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EARLY SUBSURFACE TEMPERATURE MEASUREMENTS IN THE NETHERLANDS[1]

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ABSTRACT

Visser, W. A. (1978). Early subsurface temperature measurements in The Netherlands. Geol. Mijnbouw, 57, p. 1-10.

The earliest known subsurface temperatures were obtained in 1879 in a borehole (to a depth of 365 m) in the centre of the city of Utrecht. During the years 1912 - 1914 temperatures were measured to depths as great as 1400 m in a number of wells in structurally high areas in Tertiary, Senonian, Triassic, Upper Permian and Carboniferous rocks. In 1952 additional data were obtained (Peel horst), followed in 1956 by a few measurements in the South Limburg mining district.

The various thermometers used are briefly described. The temperatures are related to lithology and stratigraphy and to the salinities of the interstitial waters. Very low geothermal gradients are present in Quaternary to uppermost Tertiary due to percolating waters of meteoric origin. In the post-Carboniferous overburden and, where shallow, in the higher parts of the Westphalian the waters are either fresh, or, if saline, do not reach sea-water concentrations. In such areas the geothermal gradients are lower than 3°C/100 m. In the Carboniferous, due to the low thermal conductivity of coal, gradients tend to be high: over 4, and reaching 5.2 to 5.6°C/100 m. In contrast, the high conductivities of anhydrite and rock salt cause low gradients (2.5 in the Buntsandstein and Zechstein formations).

INTRODUCTION

In 1975 two papers were published in this journal on subsurface temperatures in The Netherlands, by VAN ENGEN on the Groningen gas field and by SADÉE on the former coal mining area of South Limburg. The list of references in Sadée's paper led to earlier data. A short account of the inventory of subsurface temperatures and the history of the development of geological knowledge on The Netherlands has been given by FABER in his 'Geologie van Nederland' (1948, vol. I, p. 246-247).

The earliest known measurements were made by HARTING in April, 1879, in a drill hole, carried to a depth of 365.25 m, on the Vreeburg in the centre of the city of Utrecht (Fig. 1).

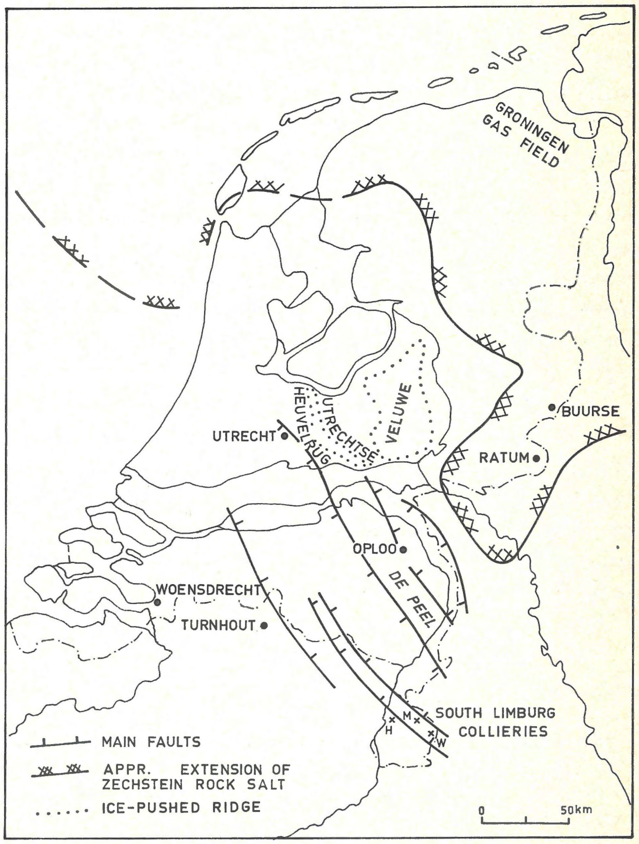

Fig. 1
Location map.

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In 1903, the 'Rijksopsporing van Delfstoffen' (ROvD – Government's Institute for Geological Exploration in The Netherlands) was founded and, since 1905, conducted drilling campaigns in various parts of the country, under W. A. J. M. van Waterschoot van der Gracht. During the years 1912 - 1914 temperature surveys were carried out in various boreholes in De Peel, in a hole near Woensdrecht and in two holes in the Gelderse Achterhoek (Figs. 1, 3). These observations were described in the Annual Reports of the ROvD 1910 - 1914 and have been summarized in the Final Report of 1918.

More recent data were obtained in South Limburg (De Braaf & Maas, 1952), again in De Peel (Schaffers & Maas, 1956; Peelcommissie, 1963) and just south of the border in a borehole on the market place in Turnhout, northern Belgium (Grosjean, 1954a, b; Gulinck, 1954, 1956).

Temperatures were plotted against depths and compiled in a number of graphs that also show the generalized lithology and stratigraphy, and, where available, the chlorine contents of the underground waters (Figs. 2, 4).

