An appraisal of the Paleozoic limestone (Dinantian) and the Chalk Group (Cretaceous-Early Paleocene) in The Netherlands in connection with the exploitation of geothermal energy; heat-flow maps and temperature maps; the quantity of geothermal energy present and its potential for exploitation.

Geological Survey of The Netherlands

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Contents list

Organization

This study is part of the National Research Programme for Geothermal Energy. This is controlled by the Energy Research Project Office of The Netherlands Organization for Applied Scientific Research at Apeldoorn (now the Organization for Energy Research Project Management PEO). Via this authority the Ministry of Economic Affairs pays 50% of the costs.
Furthermore, for the purpose of setting up this study a contract has been drawn up between the European Economic Community and the Geological Survey of the Netherlands.
The work for the first three report sections has been done for the most part by Mr. G. Milius of Assen. The present reportsection has been prepared by Dr. H.M. van Montfrans (Geological Survey, Haarlem), Mr. S. Prins (Wassenaar) and Mr. P van Rooijen (Geological Survey - Geological Bureau, Heerlen).

2. Paleozoic limestone (Dinantian)

During the Early Carboniferous (Tournaisian-Visean) (see table 1 and figure 1), marine sediments were deposited to the north of the Brabant Massif i.e. in the region north of Antwerpen-Liège.

Carboniferous	Upper	Silesian	Stephanian
			Westphalian
			Namurian
	Lower	Dinantian	Visean
			Tournaisian

Table 1 - Carboniferous stratigraphy.

The deposition environment was less monotonous than is generally supposed. The deposits are often carbonate rocks that contain almost no sand or clay: carboniferous limestone. The facies was open marine to very shallow, in or above the tidal zone. From a few borings a thickness of 800 m has been ascertained, but original thicknesses may well have been 1000 to 2000 m. Within this unit there are hiatuses. The rocks are partly dolomitized.
To the north there is a transition from these deposits to shallow-marine silicified shales with interbedded limestone. A boring made in the northern part of the North Sea has shown the presence of Lower Carboniferous paralic sediments consisting of alternations of dolomite-sandstone-shale, overlain by alternations of coal-(limestone)-shale-sandstone. The coastline ran in an east-west direction, to the north of The Netherlands. The northern limit of the above-mentioned carbonate facies is difficult to determine. Presumably limestone is present under a large part of the country. In the Friesland-Gelderland zone, the later Mid Netherlands High, large quantities of shale were deposited.
At the Dinantian-Silesian boundary there was a regression of the sea. As a result a hiatus originated, that is known in the region around the Brabant Massif. The uppermost zone of the limestone of Dinantian age became karstified at that time. Subsequently the rocks

of the Silesian (Namurian-Westphalian-Stephanian) were deposited, in a facies that changed from marine to paralic. This unit is at most a few thousand metres thick, though somewhat less near the Brabant Massif. This period of subsidence ended during the Stephanian. Then considerable uplift and erosion took place, mostly in the zone from western Friesland to southeast Gelderland (see figure 3). In the southern part of The Netherlands tilting took place. In a number of regions this paleozoic erosion reached the rocks of the Dinantian, resulting in karst formation and brecciation. This is notably the case in the south (surroundings of Maastricht) and perhaps in the middle (Venlo-Arcen) of the province of Limburg.

In the subsurface of The Netherlands the Dinantian has been reached by borings only a very few times. Its depth situation is best known in the surroundings of Maastricht, the same region where a reduction in thickness has occurred as a result of erosion still during the Paleozoic (see enclosure 1). The depth of the Dinantian elsewhere in The Netherlands is indicated in enclosure 2. This map is a very rough one. Often the borings reach only from just into the Carboniferous, and neither the exact age of the level reached nor the thickness of the Upper Carboniferous is generally well known. Equally little is known about the structural situation within the Dinantian limestone complex. During the Carboniferous and Early Permian The Netherlands formed part of the northern foreland of the Hercynian mountain belt. Immediately south of The Netherlands there runs the important, southward-dipping Midi-thrust zone, that originated during the Late Carboniferous. It is assumed that over this thrust plane a horizontal displacement of several tens of kilometres took place (see Bless, Bouckaert and Paproth, 1983). In the southern part of Limburg a rather complicated structure originated in this period (see appendix 3). The structural dips in the Heugem-1 and Kastanjelaan-2 borings (see enclosure 4 and 5, constructed on the basis of Bless et al., 1981) measure ten to twenty degrees, locally several tens of degrees. Furthermore it is assumed that fault tectonics took place. One would expect the situation to become more tranquil as the deposits occur more toward the north.

For the production of water from this limestone it is especially the stratigraphically youngest part that is of most potential value. This part is present in those places where the Upper Carboniferous has not been eroded away, at least not completely, i.e. everywhere except for the region around Maastricht and possibly near Venlo-Arcen. Especially from borings in Belgium, near the southern border of The Netherlands, it is known that these uppermost layers of the carboniferous limestone usually contain an intensely karstified zone in which a considerable porosity (estimates of up to 25%) and permeability has developed along fissures. Observed thicknesses of this zone vary from 15 to 150 m. It is assumed that from this source water could be produced with a yield of ca. 200 m^3/hr. (Vandenberghe and Bouckaert, 1980). In principle it is possible to trace such a karstified zone by means of reflection seismology, but the result of an exploratory boring is then still somewhat uncertain.
In the region around Maastricht (see enclosure 1) the Dinantian limestone has been partly eroded away. Here the rock (see the Heugem 1/1A and Kastanjelaan-2 borings, appendices 4 and 5) consists for the most part of massive or bedded limestone that is rich in organic material. The older part becomes increasingly clayey and contains interstratified shale. The primary porosity and permeability are negligibly low. In the borings mentioned a number of samples have been found to have non-representative permeability values up to 10 mD. As a result of the formation of karst (fissures, caverns) and the subsequent brecciation, in some zones a greater (secondary) porosity and permeability have developed. In Kastanjelaan-2, at a depth of between 345 and 375 m, an intensely fissured and fractured zone was found in which mud losses occurred. However, the porosity is still very low for geothermal exploitation.
Severe weathering has sometimes led to the complete dissolution and fragmentation of the limestone. The result in such cases is a soft rock with a high porosity and low specific weight. Here permeability measurements gave values of up to ca. 30 mD, but it is not certain whether these values are representative. The thickness of this weathered zone is greatest in the Heugem-1/1A boring, where it is 200 m.

To conclude, it can be stated that exploration of the carboniferous limestone of Dinantian age may well be possible where this rock is covered by sediment of Namurian age and lies between 1500 and 4000 m. The regions where such Dinantian limestone is present are shown in enclosure 2. However, the exploitation risk with this rock is greater than with the sandstone reservoirs (see reportsections 1-3).

3. Chalk Group (Late Cretaceous-Early Paleocene)

During the Late Cretaceous a major transgression occurred as a result of which the whole of The Netherlands was ultimately covered by the sea. During this time the deposition took place of a complex of chalk, chalk-bearing limestone and marly chalk, with local interbedded marl: the Chalk Group. Along the edge of the basin, in the south-east of The Netherlands, limestone and locally sandstone were deposited.

As a result of inversion movements during the Late Cretaceous these deposits were completely eroded away in those regions where basins had been present during the Late Jurassic and the Early Cretaceous, namely the Central Netherlands Basin, the Central or Roer Valley Graben and the West Netherlands basin (see figure 4). In the other parts of The Netherlands this complex is indeed present, with thicknesses varying from several hundred to more than a thousand metres. The depth of the upper surface is indicated in enclosure 6. In the south of Limburg the chalk lies at the surface or at a slight depth. In this region there is a subdivision of the chalk into the Gulpen, Maastricht and Houthem Formations. As a whole the complex has a high primary porosity of 30-40%. The storage capacity is low, however, being 0.02-0.05. The permeability is largely determined by the fact that the rock is fissured. With pump tests k-values of 1-15 m/day have been obtained. In view of the heterogeneity of the rock measurements of this kind can be valid only locally.

Especially in the extreme south this aquifer is intensively exploited by the drinking water industry. Individual production-wells generally produce 60-80 m^3/hr with widely varying draw down. The specific yield per well is 2-80 m^3/hr. It is assumed that the permeability decreases with depth.

From the Chalk Group natural gas production is being considered in one case (Van den Bosch, 1983), notably from the Harlingen field. Here the porosity is 25-30%, the permeability from 1 to at most 5 mD, and the depth of the rock concerned about 1000 m. Here there is a relation between relatively high porosity-permeability values and the filling up of the reservoir with gas at an early stage.

To conclude, it can be stated that despite the considerable thickness of the Chalk Group, this complex is unappealing for the exploitation of geothermal energy on account of its reservoir properties.

4. Temperature and heat-flow maps

In this chapter a brief outline will be given of the data and method used in preparation of the temperature and heat-flow maps. As with the Dutch part of the maps in the "Atlas of Subsurface Temperatures in the European Community" (Haenel, 1980) basic data were nearly all derived from temperature measurements in wells drilled by the oil and gas industry. A few additional data were taken from published literature (Visser, 1978). In all, 338 wells were used. Enclosure 7 shows their areal distribution.

The temperature-depth data were of two kinds:

1. Bottom hole temperature measurements, taken during the drilling phase; these are in fact drilling mud temperatures.
2. Measurements in completed wells, taken after they had been closed in for some time.

The data of the first category came from 288 different wells, with on the average just over 5 measurements per well. The second category data came from 103 wells, with on the average 10 measurements per well. In 53 wells, all situated in producing oil- and gas fields, both kinds of data were available.

In order to arrive at a homogeneous data set, it was assumed that the temperatures of the closed-in wells could be taken as representative of the actual formation temperatures. The bottom-hole temperatures needed a certain upward correction. In a very few cases the amount of data allowed an estimation to be made of the formation temperature by means of time extrapolation, as described by Dowdle and Cobb (1975). For the rest of the bottom-hole temperature data a direct conversion formula was needed. To this end, the stabilized temperature values in the 53 wells with both kinds of data were plotted against the interpolated bottom-hole temperatures in those wells at the corresponding depths. This resulted in an analytical conversion formula between 500-3500 m -MSL (mean sea level) of the form:

$$T_F = 1.775\ T_{BHT}^{0.9} \qquad (1)$$

T_F = Formation Temperature in ^oC

T_{BHT} = Bottom-Hole Temperature in ^oC

In those cases where only bottom-hole temperatures had been observed, these were converted into estimated formation temperatures with the aid of this formula. This resulted in a set of mutually comparable temperatures, that could be used as input for further calculations. It should be pointed out that this set has two inherent weaknesses:

1. The majority of the formation temperature values are not very accurate.
2. The set shows a very uneven spatial distribution.

In order to arrive at an adequately consistent set of isotherm and heat-flow maps, the procedure outlined below was followed. Each well section was subdivided into major geologic units: Quaternary, Tertiary, Chalk, Lower Cretaceous, Jurassic/Triassic, Zechstein and Rotliegend/-Carboniferous. Within each unit the value for the heat conductivity was assumed to be constant. The heat-flow was assumed to be solely in a vertical direction and constant over the entire depth interval.

From this it follows that at any location the vertical heat-flow q through n layers equals:

$$q = (T_Z - T_R)/(\sum_{1}^{N} d_i/\lambda_i) \qquad (2)$$

where

T_Z = Formation Temperature at depth Z

T_R = Formation Temperature at reference depth Z_R

d_i = thickness of i-th layer

λ_i = heat-conductivity of i-th layer.

In order to be able to find a q-value corresponding to a particular temperature at a given depth, the following heat-conductivity values were assumed:

Quaternary	3.0	$J\ m^{-1} sec^{-1} K^{-1}$
Tertiary	1.6	"
Chalk	1.9	"
Lower Cretaceous	2.1	"
Jurassic/Triassic	2.4	"
Zechstein	4.5	"
Rotliegend/Carbon.	2.7	"

Although in fair agreement with published literature (Haenel, 1983), there is no doubt that the choice of these average figures carries a certain amount of arbitrariness. A constraint used in the choice of the average conductivity figures was set by the estimated heat-flow value in well Bolderij-1 given by Houbolt and Wells (1980) as 77± 15% mWm^{-2}. The observed formation temperature in this well is 99.7°C at 2845 m -MSL. The calculated heat-flow, using the conductivity figures given above is:

$q = (99.7-14.1)/(338+491+60+183+57) = 75.8\ mWm^{-2}$

or within 2% of the value indicated by Houbolt and Wells.

The reference level was chosen at 250 m -MSL rather than at mean sea level primarily because of known irregularities in the temperature field at shallow depths. The -250 level is the deepest one for which the shallow temperature field in The Netherlands has been mapped (Van Dalfsen, 1981). All deeper maps have been generated by interpolation between the measured depths and this reference level. The elevation difference between MSL and ground level is nearly everywhere less than 10 m and was therefore deemed insignificant for temperature correction. Only for a couple of observations in the extreme south a correction was made. Along the border with Belgium the position of the isotherms was adjusted slightly in areas without observations, to bring them in line with the -250 m isotherms in northern Belgium on the map of Legrand (1975).

The thicknesses for the successive geological units needed for the heat flow calculation were taken from the Geological Surveys stratigraphic well files. In the northwestern part of the country, where the thickness of the Quaternary exceeds 250 m, the values were taken from the Base Quaternary map of Zagwijn and Doppert (1978).

At each well, a heat-flow value between the reference- and the observation depth was calculated by means of formula (2), for every temperature measurement in that well. Per well, the depth-weighted average of these heat-flow values was determined together with the depth-weighted standard deviation of the mean and this was taken as an indicator for the mutual compatibility of the temperature-depth input figures. In practice a deviation greater than 4% of the q-value was found to be satisfactory for showing the stray temperature data.

