WELDED RHYOLITIC TUFFS OR "IGNIMBRITES" IN THE PASOEMAH REGION, WEST PALEMBANG, SOUTH SUMATRA

BY

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(With map XXIII and 9 figures).

GEOLOGY OF THE PASOEMAH REGION.

The Pasoemah region S of the Goemai Mts. in W. Palembang is largely occupied by Quaternary volcanics, which form a sharply dissected plateau-like country, whose surface gradually slopes downward in an ENE direction from ± 1000 m to ± 300 m above sea-level, conformably to the courses of the Selangis and Lematang Rivers above their point of confluence. Where the Lematang River unites with the Moelak River, the acid welded tuffs of the Pasoemah highland, to which attention will be drawn in this paper, are cut off by a steep bluff, formed undoubtedly by retrogressive erosion, which was substantially facilitated by the presence of vertical cleavage planes in the rhyolitic tuff series.

In the Goemai Mts., described elsewhere in detail by K. A. F. R. Musper (1937) and also dealt with by the present writer in a previous paper (J. Westerveld, 1941), a core of strongly folded lower-Cretaceous sediments, cut by various intrusiva, is covered unconformably by a steeply tilted series of Eogene or old-Miocene andesitic tuffs and breccias, the Lower Kikim tuffs, which again are covered with slight unconformity by the old-Miocene Upper Kikim tuffs or basal section of the Batoeradja-Telisa series. The base of the Pasoemah volcanics is generally formed by the S-ward dipping Telisa beds or upper part of the latter series; a monotonous sequence of Globigerina marls and shales with intercalated andesitic tuffs and breccias, layers of glauconitic sandstone, platy or concretionnary limestones, and occasional horizons with plant remains. Below the Quaternary tuff mantles this series unquestionably merges S-ward into the late-Miocene Lower Palembang beds, which only seem to be exposed quite locally at the bottom of the Selangis gorge NE of Pageralam (Musper, 1937, p. 41). The lower and thickest portion of the flat-lying, post-Tertiary, volcanic sequence is formed by welded rhyolitic tuffs, and the upper part by andesitic tuffs and agglomerates from the andesitic volcanoes, which border the Pasoemah highland on the W (G. Dempo), the S (the volcanoes of the Semendoh highland) and the E (the G. Isau-isau). Of these eruption points the Dempo volcano and the Semendoh volcanoes lie outside the map region.

STRUCTURE, PETROGRAPHY AND CHEMISTRY OF THE PASOEMAH "IGNIMBRITES".

Introduction.

The welded rhyolitic tuffs of the Pasoemah region have hitherto unvariably been denoted as "liparites" (A. TOBLER-E. GUTZWILLER, 1912, p. 28—29, 76—78; W. BRINKSCHULTE, 1922, p. 24—30; K. A. F. R. MUSPER, 1937, p. 71—73; J. WESTERVELD, 1941, p. 1139) since their discovery by A. TOBLER. Meanwhile, extensive occurrences of so-called "rhyolites" in northern New Zealand were recognized beyond doubt by P. MARSHALL (1935) as vast and thick deposits of welded tuffs, comparable in origin, although formed on a much larger scale, with the partly indurated rhyolitic sand-flow of the Valley of Ten Thousand Smokes in the Katmai region (Alaska), described by C. N. FENNER (1923, 1937) as the deposit of a singular type of "nuée ardente", which apparently issued from large fissures in the Valley region. FENNER (1937, p. 236), realizing the differences between the phenomena attending these acid eruptions of the Katmai region and those characterizing the well-known fiery clouds of Mt. Pelée on Martinique and of La Soufrière on St. Vincent, which latter carried unsorted andesitic material and apparently only produced shattered lava in chaotical mixtures of solid fragments of all dimensions, from fine ashes to coarse lapilli and enormous blocks, the latter especially on Mt. Pelée (A. LACROIX, 1904, p. 203—212, 350—360, 380—382; T. ANDERSON and J. S. FLETT, 1903, p. 428—434), separated the former kind of outbursts as the Katmaian type of eruption. MARSHALL proposed the general term "ignimbrite" for his welded tuffs of New Zealand, which as the rhyolitic Katmai tuffs were deposited in all probability in an incandescent and partly unconsolidated state. Almost at the same time as MARSHALL's discovery similar rocks were recognized by G. R. MANSFIELD and C. S. ROSS (1935) over extensive areas on both sides of the Snake River in SE. Idaho and in the adjacent part of S. Montana, where they are found as aprons on the flanks of various mountain ranges and on the valley bottoms, forming a vast tuff sheet, which adapts itself closely to the irregular topography of that region and consequently offers an aspect somewhat different from that shown by the "ignimbrites" of the Taupo-Rotorua district in N. New Zealand, whose surface forms a flat plateau, dissected by steep gorges and cut off by markedly precipitous margins. A few years later CH. M. GILBERT (1938) gave a detailed acount of a likewise extensive deposit of welded tuffs near Mono Lake in E. California, the so-called Bishop tuff, which fills a broad depression between the Sierra Nevada and the White Mts. The occurrence of tuffs belonging to the Katmaian type of eruption was furthermore considered probable by FENNER (1937, p. 257) for various areas inside the Yellowstone Park, from which region welded pumice had already been described and pictured by J. P. IDDINGS (1899, p. 404—406; 1909, p. 331—333) a few years before the Katmai eruption of 1912. IDDINGS was of the opinion that these rocks were originally rhyolitic pumice formed on top of a vast area of incandescent lava, which by its slow movement caused the porous glass particles to collapse and weld together. His pictures, however, clearly show that the samples investigated by him were welded tuffs comparable in many respects with the New Zealand "ignimbrites". The discovery, moreover, of welded tuffs of the "ignimbrite" type at the base of the Triassic Ipswich Coal Measures near Brisbane (Queensland) by H. C. RICHARDS and

W. H. BRYAN (1933), who had taken cognizance of MARSHALL's results in New Zealand, proves that "nuées ardentes" of the Katmaian type have also been actively forming pyroclastic deposits in former geological periods.

