

AN INTERPRETATION OF SOUTH-LIMBURG SUBSURFACE TEMPERATURE DATA^{1) 3)}

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ABSTRACT

Staatsmijnen in Limburg (now named Naamloze Vennootschap DSM at Heerlen) has conducted temperature measurements in the Carboniferous rocks of the South-Limburg coalmining area. From the measuring results the temperature gradients for both the overburden and the Carboniferous are derived.

The temperature gradient of the Carboniferous averages $\delta_c = 3.0$ °C/100 m, whilst, that of the overburden, depending on the composition and the water content, appears to range between $\delta_d = 5.5$ and $\delta_d = 2.4$ °C/100 m, according to 5 separate regional groups of measurements in the South-Limburg mining area. With the aid of the data obtained a map has been compiled of subsurface temperature at datum level, (-749 m. Amsterdam Zero Level), which chart is to serve in making predictions regarding climatic conditions in underground workings.

INTRODUCTION

One of the factors determining the possibility of working a mine is the subsurface temperature pattern. The temperatures of the different types of rocks at certain levels are also decisive as regards determining for instance, economically workable coal reserves. For calculation of the climate prevailing in underground workings it is essential to know the original rock-temperature, here after indicated with T_{ν} . If the mine-climate is fully calculated from the shaft to the return side of a coal face, it will show that approximately 70% of an error in T_{ν} will be incorporated in the so calculated dry-air temperature. Moreover, for climatic calculations related to inclining air passages the increase of the rock temperature corresponding with increasing depth must be known accurately. As medically sharp limits are set for work under

severe climatic conditions, the T_{ν} error should be reduced to approx. 0.5 °C.

For this reason it was necessary to determine the exact temperature gradients of the Carboniferous as well of the overburden. From 1964 onward such studies have been made, the results of which are given in a condensed form in Table 1. Another object of this publication is to present these results against the background of recent interpretations of the Groningen data published by H. van Engen. The temperature gradients are hereafter indicated as δ_c for Carboniferous rock and as δ_d for the overburden, both expressed in °C/100 m.

MEASURING METHOD

The measuring method employed for the determination of the temperature of yet uncooled rock in 10 m deep drilled holes in the wall of underground galleries was described by Sadée, van der Put and Gerrets (1959). In several aspects this method formed an improvement on the one that had been applied so far by de Braaf and Maas (1952). The thermo-elements used by them, which were difficult to conduct, were replaced by N.T.C.- resistors. Furthermore the new measurements were, in principle, only carried out in rock that had not yet been cooled or only to a slight degree by the ventilation-air. The original rock-temperature T_{ν} could be measured directly along a large portion of a 10-metre electrical cable. It was thus no longer necessary to apply the extrapolation method according to de Braaf (1951), if a greater accuracy with measurements conducted in strongly cooled rock and the original temperature level (T_{ν}) was not reached, than the theoretical cooling graphs of Nottrot and Sadée (1966) were used, for which the cooling period, the rock properties and the coefficients of heat transfer at the wall has had to be known. The cooling time can be derived from local history, whilst the rock properties and the heat transfer coefficients are known from Sadée, (1969). The improved method moreover made it possible to measure in deep subsurface drillholes (for instance in exploratory drilling). To this end, N.T.C.- resistors were

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³⁾ With the co-operation of J. Stuffken, DSM; Calculations H. Muly, drawings G.J. Scholten.

Table 1 State Mine WILHELMINA

Measuring Point				Rock-temperature in °C	Date
No.	Place	Overburden in meters	Carboniferous in meters		
A	Grondgal. onder Nbr. 300, lg. Finefrau	110	596	33,5	'48
B	1e Z.O.-stg. 506 mv, punt 47	92	402	26,5	'48
C	Stg. naar opbr. 250, 331 mv., punt 246	85	237	19,3	'48
D	O.H.-stg. 785 mv., punt 40	95	678	37,1	26- 7-'57 19- 5-'58
	O.H.-stg. 785 mv., punt 89	95	678	37,1	26- 7-'67 19- 5-'58
E	O.H.-stg. 785 mv., (kop), punt 412	91	681	36,9	5- 4-'60 5- 4-'60
	O.H.-stg. 785 mv, (vloer) punt 412	91	681	36,9	12- 1-'61 12- 1-'61
F	Centr. toev. 785 mv., (kop) punt 227	97	657	36,0	5- 4-'60 12- 1-'61
	Centr. toev. 785 mv., (wand) punt 227	97	657	36,0	5- 4-'60 12- 1-'61
G	Centr. toev. 785 mv., (kop) punt 55	97	674	36,6	5- 4-'60 12- 1-'61
	Centr. toev. 785 mv., (wand) punt 55	97	674	36,6	5- 4-'60 12- 1-'61
H	Post 809, 785 mv.	68	672	35,5	21- 1-'64
J	Post 819, 785 mv.	60	677	35,0	21- 1-'64
α	Post 809, 785 mv., punt 570 (74 m diep)	69	741	38,8	23- 1-'64
β	Post 816, 785 mv., punt 18 (70 m diep)	65	769	38,6	29- 5-'64
γ	2e NO-stg. 785 mv., punt 300 (40 m diep)	83	726	38,0	5- 6-'64
δ	1e OH-stg. 785 mv., (36,85 m diep)	63	747	38,5	7- 8-'64

