Geology. — "*Notes on the Sopoetan-Mountains in the Minahassa.*" (First part.) By Mr. M. KOPERBERG. (Communicated by Prof C. E. A. WICHMANN.)

Since the last great eruption of Sopoetan in 1833 [1]) great tranquillity has prevailed in the so intensively volcanic central-district of the Minahassa, which in an area, hardly as large as the Dutch province of Drente, numbers at least 18 eruptive seats. Only Sopoetan itself and the crater-lake Linou continued to show some activity, though limited to fumaroles and as for Sopoetan possibly also to sporadic slight ash-eruptions [2]). The tendency to diminution of volcanism seems likewise to be indicated by a gradual declining of the hot springs.

In the last years however a series of phenomena has proved a reanimation of volcanic activity. On 29 March 1893 at about 5.30 p. m., according to a communication of Mr. E. GOEDBLOED, (Nat. Tijdschr. v. N. Indië Vol. LIV p. 206), and the description of the SARASINS (Dr. P. and Dr. F. SARASIN "Entwurf einer geologisch-geographischen Beschreibung der Insel Celebes" [3]) p. 28—35) in the saddle between the Lokon and the smaller volcano Empong suddenly an old bocca resumed activity, and in the neighbourhood some new fumaroles were formed, without the least seismic motion.

This was followed in 1901 by the formation of a new solfatara in the Sopoetan-mountains, under strong seismic disturbance all over the Minahassa, which was reported by us in the "Verslag van het Mijnwezen" of the first quarter of that year (appendix of the Javasche Courant of 16 Juli 1901 N°. 55, p. 13—14), and in the "Verslag over de Geologische en Mijnbouwkundige onderzoekingen in de residentie Menado" during the year 1901. (Jaarboek v. h. Mijnwezen 31e jaargang. 1902, p. 147—148).

According to a statement by Mr. A. LIMBURG of Tomohon, (Nat. Tijdschr. v. N.-Indië, Vol. LXV p. 125), in 1904 the Mahawoe-volcano showed a somewhat intensified activity. After the last eruption of

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[1]) Not in 1838: after Prof. Dr. A. WICHMANN, (Mon. Ber. d. D. Geol. Ges. Vol. 62, 1910, p 592).

[2]). In 1845, (Natuurk. & Geneesk. Arch. voor Nederlandsch Indië, 3. 1846 p 603), and in the night of 20 to 21 and on 24 June 1890, in the report about that year in the Nat. Tijdschr. v. N Indië Vol. LI p. 321 brought into connection with the eruption of the Makian-volcano on 29 and 30 June, but probably rightly attributed to Sopoetan by WICHMANN and the SARASINS.

[3]) On account of this work containing an elaborate compendium of the older communications about the volcanoes of the Minahassa, references may conveniently be left out here.

1789 this mountain seems to have been quiet, but had restarted smoking a couple of years back.

In 1906 and 1907 followed at last the eruptions in the Sopoetan-mountains, to be discussed afterwards.

The new solfatara of 1901 is located in a kind of atrio between Sopoetan proper and the more northern Rindengan-range, evidently part of an older crater-edge. The further course of this edge is not so distinct. In general the relief of the Sopoetan-mountains is not easily to be understood. From the reports of the various visitors it is evident that they feel that they venture on uncertain ground whenever they have to discuss the surroundings of the Sopoetan-cone.

Even with regard to the names of these mountains the different travelling-reports do not agree. This confusion is chiefly caused by the fact, that the natives themselves, who must decide in this respect, are no longer sufficiently acquainted with them, on account of the steadily increasing influence of Europeanisation; they sometimes happen to look for information in these reports, most certainly a surprising result of the work of civilisation, but not exactly favourable to correction of former errors. Moreover names are given to spots, which, according to our ideas, had not the least claim to separate denomination, e. g. the name Kětengĕn for the part of the Rindengan-wall, where the path descends towards the Pentoe [1]), and which links it to the southern Sempoe-edge. For mount Sempoe the name "Kinaälidan" was also mentioned to me; this means the place where a tree has been rooted up [1]), and so originally might not have been the name of the whole mountain or range. What is indicated on the map as Sempoe is called by the SARASINS, according to their description, "Kelelondei" (= réversed canoe), which is somewhat applicable to the oblong rounded profile. Their Sempoe or Keleloeak [2]) is the craggy range south of the path coming from the settlement Kelelondei and on the north of the old volcano Manimporok. For the reasons above-mentioned I must leave undecided which of the denominations are the correct ones.

More important than this simple question of names is the exact conception of the group of volcanoes itself. That this is so difficult to get at is in the first place due to the fact, that in the rather small culminating area, nearly coinciding with our map, several large

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1) According to information kindly forwarded by Dr. Theol. S. SCHOCH vicar of Tomohon.

