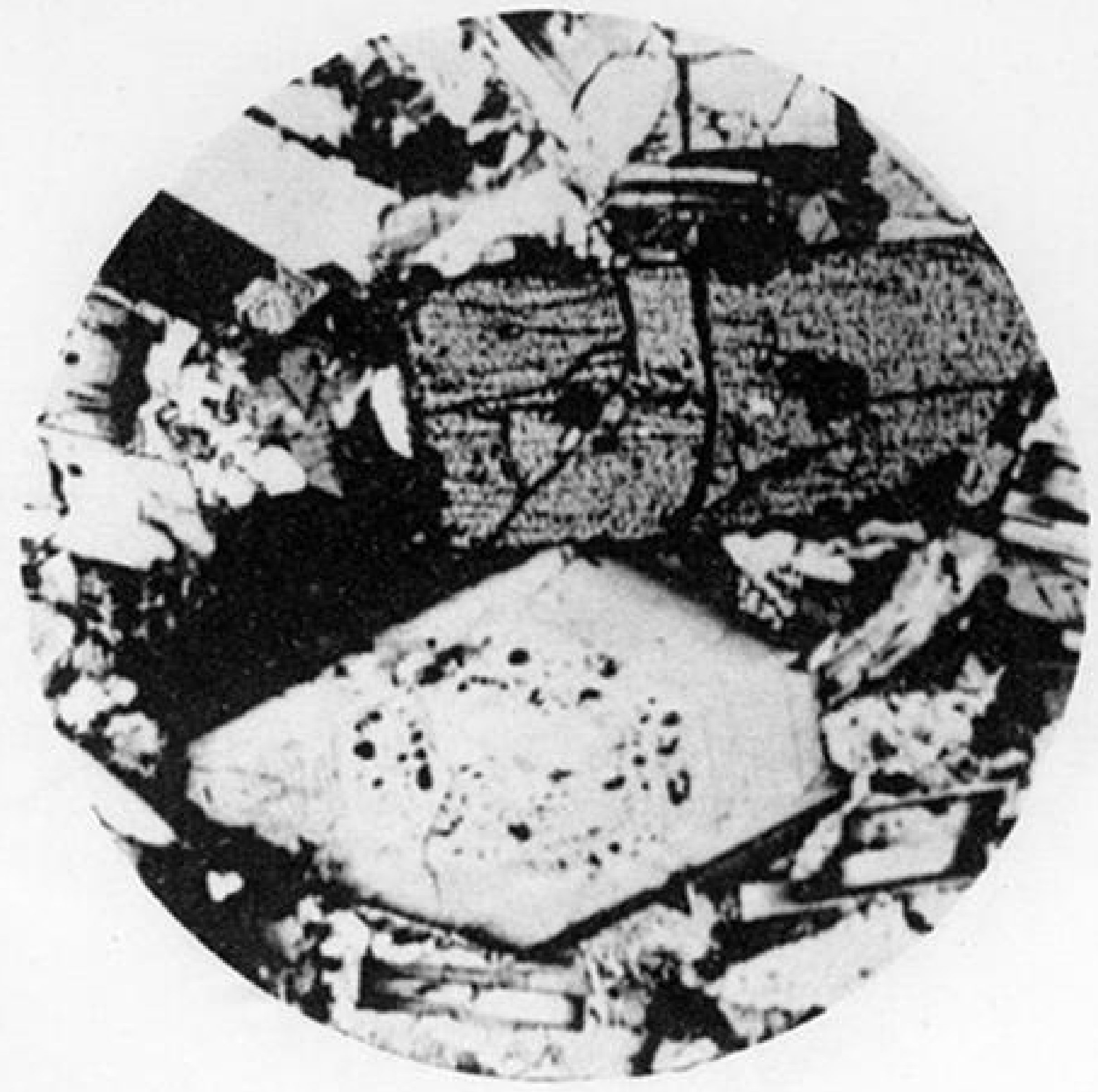

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