A comparison of his report on a geological survey of the Pasoemah region (1933) with MARSHALL's description led the present writer to the conviction that the pretended "liparites" of this highland might presumably be considered as homologues of the New Zealand "ignimbrites". In order to test this supposition by microscopical evidence, an appeal was made to the Museum of Natural History at Basel (Zwitserland) in order to obtain fragments of A. TOBLER's specimens, collected at S. Are and A. Lim Ketjil and described by E. GUTZWILLER (1912, p. 76—78). They were kindly forwarded by Dr. W. BERNOUILLI, director of the geological section of that Institution, to whom the writer wishes to express his sincere gratefulness for helping him to overcome war-time conditions, which did not allow him to get into touch with his own field collection, kept at Bandoeng (Java).

General appearance and macrostructure of the deposit.

The acid tuffs of the Pasoemah region occupy an area of at least 800 km² and are exposed in steep bluffs along the gorges of A. Selangis, A. Lematang, A. Pasemah, A. Endikat, A. Lempoeng, A. Moelak, A. Lim, S. Are and various tributaries (figs. 2, 3, 4) [1]. The northern boundary of their area of extension faithfully follows the southern contours of the steeply rising Goemai Mts., while the southern limits of the deposit are unknown and buried below the mantles of later andesitic volcanoes. Where observable, the thickness of the pseudo-lavas amounts to at least 50 m. Their main field aspects are an almost complete lacking of horizontal parting planes, a conspicuous development of coarse and vertical columnar jointing, a flat top level (figs. 1, 2), and the absence of scoracious or obsidian crusts, which might be expected along the sides of an acid lava flow. The rock generally has a light gray colour, a glassy or stony appearance, frequently a greasy luster, and besides a great number of clear feldspar "phenocrysts". Enclosed fragments of gray claystone and greenish effusive rocks are also rather common, while the less compact varieties yield easily to a stroke of the hammer and show coatings of iron oxyde on the planes of fracture. At various places (A. Moelak, A. Selangis, A. Loekoh, A. Dendan) the compact variety of these rocks was observed to be covered by light gray, more or less loosely aggregated, glassy tuffs, which microscopically appeared to show the same lithological composition as the indurated varieties.

All structural features together give the impression that the whole deposit of rhyolitic tuffs has been formed by one or two major eruptions. In its main field characteristics, as absence of horizontal parting and the development of columnar jointing, it closely resembles the welded tuffs of N. New Zealand (MARSHALL, 1935, p. 326—330). Columnar jointing, among other examples, has also been noted in some sections of the Triassic Brisbane tuff by RICHARDS and BRYAN (1933, p. 51—54) and besides appeared to be a common feature of the Bishop tuff near Mono Lake in E. California. The Bishop tuff, however, at some places shows a few horizontal parting planes at intervals of 75—200 ft, each succeeding pair apparently representing the upper and lower boundary planes of a deposit formed during one single and

[1]) A means Aer (water or river); S. = Soengei (river). The "oe" of Netherlands orthography to be pronounced as the English "u".

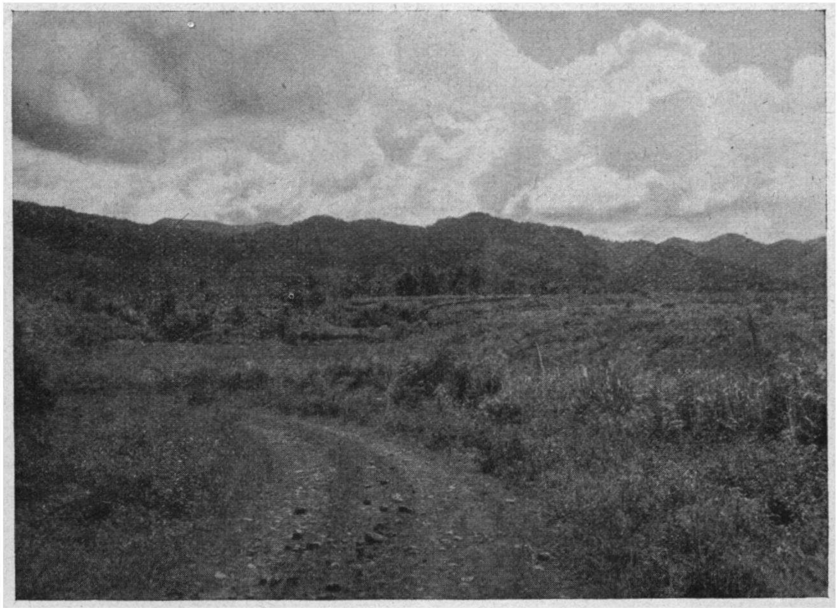

Fig. 1.

View on the Goemai Mts. over the NW. corner of the Pasoemah highland N of Pageralam, taken from the right bank of A. Dendan, the sharply incised valley of which is seen in the foreground on the left. The highest tops of the Goemai Mts. consist of old-Miocene andesitic breccias and tuffs, the lower slopes of old-Miocene Telisa shales and marls, while the top level of the plateau volcanics is occupied by late-Quaternary andesitic tuffs and breccias, which lie above the Pasoemah "ignimbrites" and related rhyolitic tuffs.