2) *Londei* is one of the manifold types of rowing- or sailing-boats, *loeak* the Indian wood-cat, the *moesang* or *moensang* of the Malays.

craters are lying close together, partly even overlapping each other, and having disturbed each other's relief. As a further cause of transformation erosion took place on those sides that were favourable to it. At last every thing is covered by the ejected coarse sand or grit and lapilli of the youngest, now all-dominating Sopoetan s. s.; the great lines of the relief would of course not have been effaced by this cause only, but it has contributed to make discrimination very difficult; the smaller rugosities were levelled, the contrasts between crater-bottoms and walls became less manifest, especially where the latter had already tumbled down, and at last the uniform grey sheet of gravel, only locally interrupted by spare bluffs, renders it next to impossible to discern on mere eye-sight the volcanic formations of various kinds.

In such cases a detailed topographical survey of the volcanic system is still the best means of unravelling the intricate relations, and of properly interpreting the geological observations. Though the survey of 1901, made under my superintendence, chiefly by Mr. W. VAN DEN Bos, topographer to the Mining-department, remained restricted to the immediate neighbourhood of the newly formed solfatara, yet the map borrowed from this surveying allows of completing in some respects the opinions of former investigators.

KOORDERS was the first to pronounce the correct view that the mountain-ridge north of Sopoetan s. s., the Rindengan-Tonderockan-range, forms an old crater-edge. He took the Sopoetan-mass to be the remains of a single old volcano, his Rindengan-volcano, on which the Sempoe — in his summary identical with Kelelondei, — and the Sopoetan are secondary and consequently younger craters. It is less clear what he understands by Sempoe or Kelelondei.

The SARASINS resume their observations in this way (l. c. p. 59) that they range Sopoetan s. s. as a chief cone Kelelondei (and Manimporok). I am of opinion that by doing so, they allow too great independence to the monticule designated by them as Kelelondei. But apart from this we need no longer doubt of the existence of a large old edge, called by them Kelelondei-somma, of which their Sempoe forms a southern part, whilst the part of KOORDERS' Rindengan-Tonderockan-wall running along the brook Masem forms a northern and western part.

Starting from my own observations and the evidence afforded by the survey, I think I may conclude that both representations have to be combined, and that in reality besides Manimporok, two old craters exist, as indicated on our map in dotted lines. In order to agree as far as possible with the former explorers the south-western

crater may be mentioned as *Rindengan-crater*, the north-eastern one as *Sempoe-crater*.

Apparently this view does not differ much from that of the SARASINS as it is expressed, if not in the text, at all events on their map of the Minahassa (l. c. Taf. XI), where around the Sopoetan-cone, to the south-, west-, and northwest-side a wide encircling wall is indicated. They founded themselves for it (l. c. p. 60 and 61) on the promontory that interrupts the cone-profile on the south-west-side and has been recognized by RINNE [1]) as a fragmentary somma. This induces them to admit of an old Sopoetan-crater concentric with the present one, and so belonging to this comparatively young volcano, consequently not to the old fragments of the crater-edge, which have doubtless been preserved in the ranges to the north of this cone. Indeed towards this side their older Sopoetan-edge remains open, and even they guess, on account of that somma, that of the three volcanoes, Sopoetan, Manimporok, and Kelelondei, the former might be the oldest.

On my first ascent of Sopoetan in May 1899 from Tombatoe, I intended, after having reached the crater from the south-east, also to visit the mentioned somma, known as *Sopoetan Patepangan*. A dreadful rain-shower however made the descent to degenerate into a wild flight of my men to the bivouac, and compelled me to give up this plan; later on I have neither found time for it. So I cannot adduce a proof for my supposition that we have not to do here with a prior stage in the history of the origin of Sopoetan proper, but really with a south-western part of the old Rindengan-edge. It is certainly remarkable that further round that mountain, i. e. over the greater part of the circumference, this presumed Sopoetan-somma cannot be pursued, not even by any irregularity in the slopes, and remained intact exactly there where it completes in a natural way the part of the Rindengan-wall situated diametrically opposite, with which it also agrees pretty well in the estimated sea-level. In my opinion consequently in the southern part of the Rindengan-crater the Sopoetan-volcano has originated, the eruptions of which have erected this volcano-cone which is to be regarded as not composite, in an uninterrupted series of eruptions.