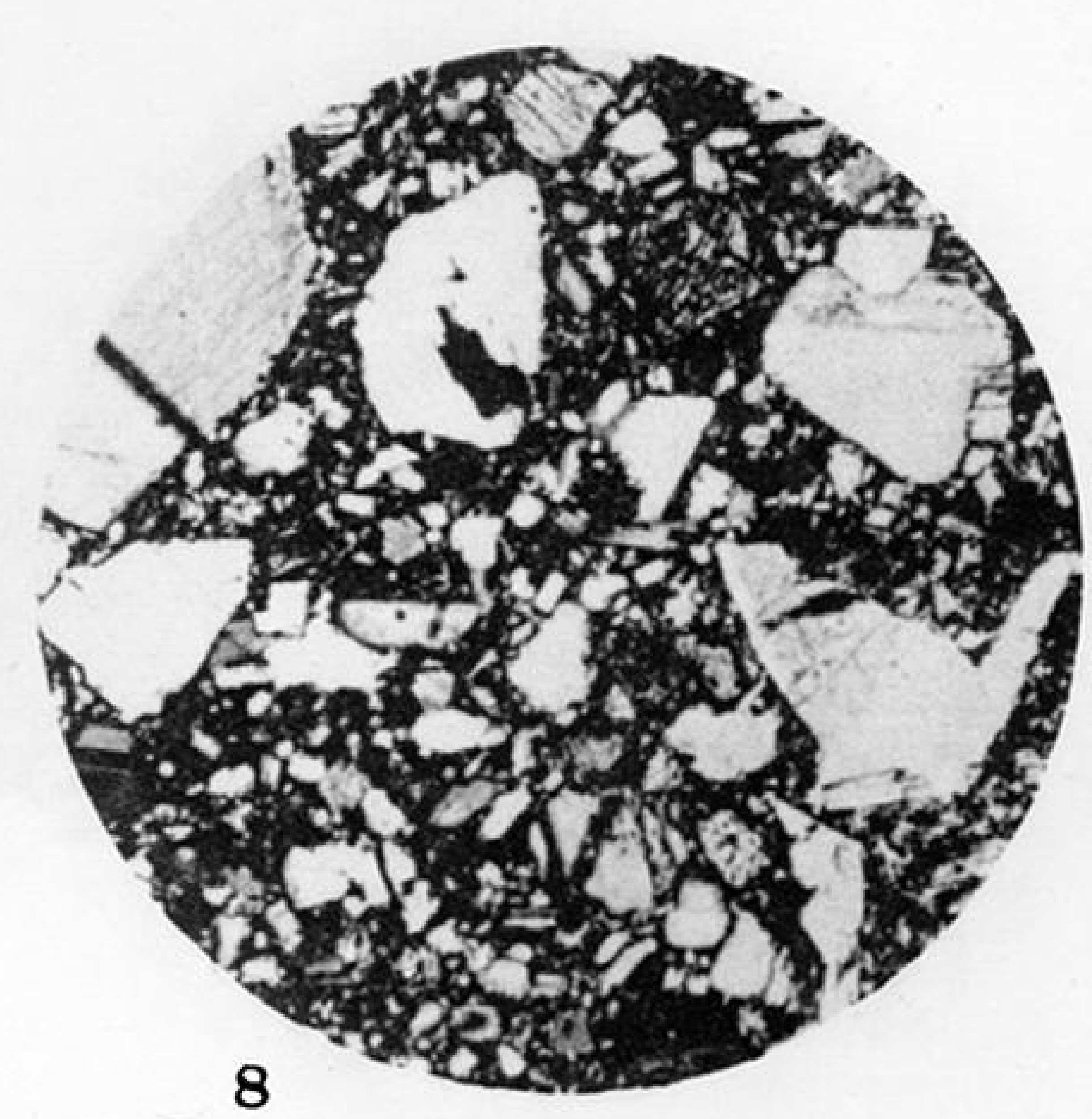

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