installed on a multi-core electrical cable at various heights and lowered into the drillhole, whereupon the hole was carefully filled with sand. When equilibrium had become restored, the temperature gradient in the Carboniferous rock could be measured directly by means of this method.

MEASURING RESULTS

In Table 1 the results are given of measurements of the temperature profile in 132 holes at 82 locations in the South-Limburg Carboniferous. The table also includes measurements by de Braaf (1951) and by de Braaf and Maas (1952). The grade line level was determined by means of a topographical chart, scale 1 : 25000, and the Top-Carboniferous with the aid of a map of the Carboniferous surface area, to a scale of 1 : 25000. The latter made it possible to establish the thickness of the overlying strata and of the Carboniferous above the measuring point.

The temperature gradients were derived from the measurements of Table 1 (with the exception of the unsuccessful ones: ϵ , α , β and δ) according to the method of the smallest squares and the formula:

$$T_{\sim} = 10.0 + (\text{thickness of overburden} \times 10^{-2} \delta_d) + (\text{thickness of Carboniferous} \times 10^{-2} \delta_c)$$

wherein: T_{\sim} = original rock temperature in °C; δ_d = temperature gradient overburden in °C/100 m; and δ_c = temperature gradient Carboniferous in °C/100 m.

It was found that the temperature gradient of the overburden amounted to $\delta_d = 2.0$ °C/100 m, and that of the Carboniferous to $\delta_c = 3.73$ °C/100 m. The average absolute deviation between the measured rock temperatures and those calculated for the measuring points on the basis of said gradients amounted to 1.2 °C, 30% of the deviations being > 2 °C, 58% > °C, and only 25% amounting to less than 0.5 °C, the maximum value still considered acceptable. The values found correspond with those of de Braaf and Maas (1952). In spite of the much greater number of observations, hardly any improvement of the accuracy appears to have been achieved. Moreover, the gradient of 3.73 °C/100 m for the Carboniferous poorly agrees with the gradient measured directly in the deep drillhole No. γ . These reasons prompted continuation of the investigations, preferably on the basis of a physical consideration regarding heat conductivity in the earth crust normal to surface.

From the foregoing the following conclusions could be drawn, in addition to those relating to the gradients found:

1. the proportion between the gradients in the overlying strata and the Carboniferous in South Limburg may (in the case of fully saturated clay) be at least in the order of $\frac{2.0}{2.6} = 0.77$ and (referred to dry sand not subject to pressure) be at most in the order of $\frac{2.0}{0.2} = 10$;
2. The ratio of the gradients calculated before for all measuring points is an impossible one, viz. 0,54;
3. the gradients in the overlying strata may show great regional differences whereas those in the Carboniferous must regionally be about the same;
4. processing of measuring data taken as one group is inadmissible. In order to achieve better results it was necessary to divide the observations into groups, depending on the nature, the composition, and the thickness of the overburden.

So far it has been assumed that the heat flow was equal throughout the area. Since there are no mountains, no deposits or vulcanic influences, and the carbonaceous rock, which is responsible for the major portion of the heat resistance, is virtually identical in composition in the entire area, said assumption might be considered justified. Locally, however, deviations in the heat flow may occur. In the proximity of shafts, the rock has been cooled for a very long time by the incoming and returning ventilation air; at return shafts the rock and the overburden may even have been heated through the top part of the shaft. Moreover, de-watering of the overlying strata through fractures along the safety pillar of the shaft is possible. These circumstances may greatly disturb the heat flow pattern. Also the heat flow may become influenced by geological faults with a throw at the surface of the Carboniferous, because Carboniferous and the overburden each with its specific heat conductivity coefficient, will locally lie side by side. The heat flow will here be deflected sideways to the material having the higher heat conductivity coefficient, which situation is represented by figure 2. The fault concerned (Feldbiss) was approached in four measuring points. In the same figure also the temperatures measured at these points are plotted. The temperature appears to decrease substantially as the area of the fault is being approached. Faults are also of importance because the nature of the overlying strata often changes there. Sometimes these strata, e.g. water-containing chalk may become de-watered. These possibilities have been taken into account when the measuring results were processed.