Within the Sempoe-crater also there is a mountain, — the Sempoe of the map, — however without a crater. On the photogram in RINNE's afore-mentioned notice (Beilage-blatt VII top-figure), taken

[1]) Prof. Dr. F. RINNE: Skizzen zur Geologie der Minahassa in Nord-Celebes. Zeitschrift d. Deutschen Geol. Gesellschaft Pl. LII 1900, Sept. p. 8 and Beilage-blatt II and III.

from the south-side, this mountain lies to the right of the Walèlang. (= Walirang). Only the greater western part is to be seen, but the missing eastern part corresponds almost with the other extremity. The shape reminds of that of the hill in the huge recent crater of Oena-Oena (Tomini-bay) said to have arisen during the eruption of 1898; (Verslag over de Geol. en Mijnbouwkundige onderzoekingen in de residentie Menado van het jaar 1900, Jaarb. v. h. Mijnwezen in N. Indië, 30ste jaarg. 1901 page 118). Probably the central monticule, which in Oena-Oena is covered like the surrounding crater-landscape with masses of sand, at the Sempoe with gravel, is in both instances a mass that has moved outward, something like what was formed in 1904 in the crater of the volcano-island of Roeang (l. c. 38th year 1909 page 222 v.v.) and has been stated already to have occurred also in the immediate neighbourhood of Sempoe in the Sopoetan-eruption of 1906. With such a mode of formation both at Sempoe and at Oena-Oena the opening through which the mass has emerged must lie directly below the highest part of the top, in this respect differing from what occurred at Roeang, where the emerging mass very soon filled the whole crater-cup.

Both sommas, as reconstructed on the map as far as possible from the present course of the walls, extend for a short distance over each other to a maximal breadth of about 150 M. Since these craters have come to rest they must have widened however by the tumbling down of their walls, which consist, as far as can be seen, of a tufaceous mass, decomposed, whitened and softened by acid vapours.

This receding of the walls however cannot have been of great amount, as appears clearly from the boundaries of what still now can be recognized as true crater-bottom, indicated on the map by thinner striped lines. The walls of the solfatare Walèlang teach us that there the old bottom of the crater does not consist of eruptive gravel, or only to a slight depth, and consequently at the end of the activity it did not lie lower than at the present moment, so that this period cannot be so long gone by.

These considerations, for which on the map abstraction should be taken of the solfatare Walèlang and the surrounding inflection of the level lines, probably dating not farther back than the beginning of the 19th century, may account both for the nose-shaped spurs projecting from the mountain-walls into the common zone of the bi-circular system and for the somewhat vague features of the relief in the middle part of this zone.

From the fact that of the two crater-walls, in so far as they

are still extant, that of Rindengan notwithstanding its greater height has remained in better condition, and that there the contrast between edge and bottom is more marked than that at the Sempoe-crater, we may conclude that the former crater is younger, or at least has come to rest later than the other one. In that part of the system where the two craters as it were interfere the Rindengan-wall, the spot indicated on the map as Kètengèn, is continued almost without interruption, and the uncertain relief is turned towards the Sempoe-side. The circular plain is here at the side of the solfatare still interrupted by a low irregular elevation. Of course the fact that on the whole the bottom of the Sempoe-crater lies more than 100 M. higher than the Rindengan-bottom may have some influence in this respect; but I think that the relief in the central part would show a quite different aspect if the former had come to rest at the same time as or later than Rindengan.

The Sempoe-crater has an almost circular shape with a diameter of 2,8 to 3 KM. The dimensions of the Rindengan-crater cannot be given because the south- and west-side are made uncertain by Sopoetan, and the map is incomplete towards those sides. It seems that this crater had an elongated shape extending from NNE—SSW. From the map we find a minimum length of 2,8 and breadth of $\pm$ 1,8 KM. These are for the Indian Archipelago not excessive dimensions; but they are of sufficient importance to conclude, that the ejected mass, if nearly adequate to the size of these vents, must to a great distance prevail in the petrographical composition of the surrounding territory.

Now the central part of the Minahassa consists, as far as visible, chiefly, and southward of the Sopoetan-mountains under the thin covering of Sopoetan-sands even entirely of pumice-tufa, partly in strata. The igneous rocks of the Minahassa-volcanoes belong chiefly to andesite [1]) and their dark colour, also in the slaggy or pumiceous varieties, often also the presence of chrysolite point to basic composition. This is especially true for the material produced by the volcanoes in the historical period; (Sopoetan s.s., Batoe Angoes and Batoe Angoes baroe). The material of Sopoetan proper is distinguished from all the other igneous rocks by the constant presence of much chrysolite, thereby showing great affinity to basalt. The rule that if in different periods of the eruptivity, the magma is varying in composition, the youngest magma is the more basic, may not always

[1]) Compare Prof. Dr. H. Bücking: Beiträge zur Geologie von Celebes; Sammlungen des Geol. Reichs-Museums in Leiden. Ser. I, Vol VII, part 1, page 199—202.

hold, in the Sopoetan mountains it is undoubtedly confirmed. What I saw in the Minahassa strongly impressed me that there is a certain contrast between these andesitic igneous rocks and the light pumice-tufa, and at least for the stratified tufa it is clear that its deposition belongs to a now-closed period. Hence on good grounds we may conclude that Sopoetan proper has nothing to do with the deposition of these beds of tufa. In how far that external contrast answers to more essential petrographic and chemical differences and if perhaps other volcanoes of the Minahassa may thus be shut out, these questions I must leave now undiscussed, the data of our Menado exploration still awaiting their final composition and for the present not being at my disposal.