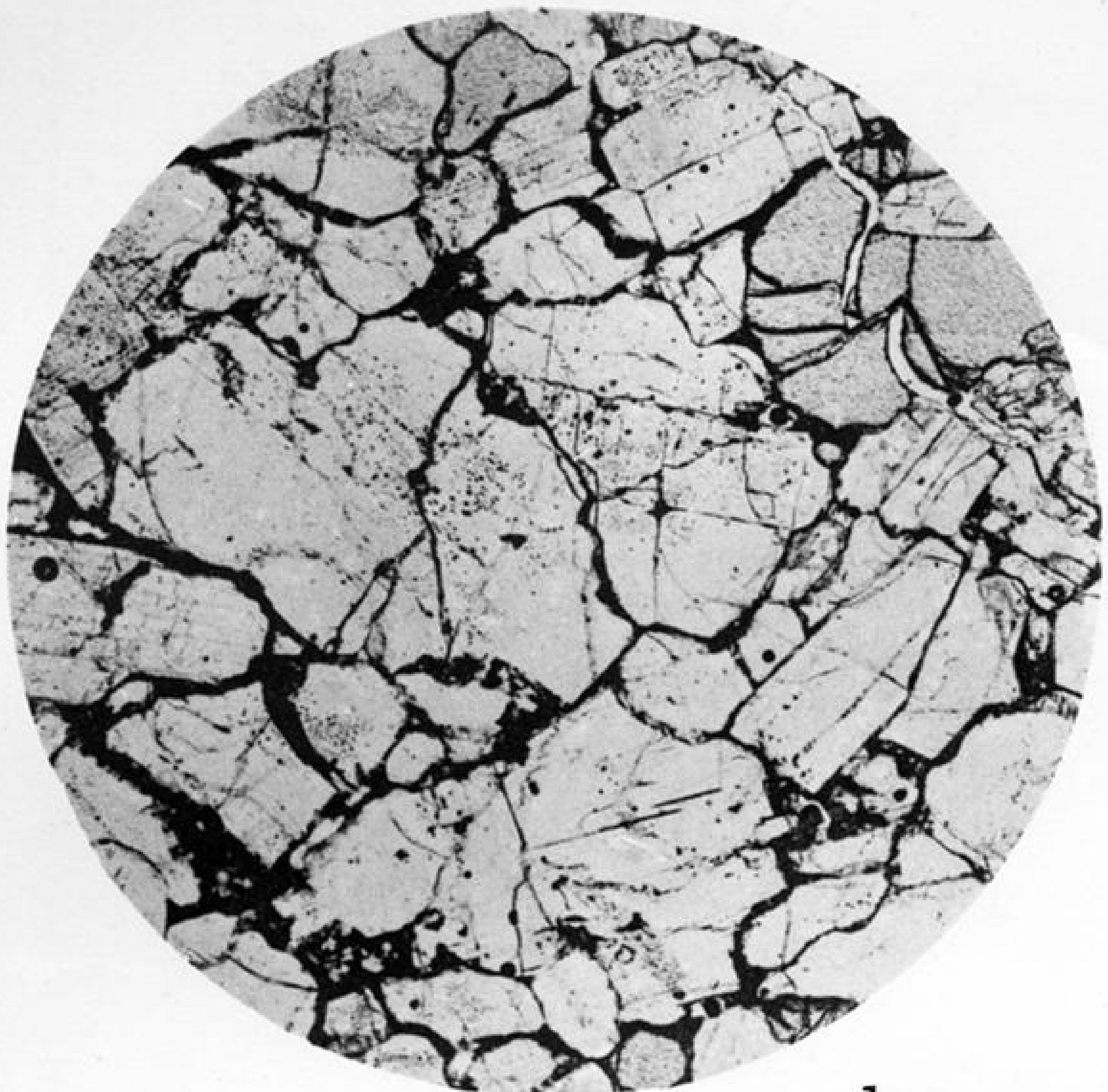

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