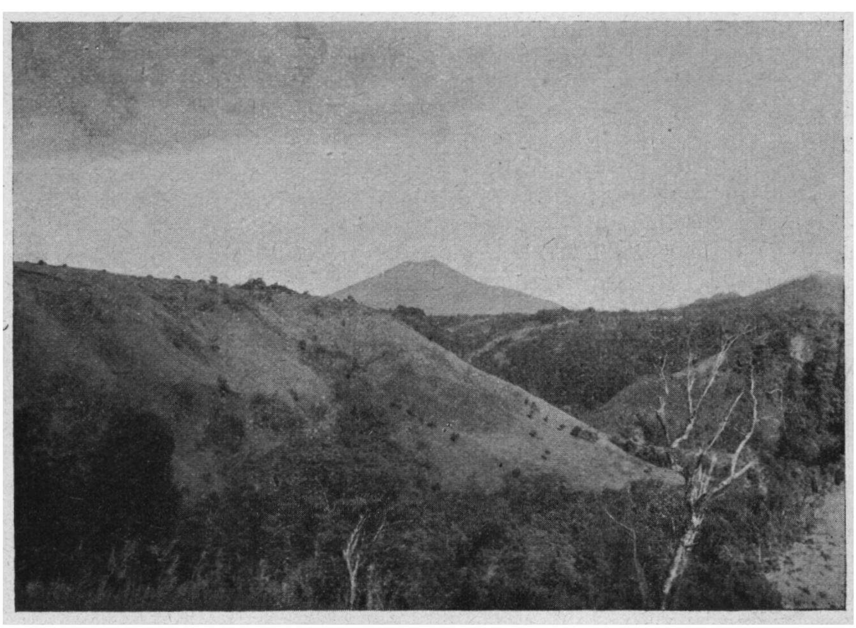

Fig. 2.

West-ward view into the Selangis Valley from a point on the right bank of this gorge S of the mouth of S. Are. The andesitic Dempo volcano is seen in the background above the plateau-like top level of the Pasoemah highland. The grass- and wood-covered slopes on both sides of the valley consist mainly of welded rhyolitic tuffs, except the top party, which consists of andesitic products of the latest eruptions. A bit of the southern slope of the Goemai Mts. can still be seen on the right above the plateau surface.

separate eruption. Prismatic cleavage has sometimes developed over the entire thickness of this latter deposit, but it may also be lacking or restricted to a single horizon (GILBERT, 1938, p. 1833—1838).

No sufficient observations are as yet available to conclude whether the loosely aggregated glass tuffs which sometimes form the top levels of the acid Pasoemah tuff stream merely represent a less compressed top facies of the same deposit or whether they are the product of a later eruption. The former relationship is suggested by observations made by MARSHALL (1935, p. 339, 340, 350—352) in N. New Zealand, where an increase of the degree of compaction from top to bottom, manifesting itself by an increase of the specific weight of the volcanic rock and a decrease of its porosity, was noticed in a couple of vertical "ignimbrite" sections. Similar observations were made by GILBERT (1938, p. 1833—1838) in E. California, where the groundmass of the Bishop tuff shows a higher degree of induration in the lower beds of the deposit, which phenomenon is accompanied by a flattening of enclosed pumice fragments according to the horizontal plane as the result of stronger compression.

Petrography of the Pasoemah "ignimbrites".

E. GUTZWILLER (1912, p. 77, 78) described plagioclase, with the composition of oligoclase-andesine and frequently displaying zonal extinction, as the most common "phenocryst" in "liparites" of S. Are and A. Lim Ketjil. The crystals were said to have dimensions of 1—3 mm and to be followed in order of abundance by monoclinic augite, green hornblende, brown biotite, orthoclase, grains or small aggregates of magnetite, zircon and quartz, all embedded in a "felsitic" groundmass, in which could be distinguished microlites of plagioclase, quartz (?), biotite (?), hornblende, magnetite and zircon. Among foreign inclusions were mentioned fragments of liparitic to andesitic rocks with pilotaxitic, microgranitic or felsitic structure, imparting a seemingly tuffaceous character to the rock of S. Are. W. BRINKSCHULTE (1922, p. 24—30), who studied two "liparite" samples from the upper Lematang and another three from the Endikat River, both sets taken at their point of intersection with the highroad from Lahat to Pageralam [1]), emphasized the seemingly tuffaceous appearance of the yellowish and porous A. Lematang specimens. Numerous crystals of alleged sanidine, with dimensions of 2—5 mm and followed in order of abundance by plagioclase (of the composition of Ab_2An_3), large individuals of magnetite and isolated grains of hypersthene and hornblende, were mentioned by this author among the enclosed crystals of the rocks from both localities. The "vitrophyric" or, as the result of a beginning of crystallization, partly "microfelsitic" groundmass was said to be characterized by an alternation of cloudy and brownish patches and clear spots, and besides by a "fluidal" structure effected by the occurrence of glass streaks, the latter frequently curved around the larger and dark parts of the thin sections. The development of "pseudospherulites" was observed around the dark streaks, while the enclosed fragments of foreign rocks were described as of an andesitic nature and giving the rocks a tuffaceous appearance. The presence of fluidal structures, however, was thought sufficient evidence to consider them as lavas.

According to the present writer's own preliminary investigation of a great many "liparite" specimens from A. Lematang, A. Selangis, A. Moelak,

[1]) BRINKSCHULTE's samples were gathered in 1915 by Dr. H. M. E. SCHÜRMANN.

