

AN INTERPRETATION OF GRONINGEN SUBSURFACE TEMPERATURE DATA

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ABSTRACT

Temperature surveys have been carried out by NAM in gas wells in and around the Groningen field. From these surveys subsurface temperatures at datum level (= 2,875 m S.S.) between 88 and 114° C have been obtained, which have been used to construct a subsurface temperature map. This map is used for volumetric gas in place calculations and the prediction of producing wellhead temperatures.

On the map a number of areas with low datum depth temperatures can be seen, which appear to correspond with overlying salt domes and ridges. In these areas the heat flow rate to the surface is found to be above average.

INTRODUCTION

From bottom hole temperature surveys carried out in Groningen gas wells in the period 1959-1966 the average Groningen subsurface temperature at 2,875 m S.S. was estimated to be 107° C (ref. 1).

Since 1966 a large number of additional surveys have been carried out at existing and new well locations with conventional bottom hole temperature recorders as well as with more sophisticated techniques (e.g. the Schlumberger high resolution thermometer). The additional data obtained allow a more detailed description of the Groningen subsurface temperature distribution (fig. 1), which is presently being used for volumetric gas in place calculations and prediction of producing wellhead temperatures.

TEMPERATURE SURVEYS

Almost all surveys have been carried out with an Amerada temperature element (coupled to a Huegel pressure recorder). During a survey measurements are made at usually 5 bottom hole stations in the gasfilled tubing, generally in the Zechstein and Rotliegend formations.

In October 1973 the detailed vertical temperature profile in the observation wells Ten Post and Bolderij has been

measured with Schlumberger's High Resolution Thermometer.

The temperature equalisation due to free convection and conduction through the steel of tubing and casing can be neglected (ref. 2). The temperature distribution, therefore, in an observation well or in a production well, that has been closed in for at least 5 weeks, can be considered to be identical to the temperature distribution in the surrounding formation.

OBSERVED DATUM DEPTH TEMPERATURES AND TEMPERATURE GRADIENTS

From the available temperature surveys the datum depth temperatures for the various well locations (fig. 1) have been determined by extrapolation of the measured temperatures from measuring depth to datum level, while for the main stratigraphical units the following temperature gradients were obtained: in tabel 1)

INTERPRETATION

Datum depth temperatures

The lowest datum depth temperature (88° C) is found in well Annerveen-Veendam, where the top of the Zechstein salts lies at 160 m S.S. The highest datum depth temperature (114° C) is found in well Usquert, with the top Zechstein at a depth of 2,330 m S.S. Apparently datum depth temperature and depth of the top Zechstein are correlated due to the good heat conductivity of the salt (fig. 2).

A temperature map at datum depth can thus be made from a number of measurements in wells, a contour map of top Zechstein (fig. 3) and the empirical correlation found (fig. 2).

Temperature gradients and heat flow rate per unit area

The heat conductivity of a large number of Rotliegend core samples has been measured, yielding an average value of $3.5 \cdot 10^{-3}$ cal/(sec. cm° C). The heat flow rate per unit area in

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Table 1 Temperature gradients derived from temperature surveys

Temperature gradients °C/100 m						
Well	Type of survey	Quaternary/ Tertiary	Cretaceous	Triassic	Zechstein	Rotliegend
Sappemeer	Amerada				1.72	3.23
Kooipolder	Amerada				1.73	not reliable
Uithuizer- meeden	Amerada				1.42	2.93
Bierum	Amerada				1.86	3.20
Stedum	Amerada				1.78	3.17
Delfzijl	Amerada				2.07	3.27
Schildmeer	Amerada				1.75	2.83
Ten Boer	Amerada				1.75	3.18
Schaaphok	Amerada				1.86	3.58
Zuiderveen	Amerada				1.92	3.43
Rode Til	Amerada				1.92	2.92
Usquert	Amerada				1.85	3.50
Ten Post	HRT	3.77	2.42	not pres.	1.83	2.92
Bolderij	HRT	3.55	4.14	not pres.	1.51	2.45
Annerveen- Veendam	Amerada				2.60	

the Rotliegend (= heat conductivity \times temperature gradient) varies from $0.85 \cdot 10^{-6}$ cal/(sec cm²) in Bolderij to $1.25 \cdot 10^{-6}$ cal/(sec cm²) in Schaaphok. Using the average Rotliegend temperature gradient (= 3.1° C/100 m) the field average value of the Rotliegend heat flow rate per unit area is found to be $1.1 \cdot 10^{-6}$ cal/(sec cm²).