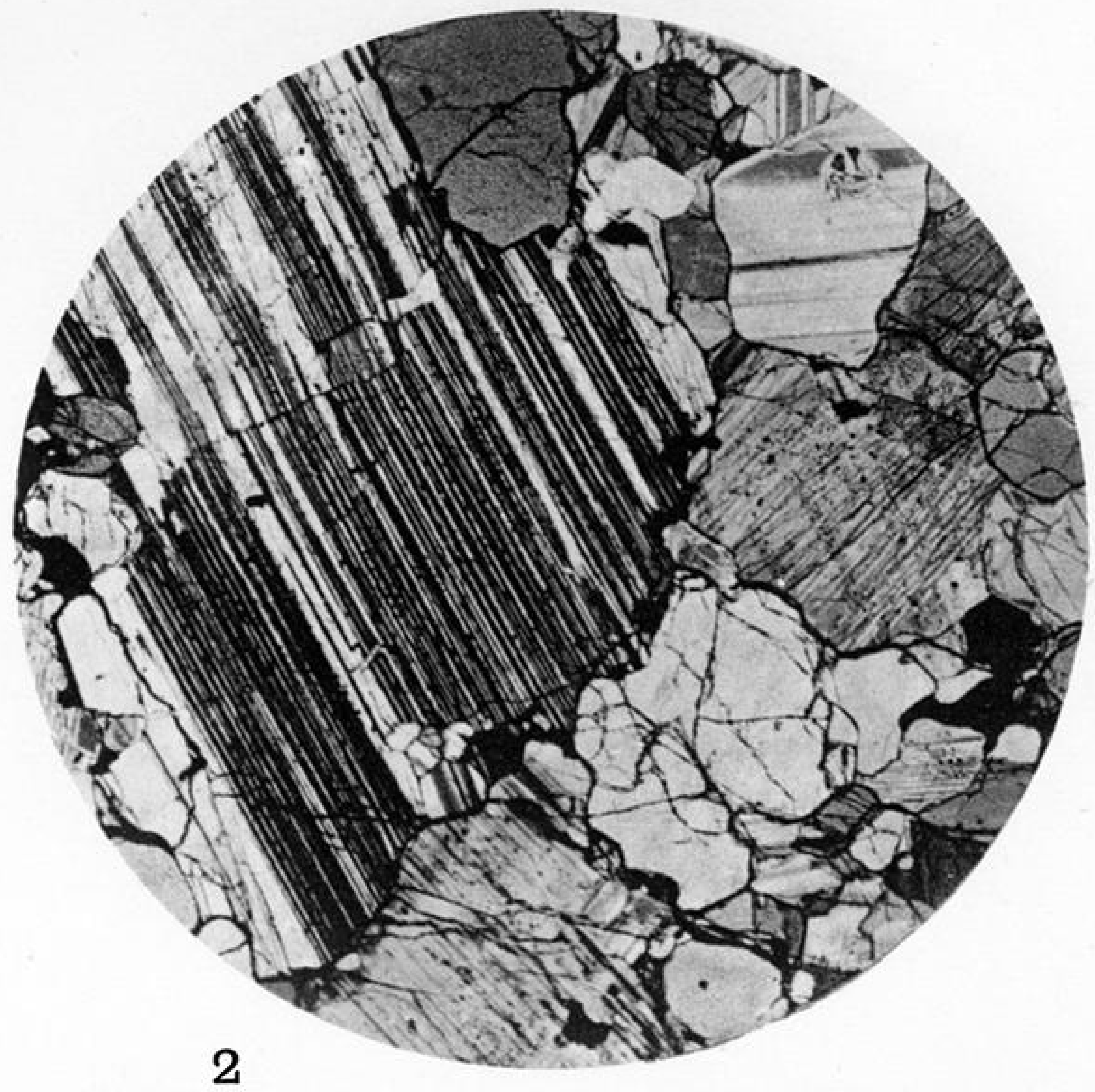

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