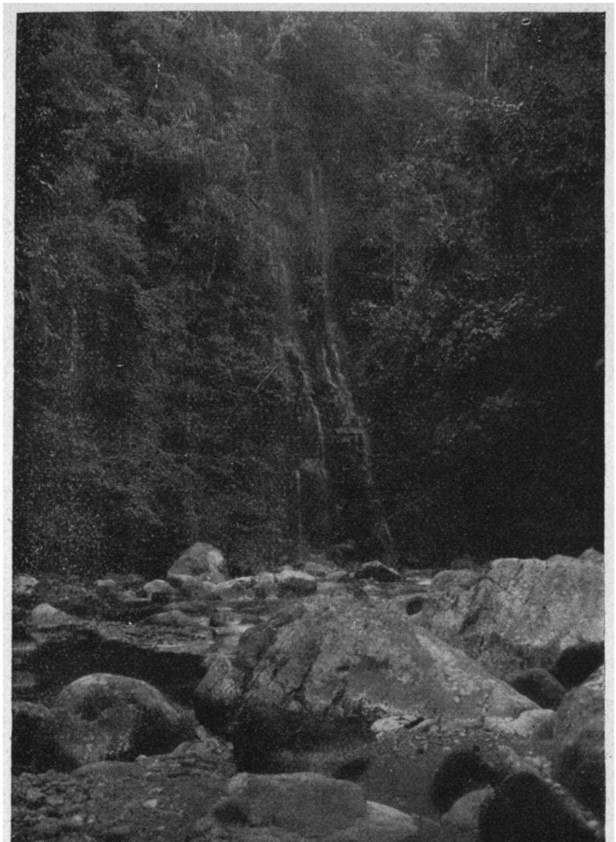

Fig. 3.

Water-fall over steep wall of welded rhyolitic tuffs on the left bank of A. Loekoh near its point of confluence with A. Selangis.

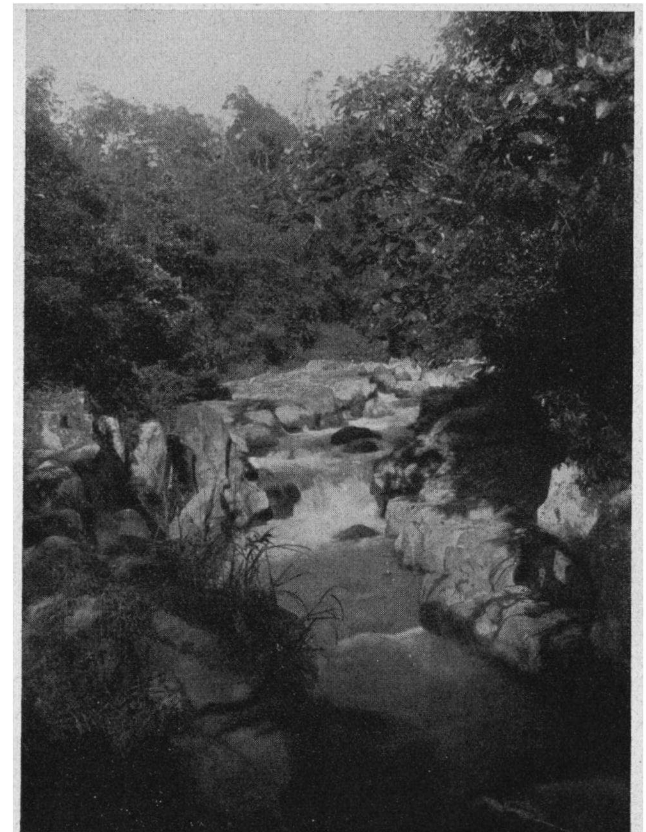

Fig. 4.

Columnar jointing in "ignimbrites" along the lower course of A. Lim.

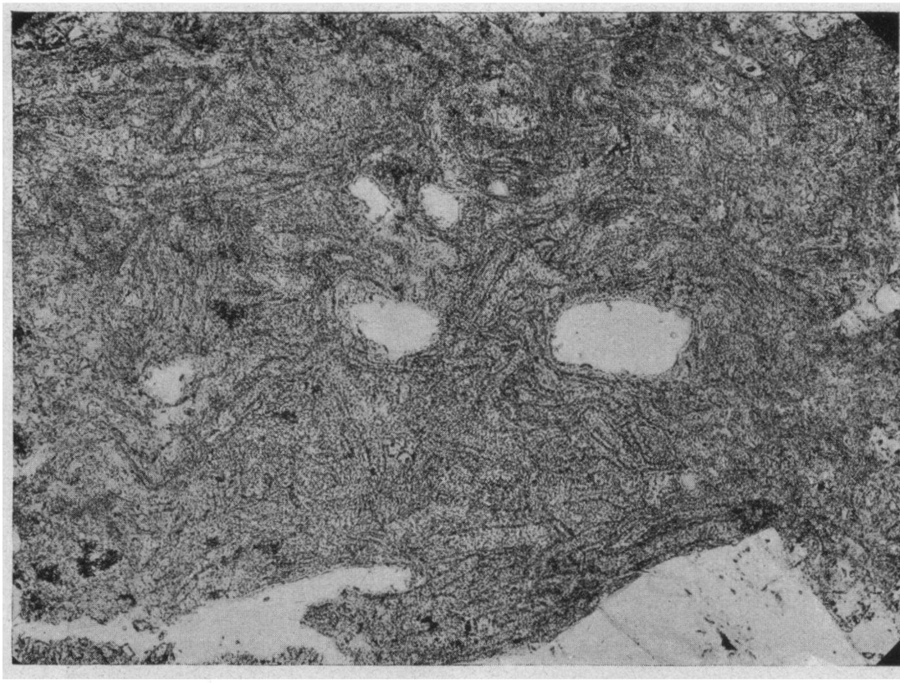

Fig. 5.

Microphoto of rhyolitic tuff with distinct "ignimbrite" structure. Contours of crystallized glass shards, consisting of fine-grained crystal growths of albite, tridymite and scattered flakes of biotite and presumably haematite, are clearly visible. In the centre of the picture a couple of open vesicles lined with minute albite and tridymite crystals. Plagioclase crystal in the right hand lower corner. Sample taken by A. TOBLER at S. Are (near its point of confluence with A. Selangis) and first described by E. GUTZWILLER (1912, p. 77, under No. 31). Magn. × 52.