The average Zechstein temperature gradient is found to be 1.8° C/100 m. In well Annerveen-Veendam, however, the temperature gradient in the Zechstein near datum depth is found to be 2.0° C/100 m, while the average temperature gradient in the Zechstein in that well is of the order of 2.6° C/100 m. This indicates that the vertical heat flow rate per unit area in the Annerveen-Veendam salt dome increases towards the top of the dome. These results indicate that the heat flow is a 3-dimensional phenomenon and that the vertical heat flow rate varies both laterally and vertically.

It is therefore expected that an improved temperature map at datum depth can only be constructed, if a (numerical) 3D heat flow model with appropriate boundary conditions is used.

SUBSURFACE TEMPERATURE MAP

The datum depth temperatures observed in the well locations, were used to plot a contour map with the help of the IBM numerical surface techniques/contouring package (direct numerical interpolation). The resulting map was manually adjusted, taking into account the seismic contour map top Zechstein (fig. 3) and the relationship between datum depth temperature and depth top Zechstein (fig. 2).

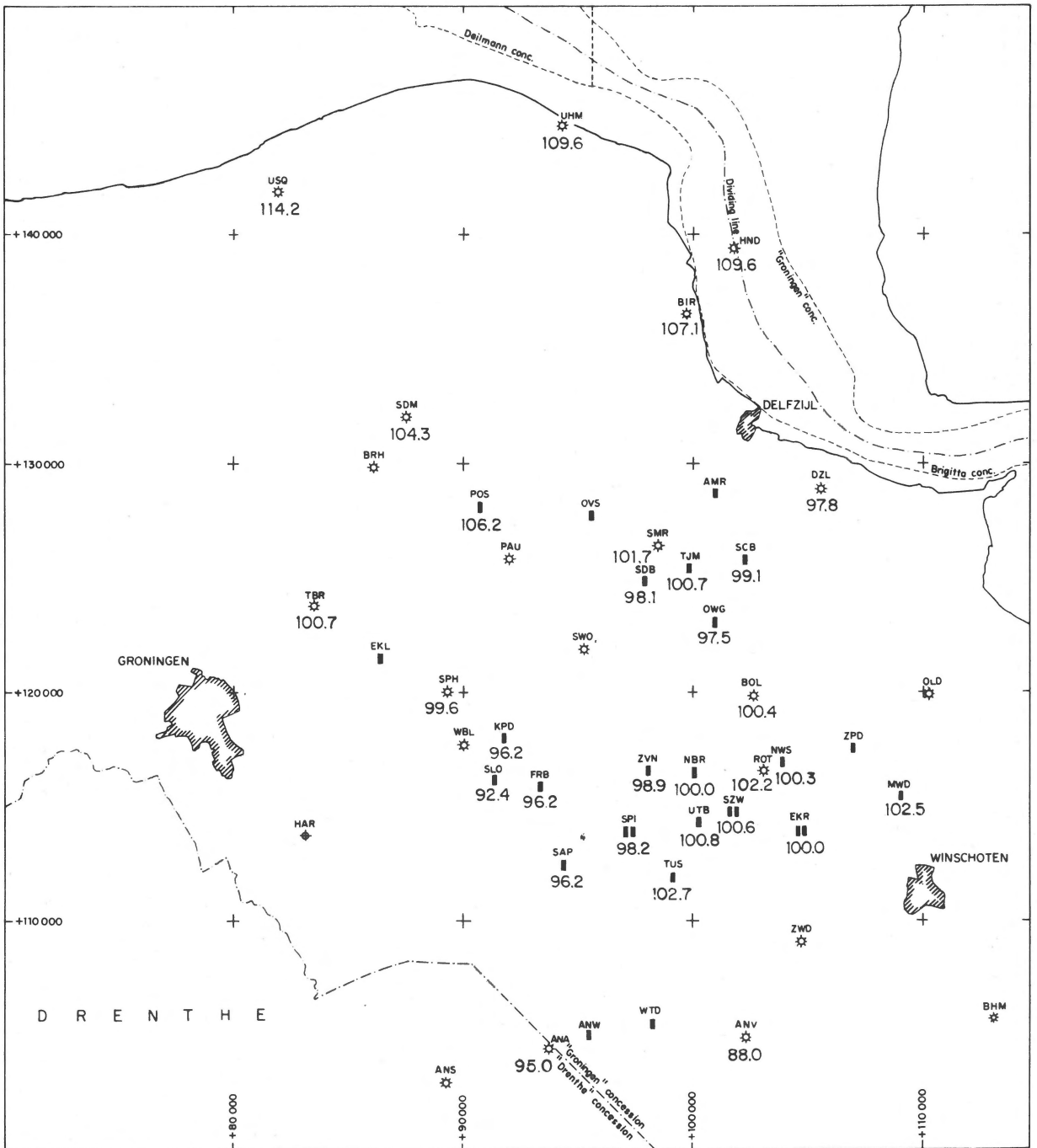
Finally, after some minor corrections had been included to account for faults, the Groningen subsurface temperature map (fig. 4) was obtained.