The measuring results are reprocessed below. On the basis of the physical consideration the measuring points have been divided into groups with an overlying stratum of the same type and practically the same thickness.

Special attention has been paid to the possibility of deviations occurring at the measuring points located near shafts and in the neighbourhood of faults.

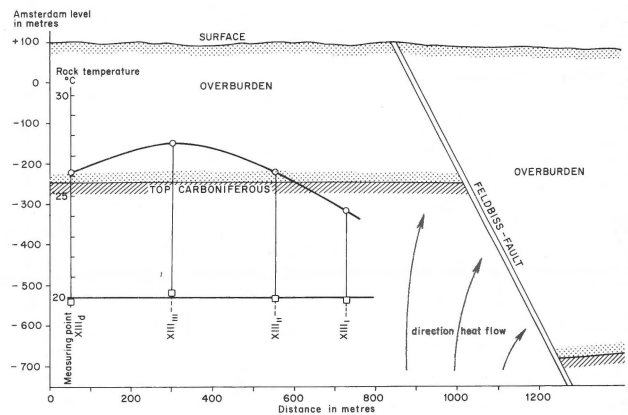


Fig. 2. Influence of a geologic fault on the original rock-temperature (T_{ν}).

RESULTS

The observations of Table 1 were grouped on the basis of the nature and the thickness of the overburden, according to the data compiled by P a t i j n and K i m p e (1961). In this way the following five groups were formed:

Group 1, *Wilhelmina area*

Location: south of the Waubach-anticline, between the Feldbiss- and the Heerlerheide-, Richterich- and Willem-faults. Overlying strata: mainly Oligocene (Tertiary) sands and clay; thickness 40 to 140 m. Measuring points: A, B, D, E, F, G, H, J, M, Q, R, S, T, U, and γ .

Group 2, *Hendrik area, South*

Location: north of the Waubach-anticline, south of measuring point XV, between the Feldbiss- and Heerlerheide-faults. Overlying strata: mainly Oligocene and Miocene (Tertiary) sands and clay; thickness 150 to 175 m. Measuring points: II, III, IV, V, XVIII, XXII, and XXIV.

Group 3, *Hendrik area, Centre*

Location: north of measuring point XV, between the Feldbiss- and Heerlerheide-faults, on the north bounded roughly by the Boekelo-fault. Overlying strata: mainly Oligocene and Miocene sands and clay, the top of the Carbonaceous rock being covered by a thin layer of limestone (Maastrichtian chalk); thickness of overlying strata 165 to 300 m. Measuring points: 3, VI, VII, X, XI, XII, XIV, XV, XVII, XIX, XX, XXIII.

Tabel 1 continued; Private Mines

Measuring Point				Rock-temperature in °C	Date
No.	Place	Overburden in meters	Carbo- niferous in meters		
K	O.H.-stg. 485 mv. Willem-Sophia	50	438	28,0	7-12-'54 18- 1-'55
L	Post 251 485 mv. Willem-Sophia	38	440	27,0	18- 3-'64
ρ	Post 653 485 mv. Willem-Sophia	42	435	26,9	21- 3-'65 2- 4-'66
σ	Post 503 485 mv. Willem-Sophia	50	433	26,8	22- 3-'66 15- 7-'66
τ	Post 937 217 mv. Willem-Sophia	80	212	18,2	23- 3-'66 14- 7-'66
ϕ	Post 507 485 mv. Willem-Sophia	73	415	26,7	24- 3-'66 5- 4-'66
M	Boring Dom No. 275 Hfd-stg. N.W., 500 mv. Dominale Mijn	40	404	25,0	1957
N	Sth. 192 b, 360 m.v. 2e ZO-stg. no.192 Julia	196	185	22,0	22-10-'54 5-11-'54
O	Front stg. 512, punt 76 540 mv. Julia	270	300	29,7	28- 1-'54 18- 2-'54
P	Stg. 507, punt 1220, 540 mv Julia	265	305	29,6	4- 2-'54 18- 2-'54
Q	Afv.-gal vanaf opbr. 144 lg XII, 378 mv. Laura	113	294	25,0	29-12-'55 7- 1-'56
R	Sch. II afdiepen Laura	95	601	35,6	29-12-'55 7- 1-'56
S	Post 0713 378 mv. Laura	126	344	27,6	7- 6-'63 3- 7-'63
T	Post 0114 550 mv. Laura	140	420	31,0	6- 6-'63 18- 6-'63
U	Toev. pijler 10 Lg XII 378 mv. (GB nr. 10) Laura	71	365	26,2 26,0	12- 8-'63 12- 8-'63
V	In lg IV boven opbr. 109, werkp. 248 250 mv. ON I	93	13	14,2	15- 6-'54 2- 9-'54
W	Front stg 250 b 250 mv. ON I	155	150	19,1	15- 6-'54 2- 9-'54
Y	Werkpunt 435 420 mv. ON I	96	331	24,1	24- 8-'54 19-10-'54