Fig. 6.

Lining of six-sided tridymite crystals, partly covering each other in the manner of roof-tiles, along wall of open vesicle in "ignimbrite" sample from S. Are (same as pictured in fig. 5). Magn. × 885.

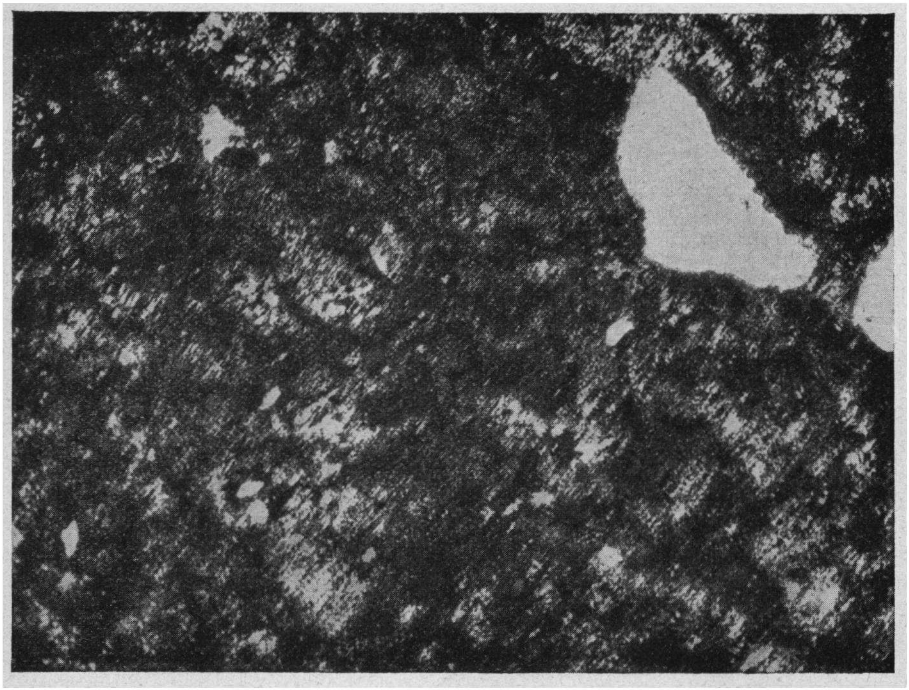

Fig. 7.

Microphoto of "ignimbrite" structure in sample of welded rhyolitic tuff from A. Lim Ketjil (near the village Goeroeagoeng), taken between crossed nicols and clearly revealing the grouping of minute birefringent crystal specks of albite into small curved areas with the contours of crystallized glass shards of the type visible in fig. 5. Sample taken by A. TOBLER and first described by E. GUTZWILLER (1912, p. 77, 78, under No. 32). Magn. × 59.5.

Fig. 8.

Microphoto of "ignimbrite" from S. Are (same as pictured in fig. 5), showing enclosed fragment of effusive rock with plagioclase microlites surrounded by crystallized glass shards. Crossed nicols. Magn. × 85.

A. Lim and their tributaries [1]), the result of which in many respects agrees with the foregoing descriptions, plagioclase (oligoclase-andesine, frequently showing zonal extinction) is the most abundant "phenocryst" in these rocks, whereas the presence of potash feldspar was only noted in a few instances, so that, in his opinion, BRINKSCHULTE has very probably been in error when designating the main feldspar as sanidine. BRINKSCHULTE's description of the latter mineral, alleged to show in part a zonal extinction as the result of a zonal shifting of the relative percentages of K and Na, and his chemical analyses of two "liparites" (see next paragraph) support the present writer's view that most of this "sanidine" must in reality have been acid plagioclase. Other, less abundant, "phenocrysts" observed by the writer were hypersthene, greenish hornblende, magnetite (frequently in well-developed octahedrons) and biotite (rare), while apatite was seen in small needles. Most of the investigated specimens also contained enclosed fragments of brownish unaltered claystone (presumably from the old-Miocene Telisa series in the Barisan Mts.) and of silicified or sericitized rocks and glassy or andesitic effusiva. Loosely aggregated tuffs of a readily discernible pyroclastic nature, found on top of the indurated pseudo-lava, e. g. along A. Moelak, A. Selangis, A. Loekoh and A. Dendan, showed the same petrographical composition as the "liparites" mentioned before.

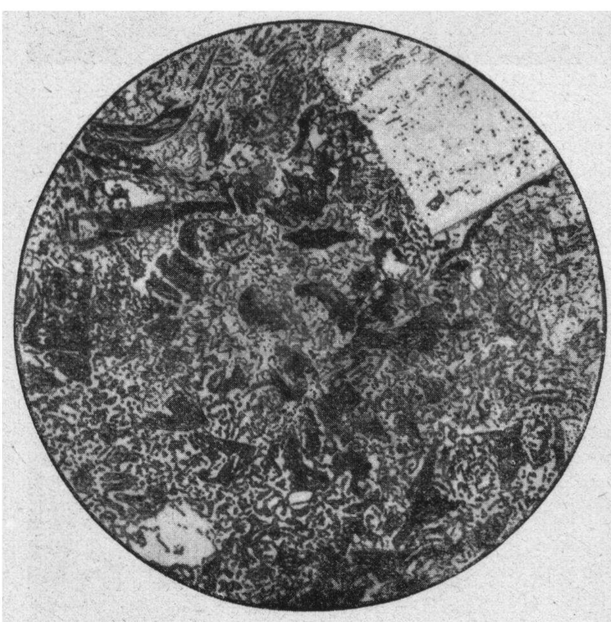

Fig. 9.