In all, this eliminated 7% of the original temperature observations, leaving 338 wells with a total of just over 2500 temperatures.
In wells with both unstabilized and stabilized temperature measurements, the average heat flow values were calculated separately. If the difference between these two average q-values was less than 4%, their average was used as definite q-value for that well location; if otherwise, the average q-value for the stabilized temperatures was adjusted by its own deviation value in the direction of the q-value for the unstabilized temperatures in that well. All q-values thus derived were used for the compilation of the heat-flow map (encl.8).
With the aid of this map, the subsurface temperature at any depth Z can be calculated at any location where the stratigraphic subdivision used in formula (2) is known. To this end formula (2) is rewritten in the form:

$$T_Z = T_R + q\ (\sum d_i/\lambda_i) \qquad (3)$$

where again $\sum d_i = Z - Z_R$ and identical conductivity values as for calculating q with formula (2) should be used.
To improve the consistency of the successive isotherm maps, use was made of a number of SW-NE border to border cross sections, recently published by IMNES b.v. and the Geological Survey (1984). The distance between these sections is 50 km; the temperatures were calculated at points 20 km apart along the section lines.
The 6 resultant isotherm maps at depths from 500 to 3000 m -MSL (enclosure 9-14) are largely self-evident. The interpolated temperature values obtained through this procedure are mutually consistent. It is felt that they give a fair representation of the temperature distribution in the subsurface in spite of the many uncertainties contained in the original data set. The procedure has the drawback, however, that it tends to smooth out most of the local features. One that remained is the area with abnormally high temperatures below 2000 m -MSL in the Wadden Sea. This anomaly is purely due to low conductivity of volcanic rock. From a geothermal point of view the area is of no economic interest, because the rock lacks permeability. In the northeastern part of the country the heat-flow map shows locally a few positive anomalies due to the presence

of salt domes. Unfortunately, the available well data were insufficient both qualitatively and quantitatively to show corresponding anomalies in the temperature maps. In general, salt domes cause a local increase in heat flow and as a result of this a temperature decrease at their base and a temperature increase at the top. Poley and Van Steveninck (1970) gave an example in this area. They demonstrated that this latter effect can for certain domes already be measured in very shallow boreholes.

In addition to the isotherm maps down to a level of 3000 m -MSL, a map at the 7000 m -MSL level has been included (encl.15). This map was made by extrapolating the 3000 m -MSL temperatures down to 7000 m -MSL with a temperature gradient equal to the local heat-flow value, divided by the Rotliegend/Carboniferous conductivity. The map shows a separate temperature figure at the well locations Tjuchem-2 (north), Winterswijk-1 (east), and Rijsbergen-1 (south). The reason for this is that these three wells have bottom-hole temperature measurements at about 6000, 5000 and 4640 m -MSL respectively. The temperature figures were obtained by extrapolation from these deepest observations. Three temperature values of 240 to 250°C at 7000 m -MSL resulted from this procedure.

The general outcome is that the temperature gradient in this country down to 7000 m appears to be about 3°C per 100 m, which is the value usually assumed for sedimentary basins.

5. Hot springs

A map is being made by the EEC to show the distribution of hot springs in Europe. These are places where water at a temperature of 20°C or higher flows on to the surface. In the immediate vicinity of The Netherlands such hot springs are present in Aachen and Bentheim. In The Netherlands there are no known springs of this kind.

6. The geothermal energy present and its potential for exploitation

The total amount of geothermal energy present in the subsurface of The Netherlands can be defined as the amount of heat above the mean annual temperature (10°C) down to a depth of 7 km. This can be calculated as follows. The amount of heat that is present in a certain volume of rock can be worked out from:

$$HIP = \sum_{V} C\ (T - T_o)\Delta V \qquad (1)$$

where

HIP = the heat content (heat in place) of the volume of rock concerned, in Joules.

C = the specific heat of a unit of rock with a volume of ΔV, in Joules m^{-3} degrees^{-1}.

T = the temperature of a unit of rock with a volume of ΔV, in degrees.

T_o = reference temperature, in degrees.

ΔV = unit of rock volume, in m^3.

In order to be able to determine the quantity of heat per unit surface, present in a rock volume down to a certain depth D, equation (1) can be written thus:

$$(HIP)_{VA} = D.\bar{C}\ (\bar{T} - T_o)\ \text{Joules } m^{-2} \qquad (2)$$

where

$\bar{C}$ = mean specific heat of the rock column, in Joules m^{-3} degrees^{-1}.

$\bar{T}$ = mean temperature of the rock column, in degrees.

T_o = reference temperature, in degrees.

If values are taken of:

D = $7 \cdot 10^3$ m

$\bar{C}$ = $2 \cdot 10^6$ Joules m^{-3}. degrees^{-1}

$\bar{T}$ = 110 degrees C

T_o = 10 degrees C

then this amount of geothermal energy present per unit surface works out at 1.4 . 10^{12} Joules m^{-2}. The total ground surface area of The Netherlands is about 3.5 . 10^{10} m^2, and assuming that neither C nor T shows lateral variation, the total amount of geothermal energy present works out at 5 . 10^{22} Joule. This is known as the resource base.

Out of this very large quantity of heat only a small part is present in reservoirs that could reasonably permit production of hot water. For the best reservoirs, namely Upper Rotliegend Group (Permian), Middle Bunter and Main Buntsandstein Formations (Triassic) and Rijnland Group in the West Netherlands Basin (Cretaceous), heat-content maps have been made. These are based on net thicknesses of sand and on temperatures (the latter being directly related to depth). The maps, enclosures 16-21, have been made for temperatures above 10°C and above 40°C. They show lines of equal energy content, with values of 5 x 10^9 to 40 x 10^9 J/m^2.

Table 2 - Heat content of aquifers below the Netherlands mainland.

Formation	Total heat content above 40°C	Heat content in most-promising areas
Lower Cretaceous	8 x 10^{18} J	3 x 10^{18} J (250 km^2)
Triassic	10^{20} J	2.5 x 10^{19} J (1400 km^2)
Lower Permian	2.5 x 10^{20} J	5 x 10^{19} J (2500 km^2)

Table 2 shows, for the case of the heat content above 40°C, the total heat content per aquifer. In order to get an idea of the quantity of heat present in the most promising parts of these aquifers, figures are also given in this table for the total heat content in the areas above 20 x 10^9 J/m^2 (for the Lower Cretaceous, values above 10 x 10^9 J/m^2 have been chosen, in view of the better permeability). These areas are shown also in fig. 5. The heat content thus estimated amounts to 7.8 x 10^{19} J in total. For comparison: this is approximately the original heat content of the Groningen gas field. The fact that the permeability of the different aquifers shows a wide variation means that it is impossible to make a meaningful estimate of the total productivity, or even a rough estimate. In any case, from an economic viewpoint preference should be given to those areas where the aquifers have a good permeability. Furthermore, in practice only part of the heat content of a certain aquifer can be exploited. In this connection the following factors play a role:

- the presence of built-up areas or the exploitation of hydrocarbons
- the possibilities for distribution of the heat made available.
- the efficiency of the production: only part of the heat present can be produced.

7. Conclusions and recommendations

In The Netherlands there are no active volcanic areas. There is thus no possibility of exploiting high-enthalpy geothermal energy, e.g. in the form of hot water and steam at temperatures up to 350°C at slight depth.

As for the exploitation of relatively hot rock such as granite, involving some artificial means of obtaining the necessary permeability, this too is equally unfeasible at the present time. The technique is still in the stages of development, and no such rock is known to occur in The Netherlands.

For the exploitation of low-enthalpy geothermal energy, in the form of warm or hot water up to 125-150°C, there are good possibilities in The Netherlands. Much is known about the subsurface. There are good reservoir rocks (sandstone) of Early Permian, Triassic and Early Cretaceous age. The transmissivity in these rocks (product of permeability, in Darcy, and net sand thickness, in metres) will often be greater than 10-15. The depth at which these rocks lie, and thus the temperature of the formation water, make exploitation attractive. At the same time there may be possibilities of exploitation of the karstified limestone of Dinantian age. At least some of the reservoirs occur in the regions where the geothermal energy available could be effectively utilized. It is not possible to make a reasonable estimate of the potential, but it could certainly be called considerable. The heat content (above 40°C) of the most promising parts of the above-mentioned sandstone reservoirs is equal to that of the Groningen gas-field. In practive only a small proportion of this heat content can be produced.

The obvious way to set about now would be to establish some kind of cooperation with already existing activities of the oil and gas industry. This would have a favourable influence on the process of acquiring the necessary know-how. In the exploitation of geothermal energy the cooled-off water would be injected into the same reservoir (doublet system). The - underground - region where a temperature drop occurs is not very big. Generally speaking it can be foreseen that there would be no negative influence on the exploitation of hydrocarbons.

The reservoir rocks mentioned earlier are clearly different, in terms of both their lithological and hydrochemical properties. For this reason it is clearly necessary to acquire practical experience with each of the reservoirs. This could be in the form of research and development projects, and possibly demonstration projects. Naturally the incentive to engage in these operations is closely connected with the degree of economic viability, that would have to be estimated for each separate project. The most important uncertainties in this context lie in the subterranean part of the system. Experience is necessary in this field, in the form of the identification and solution of the various problems. Only after such experience has been gained will it be possible to determine the future role of geothermal energy in the overall energy supply of The Netherlands. The time necessary for gaining the knowledge required is long compared to the relatively short period of time in which essential external factors, such as oil and gas prices, may change. There is thus good reason for making a start at the present time to gain this vital experience.

8. List of enclosures

9. References

1. Heybroek, P. (1974)
Explanation to tectonic maps of the Netherlands
Geol. Mijnbouw 53 nr. 2 pp 43-50.

2. Staalduinen, C.J. van, H.A. van Adrichem Boogaert, M.J.M. Bless, J.W.Chr. Doppert, H.M. Harsveldt, H.M. van Montfrans, E. Oele, R.A. Wermuth and W.H. Zagwijn (1979)
The Geology of the Netherlands
Mededelingen Rijks Geologische Dienst vol. 31-2.

3. Bless, M.J.M., J. Bouckaert and E. Paproth (1983)
Recent exploration on Pre-Permian rocks around the Brabant Massif in Belgium, The Netherlands and the Federal Republic of Germany
Geol. Mijnbouw 62 nr. 1 pp 51-62.

4. Bless, M.J.M. c.s. (1981)
Preliminary report on Lower Tertiary-Upper Cretaceous and Dinantian-Famennian rocks in the boreholes Heugem 1/1A and Kastanjelaan-2 (Maastricht, the Netherlands)
Mededelingen Rijks Geologische Dienst vol. 35-15.

5. Vandenberghe, N. en J. Bouckaert (1980)
Geologische aspekten van de mogelijkheid tot de aanwending van geothermische energie in Noord België.
Aardkundige Dienst van België Prof. Paper nr. 168.

6. Bosch, W.J., van den (1983)
The Harlingen Field, the only gas field in the Upper Cretaceous Chalk of The Netherlands
Geol. Mijnbouw 62 nr. 1 pp 145-156.

7. Commission of the European Communities (1980)
Atlas of Subsurface Temperatures in the European Community (compiled by R. Haenel)
Brussels-Luxembourg.

8. Visser, W.A. (1978)
Early Subsurface Temperature Measurements in the Netherlands
Geol. Mijnbouw 57, nr. 1, pp. 1-10.

9. Dowdle, W.L. and W.M. Cobb (1975)
Static Formation Temperatures from Well Logs - An Empirical Method
Journal of Petroleum Technology, November 1975.

10. Haenel, R. (1983)
Geothermal Investigations in the Rhenish Massif
In: K. Fuchs et all. (eds.): Plateau Uplift
Springer Verlag, Berlin-Heidelberg.

11. Houbolt, J.J. and P.R.A. Wells (1980)
Estimation of heat flow in oil wells based on a relation between
heat conductivity and sound velocity
Geol. Mijnbouw 59, nr. 3, pp 215-224.

12. Van Dalfsen, W. (1981)
The shallow Subsurface Temperature Field in the Netherlands
Report on project G/A9- Contracts 073-76 and 414-77-11 EGN
Groundwater Survey TNO, Delft.

13. Legrand, R. (1975)
Jalons Geothermiques
Toelichtende Verhandelingen voor de geologische en Mijnkaart van
België, no. 16.

14. Zagwijn, W.H. and J.W.Chr. Doppert
Upper Cenozoic of the Southern North Sea Basin: Paleoclimatic and
Paleogeographic Evolution
Geol. Mijnbouw 57, nr. 4, pp. 577-588.

15. Investering Maatschappij Nederland Energy Services B.V. (ed.),
The Hague and Rijks Geologische Dienst, Haarlem (1984)
Geological Sections through the onshore and adjacent part of the
continental shelf.

16. Poley, J.Ph., and J. van Steveninck (1970)
Geothermal prospecting-delineation of shallow salt domes and surface faults by temperature measurements at a depth of approximately 2 metres.
Geophysical Prospecting, Vol. XVIII, Suppl.