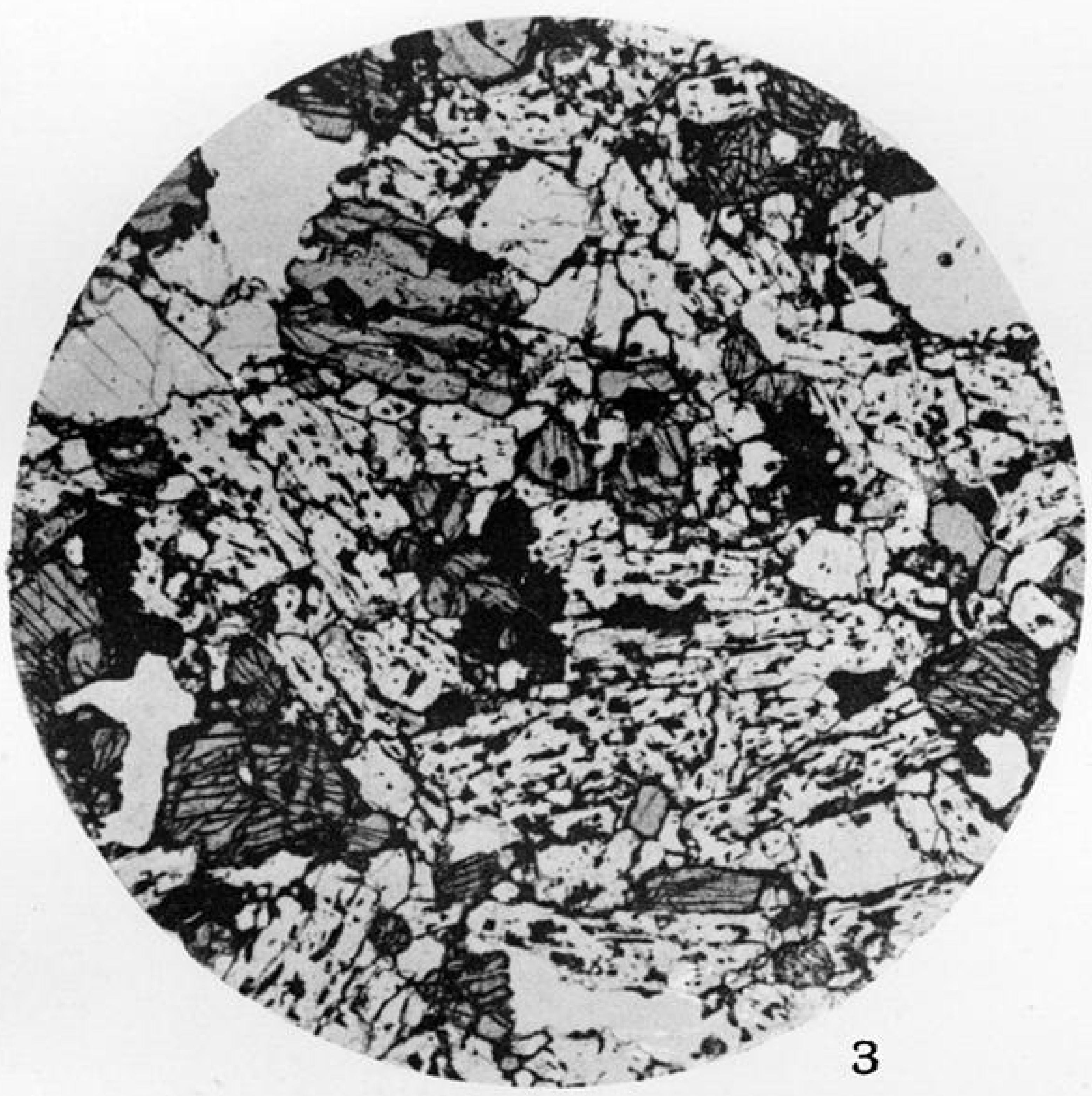

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