If for valid reasons the conception of the Tondano-plateau with its comb-shaped eastern margin and the adjacent tufa-layers dipping and shelving towards the sea as a gigantic volcano, might in the end prove to be untenable, as I am inclined to believe, it will not be difficult to find any other of the neighbouring eruptive seats apt to be held responsible for these tufa-deposits.

On the southern flanks of the plateau it is different. The tufa-layers occur here in ground that belongs unmistakably to the common volcano-foot of the group Sopoetan-Manimporok. So their presence has here the demonstrative power that we must as yet deny to those of the just-mentioned Lembean-chain. Once induced to conclude that the older volcanoes of that group have given vent to the material for the pumice-tufa, in so far as this forms their own mantle, we may readily admit that the eruptions from these large craters have also spread the pumice-tufa to a great distance in the surrounding country. If it is confirmed that the circular walls and bottom of the Rindengan- and Sempoe-craters are composed of the like material, then a more direct proof is given of the part that has been assigned here to these volcanoes.

With regard to the details of location there is an almost perfect congruence between the solfature of 1901 and the neighbouring Walèlang. In both cases the solfatare lies upon the channel longitudinally cut by the brook in the valley-flat, Walèlang on the brook Masem, the solfatare of 1901 on the Pentoe. Relating to Walèlang we may remark that by some authors the name of Masem is likewise given to the solfatare; the SARASINS even speak of *Masem-crater*; this must be a mistake; the name of *Masem* belongs exclusively to the brook. Classing these solfatares with the craters may only be allowed for, if the so-called explosion-craters are ranged under this category. Indeed one may speak as well of water-volcanoes as of

mud-volcanoes, but then a great number of geysers belong to the volcanoes. Our solfatare unites the characteristics of the explosion-craters, the mud-craters and the geysers. A heightened rim, the sign of continued real eruptive action, fails however, as also at the older Walèlang; eruptive activity took place only at the breaking out but not afterwards.

Whereas the authors represent the Walèlang as a lake and mention that it has no outlet, it may be stated that this small basin is in reality a rather abrupt expansion of the upper dry part of the Masem-ravine. On the photogram by RINNE (o.c. Beilagebl.VI), this gully can be seen both upward and downward; on the downwardside the solfatare is however barred by a low saddle, rising until $\pm$ 20 M. above water-level, as it were a low dam, which in case of highly increased water-afflux evidently might serve as an overflow. It is only at some distance downward that the creek itself, fed by small branches, becomes water-bearing. The name of the brook however indicates already that in it, underground at least, part of the tart, acid-loaden water of the solfatare assembles. Muddy half-dried tongues of land, especially on the left bank, show that the level of the water must have been higher in former times than it is now, whereby the formation of the overflow may be explained.

At the solfatare of 1901 the chasm is situated in the left bank a few meters apart from the brook; the basin is not open in the direction of the brook, but in the downward corner there is a narrow connection with the bed and through this the emerging mud-water discharged itself as a rather rapid stream into the clear water of the Pentoe. It was observed at Amoerang, where this mountain-stream reaches the coastal plain that the water suddenly turned muddy, and if the exact moment had been noticed, this might have been of use to give some information on the initial history of the solfatare.

The hot spring Roemèrèga on the Pentoe downward, which gives evidence of being an old solfatare by at present only faint vapours, smelling somewhat of sulphur, is again in the immediate neighbourhood of the brook-bed.

The SARASINS mention a second solfatare also on the Sempoe-side northward of the central elevation and thus here also inside the circularwall. Whether it lies also on the bank of the brook, here the Masem, I do not know. That such is however the case with all three solfatares under discussion most surely cannot be attributed to mere chance, and rather seems to indicate that the proper seat of the activity of which the solfatares are the results must lie in

shallow depth, to be able to react so locally on the local differences of the surface.

Near the solfatare of 1901 the Rindengan-atrio is interrupted by a steep hill-range, on account of some groups of blocks found on its back, a rather conspicuous feature in the wholly gravelous or sandy surroundings, most likely an old covered stream of block-lava, having issued from or at the foot of the Sopoetan-cone and being moved radially onward towards the circular wall. Above (page 226) we have already alluded to the fact that in the immediate neighbourhood such a slow eruption was realized in 1906 and 1907. The considerable eruptive mass that was produced on that occasion is sketched on the map according to indications for which I am indebted to Dr. Schoch. I intend to revert to this eruption in the second part of these notes.