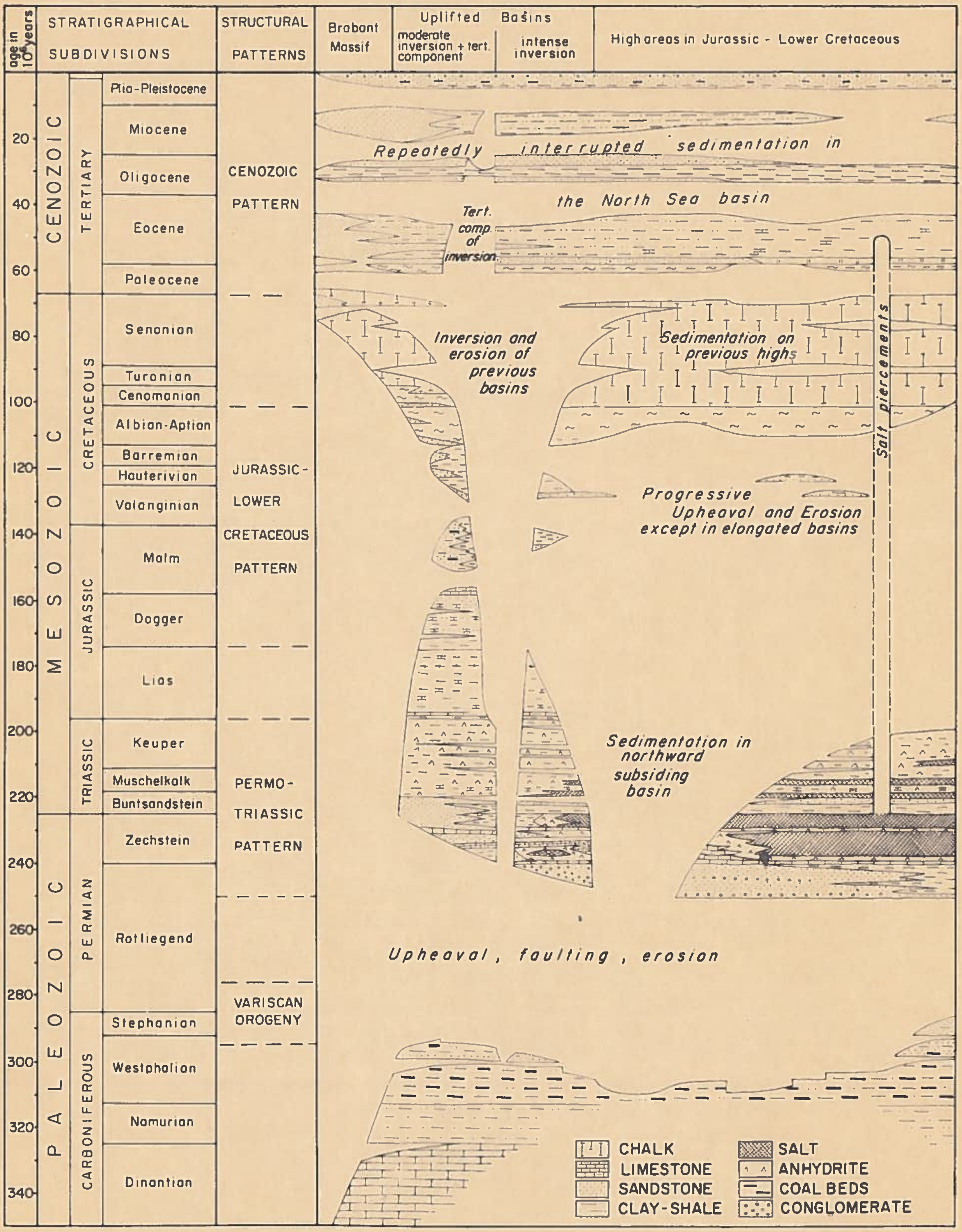


Fig. 1 Scheme of geological events in The Netherlands (lit. 1)

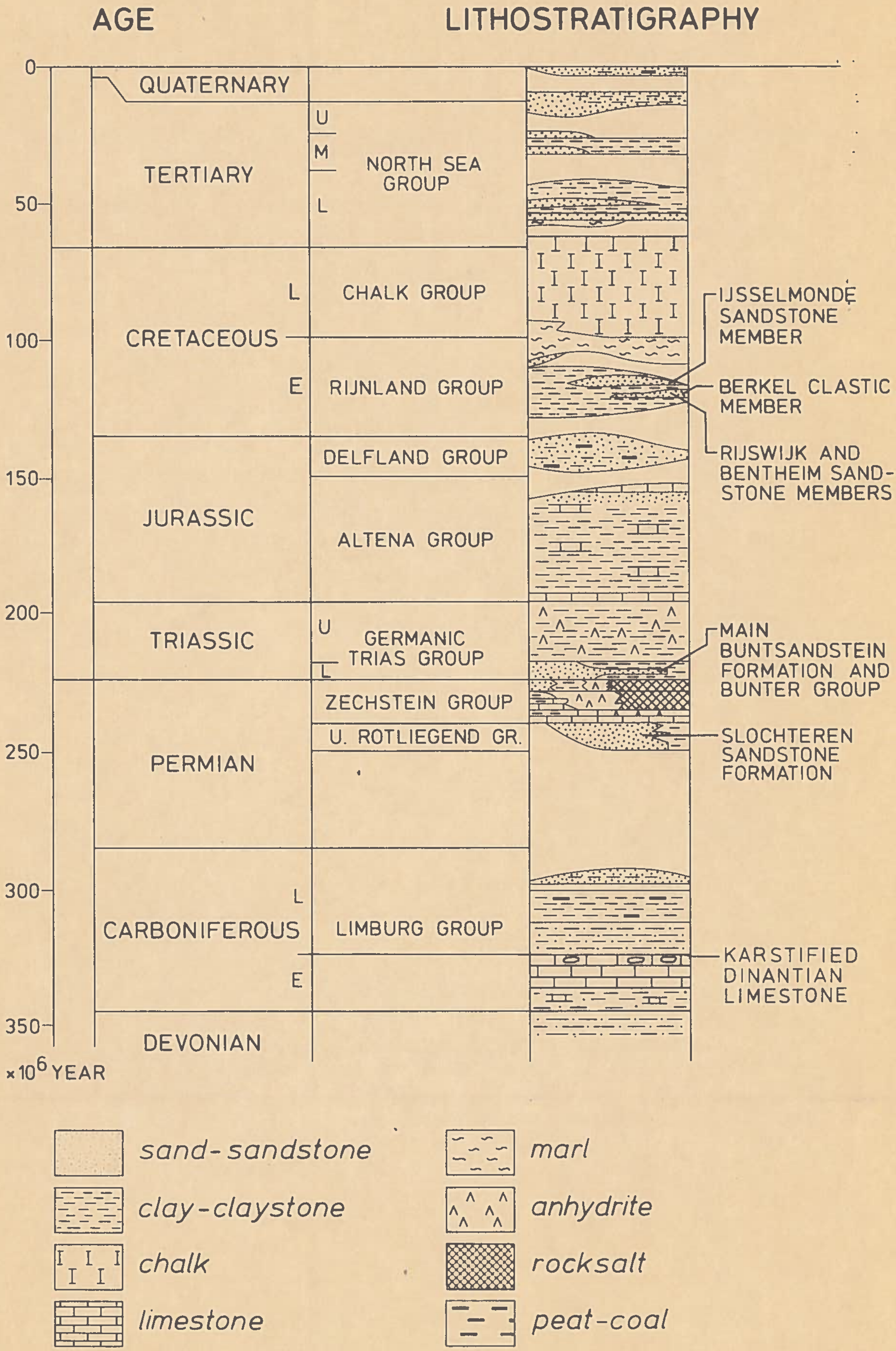


Fig. 2 Deep lying aquifers in The Netherlands

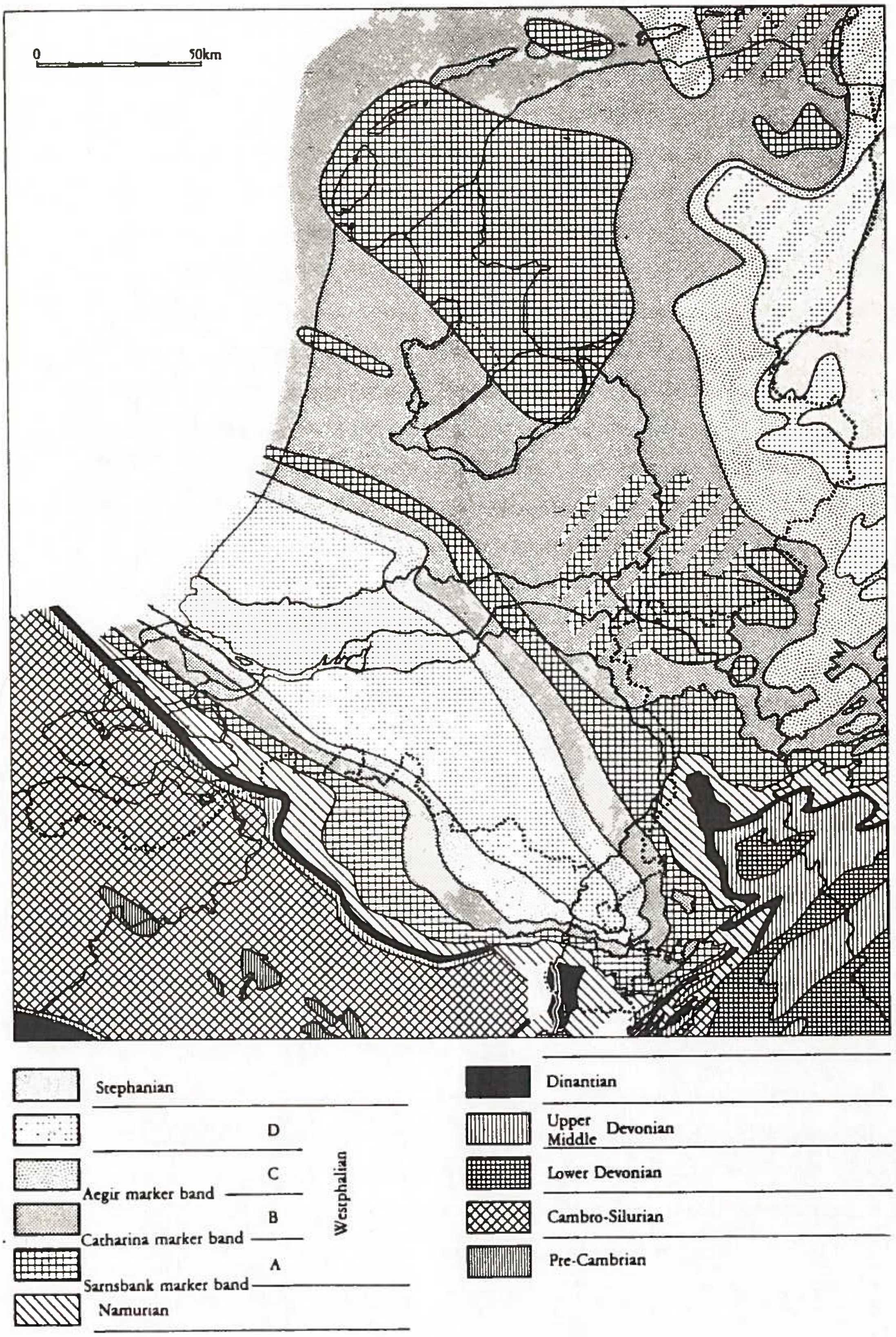


Fig. 3 Pre - Permian Subcrop (lit. 2)

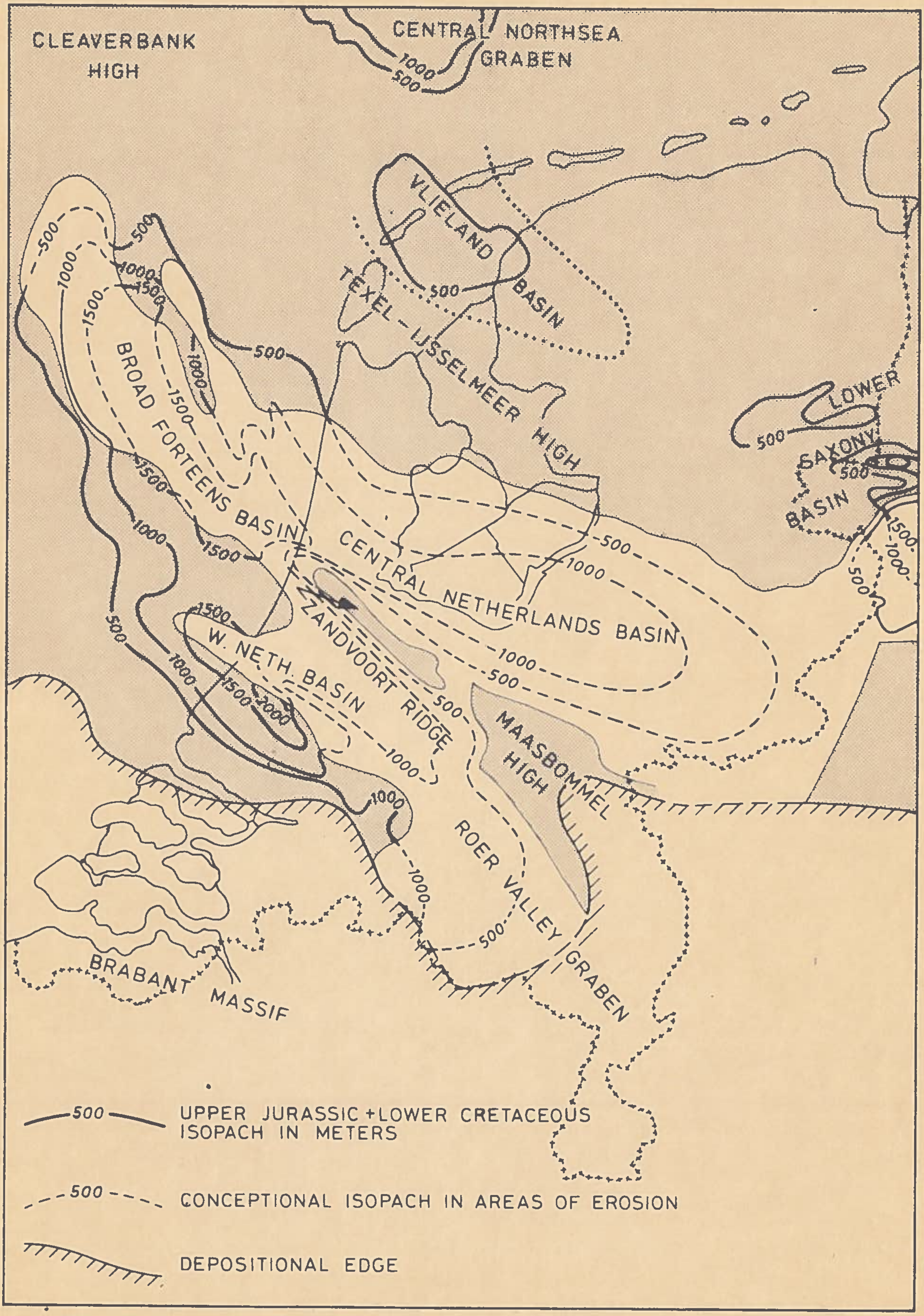


Fig. 4 Sedimentary basins of the Late Jurassic and Early Cretaceous (lit. 1)