Micropicture of rhyolitic tuff from the point of intersection of the highroad Lahat-Pageralam with the upper course of A. Lematang. The picture, redrawn after a photo taken by W. BRINKSCHULTE (1922, p. 26), shows distinctly outlined glass shards in a much less contorted and compressed state than in fig. 5. To judge from BRINKSCHULTE's photograph the shards are not crystallized. Plagioclase crystal in upper portion.

A microscopical re-examination of E. GUTZWILLER's (A. TOBLER's) "liparite" specimens from S. Are and A. Lim Ketjil by the present writer revealed the – hitherto unobserved – interesting fact that the glass "streaks" of the groundmass are in reality distinctly separated tiny shreds with clearly visible sides and extremities. The outlines of these particles, which beyond doubt betray the pyroclastic origin of these "liparites", may be rather sharp, as in the sample from S. Are (fig. 5) or, as the result of crystallization, which affected both samples very strongly, rather vague, as in the more compact rock from A. Lim Ketjil. In this latter case, however, the former existence of glass shreds still revealed itself between crossed nicols,

[1]) An abstract of his report is given by MUSPER (1937, p. 72).

because the entirely crystallized groundmass then appeared to consist of distinctly segregated small groups of microlites with low birefringence and still showing the curved outlines of the original glass shreds, which had been completely replaced (fig. 7). Almost similar structures are visible on three microphotographs of "liparites" from A. Lematang and A. Endikat given by BRINKSCHULTE (1922, p. 26, 28). One of these, a micropicture of a sample from A. Lematang, which has been reproduced in fig. 9 of the present writer's article, shows the tuffaceous origin of the rock very distinctly by its sharply outlined and apparently little or not crystallized glass shards. In another of these photographs appears an enclosed fragment of an andesitic rock with plagioclase microlites, grains of magnetite, etc., while the well-outlined glass shards of the groundmass around this fragment have a speckled appearance, apparently as the result of crystallization. The same can be said of the groundmass on the 3rd photograph. A slightly curved or rectilinear shape is mostly observed with the glass shreds in the rock specimen from S. Are, but a triangular configuration with concave sides may also be observed in this sample and on BRINKSCHULTE's microphotographs of the A. Lematang and A. Endikat "liparites". These forms can easily be recognized as those of the thin walls and sutures of tiny glass bubbles, which were disrupted by gas pressure at the moment of the sudden expansion of the rhyolitic parent magma when it left its orifices of eruption.

Another fact of importance revealed by microscopical examination is that the originally glassy groundmass of the re-investigated specimens is entirely crystallized and is now almost wholly made up of microcrystalline aggregates of albite and tridymite (figs. 7, 8). Albite, recognizable by $n_{alb.} < n_{can.balsam}$ and an angle of extinction of 15—20° with regard to basal cleavage lines in sections $\perp n\gamma$, showed itself as the main product of alteration in the glass shreds, in which it frequently developed as small fibres radiating from the side planes toward the centre of the particles. Albite and tridymite, the latter mineral developed as characteristic, six-sided, thin flakes, which often cover each other in the manner of roof-tiles (fig. 6), together also form the fillings of former vesicles. Many of these were still seen open in the S. Are specimen and with their walls lined with small crystals of albite and tridymite (figs. 5, 6) [1]. The crystallized shreds besides contain scattered small flakes of biotite and of a mineral which is probably haematite.

Partial or complete crystallization of the glassy groundmass has been mentioned in almost all existing descriptions of welded rhyolitic tuffs. In the rhyolitic sand-flow of the Valley of Ten Thousand Smokes, e. g., which appears firmly consolidated especially in the upper part of the Valley, where the temperature must have been higher, the individual shards were seen to be permeated by cryptocrystalline growths mostly consisting of tridymite and orthoclase (FENNER, 1937, p. 236). Albite is not mentioned among these pneumatolytic minerals, which seems strange in view of the fact that the white pumice of the sand-flow apparently only carries acid plagioclase (with a little quartz) among the feldspar "phenocrysts", while the composition of the parent magma, to judge from the chemistry of the light bands in the rhyolitic plug of the Novarupta volcano which stands near the rim of the Valley, has very probably been that of a soda rhyolite with Na_2O rather

[1]) The writer wishes to thank Dr. W. P. DE ROEVER for his assistance in the determination of the groundmass minerals.

much in excess over K_2O according to FENNER's data (1923, p. 38, 57) [1]). No analysis, however, has been given of the indurated Valley tuffs. The glass particles of the "ignimbrites" of N. New Zealand among which MARSHALL (1935, p. 357—360) described many varieties according to rate of compaction, nature of the inclusions and degree of pneumatolitic alteration, are reported by this author to be permeated in the crystallized specimens by slender, colourless needles of feldspar (which feldspar is not indicated) perpendicular to the surface of the shreds and often surrounding a central core made up of tiny flakes of tridymite. The name "pectinate structure" was given by MARSHALL (1935, p. 345, 346) to these microlite patterns, which besides are regularly accompanied by spherulite (radial) and axiolitic growths. Some of MARSHALL's microphotographs of New Zealand "ignimbrites", especially Pl. 69, fig. 1, offer almost the same picture as the rock from S. Are (fig. 5 in this paper), and by the composition of their enclosed crystals, too, as illustrated by the occurrence of numerous "phenocrysts" of oligoclase and lesser quantities of sanidine, andesine, quartz, hypersthene, biotite, greenish hornblende, augite and magnetite (MARSHALL, 1935, p. 332—335), the acid New Zealand tuffs are petrographically very similar to their Pasoemah counterparts. Development of spherulitic structures as the result of epigenetic crystallization has also been observed in lithoidal varieties of welded tuffs in SE. Idaho by MANSFIELD and ROSS, who described the microcrystals of the spherulites as consisting of alkalifeldspar (whether sodic or potassic is not indicated) and a minor amount of tridymite, while oligoclase, and in a lesser degree quartz, orthoclase and some augite, are mentioned as the chief "phenocrysts" in these rocks, which in glassy varieties have sometimes conserved gas bubbles (MANSFIELD and ROSS, 1935, p. 319—320). In the Bishop tuff of E. California, which carries a large amount of quartz and sanidine crystals beside smaller quantities of oligoclase and some biotite, haematite and magnetite, pneumatolytic alterations are apparently of a potassic type, because K-feldspar (probably sanidine) and tridymite are mentioned as the constituents of the crystallite growths (GILBERT, 1938, p. 1838—1839, 1849—1851). The parent magma itself has obviously been richer in potash in this case, as may be inferred from the preponderance of sanidine among the enclosed feldspars in the Bishop tuff. In E. California as well as in New Zealand the above cited pneumatolytic alterations appeared to be more strongly developed in the upper levels of the tuff masses, which were less affected by compression and more exposed to the action of rising gasses emitted by the still incandescent and viscous glass particles of lower levels immediately after the emplacement of the deposits.