THE MEASUREMENTS

The Vreeburg well in Utrecht was drilled in 1872 with the purpose of exploring deeper beds for 'uncontaminated drinking water' (Veeren, 1910). Many technical difficulties were encountered, and drilling had to be stopped due to a stuck drill pipe at a depth of 365.25 m. In November 1875 a water sample was taken from a depth of 302 m; analysis showed 'not more than 75 mg NaCl/l' and a drying rest of 260 mg/l. In 1879 a water analysis from a depth of 98 m showed 25 mg NaCl/l and 54 mg CaO/l. The water quality was considered unsatisfactory. Because of protests from the local inhabitants (indeed, Harting considered the drilling shed an ugly sight) operations were discontinued and the hole covered by a stone slab. In April 1925, however, another water sample was taken from a depth of 102 m (Netherlands Institute for Drinking Water Supply, archives, well number 31H-172). A complete analysis was made, showing a calcium-hydrocarbonate type of water with 11 mg Cl^-/l.

Due to the wish of the City Board to close the well quickly, only one week was available for measuring the temperatures. Harting (1879) made use of three types of thermometers. His 'geothermometer'[3] consisted of a cylindrical reservoir topped by a tube with two right angled bends and ending in a narrow orifice. The apparatus was filled with about 120 grams of mercury. Upon thermal expansion drops of mercury were detached from the orifice. After drawing-up the subsurface temperature at the depth reached was found by placing the geothermometer together with a conventional mercury thermometer in a water bath that was slowly heated and stirred continuously. The moment the mercury began to overflow the temperature was read. It appeared, however, that the sizeable geothermometer heated up far slower than the conventional one, so that temperatures found were 'notably higher than the real ones'. Unfortunately this was only noticed towards the end of the survey; it was partly remedied by placing the reference thermometer in a mercury bath of the same size as that of the geothermometer.

The second type of thermometer was Harting's own design, a 'weight thermometer'. Its construction was similar to the geothermometer, but here the difference in weight of the original amount of mercury and that remaining in the reservoir was a measure of the temperature reached. The apparatus was calibrated by weighing it first at zero and then at 100°C, so that the equivalent of 1° could be expressed in mg of mercury. A source of inaccuracy proved to be the size of the drop of mercury that could be too small to become detached from the orifice and was consequently sucked back into the tube upon drawing-up the apparatus. This resulted in too low figures. The error, however, amounted to not more than 0.7°C or, if the apparatus was shaken before drawing-up, to not more than 0.024 to 0.16°C.

The third thermometer used was that of Casella-Miller, a meteorological maximum instrument of the constriction type, loaned to Harting by his colleague, Buys Ballot.

The thermometers were fastened to a copper frame that was covered by a slightly conical case, 50 cm long and open at its base; above and below the case rubber-coated iron discs were hung to prevent water movement in the borehole during a measurement. Two series were run at depths of 65, 165, 265 and 365 m; down-hole times varied from 2 to 21 hours (Fig. 2; Table I). Harting considered the Casella readings to be the most reliable, and he thought the weight thermometers to give an approximation only due to the non-detachment of the last drop of mercury. That is why in his table the maximum readings were repeated with the averages; they 'seem to have the greater claim to accuracy'. It will be noted that the largest difference in the two series of runs is only 1.3°C.

Harting further envisaged possible errors due to convection in the hole (16 cm in diameter), lack of thermal equilibrium between the contents of the hole and surrounding rock and conduction by the iron casing. It now seems likely that the effects of both convection in the hole and conduction by the casing are negligible. Thermal equilibrium was certainly reached 7 years after drilling. However, the water in the hole must have been seriously disturbed when lowering the cone; from the consistency of the results (and recent surveys) it appears that down-hole times were sufficiently long for the original temperature distribution to be restored.

At the end of his paper Harting discussed the geothermal gradients found, which in the subsurface 'is put at an average

[3] In present usage a geochemical thermometer (in literature often abbreviated to geothermometer) means a number of chemical indicators of subsurface temperatures in relation to the origin of the water in a geothermal system (*Kappelmeyer & Haenel*, 1974, p. 139, 140).