Group 4, Emma-Hendrik area, North

Location: north of the Boekelo-fault, between the Feldbiss- and Heerlerheide-faults. Overlying strata: mainly Oligocene and Miocene sands and clay, with a thin layer of limestone (Maastrichtian chalk) topping the Carbonaceous sediments. The overlying strata in this area have become strongly de-watered ($2.5 \text{ m}^3/\text{min.}$) since 1933 as a result of underground working: thickness 320 to 360 m. Measuring points 2, I, XIII_d, XIII_I, XIII_{II}, XIII_{III}, 7, 8, and 9.

Group 5, Maurits and Emma areas, Centre and South

Location: between the Heerlerheide-fault and the national frontier, north-west of the 70-metre fault. Overlying strata: sand and clay from the Tertiary and the Upper Cretaceous and limestone strata from the Upper Cretaceous; thickness of the overlying strata 240 to 340 m. Measuring points: 1, 4, 5, 6, a, b, c, d, e, f, g, h, j, k, l, m, n, p. q. and r.

Tabel 1 continued; State Mine EMMA

1	be 7 stg W 700 mv., punt 313	233	442	28,2	6- 9-'53 20-10-'53
2	2e N stg W 700 mv., punt 264	311	367	29,4	22- 8-'53 10-10-'53
3	1e NW stg O 700 mv., punt 149	283	413	31,0	8- 8-'53 11- 9-'53
	1e NW stg O 700 mv., punt 149	290	410	31,0	8- 8-'53 11- 9-'53
4	W.H. stg 700 mv., punt 516	219	475	32,0	10- 8-'53 11- 9-'53
5	In fietsenloods 700 mv (t.o.-tel. centr.)	199	676	39,1	8- 6-'56
	In fietsenloods 700 mv (t.o. tel. centr.)	199	636	38,4	8- 6-'56
	In fietsenloods 700 mv (t.o. tel. centr.)	199	595	37,2	8- 6-'56 juli t/m
6	4e N stg W 546 mv., afd. A ² lg IX ^f	239	263	24,2	okt. '58
	4e N stg W 546 mv., afd. A ² lg IX ^f	239	253	24,0	okt. '58
	4e N stg W 546 mv., afd. A ² lg IX ^f	239	243	23,9	okt. '58
7	2e N stg W 700 mv. in toev.-gal lg G	342	314	27,5	22- 8-'62
	afd. B ² oost, punt 24 kop				4- 9-'62
	2e N stg W 700 mv. in toev.-gal lg G	342	326	27,7	4- 9-'62
	afd. B ² oost, punt 30 wand				
8	5e N stg. W. 700 mv. in afv.-gal. lg G	341	409	30,3	7- 8-'62 13- 8-'63
	punt 37 (kop)				
	5e N stg W 700 mv. in afv.-gal. lg G	341	421	30,7	13- 8-'63
	punt 37 (wand)				
9	7e N stg W 700 mv. in toev.-gal lg E,	356	329	27,5	11- 2-'63 14- 8-'63
	punt 242 wand				
	7e N stg W 700 mv. in toev.-gal lg E,	356	319	27,3	14- 8-'63
	punt 248 kop				