Since the construction of the reservoir temperature map in 1971 eight appraisal wells have been drilled in the Groningen field, in which temperature gradient surveys have been carried out. The recently observed temperatures are in good agreement with the temperature map as can be seen from the following table:

Table 2 Recently observed datum depth temperatures compared with map

Datum depth temperature °C				
Area	Location	Type of survey	Observed	From map
South Central	Froombosch	gradient survey	96.2	95.8
	Oudeweg	gradient survey	97.5	101.7
	Tjuchem	gradient survey	100.7	101.2
	Siddeburen	gradient survey	98.1	101.4
	Schaapbulten	gradient survey	99.1	100.0
	Bolderij	High Resolution Thermometer	100.4	102.7
North East	De Hond	gradient survey	109.6	108.7
North West	Ten Post	High Resolution Thermometer	106.2	103.6

Fig.1



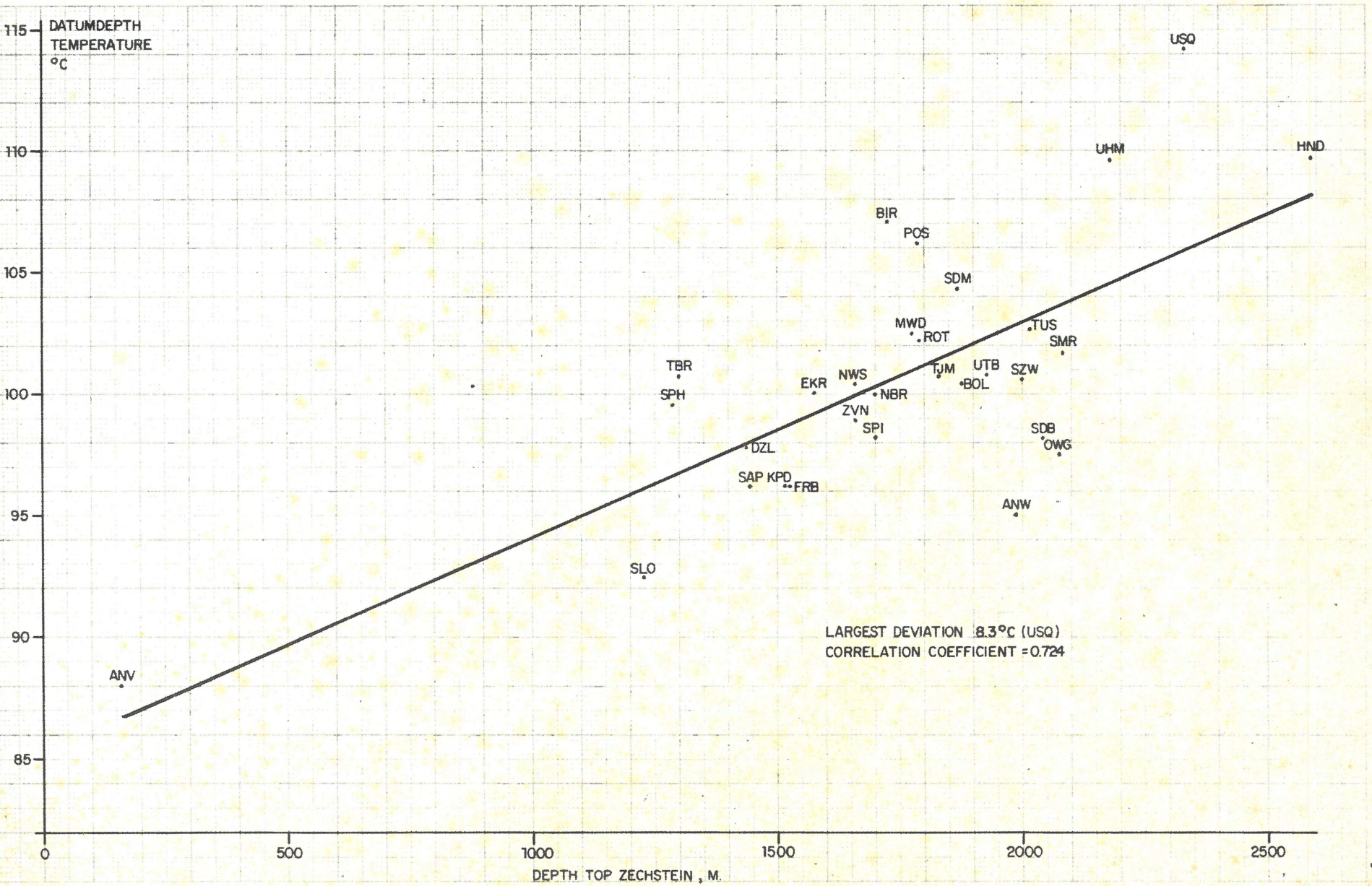
LEGEND

■ CLUSTER

☆ APPRAISAL WELL / OBSERVATION WELL

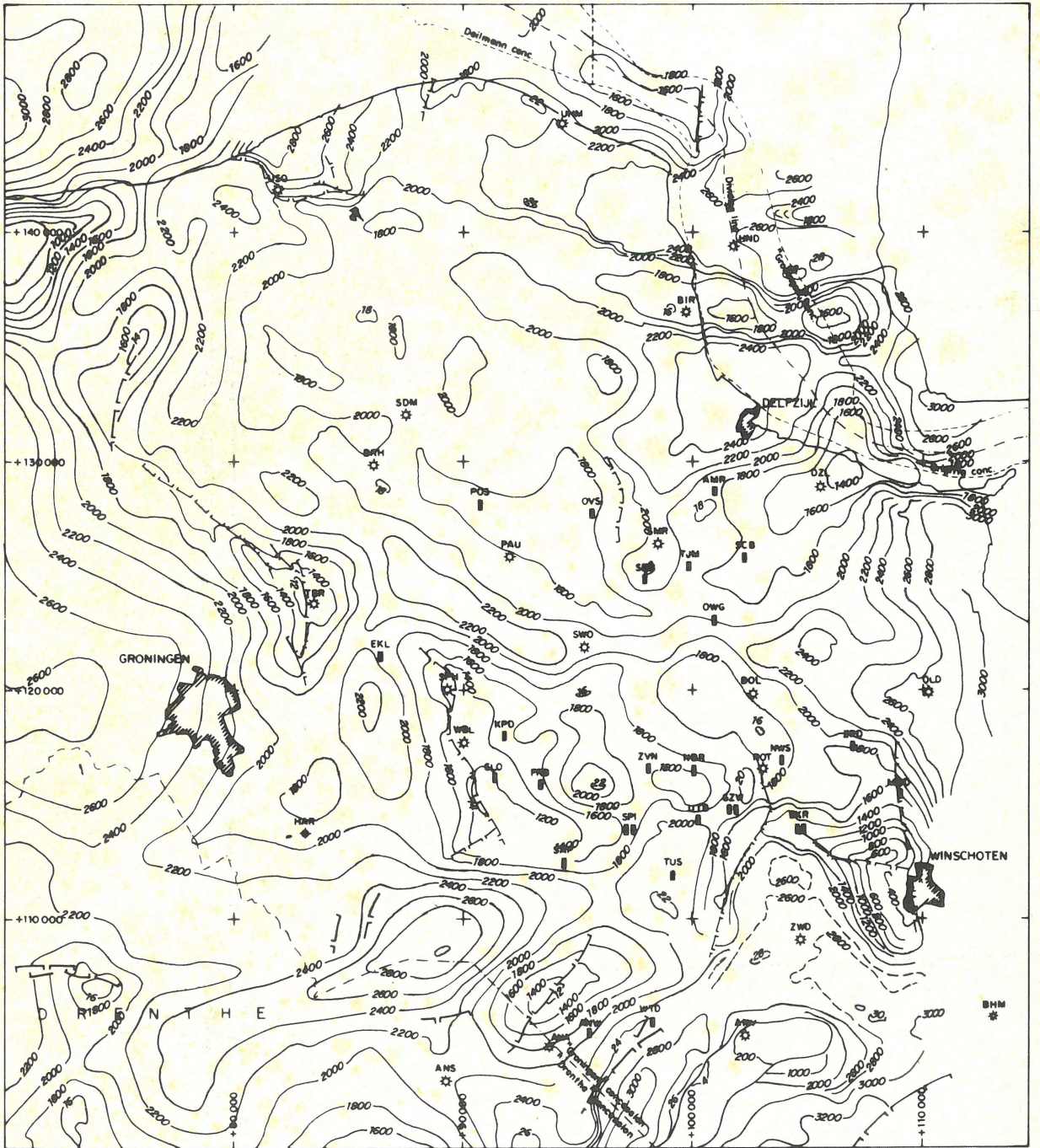
101.7 OBSERVED DATUMDEPTH TEMPERATURE °C

N.A.M.	ASSEN	PROD.
GRONINGEN		
OBSERVED DATUMDEPTH		
TEMPERATURES		
1 : 250,000		
Author : PER	Date : September '74	
Rep.no.TM 5631	Encl.	Dr.no.: P 28,343



Datumdepth temperature versus Depth Top Zechstein

Fig. 3



LEGEND

■ CLUSTER

☆ APPRAISAL WELL / OBSERVATION WELL

— 1000 — CONTOURS ON TOP ZECHSTEIN (200 m INTERVAL)