The solfatare lies exactly there where the hill-range in question ends against the Pentoe. The left-bank of the brook-channel which does not exceed two meters in width and in depth, can at present only be recognized with difficulty; that channel-wall now gradually passes over into the adjacent foot of the hill by the regular covering of mud ejected by the solfatare. This sloping mud-field had a peculiar parallel-striped appearance by the downward running furrows made in it by the rains right through to the under-lying Sopoetan-gravel.

The solfatare itself, a pool estimated at three to four meters wide and at that time in a violently boiling condition, lies in a hole with steep walls, which must have been formed at the initial outburst, had enlarged itself afterwards by the tumbling down of the wall at the higher side, and at the time of our visit may have been about twelve meters wide, measured along the edge. There was no possibility of getting down into this hole and to the sides of the hot pool. So the dimensions given here are but rough estimations.

Standing on the outer edge I could not fully account for what really occurred under the dense cloud of vapours. But from the hardly three meter long connection of that hole, sliding off obliquely to the Pentoe-bed, we could observe that the boiling was attended by the throwing up of perpendicular jets, the height of which until their vanishing into the dense steam-cloud, might be estimated at about one meter; their formation is doubtless connected with the viscosity of the boiling mass, but likewise indicates the great pressure with which this mass was driven out, most likely through several narrow canals. In the nearest vicinity a smell of sulphuretted hydrogen was easily, sometimes even strongly, to be observed.

For want of a direct determination of temperature we may mention that in a bottle of mud-water, taken from the outlet to the Pentoe and already cooled down by rain- and brookwater, the thermometer still showed 75° C. The volume-ratio of suspended solid matter of this mud-water amounted to 12,2 %.

In a sample sent for chemical examination to the Head-office of the Mining-Department, were found — by the mining-engineer E. C. ABENDANON, (Verslag van het Mijnwezen van het 9e kwartaal van 1901, bijlage der Jav. Ct. van 15 Nov. 1901 N°. 91 p. 1-2):

A. Mud, dried at 120° C.:

Insoluble in HCl 83,35 %

in which SiO_2 73,95 % (perhaps meant of the residue, then in reality 61,64 %);

Soluble in HCl:

Fe_2O_3	0,0455 gr.	=	2,27 ,,
Al_2O_3	0,1680 ,,	=	8,40 ,,
CaO	0,0555 ,,[1]	=	1,44 ,, [1]
			95,46 %

Whether the remaining 4,54 % has been controlled by direct determination does not appear. This remaining part should contain especially the amount of alkalies and perhaps of colloidal solved silicious acid, to which as well as to the possible presence of free SiO_2 no attention seems to have been paid.

B. Per 300 cM³ of the water obtained:

Al_2O_3 0,0265 gr. = 0,88 gr. p. L. (ought to be 0,088 gr. p. L.)
$CaCO_3$ 0,1575 ,, = 0,714 ,, $CaSO_4$ p. L.
$BaSO_4$ 0,6540 ,, = 0,96 ,, H_2SO_4 ,, ,, (in reality 0,917 gr. p. L.).

HCl, HNO_3, Mg and K-salts absent, strong acid reaction by free sulphuric acid.

The contradictions in the figures quoted allow only of presuming that the water contained per liter:

bound by	Al_2O_3	0,253 gr.	sulphuric acid
,, ,,	CaO	0,514 ,,	,, ,,
		0,767 gr.	,, ,,

and consequently per liter 0,917—0,767 = 0,150 gr. free sulphuric acid.

Sulphuretted hydrogen could not be detected at Batavia, but at the spring it could be very distinctly by the comparatively rough

[1] If these figures refer to the same quantity of 2 gr. of mud used for the determination of Fe and Al, they need correction.

reaction of the blackening of silver coins. The vanishing of H_2S, apparently less by escaping than by change into H_2SO_4 has already been observed by HERINGA [1]).

As far as the determinations go, the water may be taken to be mineralized only by the ordinary process i. e. lixiviation of rock by newly formed sulphuric acid. Most likely this would be more obvious if the investigator had also determined iron and especially natrium, instead of rather strangely restricting himself to kalium, the absence of which is striking but for the rest not so astonishing, as we have to do here chiefly with plagioklastic rock.