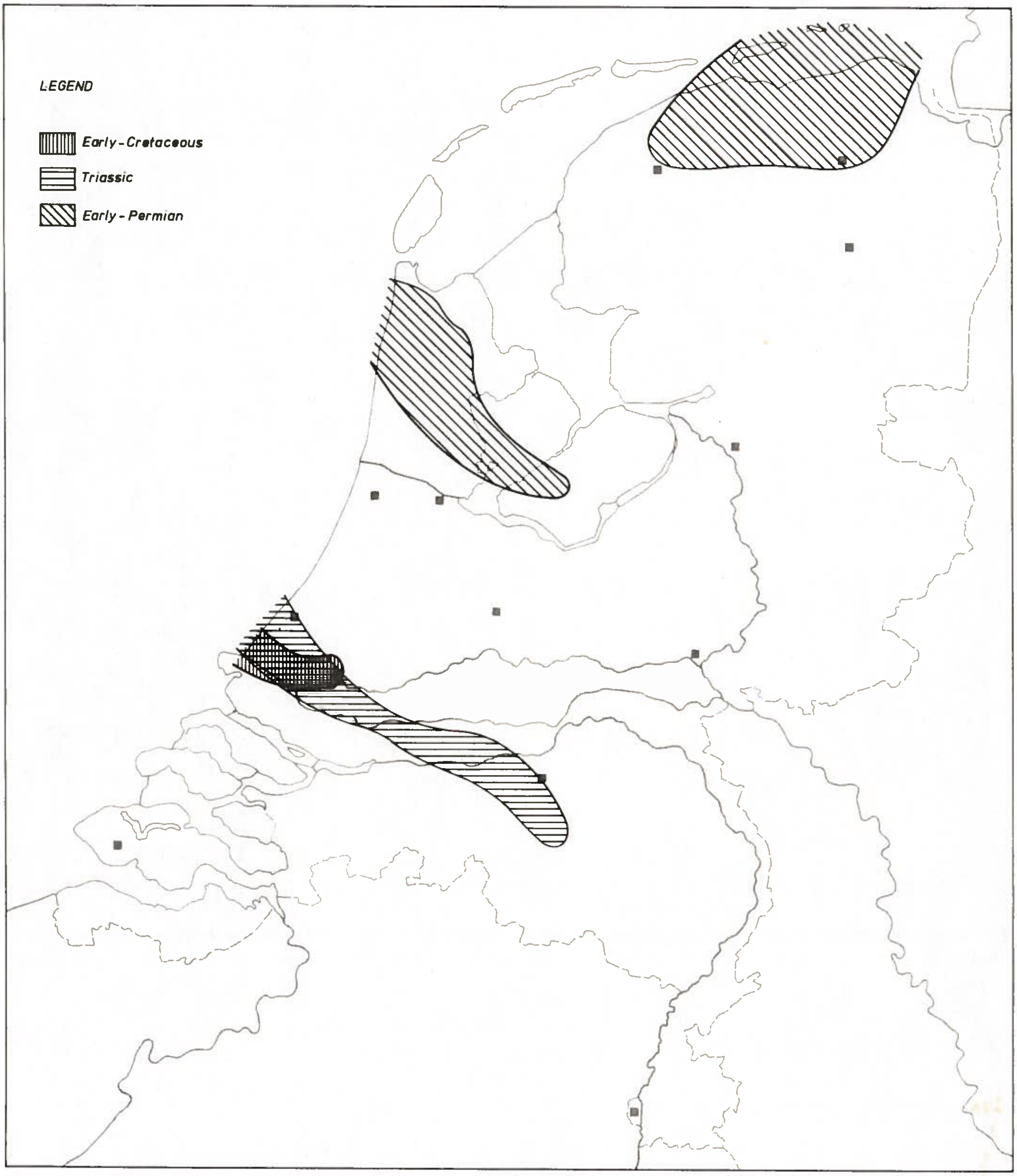
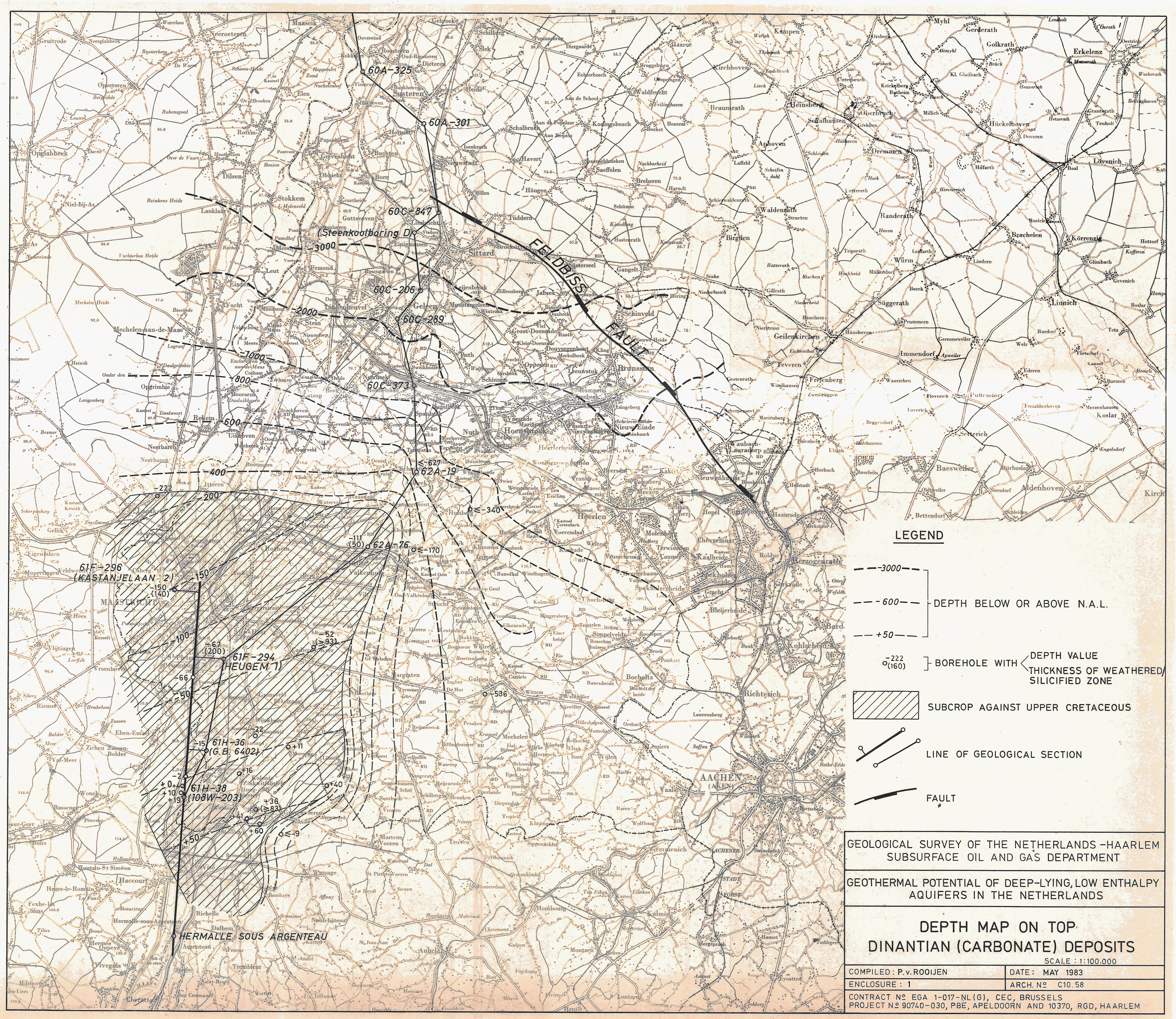
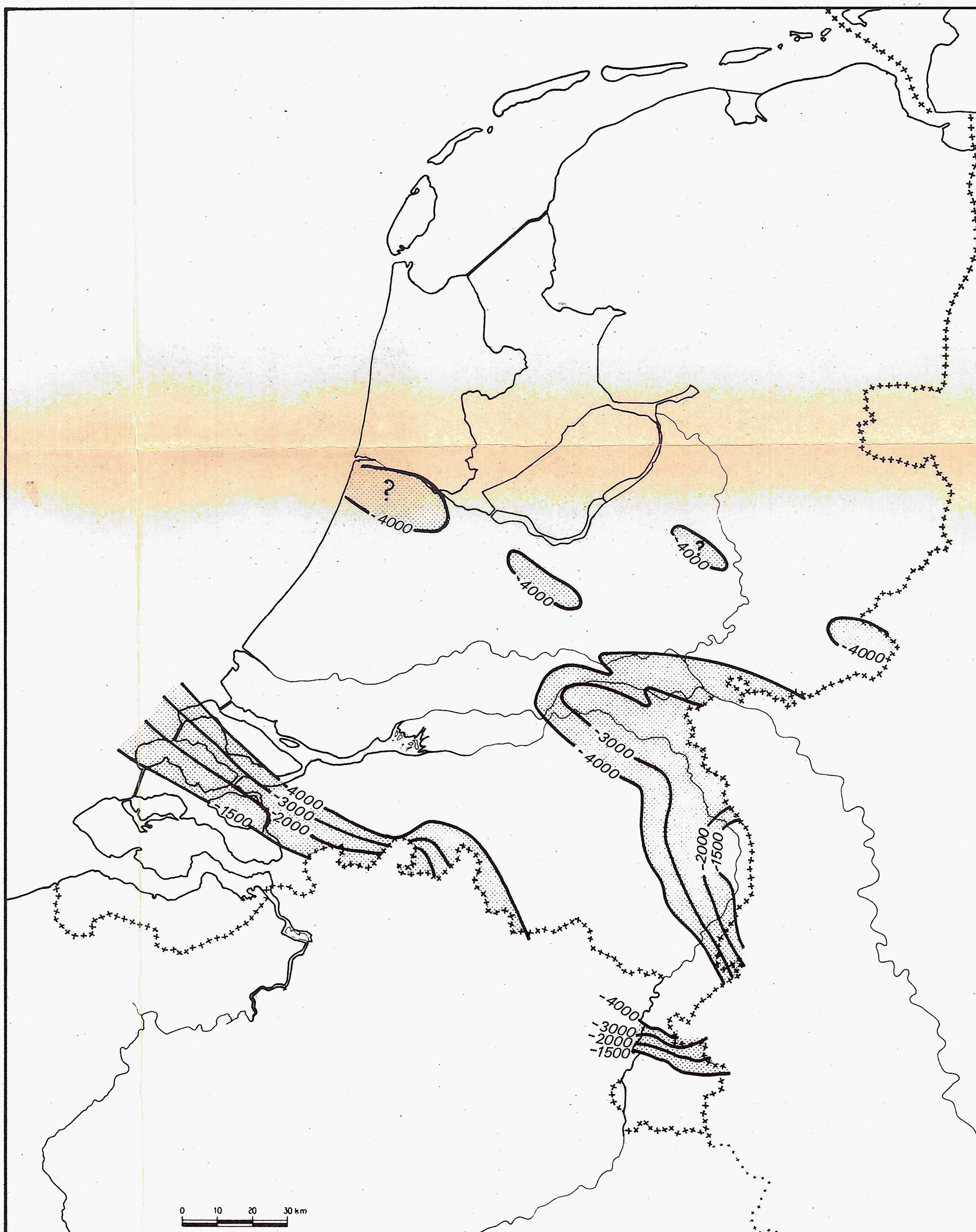


Fig. 5 Summary map prospective areas geothermal energy


LEGEND
-3000-
-600-
+50
DEPTH BELOW OR ABOVE N.A.L.
-222 (160)
BOREHOLE WITH
DEPTH VALUE
THICKNESS OF WEATHERED/ SILICIFIED ZONE
SUBCROP AGAINST UPPER CRETACEOUS
LINE OF GEOLOGICAL SECTION
FAULT
FELDBISS FAULT
60A-325
60A-301
60C-847
(Steenkoolboring D)
60C-206
60C-289
60C-373
62A-19
62A-76
61F-296 (KASTANJELAAN 2)
61F-294 (HEUGEM 1)
61H-36 (G.B. 6402)
61H-38 (108W-203)
HERMALLE SOUS ARGENTEAU
GEOLOGICAL SURVEY OF THE NETHERLANDS-HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
DEPTH MAP ON TOP DINANTIAN (CARBONATE) DEPOSITS
SCALE 1:100.000
COMPILED: P.v.ROOIJEN
DATE: MAY 1983
ENCLOSURE: 1
ARCH. Nº C10.58
CONTRACT Nº EGA 1-017-NL(G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

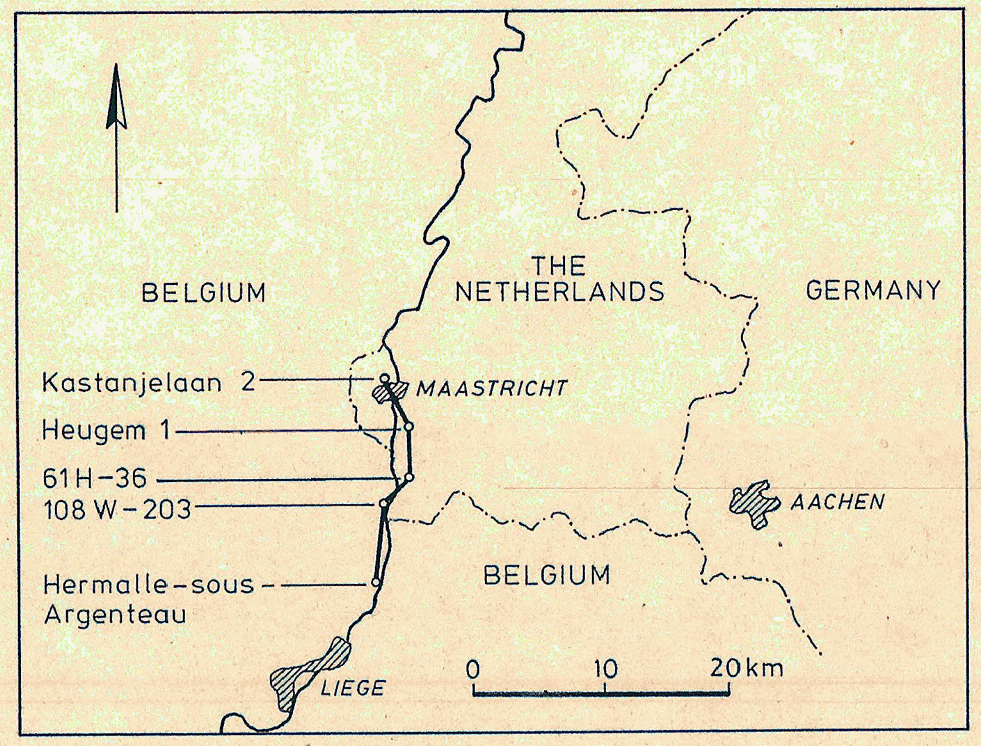
GEOTHERMAL POTENTIAL OF DEEP LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