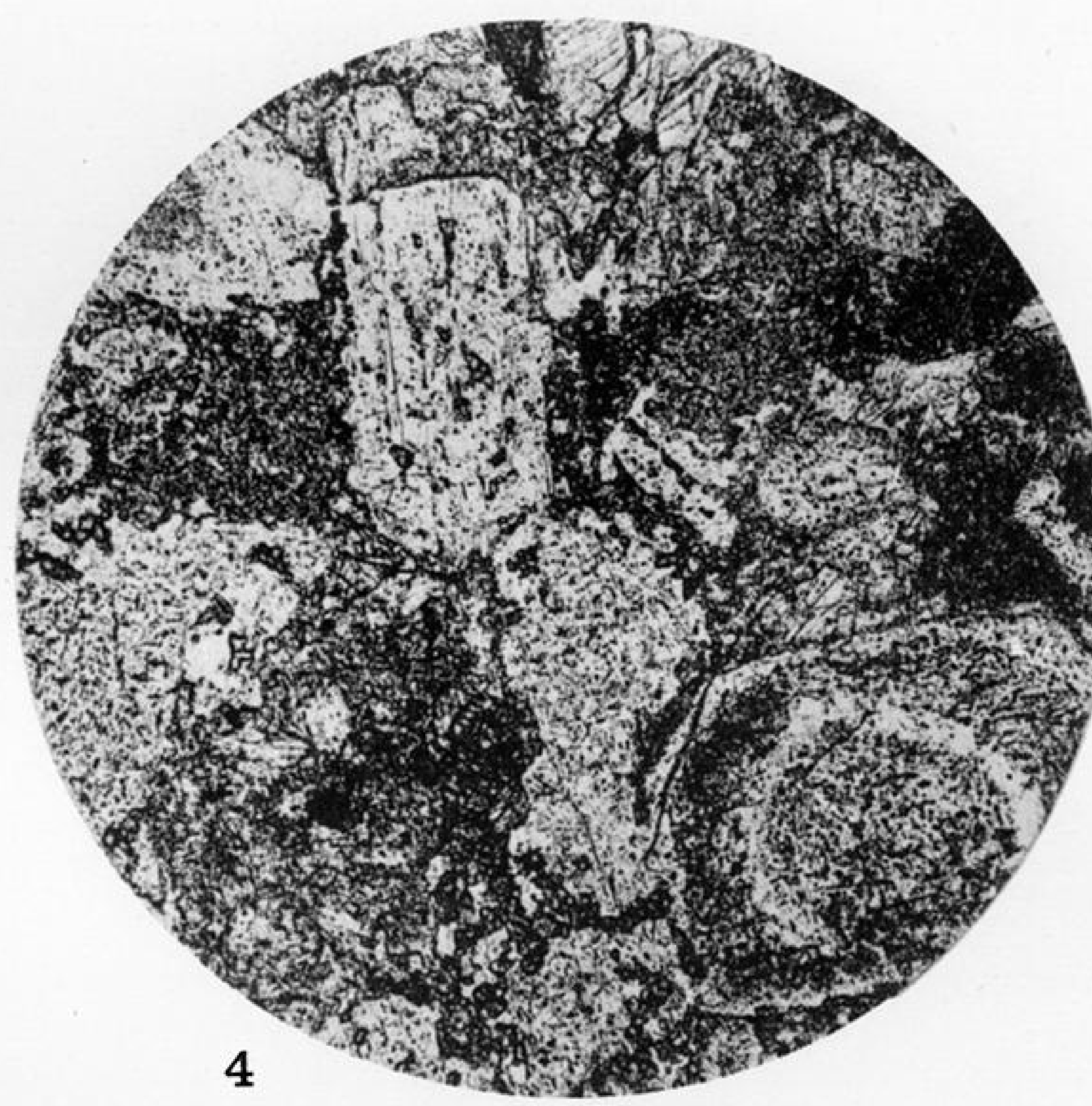

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