Tabel 1 continued; State Mine MAURITS

a	Z.W.-stg. 391 mv., punt 620	298	83	20,0	9- 6-'39
b	Z.H.-stg 660 mv., punt 120	299	348	28,2	3- 6-'39
c	1e ZO-stg 660 mv., punt 217	284	351	29,2	'48
d	6e Z stg W 660 mv., punt 740	340	300	28,4	'48
e	2e N stg O 391 mv., punt 456	262	122	18,0	'48
f	9e Z stg W 548 mv., punt 875	342	169	25,7	'48
g	1e N stg O 548 mv., punt 570	276	256	23,0	'48
h	verl. N laadpl. 810 mv., punt 107	298	505	33,5	12- 5-'54 10- 6-'55
	verl. N laadpl. 810 mv., punt 107	298	505	33,5	12- 5-'54 10- 6-'55
j	verl. 5e N stg W 660 mv., punt 235 m	365	415	30,0	19- 8-'63
	links post 1063 lg C afd.: Z, kop				
	verl. 5e N stg W 660 mv., punt 235 m	365	416	29,9	19- 8-'63
	links post 1063 lg C afd. Z, wand				
k	W.H. -stg 810 mv., punt 164	302	516	33,5	jan. '54
	W.H. -stg 810 mv., punt 164	302	516	32,0	jan. '54
l	Std. in lg XIX 9e ZW: 548 mv.	337	194	25,8	21- 7-'64 21- 9-'64
	bouw 210 = 165 m voor het front				
	Std. in lg XIX 9e ZW: 548 mv.	337	194	25,9	21- 7-'64 24- 9-'64
	bouw 210 = 165 m voor het front				
m	5e Z.O.-stg. 660 mv. front stg	278	368	30,0	23- 7-'64 27- 8-'64
	bouw 895 = 703 m, rechts				
	5e Z.O.-stg. 660 mv. front stg	278	368	29,6	23- 7-'64 27- 8-'64
	bouw 895 = 703 m, links				
n	front afv.-band afd. K ¹ lg XXII 2e verl. OH	264	249	25,4	31- 7-'64 13-11-'64
	548 mv., bouw 1387				
p	afd. E ¹ 8e Z 660 mv. afv. band,	334	267	27,7	9- 9-'64 29-10-'64
	bouw 937 = 801 m				
q	2e Z 660 mv., diepboring punt 618	323	372	30,5	11- 9-'64 12- 3-'65
r	4e Z stg W 810 mv., bouw 847 = 783 m	335	457	34,2	8- 2-'65 28- 4-'65

Apart from the unsuccessful measurements a , β , δ , and C there were other measurements that could not be classified under one of the above groups, notably N , O , P , V , W , Y , VII , IX and XVI . Further, a group of measurements conducted in the area south of the Willem fault has not been incorporated; this concerns K , L , σ , τ , ϕ , and ρ . These measurements might, indeed, form a separate group, but the differences in the thicknesses of the overlying strata and the Carbonaceous deposits are too small to produce reliable data by application of the method of least squares.

Each of the groups was processed as such by means of the method of least squares. Deviations resulting from cooled areas were eliminated in the groups by solving the formula describing the original rock temperature, for all pairs of measurements that can be formed. It now proved that measurements carried out at a distance of approximately 400 metres to faults with a throw in the overlying strata, as well as measurement near shafts, produced data which were most unlikely and which confirmed the suspicions expressed previously. For this reason the results of the following measurements could not be used:

- Group 1: None;
- Group 2: II and XXII;
- Group 3: VI, VII, XIX, XX and XXIII;
- Group 4: 2 and XIII₁;
- Group 5: c , e , g , j , m , l , 4, and 5.

Of the original 82 measuring points 46 observations remained, which together, yielded as gradient:

$$\delta_d = 1.97 \text{ }^\circ\text{C}/100 \text{ m and } \delta_c = 3.69 \text{ }^\circ\text{C}/100 \text{ m}$$

Physically, however, the ratio $\delta_d/\delta_c = 0.53$ is an impossible one and the average absolute deviation between the measured temperature and that calculated with the aid of said gradients still amounted to 1.0°C . Subsequently, therefore, the gradients, the average absolute deviation between the calculated and measured temperatures, and the ratio between the gradients of the overlying strata and the Carboniferous sediments were determined separately for each group. It appeared that the deviation can yet be greatly reduced by disregarding the following measuring points:

- Group 1: A and B (inaccurate, see Table 1);
- Group 3: XV;
- Group 5: f (accuracy unknown) and r .