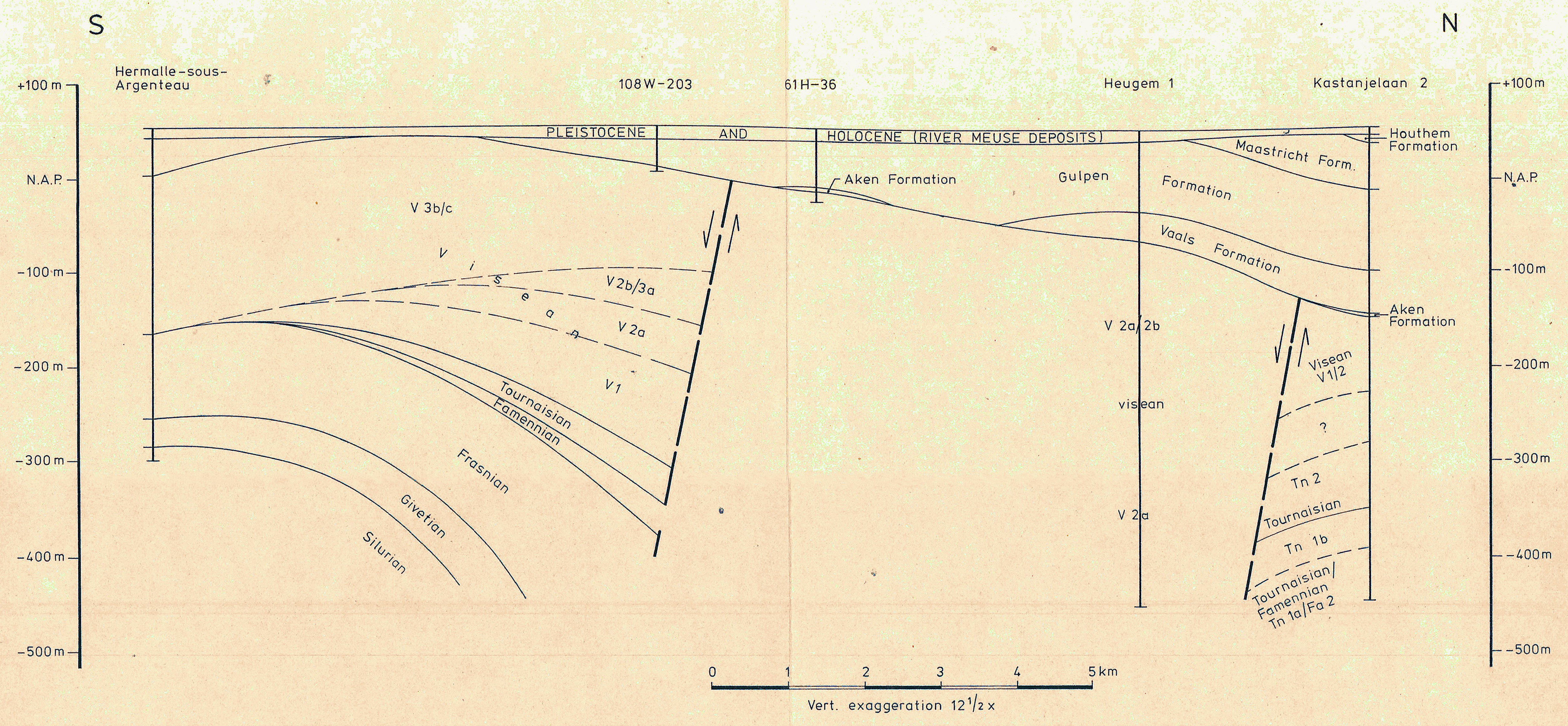
PRESUMED DEPTH OF TOP DINANTIAN (CARBONATE) DEPOSITS BETWEEN 1500 AND 4000 m. BELOW M.S.L.

SCALE : 1: 250000

COMPILED: P. v. ROOIJEN	DATE: JUNE 1984
ENCLOSURE: 2	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740 030, PBE, APELDOORN AND 10370, RGD, HAARLEM





AGE			LITHOSTRATIGRAPHY
QUATERNARY	HOLOCENE		
	PLEISTOCENE		
TERTIARY	PALEOCENE		HOUTHEM FORMATION
CRETACEOUS	MAASTRICHTIAN		MAASTRICHT FORMATION
			GULPEN FORMATION
	CAMPANIAN		VAALS FORMATION
			AKEN FORMATION
	SANTONIAN		
CARBONIFEROUS	NAMURIAN		
	VISEAN	DINANT.	
	TOURNAISIAN		
DEVONIAN	FAMENNIAN		
	FRASNIAN		
	GIVETIAN		
SILURIAN			

GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

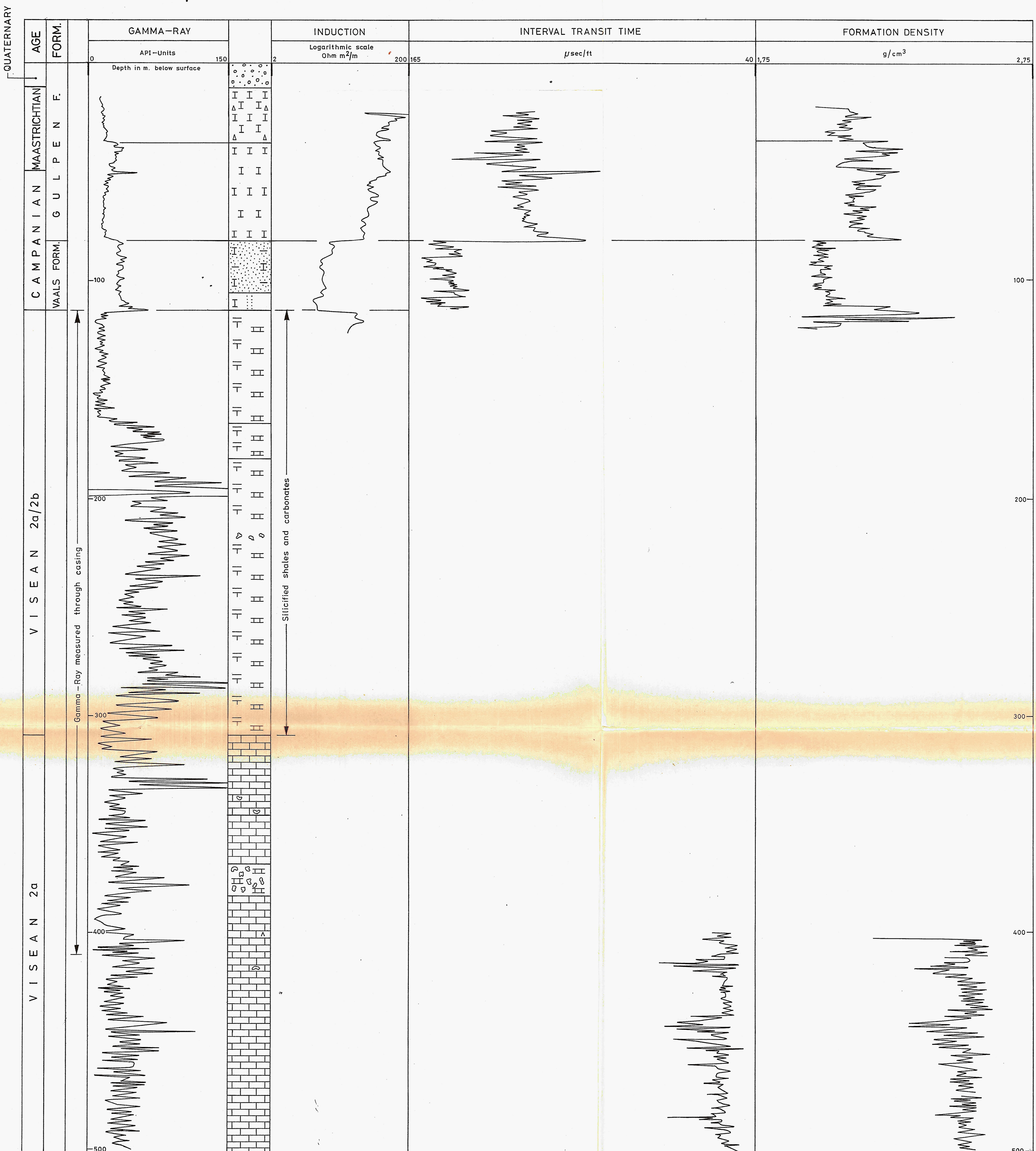
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

GEOLOGICAL SECTION THROUGH THE CARBONIFEROUS IN S. LIMBURG

COMPILED: AFTER BLESS c.s. (lit. 4)	DATE: 1983
ENCLOSURE: 3	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL(G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM

HEUGEM 1/1A



GEOLOGICAL SURVEY OF THE NETHERLANDS-HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

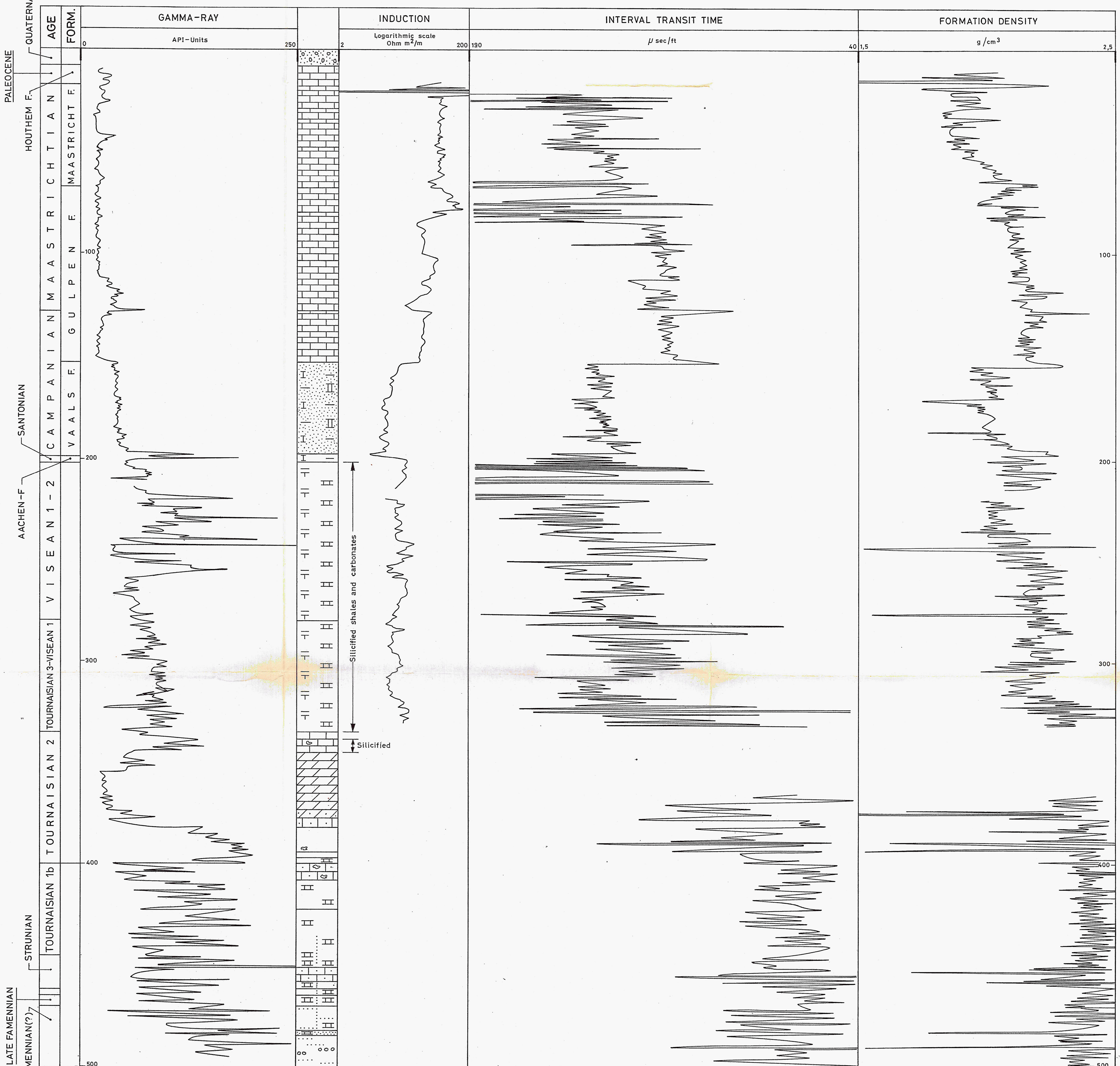
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

WELL SUMMARY HEUGEM 1/1A

COMPILED H.M v MONTFRANS (lit.4)	DATE: FEBR. 1983
ENCLOSURE 4	ARCH. Nº C 10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM

KASTANJELAAN 2



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

WELL SUMMARY KASTANJELAAN 2

COMPILED. H.M. v. MONTFRANS (lit. 4)	DATE: FEBR. 1984
ENCLOSURE: 5	ARCH. Nº C10. 58

CONTRACT Nº EGA-1-017-NL(G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM

Bijlage 6: Basis van de North Sea Groups
wordt U z.s.m. nagezonden.

Enclosure 6: Base of the North Sea Groups will be
sent to you as soon as possible.

GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

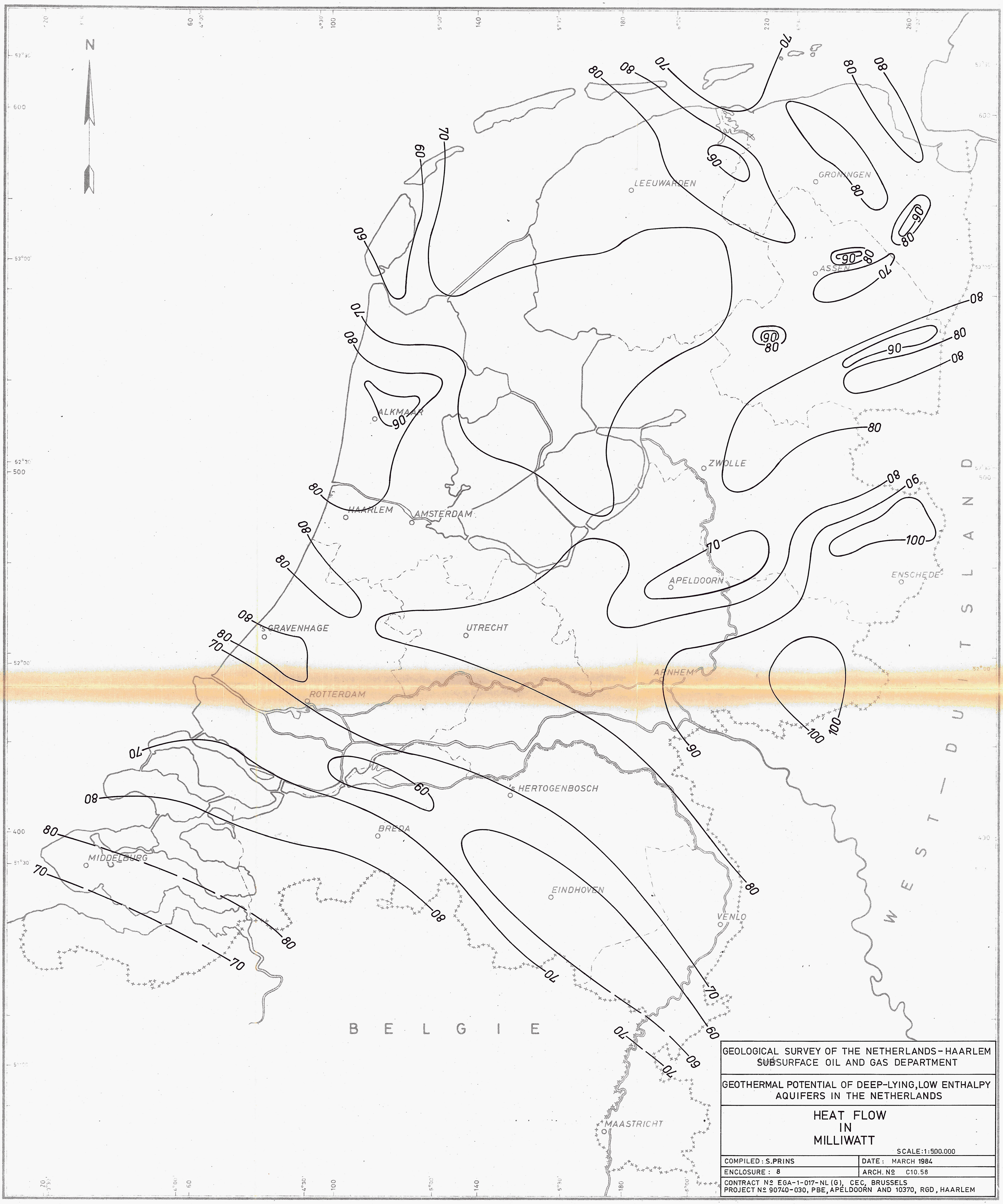
GEOTHERMAL POTENTIAL OF DEEP LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

WELLS USED FOR HEAT FLOW AND TEMPERATURE MAPS

SCALE: 1: 500.000

COMPILED: S. PRINS	DATE: JUNE 1984
ENCLOSURE: 7	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740 030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS – HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

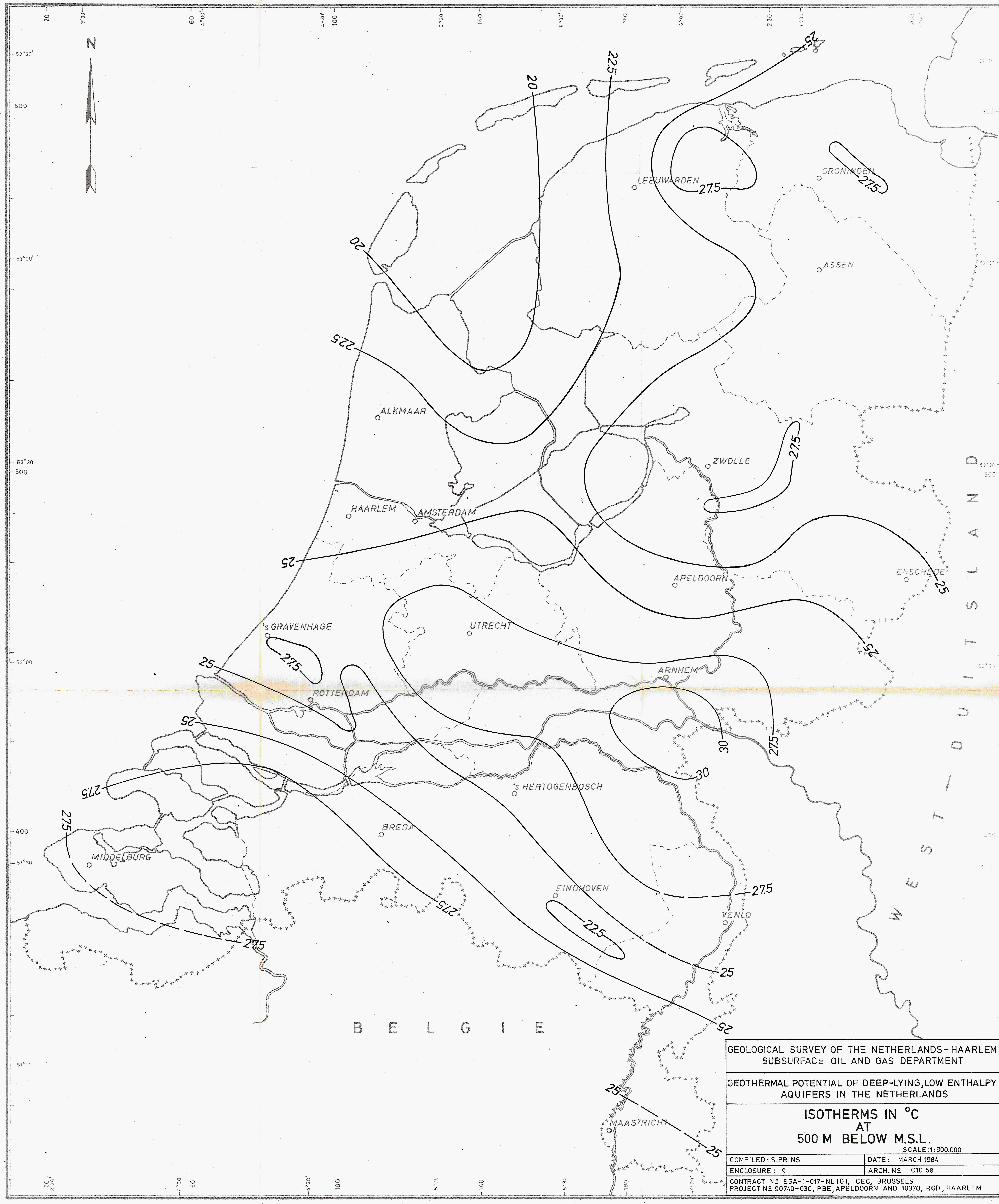
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

HEAT FLOW
IN
MILLIWATT

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 8	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

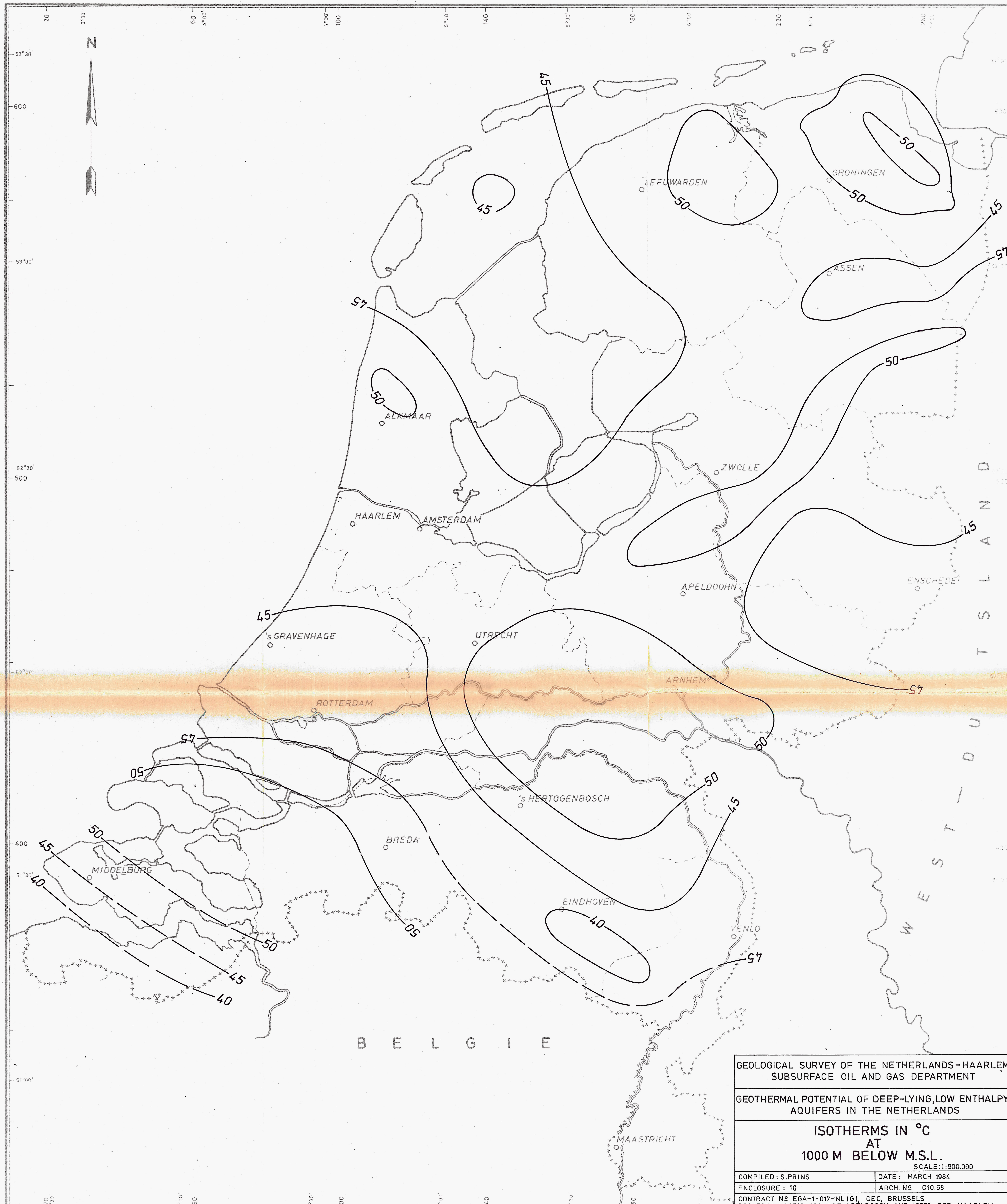
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 500 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 9	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS-HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

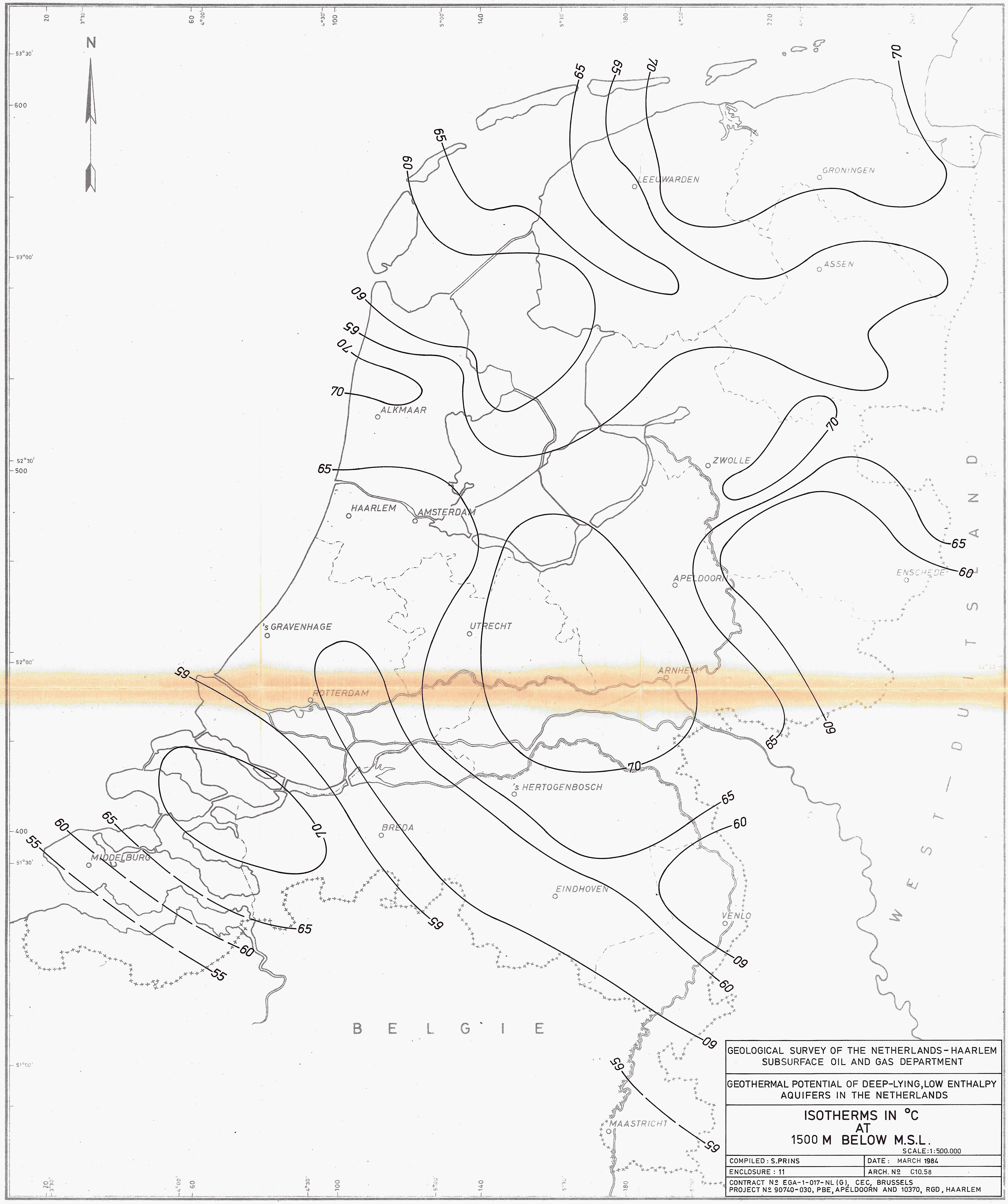
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 1000 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 10	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS – HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