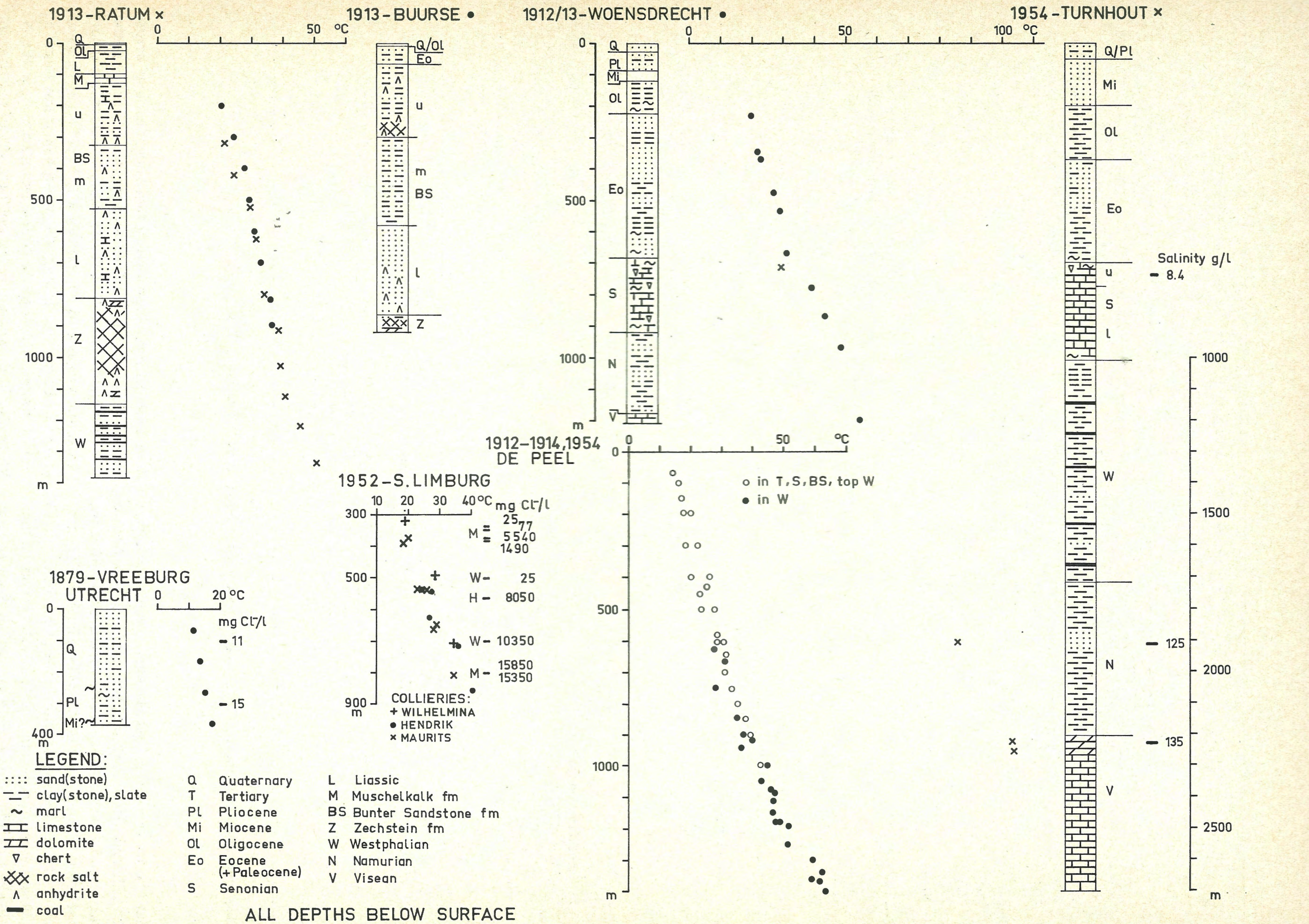

Fig. 2
Temperature-depth graphs with chlorine contents of subsurface waters and generalized lithology and stratigraphy.

depth (in m)	down-hole time (in h)	Temperature (in °C) Casella	weight thermometers		geothermometer
1st series					
65	2.5	12.0	12.1	11.1	
165	16	13.7	13.9	13.3	
265	2.75	15.4	15.3	14.1	
365	17	17.7	17.1	16.7	
2nd series					
65	18	11.8	11.6	10.9	
165	3	13.7	13.1	13.6	13.4
265	21	15.3	15.3	15.0	
365	18	17.8	17.3	17.3	17.2
averages					max. readings of geothermometers
65		11.9	11.55		12.1
165		13.7	13.5		13.9
265		15.35	14.9		15.3
365		17.75	17.1		17.3
geothermal gradients (°C/100 m)					
65-165		1.8	1.195		1.8
165-265		1.65	1.4		1.4
265-365		2.35	2.2		2.2
geothermal steps (m/1°C)					
65-165		55.6	51.2		55.6
165-265		60.6	71.4		71.4
265-365		42.6	45.5		50.0
65-365		51.7	54.5		57.7

Additional temperatures were obtained with the Casella thermometer, down-hole times 15 minutes:

25 m	11.2 °C
35	11.2
45	11.4
55	11.5

Table I
Subsurface temperatures in the Vreeburg borehole in Utrecht, measured by P. Harting (1879).

of about 1° C for every 30 m, but amounts here to a little over half of it'. He considered the most likely explanation to be that the cold waters of the North Sea exerted a noticeable influence on the subsurface temperatures. We will see later that Harting was near to the modern explanation of the phenomenon, in so far as the influence of infiltrating surface water is considered.