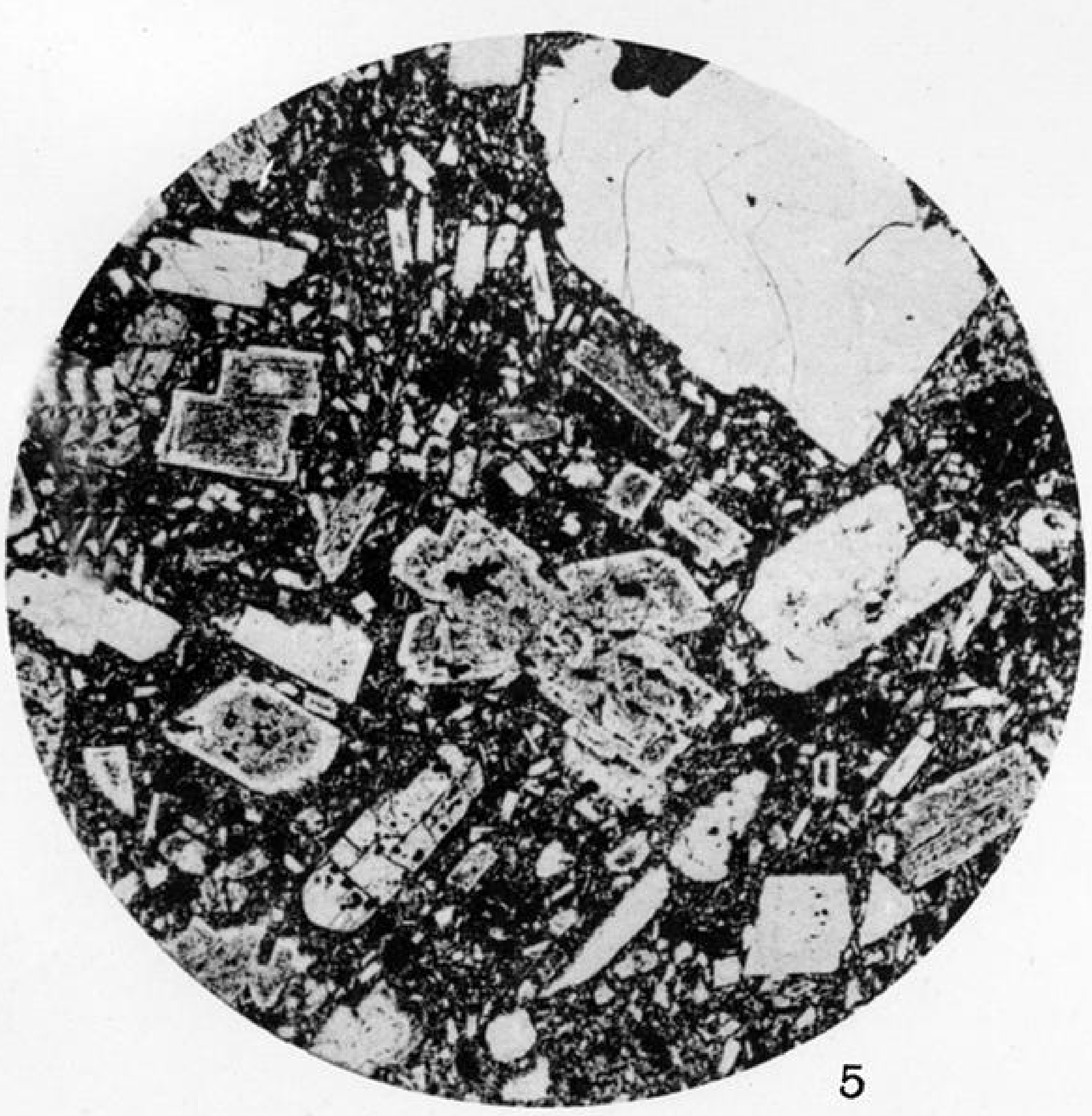

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