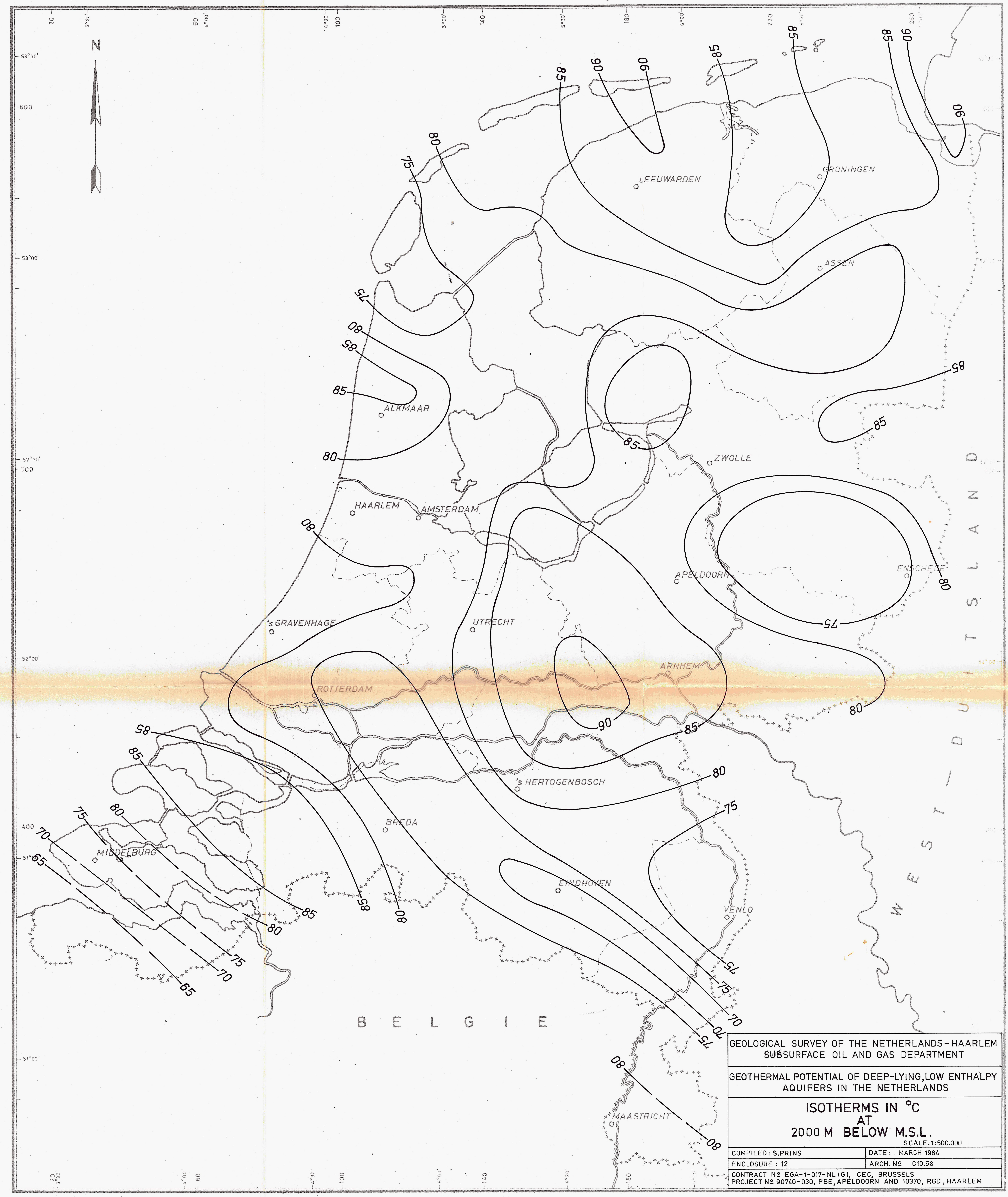
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 1500 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 11	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS – HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

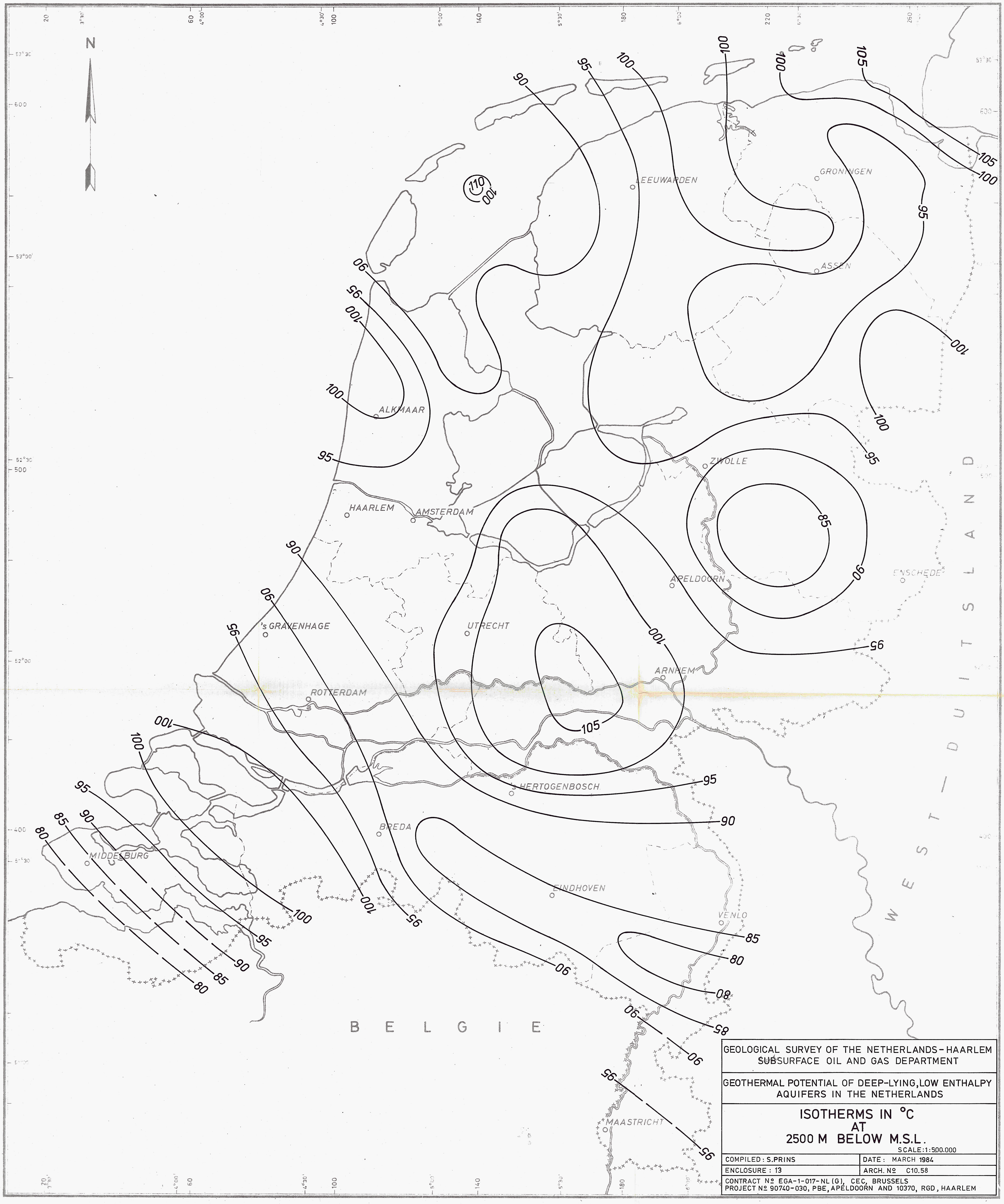
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 2000 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S. PRINS	DATE: MARCH 1984
ENCLOSURE: 12	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS-HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

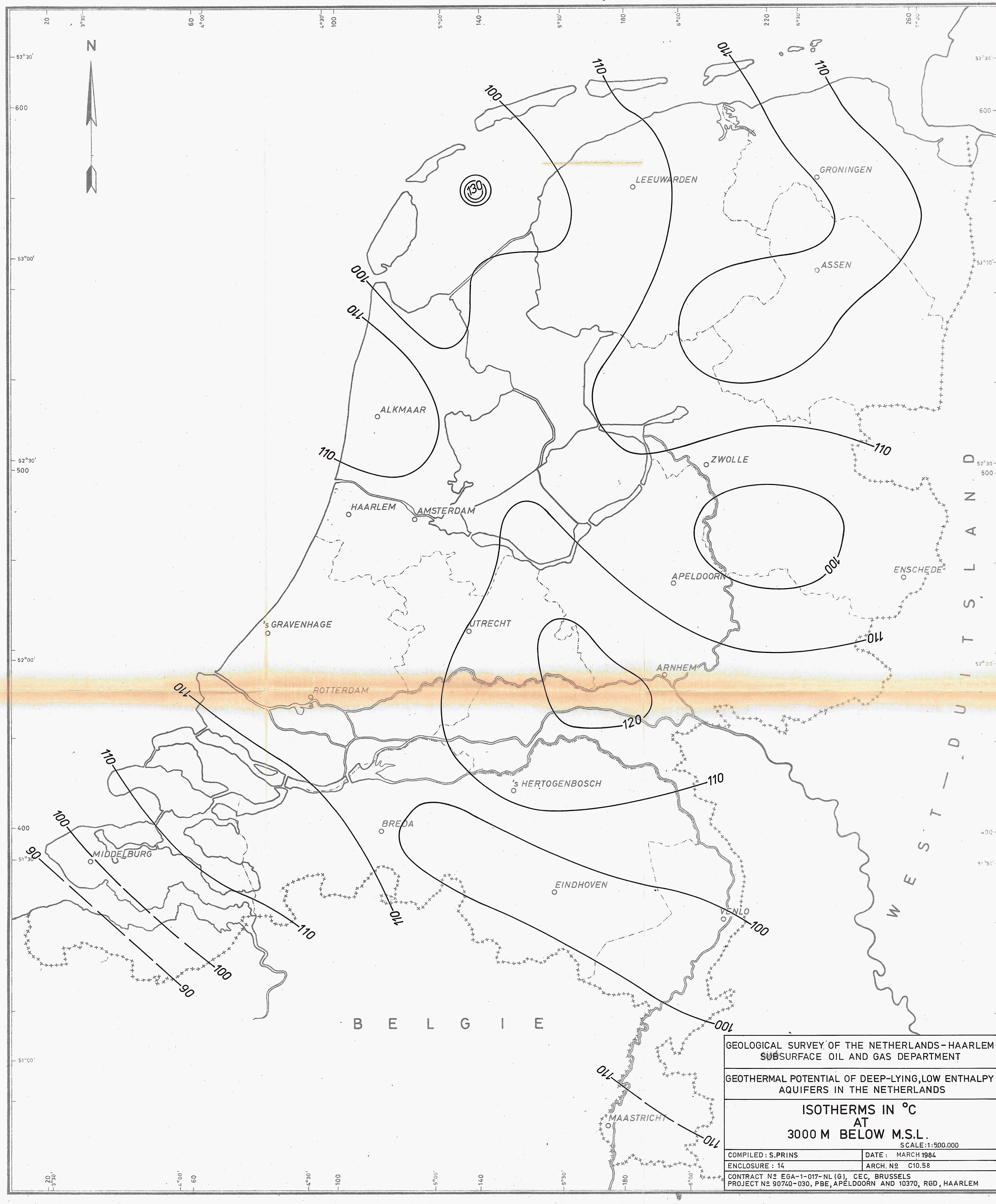
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 2500 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 13	ARCH. № C10.58

CONTRACT № EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT № 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

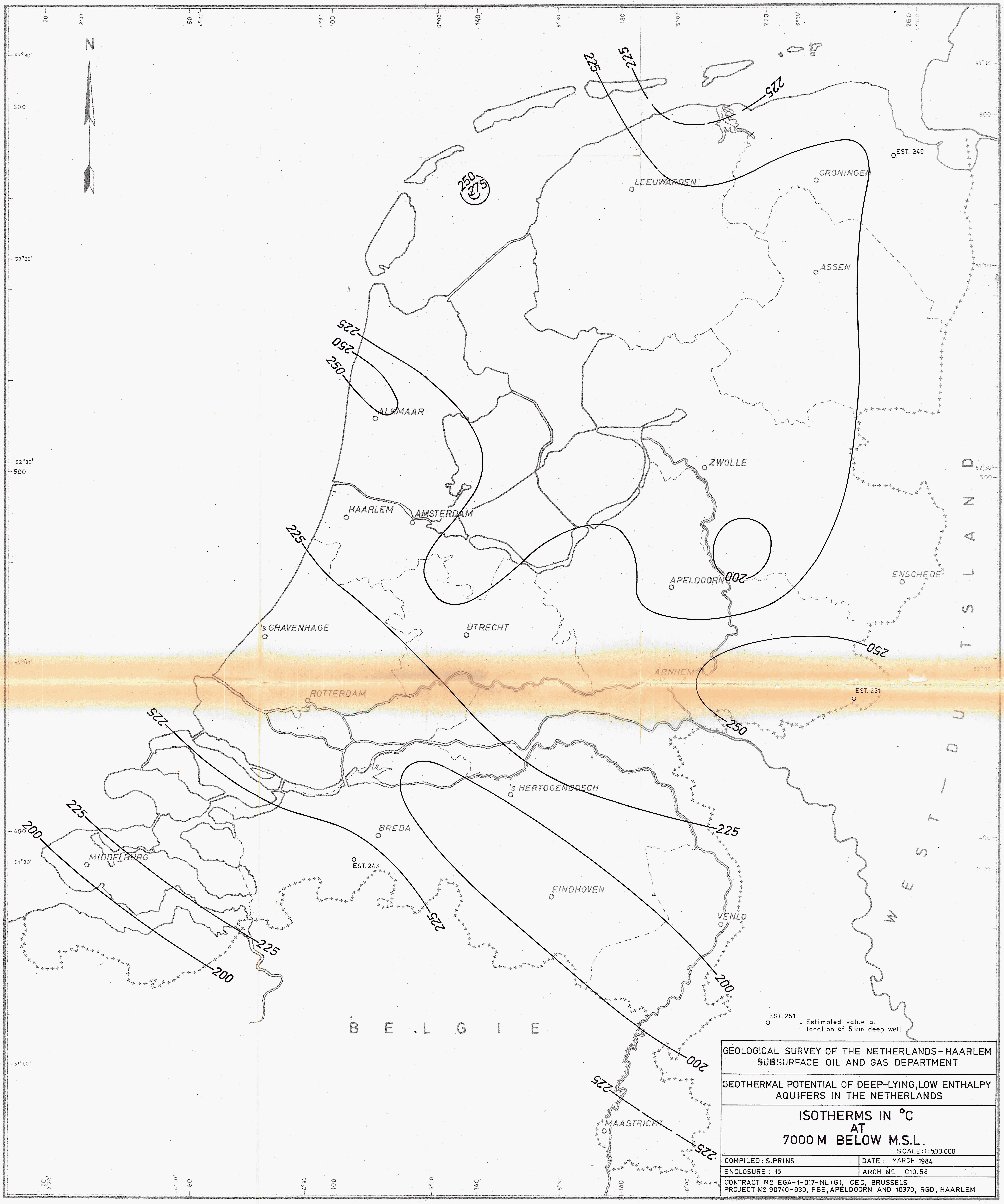
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 3000 M BELOW M.S.L.

SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 14	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

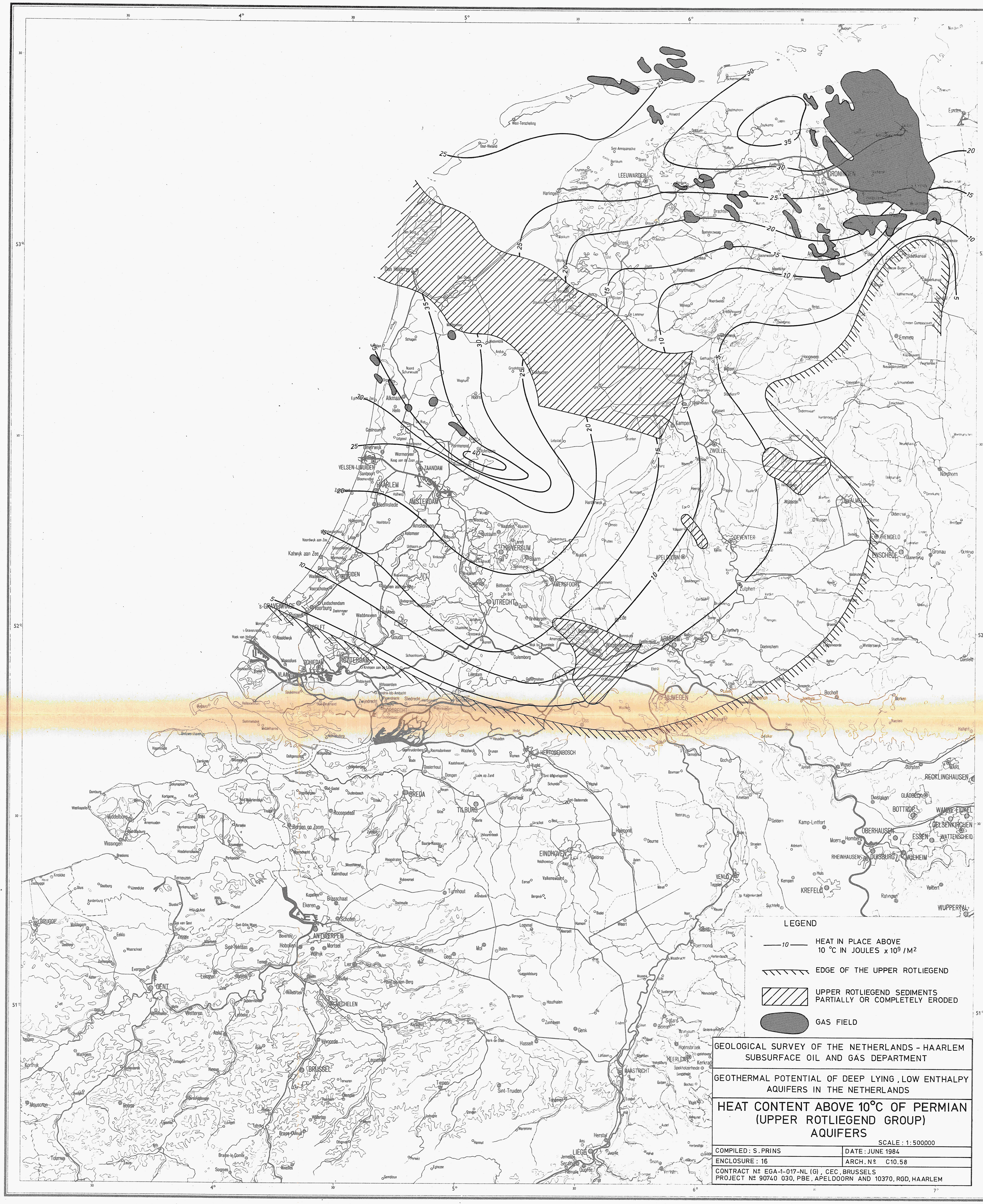
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

ISOTHERMS IN °C AT 7000 M BELOW M.S.L.

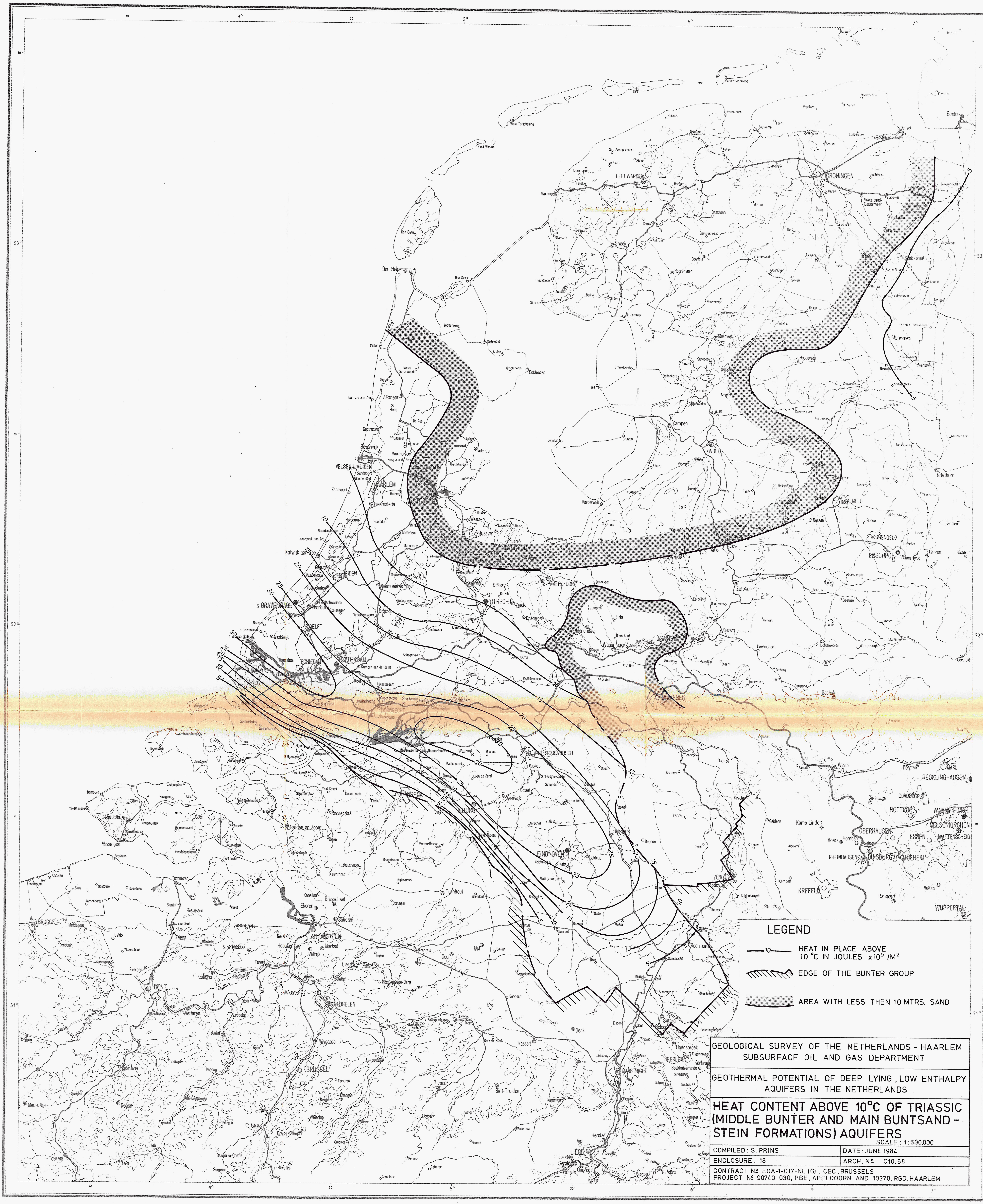
SCALE: 1:500.000

COMPILED: S.PRINS	DATE: MARCH 1984
ENCLOSURE: 15	ARCH. Nº C10.58

CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM


LEGEND
10
HEAT IN PLACE ABOVE 10 °C IN JOULES x 10^9 / M^2
EDGE OF THE UPPER ROTLIEGEND
UPPER ROTLIEGEND SEDIMENTS PARTIALLY OR COMPLETELY ERODED
GAS FIELD
GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
HEAT CONTENT ABOVE 10°C OF PERMIAN (UPPER ROTLIEGEND GROUP) AQUIFERS
SCALE : 1:500.000
COMPILED : S. PRINS
DATE : JUNE 1984
ENCLOSURE : 16
ARCH. Nº C10.58
CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740 030, PBE, APELDOORN AND 10370, RGD, HAARLEM


LEGEND
HEAT IN PLACE ABOVE 40°C IN JOULES x10^9/M^2
EDGE OF THE UPPER ROTLIEGEND
UPPER ROTLIEGEND SEDIMENTS PARTIALLY OR COMPLETELY ERODED
GAS FIELD
GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
HEAT CONTENT ABOVE 40°C OF PERMIAN (UPPER ROTLIEGEND GROUP) AQUIFERS
SCALE: 1:500.000
COMPILED: S.PRINS
DATE: SEPTEMBER 1983
ENCLOSURE: 17
ARCH. Nº A10.58
CONTRACT Nº EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM



GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT

GEOTHERMAL POTENTIAL OF DEEP LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS

HEAT CONTENT ABOVE 10°C OF TRIASSIC (MIDDLE BUNTER AND MAIN BUNTSAND-STEIN FORMATIONS) AQUIFERS

SCALE : 1:500.000

COMPILED: S. PRINS	DATE: JUNE 1984
ENCLOSURE: 18	ARCH. № C10.58

CONTRACT № EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT № 90740 030, PBE, APELDOORN AND 10370, RGD, HAARLEM


LEGEND
10 HEAT IN PLACE ABOVE 40°C IN JOULES x 10⁹/M²
EDGE OF THE BUNTER GROUP
AREA WITH LESS THAN 10 MTRS. SAND
GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
HEAT CONTENT ABOVE 40°C OF TRIASSIC (MIDDLE BUNTER AND MAIN BUNTSANDSTEIN FORMATIONS) AQUIFERS
SCALE: 1:500 000
COMPILED: S.PRINS
DATE: APRIL 1983
ENCLOSURE: 19
ARCH. No C10.58
CONTRACT No EGA-1-017-NL(G), CEC, BRUSSELS
PROJECT No 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM


NOORDZEE
SCHEVENINGEN
's GRAVENHAGE
LEIDEN
DELFT
Hoek van Holland
LEGEND
HEAT IN PLACE ABOVE 10 °C IN JOULES x 10⁹ /M²
EDGE OF LOWER CRETACEOUS DEPOSITS
OIL FIELD
GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
HEAT CONTENT ABOVE 10°C OF LOWER CRETACEOUS AQUIFERS IN THE WEST NETHERLANDS BASIN
SCALE : 1:100.000
COMPILED: S.PRINS
DATE: JUNE 1984
ENCLOSURE: 20
ARCH. № C10.58
CONTRACT № EGA-1-017-NL (G), CEC, BRUSSELS
PROJECT № 90740 030, PBE, APELDOORN AND 10370, RGD, HAARLEM


NOORDZEE
SCHEVENINGEN
'S GRAVENHAGE
LEIDEN
DELFT
GOUDA
Hoek van Holland
Katwijk aan Zee
Noordwijk aan Zee
VLAARDINGEN
SCHIEDAM
Maassluis
LEGEND
HEAT IN PLACE ABOVE 40°C IN JOULES x 10⁹/M²
EDGE OF LOWER CRETACEOUS DEPOSITS
OIL FIELD
GEOLOGICAL SURVEY OF THE NETHERLANDS - HAARLEM
SUBSURFACE OIL AND GAS DEPARTMENT
GEOTHERMAL POTENTIAL OF DEEP-LYING, LOW ENTHALPY AQUIFERS IN THE NETHERLANDS
HEAT CONTENT ABOVE 40°C OF LOWER CRETACEOUS AQUIFERS IN THE WEST NETHERLANDS BASIN
SCALE: 1:100.000
COMPILED: S.PRINS
DATE: OCT. 1983
ENCLOSURE: 21
ARCH. Nº C10.58
CONTRACT Nº EGA-1-017-NL(G), CEC, BRUSSELS
PROJECT Nº 90740-030, PBE, APELDOORN AND 10370, RGD, HAARLEM