All drilling by the 'Rijksopsporing van Delfstoffen' was done in structurally high areas. From known geology across the German frontier and from topographical features in the southern Netherlands Van Waterschoot van der Gracht surmised the presence of a horst below the Peel area. This was proved to be true by drilling; the Westphalian was found at depths around 500 m in the S and around 850 m in the N. Woensdrecht is situated on the northern rim of the Brabant

date	depth (in m)	temperatures (in °C)		
1912 - Nov. 16/18	643	30.0	30.0	30.50
Dec. 1/ 2	643	30.50	30.50	31
Nov. 24/27	750	34.0	34.0	34.0
1913 - Jan. 10/11	750	34.0	34.0	34.50
Jan. 18/20	850	36.5	37.0	37.0
Jan. 25/26	850	37.0	37.5	37.5
Feb. 2/ 4	893	38.5	38.5	39.0
Feb. 5/10	893	39.0	39.0	39.0
March 1/ 3	1000	41.5	41.5	42.0
March 29/31	1000	42.0	42.0	

Table II
Subsurface temperatures in the borehole Oploo below 640 m depth (ROvD, Annual reports).

Massif; Namurian shales were encountered below Senonian chalks at a depth of a little more than 900 m. In the Gelderse Achterhoek Triassic outcrops, and here the Westphalian was found at around 1150 m. Moreover, the two economically valuable rock-salt deposits, known in Germany as the Röt member of the Upper Buntsandstein Formation and as the Zechstein Formation, were discovered to extend below The Netherlands territory (compare the maps compiled by Heybroek, 1974).

It is mentioned in the Annual Reports that in preliminary experiments with various types of maximum thermometers no reliable results were obtained. The riders were displaced irregularly during drawing-up, resulting in widely divergent readings. From January 1912 onward use was made of 'overflow thermometers', that is Harting's geothermometer, with which 'highly satisfying results were obtained'. Mention is made of the advantage of shaking the apparatus before drawing-up to ease detachment of the last drop of mercury. No reference, however, was made to Harting's objection to this method. Three thermometers were lowered simultaneously and the readings averaged; consistent results were obtained, also when measurements were made a few weeks apart. As an example the deeper data from boring 16 (Oploo in the northern Peel area) are given in table II. The 'bulge' between 500 and 570 (Fig. 4), attributed to water influx from deeper levels along a fault is noticeable. From 572 m 'the source was largely shut-off and temperatures became normal again'.

Exploration on the Peel horst was resumed in the fifties by the Dutch State Mines (Peelcommissie, 1963) with seismic surveys and drilling.

A resistivity thermometer with a negative temperature coefficient was used for the temperature measurements (Schaffers & Maas, 1956). The purpose was to see whether it would be possible to determine original rock temperatures from a number of observations made during a one to two day suspension of drilling activities, that is during part of the time that the thermal equilibrium was being restored. The temperatures obtained should approach the original rock temperature asymptotically, but the authors stated that no accuracy greater than 1 - 2°C could be reached mainly due to insufficient knowledge of the thermal properties of the drilling mud and of the rock surrounding the hole.

All subsurface temperatures from the Peel horst have been plotted on graphs (Fig. 3); in figure 2 they are gathered on a composite graph. There is some spread but the difference in geothermal gradient between overburden and Westphalian can be seen clearly. This was noted by Schaffer and Maas and tabulated in the Report of the Peelcommissie (Table III). In the southernmost wells, Elmpt and Maasniel (Fig. 3), the gradient in the Westphalian is somewhat higher than further north. It is interesting to see that the higher gradients occur in an area where Patijn (1963) noted a comparatively high coalification.

Waters from the 1954-boreholes have been analyzed; the analyses were interpretated geochemically by Kimpe (1962). There is a general increase of salinity with depth (Fig. 4), but concentrations only approach that of sea water or are slightly higher in the deeper parts of the Westphalian.

The temperatures from the ROvD well at Woensdrecht compare rather favourably with those from Turnhout (Fig. 2). Grosjean (1954a, b) used three mercury thermometers simultaneously; between the division marks of zero and 100°C these were 225 mm long. One was cut near the mark of 70°, the others at 67°. The temperatures at which successive drops of mercury were ejected were measured in the laboratory. By averaging accurate subsurface temperatures were obtained (Table IV). The temperatures from the Namurian and Visean of Turnhout between 1877 and 2185 m below sea level are indicative of a high geothermal gradient, 5.6°C per 100 m. The temperature at 1000 m has been calculated from the less accurately measured temperature at 687 m on the assumption that a constant geothermal gradient exists between 25 and