Without proper analysis it is impossible to enter into a discussion of the questions connected with the chemical composition of the solfatare-material; however unwillingly I must restrict myself to hint at them only to indicate that they are not devoid of interest. Thus the composition of the mud might be of use for the solution of the question to which phase of volcanism the formation of the solfatare corresponds, to the basic Sopoetan-eruptions, or — as after-effect — to the Rindengan-Sempoe-activity with its more acid products. The high amount of silicious acid if irrefutable and original might have led us to look for some co-relation with the dacite found by RINNE [2]) near the Walèlang, and so possibly to the unveiling of an eruptive phase of still more acid material and presumably higher antiquity. Confirmation of the supposition just ventured about the mineralization of the water might on the contrary be an indication that we have to take the solfatare only as the result of the contact of infiltrating atmospherical water with hot masses containing sulphides, a phenomenon of only partial volcanic nature. This conclusion would be supported by the circumstance that many of the stones ejected with the mud are rich in pyrites.

In March 1910 the mud-field around the spring extended over an area, the length of which I estimated at more than 250 M. in the direction along the Pentoe upwards. Downwards the coating of mud did not reach so far, hardly one hundred meters; on the right bank of the Pentoe where the Ketengen-Rindengan-wall hindered the extension sideways, it was however likewise restricted in the upward

[1]) JOH HERINGA: "Onderzoek van eenige bronnen en modderwellen in de Minahassa." Nat. Tijdschr. v. N.-Indië Dl. LIV p. 93 et seq. So his opinion that the smell of sulphuretted hydrogen might be locally peculiar to the atmosphere only, and the water itself would be free from it, is not valid for our case.

[2]) Prof. Dr. F. RINNE: Beitrag zur Petrographie der Minahassa in Nord Celebes. Sitz Berichte der K. Preussischen Akademie der Wissenschafte, Phys.-Math. Classe, 1900 XXIV p. 482/483.

and downward direction. The spring has consequently a very excentric situation in the mudfield that has been formed by it. It was clearly visible on the spot that towards the higher side a big piece of ground had been removed by the breaking-out of the solfatare; now it is remarkable that we found the chasm separated from the adjacent Pentoe-bed by a narrow strip of undisturbed ground, only interrupted by the channel evidently cut in by the escaping mud-water, whilst it might have been expected that the great hydraulic pressure would have had the greatest effect towards the weakest side i. e. towards the bed of the brook. Both phenomena can, in my opinion only be explained, if we admit that the first break-out was not vertical but in a diagonal and upward direction, away from the Pentoe, tending nearly towards the Sopoetan-axis.

I found the last-mentioned peculiarity likewise at the Roemĕrĕga. This spring is situated to the right of the Pentoe, here already a rather strong though still small mountain-stream, only a few meters apart from the bed of the brook, at the foot of a wall showing the ravinated superposition of the black Sopoetan sand on the greyish tufaceous material. The bottom of the hole, enclosed by that wall and the little dam at the side of the brook, is covered with luke-warm clear water, which again has its out-flow to the brook on the downward side. Of supply-orifices nothing was to be seen.

About 40 M. ahead, nearly one kilometer below the new solfatare, the mud-stream still formed a separate central vein with a temperature of ± 70° in the here about 1½ M. wide and 0,1 M. deep water-bed of the Pentoe. That as yet no mixture had taken place may be considered, in my opinion, as another indication of the viscosity of the mud, resulting again from the presumed presence of colloïdal free silica. The presence of sulphuretted hydrogen could be ascertained in the mud and also by the smell in the atmosphere. On either side of the bed there was a fringe about 1 M. wide of the soft, grey mud, apparently dating from former stronger periods in the efflux, when the stream of mud may have filled the whole bed.

Even on the edge of the new chasm, notwithstanding the violent boiling inside, we could not observe any spirting of the mud. This must have occurred during still more powerful initial activity, which in the very beginning must have shown a paroxysmal character. This hardly 5 cM. thick sheet of mud would certainly not have stood against such tremendous rains as one can only enjoy on the mountains in our tropical archipelago-climate, during the couple of weeks that had elapsed at the time of our visit, since the formation of the spring. I think this entitles me to conclude that such

paroxysmal increase of activity must have repeatedly occurred. It may indeed be expected that with such newly formed springs a state of permanent equilibrium ensues only after a perhaps rather long lapse of time. It seems even that the Walèlang, dating from before 1821 [1]), was not yet in a state of regularized activity when it was visited by RINNE in 1899. This is perhaps the cause that the descriptions of its appearance are greatly at variance. Even now this solfatare had not yet quieted down. We observed some bubbling near the north-east corner and now and then in a little round puddle in the half dried up western part on the sulphur-crusted land-tongues.

Notwithstanding the apparent contrast between the minute boiling chasm of 1901, the comparatively gently steaming but 300 by 160 M. measuring lake of Walelang and the lukewarm pool of Roemer ga the differences are in my opinion rather of a gradual nature with regard to size as well as to intensity. Numerous more or less radiating rents at the foot of the Ketengèn-wall, in which the white underground and some sulphur was visible, and which gave some idea of the great subterranean pressure that has caused the eruption of the mud-stream, in the mean-time enforced the impression that with undiminished power the chasm would enlarge itself still considerably also towards this side.