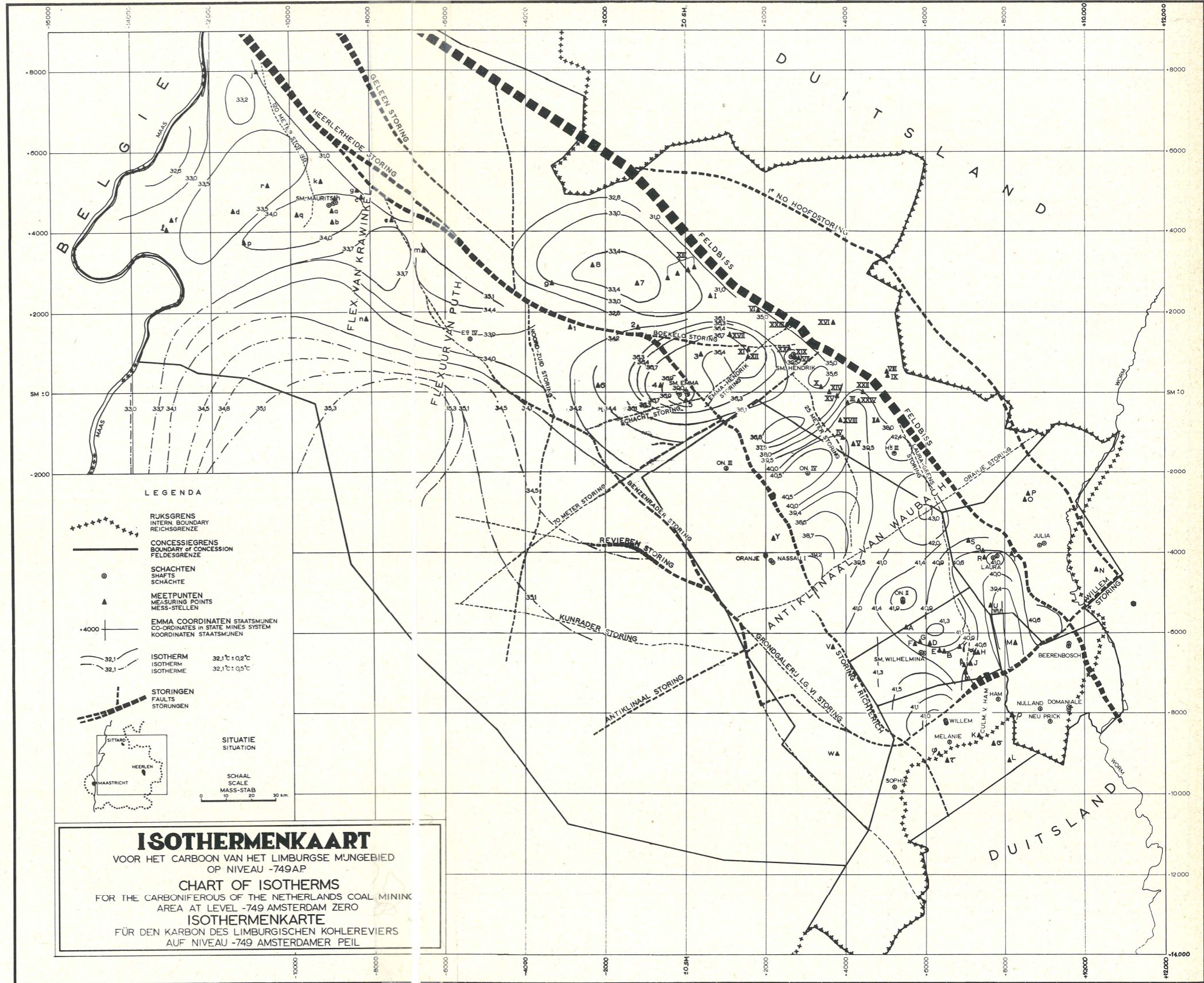
Table 2 gives the results.

The following conclusions could be drawn from the 41 measurements left, which were divided into five groups:

1. as expected, the overlying strata gradients appeared to show considerable differences; the lowest value, viz. $\delta_d = 2.36 \text{ }^\circ\text{C}/100 \text{ m}$, has been found for group 4 (Emma-Hendrik, North area.) Most likely, this is accounted for by the strong, continual de-watering of the overlying strata, resulting in cooling and severe settling (attended by a lower porosity and a higher heat conductivity coefficient);

Fig. 3.

Chart of Isotherms of the Netherlands Coal Mining Area at level -749 m. Amsterdam Zero.