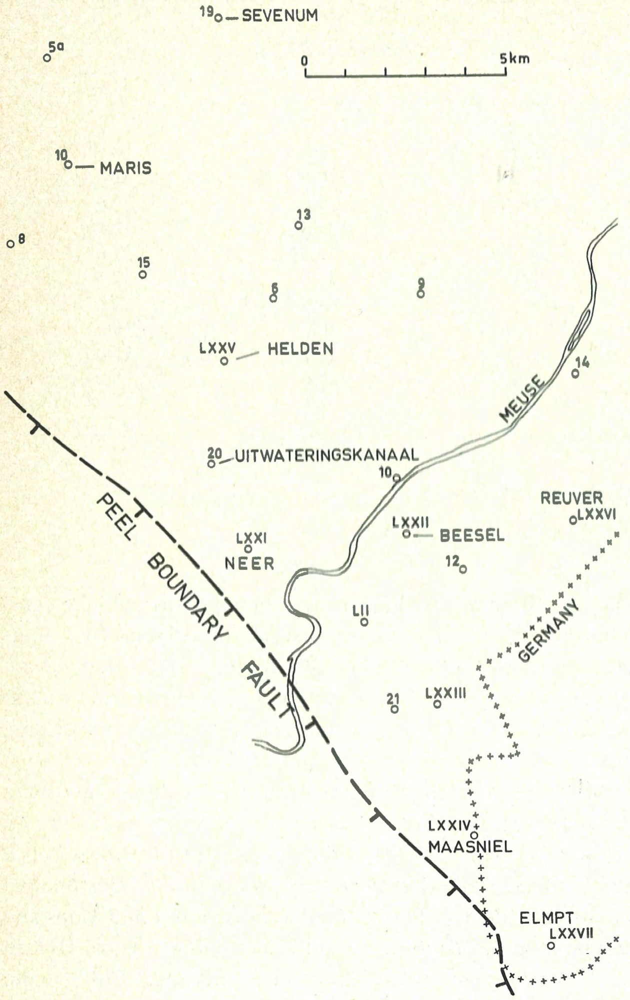

Fig. 3
Location map Peel area.

1000 m (2.94), and, therefore, Grosjean exerted caution on the gradient of 5.3°/100 m between 1000 and 1872 m.

A peculiar shift is present in Woensdrecht between 1200 and 1000 m depth; however, the general gradient in Turnhout and Woensdrecht between 700 and 1200 m depth (in Senonian, Namurian and Westphalian) seems to be about 5°. From the temperatures of the lower Tertiary in Woensdrecht a gradient of about 3.2. can be derived.

In the Senonian of Turnhout salinity is far less than that of sea water; in the Carboniferous brines are present (Gulinck, 1956). No analyses were made in Woensdrecht. The temperatures obtained by De Braaf & Maas (1952) in three collieries completed the early data from the southern Netherlands (Fig. 2). They succeeded in measuring original rock temperatures before cooling as a result of mining activities. A nearly horizontal hole, about 10 m deep, was drilled perpendicular to the wall of a stone drift under construction, A constantan wire was inserted, to which an insulated copper wire was soldered at four points, each point serving as the contact of a thermocouple. A fifth point was located outside the hole with a calibrated thermometer as a reference. Thus the temperature differences between the latter and the four points at different depths could be measured. The measurements were repeated until they remained constant. From a limited number of 16 observations De Braaf and Maas derived average gradients of 2.15 and 3.84°C per 100 m for overburden and Westphalian respectively. De Braaf & Maas mention that their results are in good agreement with two observations in Belgium, 32 km W of Maurits colliery, namely a gradient in the overburden of 2.4 and of 4.55 in the Carboniferous, and with those in Utrecht by Harting: 2°C per 100 m.

According to the data collected by Kimpe (1962), in South Limburg the waters in the overburden and in places in the Carboniferous are fresh; a concentration higher than that of sea water was only found in one place at depth.

Finally, the wells of Ratum and Buurse show a different stratigraphy from the wells in the south (Fig. 2). Three geothermal gradients appear to be present; a high one in the

boring (from S to N)		geothermal steps (m/°C) overburden	geothermal steps (m/°C) Westphalian	approximate geothermal gradients (°C/m) overburden	approximate geothermal gradients (°C/m) Westphalian
LXXVII	Elmpt	46.8 ± 0.3	22.3 ± 0.2	2.2	4.5
LXXIV	Maasniel	40.2 ± 0.9	22.0 ± 0.4	2.5	4.55
LXXII	Beesel	36.5 ± 0.6		2.7	
LXXVI	Reuver	34.5 ± 0.45	26.85 ± 0.45	2.9	3.7

Table III
Subsurface temperatures in boreholes on the Peel horst (Peelcommissie, 1963). Gradients added by the present author.