Chemistry of the welded Pasoemah tuffs.

In the table below two analyses of Pasoemah "liparites", given by BRINKSCHULTE (1922, p. 30) and respectively representing a sample from A. Lematang (No. 1) and another one from A. Endikat (No. 2), are put together for comparison with an analysis of an "ignimbrite" from Waikino in N. New Zealand (No. 3), as published by MARSHALL (1935, an. G., p. 344), and with the analytical figures for the light bands in the acid plug of the Novarupta volcano in the Katmai region, which obviously was fed by the

1) FENNER's analysis of the Novarupta light bands is reproduced as analysis no. 4 on p. 213 of this article.

	No. 1	No. 2	No. 3	No. 4
SiO_2	73.11	72.08	72.30	74.75
Al_2O_3	15.05	9.33	12.50	13.01
Fe_2O_3	2.29	4.96	2.12	0.82
FeO			0.47	1.43
MgO	0.20	0.12	0.10	0.70
CaO	0.18	0.77	1.35	2.12
Na_2O	6.52	7.62	3.25	4.32
K_2O	1.38	3.61	3.58	2.62
H_2O +	0.96	1.05	3.54	0.20
H_2O —			0.46	0.05
TiO_2			0.12	0.28
P_2O_5			0.31	0.09
MnO, BaO, S, Cl				0.25
	99.69	99.54	100.10	100.64

same magma hearth as the acid tuff deposit of the Valley of Ten Thousand Smokes (No. 4, taken from FENNER, 1923, p. 57).

The figures quoted above suggest a great similarity in composition between the three kinds of rocks which they represent. The welded tuffs of the Pasoemah region are apparently more sodic and less calcic than the New Zealand "ignimbrites" and the light-banded portion of the Novarupta plug, which latter presumably will be very much related in composition to the indurated sand-flow rock of the Valley of Ten Thousand Smokes. It must, however, be confessed, that the two analyses of the Pasoemah rocks do not give the impression of great accuracy, so that the conclusions given here must be regarded as in some way provisional. Considering the distribution of the various oxydes over the mineral and glass particles of which the acid Pasoemah tuffs are composed, Fe-oxyde and MgO are probably almost entirely restricted to the crystals of hypersthene, hornblende, biotite, magnetite and haematite, Fe-oxyde in addition being a constituent of the secondary coatings of limonite; CaO, on the other hand, mainly comes from the plagioclase "phenocrysts" and K_2O probably principally from rare individuals of K-feldspar and from biotite. The colourless constituents of the groundmass consequently seem to consist almost entirely of SiO_2, Al_2O_3, Na_2O, and some K_2O, which deduction turns out to be in good agreement with the result of petrographical examination according to which the pneumatolytically altered groundmass of the S. Are and A. Lim Ketjil specimens consists almost exclusively of cryptocrystalline growths of albite and tridymite.

ORIGIN AND MODE OF EMPLACEMENT OF THE PASOEMAH "IGNIMBRITES".

In their field relations and lithological characteristics the Pasoemah "liparites" are comparable in every respect with the welded tuffs of the North American Cordilleran region and N. New Zealand and may therefore be classed among the "ignimbrites", the origin and mode of emplacement of which has been compared by MARSHALL (1935) with that of the rhyolitic sand-flow of the Valley of Ten Thousand Smokes in Alaska. The induration of the glassy groundmass of the acid Pasoemah tuffs must be explained as a result of compression and contortion of glass shreds erupted in an incandescent and still viscous state, and welded together immediately after deposition by the weight of the overlying material, which fact at the same time explains the more loosely aggregated structure of the upper levels of the deposit observed at many places. The permeation of albite-tridymite growths into the glass shreds of the groundmass must have been brought about by the pneumatolytic action of gasses (presumably mainly water vapor), which probably were entrapped in part between the rock fragments at the moment of emplacement of the tuff mass, or otherwise expelled from the cooling glass particles shortly after deposition. The explanation of columnar jointing in the "ignimbrites" of N. New Zealand and in the welded tuffs of E. California — which two deposits are showing a stronger relationship to the homologous rhyolitic Pasoemah tuffs than other known examples of this kind — as the effect of slow cooling on a hot and completely motionless rock mass (MARSHALL, 1935, p. 329—330; and GILBERT, 1938, p. 1851—1854) can also be applied without hesitation to the South Sumatran occurrence.