Tabel 1 continued; State Mine HENDRIK

Measuring Point				Rock- temperature in °C	Date
No.	Place	Over- burder in metres	Carbo- nifereus in metres		
I	1e NW-stg 730 mv., punt 1722	323	392	29,5	31- 7-'56
II	1e ZO-stg 537 mv., punt 2517	174	374	27,5	27- 9-'56
III	1e ZO-stg 730 mv., punt 1275	172	543	35,8	april '64
IV	4e ZO-stg 730 mv., punt 985	150	577	36,3	okt. '40
V	4e ZO-stg 730 mv., punt 1255	152	584	35,5	10- 1-'56
VI	A.N.W. afd.-stg 730 mv., post 1474	269	418	30,5	4- 2-'56
VII	Schacht I 855 mv.	203	634	40,4	jan. '56
VIII	Grondgal, 1g XIV t.O. 1e ZO. -stg t.O. Feldbiss 537 mv.	449	83	24,5	jan. '57
IX	1e ZO-stg t.O. Feldbiss 636 mv: punt 700	437	181	26,6	juni '38
X	1e ZO-stg 855 mv., punt 495 links (wand)	171	664	36,0	mei '39
	1e ZO-stg 855 mv., punt 495 rechts (wand)	171	664	36,0	april '39
XI	1e ZW-stgal. 730 mv., punt 663	253	454	32,5	21- 5-'62
XII	1e ZO-afd.-stg, afd F. 1g XII, 730 mv.	248	478	32,3	27- 8-'63
XIII	Afd. L ^{II} Lg. D 636 mv. (22 m diep)	345	291	26,4	21- 5-'62
XIII	Afd. L ^{II} Lg. D 636 mv. punt I	345	288	24,5	27- 8-'63
XIII	Afd. L ^{II} Lg. D 636 mv. punt II	345	282	26,2	9- 2-'63
XIII	Afd. L ^{II} Lg. D 636 mv. punt III	345	270	27,2	27- 8-'63
XIV	1e ZO-stg 855 mv., punt 667 Links (wand)	165	666	35,8	jan. '44
	1e ZO.stg 855 mv., punt 667 rechts (wand)	165	666	35,8	3- 8-'62
XV	1e ZO.stg 855 mv., punt 1017 links (wand)	167	668	37,6	27- 8-'63
	1e ZO.stg 855 mv., punt 1017 rechts (wand)	167	668	37,6	9- 2-'63
XVI	3e NO.stg 636 mv., punt 1171 wand	555	74	24,8	27- 8-'63
XVII	W.H.-stg. 855 mv., punt 960 links	299	547	36,8	15-10-'62
	W.H.-stg. 855 mv., punt 960 rechts	299	547	36,9	5- 1-'63
XVIII	Afd. Z 730 mv. Lg XVII, 1e ZO afv.-band	153	511	34,0	26- 6-'63
XIX	Verl. N. Laadpl. Sch. II, punt 221, 855 mv.	202	635	38,0	26- 7-'63
	Verl. N. Laadpl. Sch. II, punt 221, 855 mv.	202	635	38,2	26- 6-'63
XX	N. landpl. van Sch II en Sch VI 855 mv. punt 372 m	211	619	39,7	26- 7-'63
XXII	Front afv.-gal. Afd. N Lg XVIII 855 mv., punt 140 m	211	641	37,7	26- 7-'63
XXIII	2e NO stg 537 mv., punt 620	234	272	22,5	28- 5-'63
XXIV	Afd.N.Lg XVIII 855mv.,suppl.luchtw.rechts	173	613	38,0	15- 7-'55
	Afd.N.Lg XVIII 855mv.,suppl.luchtw.links	173	613	37,9	15- 7-'55
					mrt. '54
					15- 7-'55
					4- 9-'54
					15- 7-'55
					6- 8-'64
					15- 6-'40
					jan. '65
					jan. '65

2. the gradients of the Carboniferous rocks hardly show any differences between the groups. Also this had been expected on the basis of the physical considerations. The gradients are in agreement with the average value found all over the earth, viz. about $3.0^{\circ}\text{C}/100\text{ m}$ Königsberger and Mühlberg (1909/1910). The gradient relating to the Carbonaceous rock of group 1 agrees with that measured directly at point γ in this group (most probable value $\delta_c = 3.33^{\circ}\text{C}/100\text{ m}$);
3. the average deviation between the measured and the calculated temperatures ranges between 0.28 and 0.40°C , which satisfies the demand made on the accuracy (0.5°C);
4. all of the gradient ratios are within the range established from physical considerations.

For these reasons, as well as in view of the fact that all rejected results relate to measuring points located in narrow strips along fault areas, so that the regional spread of the measuring points is retained in spite of said rejection the established values may be regarded as reliable and representative of the various areas concerned.