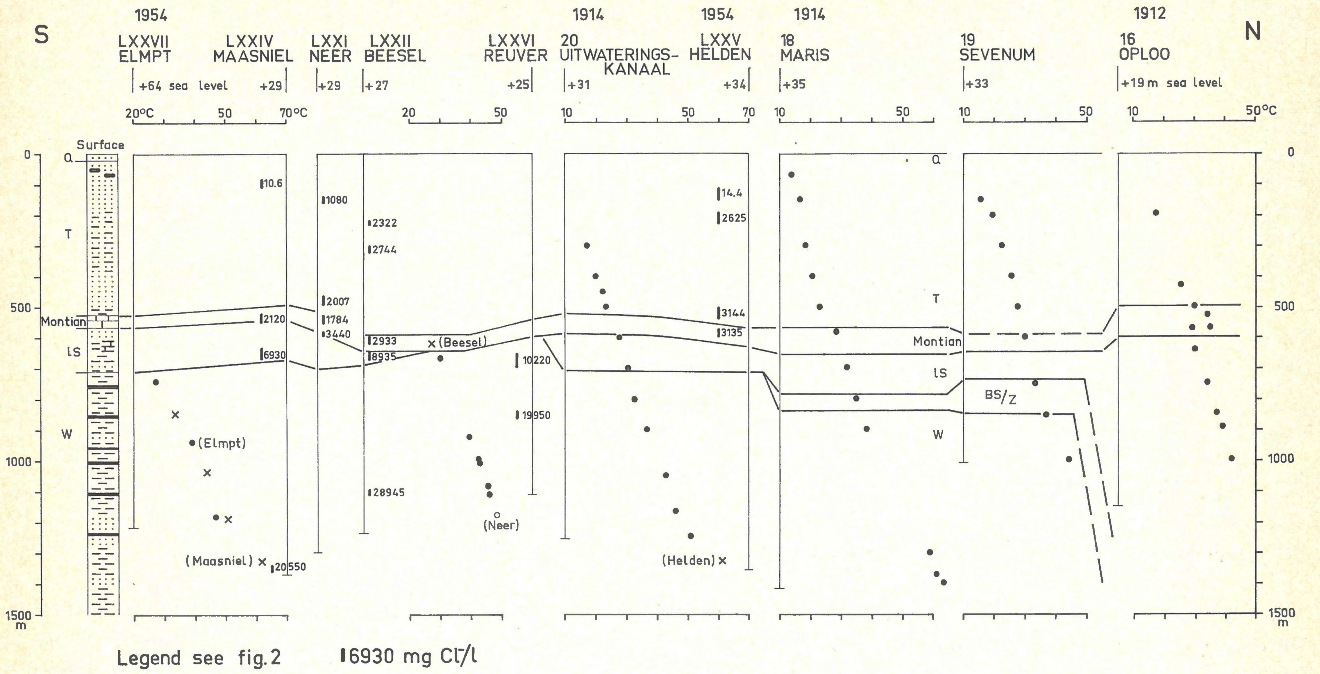

Fig. 4
Peel horst; temperature-depth graphs, chlorine contents, generalized lithology and stratigraphy.

Carboniferous (ca. 5°C/100 m) comparable to the ones found in the south; a low gradient (ca. 2.5) in the Zechstein rock salt and the lower Buntsandstein anhydritic sand- and claystones, whereas in the higher parts of the Buntsandstein the gradient is again higher (ca. 3.5).

DISCUSSION

The consistency of the results of the various subsurface temperatures, widely spaced in time and carried out with a variety of instruments, enhances their reliability. There is some spread in the obtained values, but this should not prevent a reasonable interpretation.

Both the temperatures and the freshness of the water in the Vreeburg well, reflect the Badon Ghyben/Herzberg effect from the Utrechtse Heuvelrug, an ice-pushed ridge to the NE and S of the town (Fig. 1). The presence of fresh water to a depth of almost 300 m was confirmed by recent surveys and drilling, and was shown on a section by Breeuwer & Jelgersma (1973). This section was reproduced, together with two others, in the Scientific Atlas of The Netherlands in 1976 (maps II-3,4).

A recent survey (early 1977) by the Groundwater Survey TNO on and around the ridge confirmed the low temperatures

depths below sea level (in m) (surface + 29 m)	temperatures (°C)	geothermal steps (m/°C)	average geothermal gradients (°C/m)
25	10°00 (estim.)		
		34.00	
687	29°50 (approx.)		2.94
		34.00	
1000	38°70 (calcul.)		top Carboniferous
		18.77	5.3
1877	85°43 (observ.)		
		17.67	5.6
2185	102°86 (observ.)		
		57.10	
2225	103°56 (observ.)		