These crevices must be well distinguished from the long, narrow crevices, almost hair-fissures, observed in the gravel-field to the south of our Sempoe, and on the top of the Sopoetan-cone from the crater-edge to about fifteen meters down along the northern and north-eastern slopes. Here they follow pretty well the level lines. The vapours constantly issueing from this highest part of the volcano-mantle, now mostly rose from these crevices, which did not exist at the time of my former visit. South of Sempoe the direction of the crevices was about N. 40° East. In my opinion they are of seismic origin and as such likewise known from other places. The pretty compact coarse sand has sufficient coherence to prevent these traces of the effects of the earthquakes from disappearing again immediately after the shocks. Fresh landslips in the Sopoetan-crater proved that the loosening of the mass of the edge along concentrically running lines had gone a little further. Such slips of band-shaped, concentric masses from the upper edge inside the crater are not restricted to the latest earth-quake-period; they have also been observed by the SARASINS (l. c. p. 60); and have left at the north-eastern wall in a

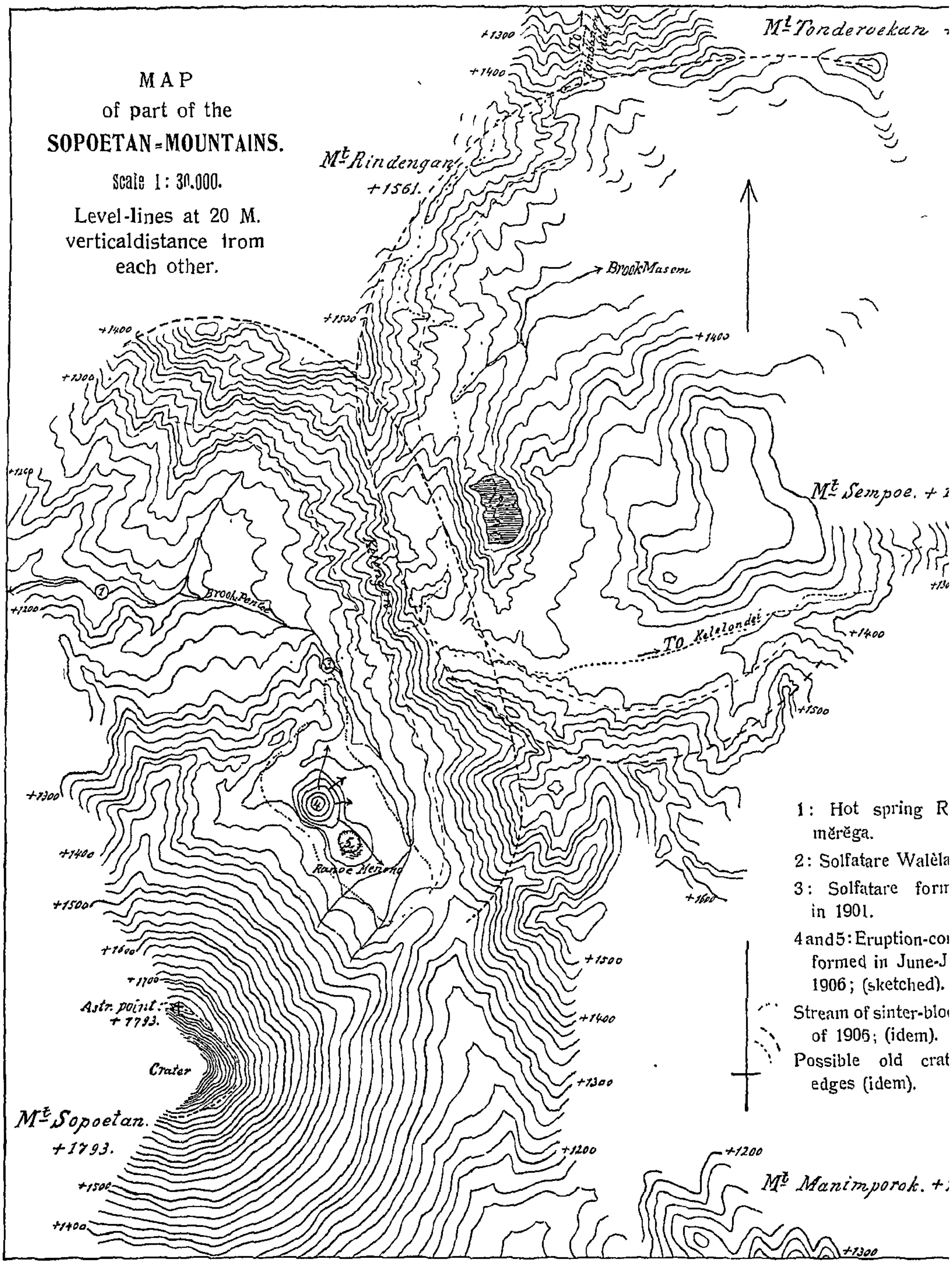
[1]) Mentioned by REINWARDT, who visited this solfatare in 1821.

funnel-shaped widening towards the crest and a straightly descending striping a grand reminiscence.