SUBSURFACE TEMPERATURE CHART OF THE CARBONIFEROUS IN SOUTH LIMBURG

With the aid of the data obtained it was possible to plot a chart of isotherms representative of a certain depth in the South-Limburg Carboniferous. Allowing for the deepest levels in the Staatsmijnen underground works the depth chosen was -749 m Amsterdam Zero level. With the help of the gradients found for the various groups the rock temperatures at this depth were calculated for approximately 300 spots. Moreover, for all measuring points of Table 1, including those at faults and shafts, the measured values were extrapolated to this depth by means of the Carboniferous gradient established for the area concerned. Isotherms were then drawn through the temperatures so found, as shown in figure 3, whereupon it was possible to determine the rock temperature for each spot using δ_c and starting at the depth of -749 m Amsterdam Zero Level. The isotherm pattern at the same time serves to establish the levels at which certain temperatures prevail. Said levels can be calculated on the basis of the isotherms. This is of significance since investigations have proved that certain measures taken to cope with climatic difficulties can be well correlated with a certain rock temperature. By plotting the intersection of the coal strata and the geoisothermic plane applicable to said rock temperature, it may be rapidly concluded to what extent these strata can be worked without presenting problems of a climatic character and necessitating special measures. In addition, a map of isotherms can be prepared for a coal seam with the aid of the gradients found, as is illustrated by figure 4. In this way it is possible, already on first sight, roughly to predict the difficulties likely to occur, as well as to judge in which parts of the seam they will be encountered and what measures should be taken to overcome them.

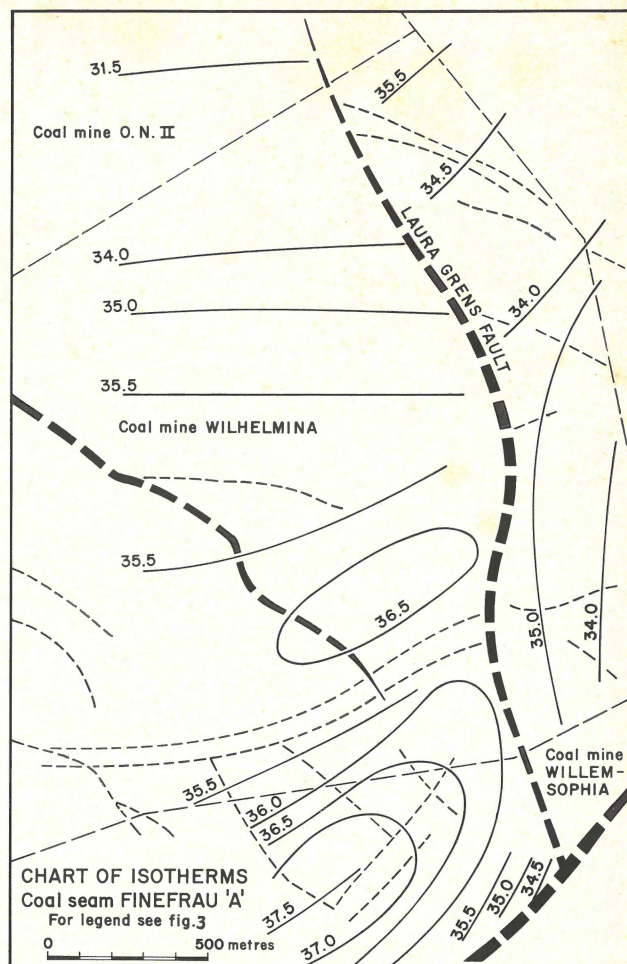


Fig. 4.
Chart of Isotherms of the Coal Seam Finefrau 'A' (G.B. no. 4b/c).

The accuracy of the rock temperatures calculated, depends on the accuracy of the method of calculation. In spite of the Carboniferous rock area having been divided into regions, the accuracy of the method seems to be not fully correct. Particularly the distance between Amsterdam Zero Level and the "grade line" plays a part here because local hills and valleys influence the outcome of the calculation, but they do not in the case of larger depths, owing to temperature adjustment. The average deviation between the measured temperatures and those calculated with application of this method amounts to approx. 0.34°C . The chart of isotherms was plotted using temperatures extrapolated from the measurements with an accuracy not exceeding 0.20°C and temperatures calculated with an average deviation of approx. 0.34°C starting at grade. When the isotherms were plotted, the measured temperatures were used for principal orientation. Moreover, allowance was made for the height of the grade level above Amsterdam Zero Level, the depth of the Carboniferous top, and the thicknesses of overburden and the Carboniferous, as a result of which an unreal

influence of local hills and valleys was eliminated. The accuracy of the isotherms for areas where measurements have been made may, therefore, be taken as approx. 0.2 °C, and for areas which have not been examined as approx. 0.5 °C.

tabel 2 Results for the different groups.

group	δ_d °C/100 m	δ_c °C/100 m	average absolute deviation °C	ratio δ_d/δ_c	thickness of over- burden in
1	5,12	3,27	0,28	1,56	40-140
2	5,55	3,00	0,28	1,85	150-175
3	3,08	3,12	0,34	0,99	165-300
4	2,36	2,96	0,39	0,80	320-360
5	2,81	2,97	0,40	0,94	240-303

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