Table IV
Subsurface temperatures in a borehole in Turnhout, measured by A. Grosjean (1954b). Gradients added by the present author.

year	area or borehole	gradient	age or formation
1879	Utrecht	1.4 - 2.0	Quaternary, Pliocene
1912 - 1913	Woensdrecht	3.2	lower Tertiary
1956	South Limburg	2.15	1. Tertiary, u. Senonian
1954	Turnhout	2.94	Tertiary, Senonian
1912-'14, '54	de Peel	2.2 - 2.9	Tertiary, Senonian, (Bunter)
1913	Ratum, Buurse	3.5	upper, middle Bunter
1913	Ratum, Buurse	2.5	lower Bunter, Zechstein
	(Groningen gas field	1.8	Zechstein; 1975)
	(„	3.1	Rotliegendes; 1975)
1912 - 1913	Woensdrecht	5	Senonian, Visean
1913	Ratum, Buurse	5	Westphalian
1912-'14, '54	de Peel	3.7 - 4.55	„
1956	South Limburg	3.84	„
1954	Turnhout	5.3 , 5.6	Namurian, Visean

Table V
Approximate geothermal gradients from early subsurface temperature measurements.

(W. van Dalfsen, pers. comm.). From such a survey an insight can be obtained in shallow ground-water flows. This type of investigation was initiated by CSONKA (1968) in the NW edge of the Veluwe and the adjacent polder area. In 1973 it was extended to the area between Veluwe and Utrechtse Heuvelrug by W. M. Wiemer and S. J. de Jong (unpublished master's degree theses). It was found that descending ground-water flows in infiltration areas cause low temperatures and, as a consequence, low (sometimes zero or even negative) gradients, whereas ascending waters in seepage areas cause somewhat higher temperatures.

In South Limburg Miocene, Oligocene and Senonian contain fresh water bearing aquifers (PATIJN, 1968); according to KIMPE (1962) the transition from waters containing less than 350 to more than 1,000 mg Cl^-/l (resp. 10 and 30 meq Cl^-/l) is situated around depths 400 to 500 m below the surface, that is from 400 m below the top of the Carboniferous in the SE of the mining district to the base of the Cretaceous in the NW. Below the transition salinities increase with depth (in Cl^--Na^+ types of waters), but the concentration of sea water is only exceeded in one place. Kimpe mentioned the likelihood of ascending waters in a few places; they show higher salinities and temperatures than the surroundings and locally they have caused mineralization or contain 'juvenile gases'. As has been mentioned before, similar conditions are present in the Peel area. Concentrations slightly higher than that of sea water were also found here in only a four places.

During diagenesis formation waters slowly reach chemical equilibrium with the sediment, and reach concentrations higher than that of sea water and moreover obtain different ion ratio (VISSER, 1974). It appears likely that in both heavily faulted areas, the Peel and South Limburg, infiltration of fresh surface waters has taken place to considerable depths, and that the low gradients in the overburden are due to the cooling effect of these slowly circulating waters. The reported, approximated temperatures in the Maastrichtian chalks of Turnhout yield a gradient smaller than the continental average. Considering the low salinity of the water in the chalks, it seems likely that meteoric waters percolate down dip from the outcrops and near-outcrops to the south. Here also a cooling effect can be inferred, which is not discernable in Woensdrecht, where temperatures and gradient are higher (Table V).

In the Carboniferous gradients are high, as a rule 5°C/100 m or more (Table V). This appears to reflect the extremely low thermal conductivity of coal (Table VI). However, in the Peel horst and in South Limburg gradients are lower, probably due to deeply penetrating meteoric waters, but partly and in places influenced by ascending waters or (recently?) enhanced coalification.

The gradients obtained by SADÉE (1975) deviate from those reported by other authors (Table VII). For an area of infiltrating waters his overburden gradients appear to be far too high, and those in his groups 1 and 2 especially can only be possible if the overburden is entirely dry. Although there is a paucity of information on ground-water levels, those available indicate levels of 5 to 10 and locally down to 30 to 40 m below surface. Sadée obtained his results by a selection of the data so as to discard observations near shafts (admissable because an artificial influence) and near faults (inadmissable because a natural cause of variation); in a later stage more data were eliminated in order to reduce the deviation. Moreover, the wish, on theoretical grounds, to increase the ratios of the gradients in overburden to those in the Carboniferous resulted in a further reduction of the number of observations eventually used. Information that could not be accommodated in one of the five groups was not incorporated in the calculations. As a result only about half the observations were used to calculate the gradients in overburden and Carboniferous by combining all possible pairs.

Bij this procedure for each group one gradient in the overburden and one in theCarboniferous is obtained, thus con-

lithology	Kappelmeyer and Haenel (1974, p. 54, 211) range	average	Van Engen (1975)	Sadée (1975) overburden (Miocene, Oligocene, Maastrichtian)
sand	2.5 - 5.04			6.7
clay	5.20 - 5.40	5.30		7.25
limestone	4.05 - 6.40	5.28		5.76
			Rotliegendes formation	Westphalian
sandstone	5.20 - 12.18	7.75		
quartzite	10.10 - 13.90			
claystone	4.17 - 8.18	5.68		
slate		6.20		
„ perp. cleav.		4.51		4.59
„ paral. cleav.				6.9
sandy slate				7.55
coal		ca. 0.6		
average			3.5	
	9.80 - 14.50	12.61		
rock salt	10.07 - 13.7	13.19		
water		1.4		1.4
dry sand	0.8 - 1			0.56
dry limestone				4.14