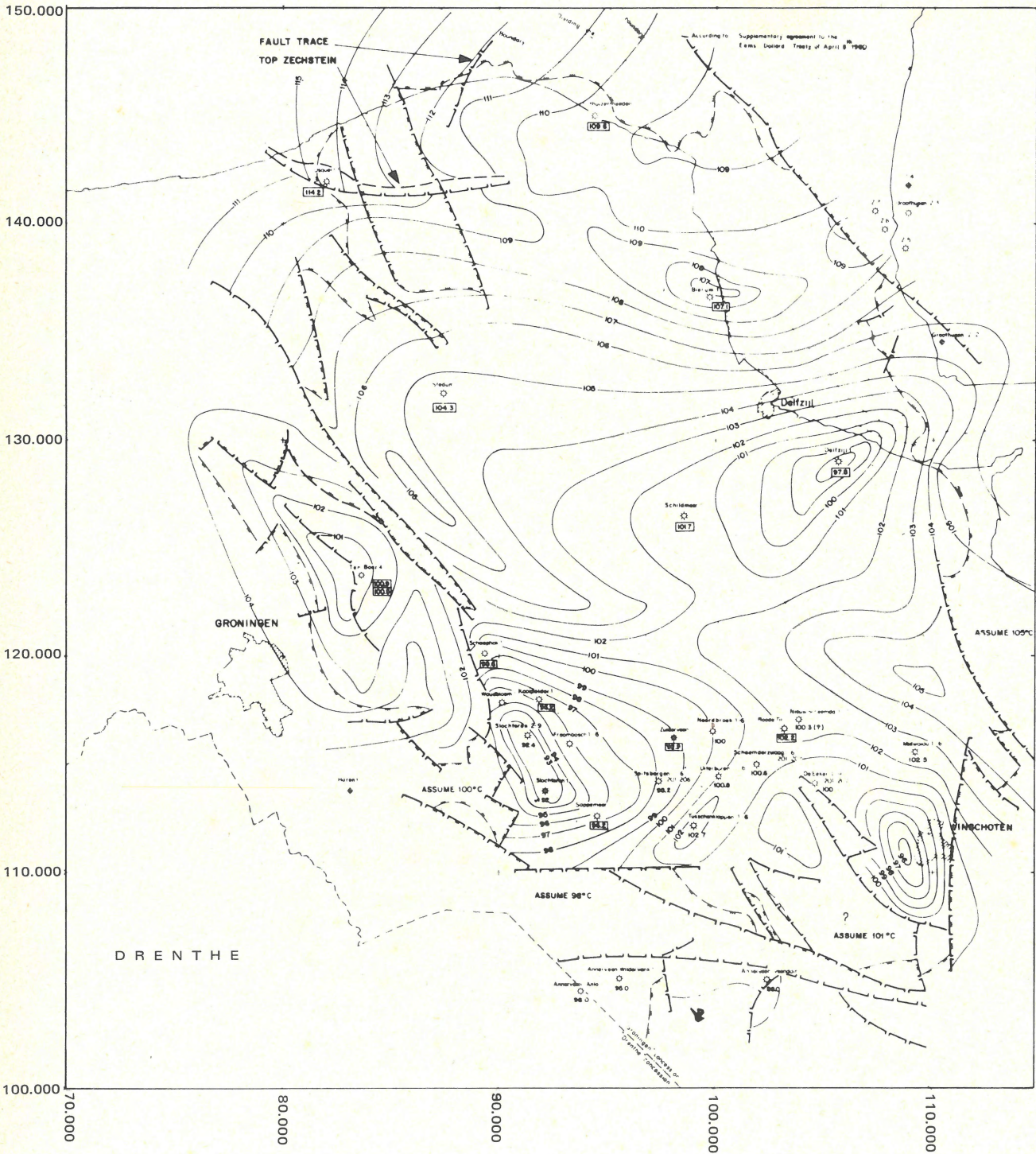
N.A.M. ASSEN PROD.

GRONINGEN
DEPTH CONTOUR MAP
TOP ZECHSTEIN





1: 250,000

Author: PER	Date: September '74
Rep. no.: TM 5631	Encl.: Dr. no. P28,559

Fig. 4



LEGEND

-  ISOTHERM AT 2875 m. BELOW N.A.P.
-  OBSERVED DATUMDEPTH TEMPERATURE °C
-  MAIN FAULTS (INFLUENCING TEMP. DISTRIBUTION)
-  GAS WATER CONTACT

N.A.M.	ASSEN	PROD.
GRONINGEN GAS FIELD ISOTHERMAL MAP AT DATUMDEPTH (2875 m. below N.A.P.) Scale 1 : 250 000		
Author: PES/GR		Date: January 1971
TM Rep. 5631	Fig. 4	Dr. nr. P 28 344

The map is considered to be sufficiently accurate for practical purposes (gas in place calculations and prediction of producing wellhead temperatures). A more sophisticated temperature study with a 3D heat flow model was, therefore, not required.

CONCLUSION

Bottom hole temperature surveys, carried out in gas wells in and around the Groningen field indicate temperatures between 88 and 114° C at a depth of 2,875 m S.S. ("datum depth"). Relatively low datum depth temperatures were found to correspond with salt uplifts.

A subsurface temperature map has been constructed from measurements in wells and interpolation using a seismic contour map of top Zechstein. This map is sufficiently accurate for volumetric gas in place calculations and prediction of producing wellhead temperatures.

Datum depth temperatures, measured in wells that were drilled after the construction of the map, confirmed the validity of the map.

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