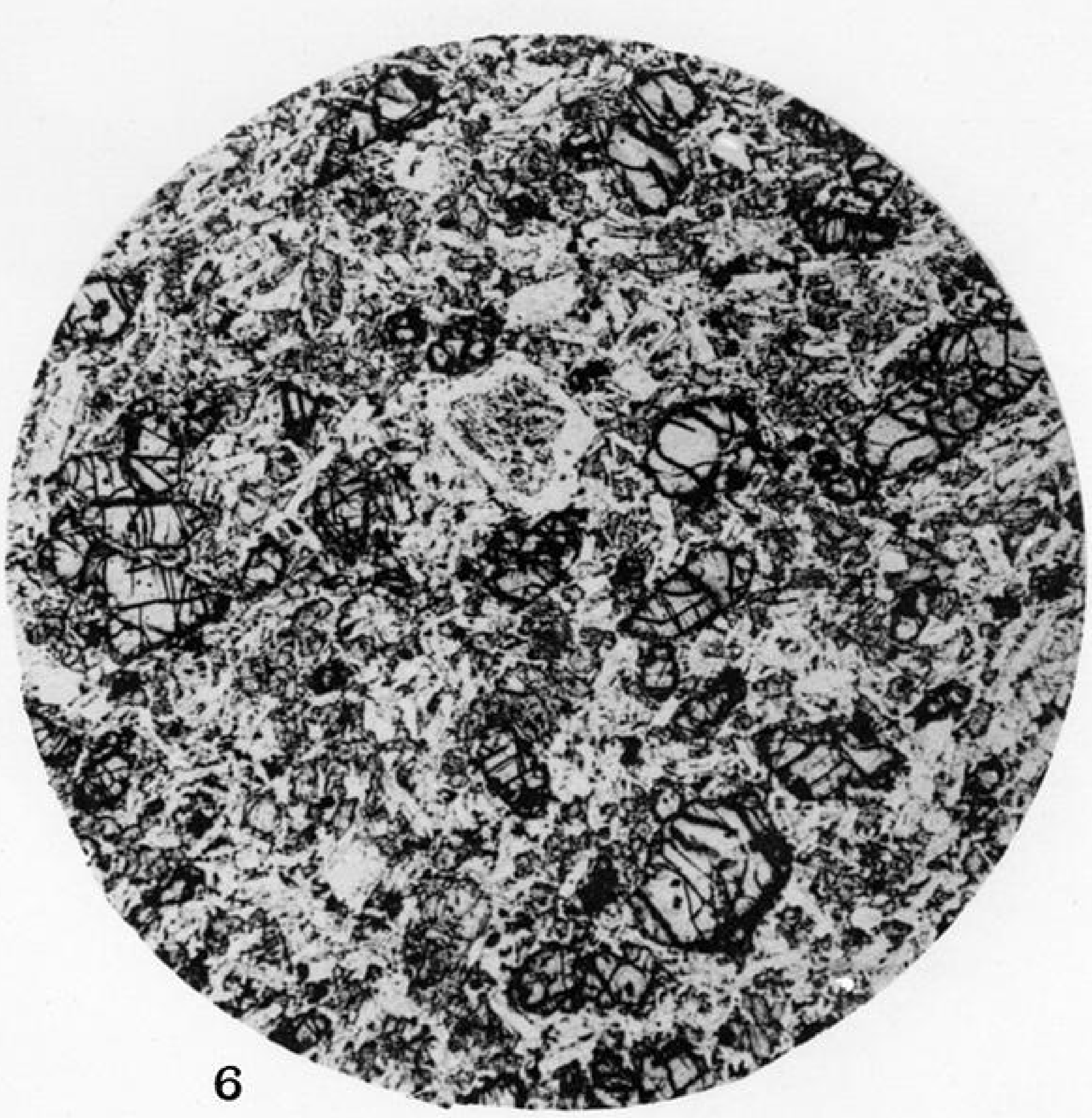

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