It seems most likely that the material of the Pasoemah "ignimbrites" was forced upwards through fissure-shaped channelways opened on the E-side of the late-Miocene Barisan Range somewhere south of the Dempo volcano, the mantle of which cone, together with that of other later andesitic eruption points, now conceals the original foci of the voluminous tuff eruption. The outburst evidently was of an initial and paroxysmal nature („Initialausbruch") and of a rather short duration, as appears from the facts that its products were deposited immediately above folded Miocene rocks and that the tuff deposit shows all signs of having been laid down by one or a very small number of major eruptions. The rhyolitic glass, mixed up with already formed crystals and fragments of old-Miocene claystones and effusiva from the walls of its eruption channels, apparently reached the earth's surface as an incandescent silicate froth, which after its sudden disruption was pushed downward with great velocity into the broad depression S of the Goemai Mts. as a fiery dust-and-gas mixture, able to overcome acclivities on its way and keeping itself in a state of fluidity — as FENNER (1923, p. 43—47, 70—74) saw it for the tuff eruption of the Valley of Ten Thousand Smokes — by the continuous evolution of gas from the glass particles, which not only eliminated almost completely the contact friction between the rock fragments, but also tended to drive them apart somewhat forcibly, causing them to spread almost as freely as a true liquid over the area of deposition.

The temperature of the tuff fragments at the moment of eruption was evaluated by MARSHALL (1935, p. 343, 344) for his "ignimbrites" at more than 1000° C on account of the presence of tridymite in the glass particles and their state of viscosity when deposited. GILBERT (1938, p. 1854—1859), however, pointed to recorded observations proving the possibility of the formation of tridymite under hydrothermal conditions far below the inversion point of this mineral (870° C); furthermore to the predominance of the normal green over the basaltic variety among the hornblende crystals found in his Bishop tuff, which latter fact should require a temperature of eruption only slighter higher than 750° C, the temperature of inversion of green into basaltic hornblende according to KOZU's tests cited by him. As regards the presumably great quantity of tridymite in the Pasoemah "ignimbrites" at various places of their area of extension, attention is drawn to the detection of this mineral in hydrothermally altered dacites and andesites near hot springs in the Lassen Volcanic National Park, where it was observed by CH. A. ANDERSON (1935, p. 245, 246) in association with newly formed pyrite, chalcedony, opal, clay minerals and alunite, all minerals being apparently formed at the temperature of 90—94.1° C of the thermal waters. Hydrothermal tridymite as an alteration product formed by thermal waters in rhyolitic lavas has been mentioned by FENNER (1936, p. 289—308) from the Yellowstone National Park, where it was found replacing the groundmass of the acid extrusiva together with orthoclase and quartz in samples from a bore-hole drilled in the Norris basin, in which a maximum temperature of 205° C was noted. The present writer therefore rather inclines towards GILBERT's view on account of these latter observations, bearing also in mind the astonishingly unaltered state of enclosed claystone and andesite fragments in the Pasoemah "ignimbrites". The great amount of volatiles still solved in the magma at the moment of its eruption, and still afterwards in the incandescent glass shreds, undoubtedly allowed the particles of acid silicate glass to preserve their viscosity to a much lower temperature than would have been possible in a dry state. Epigenetic crystallization of the glass shreds was apparently effected after the emplacement of the tuff deposit under conditions which may be termed "pneumatolytic", that is probably at temperatures between 400° and 600° C or still lower.

THE QUANTITY OF MATERIAL EJECTED BY ERUPTIONS OF THE KATMAI TYPE.

The prehistoric and, with the exception of the Triassic Brisbane tuff, mostly Pleistocene to late-Tertiary examples of deposits formed by "nuées ardentes" of the Katmai type referred to in the foregoing paragraphs all comprise a much vaster amount of material than the historic example offered by the 1912 eruption in the Valley of Ten Thousand Smokes in Alaska. This fact distinctly brings into relief the important part evidently played by eruptions of the Katmaian type in the formation of pyroclastic deposits all around the Pacific Ocean during phases of old-Quaternary and still earlier volcanism. Extended reconnaissance of acid volcanic rocks in the circumpacific region undoubtedly will bring to light much more examples of welded tuff deposits than are now known to exist. In N. Sumatra, for instance, "ignimbrites" are certainly found on a large scale in the Lake Toba region, as the writer hopes to demonstrate in a following paper. The size of Katmaian eruptions can be read from the following table, in which

	Area of deposition	Thickness of deposit	Quantity of ejected material
Valley of Ten Thousand Smokes (Katmai region, Alaska)	± 38.5 square miles = ± 99.7 km²	10—200 ft = 3—61 m	> 1 cubic mile = > 4.17 km³
Taupo-Rotorua district (N. New Zealand)	± 10.000 square miles = ± 25.900 km²	60—500 ft = 18.3—152.5 m; generally not more than 100 ft = 30.5 m	± 750 km³ (roughly estimated)
Brisbane (Queensland); the Brisbane tuff	> 34 × 9 square miles = > 790 km²	200—500 ft = 61—152 m	Between 47 and 118 km³
Snake river region of SE. Idaho and S. Montana	± 5000 square miles (roughly estimated) = ± 13.000 km²	20—50 ft = 6.1—15.2 m	Between 80 and 200 km³ (roughly estimated)
E. California; the Bishop tuff	400—450 square miles = 1028 — — 1165 km²	400—500 ft = 122—152 m	± 35 cubic miles = 146 km³
Pasoemah region, South Sumatra	> 800 km²	± 50 m	> 40 km³

estimated areas of deposition of the ejectamenta, the thickness of the deposits and estimated quantities of erupted material are gathered according to data afforded by FENNER (1923, p. 67), MARSHALL (1935, p. 357—359), RICHARDS and BRYAN (1933, p. 51—54), MANSFIELD and ROSS (1935, p. 311, 312), GILBERT (1938, p. 1833) and by the present writer.

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