The communications about the volcanic phenomena of 1901 in the East-Indian Archipelago (Nat. Tijdschr. v. Ned.-Indië, vol. LXII, p. 170) contain two reports about Sopoetan. In one of them, dated 14 February, by the district-officer of Tondano, the phenomenon is in the main correctly stated. Of a second mud-spring mentioned there I have however not discovered any trace on the spot, its existence is in fact contradicted by the other communication, issued by Mr. LIMBURG, in which only one new hole is recorded.

This hole must have been formed before 4 February, the date of this latter communication. I could no longer ascertain whether, as is mentioned in the report, in the beginning an eruption of ash had taken place, which would have given to the outbreak of the solfatare in reality the character of a little volcanic eruption. For the rest it is characteristic to the nature of the phenomenon, that in the beginning sand and gravel may, as it were, have been blown up, — though we need not yet think of a real ash-eruption, — unless the mud immediately made its appearance at the initial explosion.

The reports published about the earth-quakes, (l. c. p. 188 et seq.) do not give a complete picture of the seismic disturbance prevailing in the Minahassa from 2 February as late as March, possibly even in April. In February hardly a day passed without earth-quakes, which especially in the first half of the month almost constantly were felt in swarms so as to make it rather arduous to notice the separate shocks. In a sense the reports may be regarded as rather signalling the critical days. None of the movements was of excessive intensity; most of them remained between degrees III and VI of the scale of ROSSI—FOREL. In the southern part of the plateau of Tondano a few shocks seem to have reached the intensity VII (or VIII Mercalli). In the Sopoetan mountains the crevices indicate a greater intensity, especially in the southern Sempoe-atrio, less on Sopoetan itself, where the relief must have facilitated their formation. In the whole district no accidents have occurred, and during my investigation I did not hear of any damage. It was not so much the violence as the frequency of the shocks, that, connected with the phenomena near Sopoetan, troubled the natives, and even caused the beginning of a panic in the southern settlements of the plateau. The fact of our investigation next induced the fugitives to return to their homes and to show themselves more or less ashamed of their anxiety. It was curious for us Europeans to hear by way of excuse


MAP
of part of the
SOPOETAN-MOUNTAINS.
Scale 1: 30.000.
Level-lines at 20 M. verticaldistance from each other.
Mt Tonderoekan
Mt Rindengan
+1561.
Brook Masem
Mt Sempoe.
To Kelelondei
Astr. point
+1793.
Crater
Mt Sopoetan.
+1793.
Mt Manimporok.
+1300
+1400
+1500
+1600
+1700
+1200
1: Hot spring R
mĕrĕga.
2: Solfatare Walèla
3: Solfatare forn
in 1901.
4and5: Eruption-co
formed in June-J
1906; (sketched).
Stream of sinter-blo
of 1906; (idem).
Possible old crat
edges (idem).

that only the valid inhabitants had fled, thus leaving the sick and the old to their fate.

In my quieting report (comp. the already cited annual and quarterly report) was based in the main on the clearly discernible connection between the seismic disturbance on the one hand, the formation of the Pentoe-solfatare on the other hand, and on the total absence of any other symptom of increasing local activity. The Sopoetan-crater, from which in the first place an eruption could be apprehended, the more so as according to tradition its former eruptions had always been preceded by some earth-quakes, was in the same state of calm and feeble fumarole-activity, as I had seen it about two years previously. From two boccas in the southern part of the bottom of the crater the rising of steam seemed even to have somewhat diminished. As likewise the existing solfatares, and hot springs, in so far as we could observe, or gather from reports, did not show any marked change in their activity, the formation of the new solfatare, also taken as a hydro-thermal phenomenon, could be considered as entirely isolated and of a local nature.

After it was ascertained that there was no other cause for the seismic disturbance, the coincidence of its beginning and maximal violence with the formation of the Pentoe-solfatare got a primary importance. The causal connection which thereby had become very probable was, as we have already indicated, further supported by the fact that the pleistoseistic region proved to agree with the nearest surroundings of this solfatare. At Tombatoe the earth-pulsations were not stronger than on the Tondano-plateau, and at Amoerang the intensity and frequency must have agreed nearly with those at Menado. It seems that on the whole the seismic phenomena, south and west of the Sopoetan-mountains, were somewhat weaker than in the north and the east.

Utrecht, May 1911.