Table VI
Thermal conductivities of some selected rock types (in 10^{-3} cal.cm^{-1}. sec^{-1}. deg^{-1}; = 0.24 Wm^{-1}.K^{-1}).

sidering a straight-line extrapolation to be justified from the intervals over which the gradients were calculated to the top of the Carboniferous. These intervals are well below this level and they straddle the significant transition from waters containing less than 350 to more than 1,000 mg Cl^-/l. Considering the total information on subsurface temperatures in the mining district, large variations obviously exist, probably due to geological and hydrological conditions in this complex area. A careful interpretation of the information is worthwhile, but goes far beyond the scope of this paper.

The effect of thermal conductivity is obvious in the boreholes of Ratum and Buurse. Rock salt and anhydrite possess high conductivities (Table VI). There is a low gradient interval in the anhydritic lower Buntsandstein shales and the Zechstein rock salt between higher gradients in the over- and underlying beds. In the Groningen gas field Van Engen (1975) reported an average gradient of 1.8° C/100 m for the Zechstein and for the underlying Rotliegend Formation an average gradient of 3.1. To quote: 'Apparently datum depth (2875 m below sea level) temperatures and depth of the top Zechstein are correlated due to the good heat conductivity of the salt'. It is interesting to compare the Visean temperature in Turnhout (103° at a depth of 2200 m) with those in the Rotliegend Formation in Groningen (between 88 and 114° at a depth of

group	geothermal gradients (°C/100 m) overburden	Westphalian	absolute average deviation (°C)	ratio of gradients, overburden/ Westphalian	thickness of over-burden (m)	observations depth interval (m)	number
1	5.12	3.27	0.28	1.56	40-140	407-809	14
2	5.55	3.00	0.28	1.85	150-175	664-786	5
3	3.08	3.12	0.34	0.99	165-300	696-846	7
4	2.36	2.96	0.39	0.80	320-360	615-762	11
5	2.81	2.97	0.40	0.94	240-303	381-818	13

Table VII
Geothermal gradients in South Limburg (Sadée, 1975). The columns headed 'observations' are added by the present author.

2875 m), obviously reflecting the difference in conductivity between Carboniferous and Zechstein.

The effect of secular variations of surface temperature and of glacial periods is long-lasting and deeply penetrating. Estimates have been made by GOGUEL (1975, p. 19, 20) and by KAPPELMEYER & HAENEL (1974, p. 94, 95). Goguel gives, as an example of the results of his calculations, an amplitude of temperature variations of 10° in a period of 100,000 years causing a temperature amplitude of 3.7° at a depth of 1000 m. Kappelmeyer and Haenel considered a sudden rise of annual mean temperature from zero to 9° at the end of the last glaciation, 10,000 years ago, and thus obtained a maximum decrease in geothermal gradient amounting to 10% at a depth of 1000 m; below 1500 m the effect can be neglected but would be present up to 2000 m.

It is clear that these effects are far smaller than those resulting from the infiltration of meteoric waters. The glacial effects probably have been obliterated by Holocene groundwater flows, as is obvious from the comparison of the high gradient in the impervious Mesozoic rocks of Ratum and Buurse with the low ones, for instance in the overburden of the Peel and in the Vreeburg well.

CONCLUSION

The information at present available on subsurface temperatures in The Netherlands confirms opinions expressed in the literature that their interpretation should be related to lithology (that is varying thermal conductivity), to structure (heat flow as a three dimensional phenomenon) and to the origin of the waters which the rocks contain; hence to the geological and hydrological history of the area. Extrapolation of temperature data is likely to lead to erroneous results.

The temperatures dealt with in this paper were obtained in areas that cannot be considered to be representative for the larger part of the country. Apart from the shallow data from fresh-water bearing sediments, all early temperatures are obtained in structurally high areas with shallow Carboniferous. With the exception of the Groningen gas field, virtually no reliable temperature data are yet available from the deep basinal parts, where in places the top of the Carboniferous lies at depths of 5000 m or slightly more. Extrapolation to these parts, either from the structurally high areas or from the area with thick and extensive rock salt, is not to be recommended.

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POSTSCRIPT

After completion of this paper the author had a discussion with W. Kimpe (Geological Bureau of the Limburg Mining District) and J. Stuffken (Dutch State Mines). In boreholes below the impervious Middle Oligocene clay, the sands overlying the Westphalian do not contain free water. Due to mining activities, STUFFKEN & ARTS (1965) have calculated the geothermal gradients in South Limburg from 56 temperature measurements. As averages they obtained at a mean surface temperature of 10.2° gradients of 2 and 3.76° C/100 m respectively in overburden and Westphalian.

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