Geo-resistivity and geo-hydrology of the Snoldelev area (Denmark).

By

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Abstract

A WENNER geo-resistivity survey carried out near Snoldelev (Sjælland, Denmark) is described and interpreted on the basis of the records of the wells drilled in the area, on file at the Danish Geological Survey. Aquifers have been outlined in the glacial drift by means of trenching mapping. Depths to the Danian- Paleocene bedrock have been suggested on the basis of vertical measurements. Various geological and hydrological maps have been compiled in order to relate the geophysical data to the geohydrology of the area.

Introduction.

As part of his geo-hydrological studies at the Technical University of Denmark, the writer carried out a resistivity survey near Snoldelev (Sjælland) from 8th May to 25th June 1962.

The goal of the survey was to map the geo-resistivity of the area and, as far as possible, to relate the resistivity features to geology and geohydrology.

The Snoldelev area was chosen on account of its shallow pre-Quaternary bedrock, consisting of Danian limestone partly superposed by Paleocene limestone, marl and clay. It was logic to assume that the resistivity contrast (1) between the limestone and the superposed argillaceous formations, and (2) between the overlying boulder clay deposits and coarse clastics of the glacial drift would be clearly reflected by the resistivity data.

The surveyed area is situated south-west of Copenhagen, on sheets M 3327 and M 3328 of the Topographic Map of Denmark, scale 1:20.000, by the Danish Geodetic Institute[1])

The paper treats the following subjects: a) the surface and subsurface geology and hydrology, b) the geo-electric survey carried out, c) geohydrologic conclusions.

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[1]) The map sheets M 3327 and M 3328 of the Danish Geodetic Institute correspond to the sheets 206 IV and 207 III of the file of the D.G.U. (Danmarks Geologiske Undersøgelse = Danish Geological Survey), respectively.

The logs of the wells drilled in the area[1]) were studied in the Well Record Department of the Danish Geological Survey (see: ØDUM og BERTHELSEN, 1953).

The field resistivity measurements were carried out by the writer, who was assisted by members of the staffs of the Technical University of Denmark and the Danish Geological Survey.

Surface geology and hydrology.

The surface geology has been described by K. RØRDAM (1899) and by V. MILTHERS (1935). The following is a brief summary of the main features.

The surface deposits mainly consist of boulder clay (fig 1). Minor areas with fluvioglacial sand and gravel occur near Snoldelev. Peat and other postglacial freshwater deposits are found in the small hollows and basins of the moraine topography. The topography is that of a slightly rolling glacial drift landscape. The regional slope is mainly southward. However, a "tunnel valley" crossing the area with an ESE-WNW trend breaks the regional slope. This valley, which genetically is a subglacial meltwater course, appears as a system of minor basins and irregular valleys in which postglacial sediments, i.e. peat, clay, or sand are deposited.

The tunnel valley is crossed by a surface watershed in the central part of the area. From this watershed the surface waters run off towards east to "Köge Bugt", and towards west in direction of "Roskilde Fjord".

Subsurface geology and hydrology.

The subsurface geology has been outlined by K. RØRDAM (1899) and V. MILTHERS (1935) in their regional surveys. Contour maps of the top of the Danian and of the pre-Quaternary bedrock topography are found in Milthers' paper. The writer has revised these maps and included new data for the Snoldelev area on file in the Well Record Department of the D.G.U. Special maps have finally been prepared for the present survey (fig. 2–3).

Several wells outside the investigated area have been considered, in order to get a more precise representation of conditions in the investigated area proper.

The Danian limestone underlies the glacial drift in the eastern part of the investigated area. In the western part the Danian is superposed by more or less marly and argillaceous Paleocene "greensand", the sand content of which is probably rather negligible. The Paleocene-Danian boundary crosses the area approximately north-south. The westward dip of the Danian limestone west ot the Danian-Paleocene boundary is assumed

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[1]) The major part of the wells was drilled by Københavns Vandforsyning (Copenhagen Water Supply). In the filing system of the Geological Survey each well has a file number consisting of the number of the map on which the well is located, followed by a serial number.

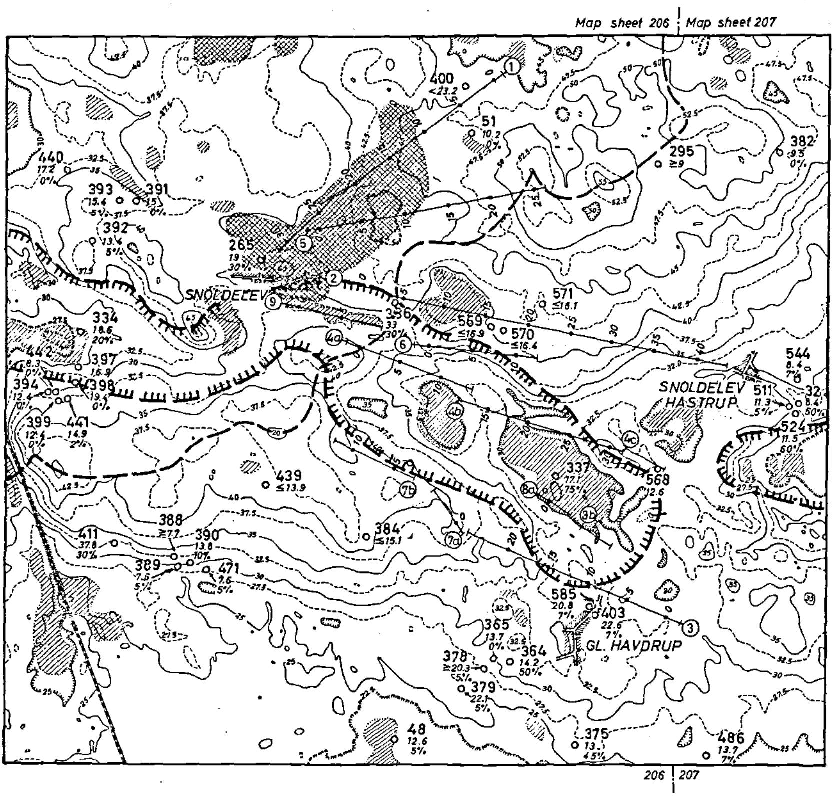

Fig. 1. SURFACE TOPOGRAPHY
AND
SOME QUATERNARY FEATURES

Legend:

365 Well File No.
O 17.3 Thickness of the Glacial Drift in m.
0% Percentage of sand & gravel in the Glacial Drift.
Postglacial peat deposits
Trenching line
Blank areas: mainly boulder clay, glacial drift.

Contours: elevation above sea level; interval: 2.5 m.
Surface watershed
Sand & gravel, glacial drift
Tunnel vally

1000 m 500 0 1 Km

Base map: Geodætisk Institut. M 3327 and M 3328

Compiled by G. LATMIRAL 1962
Traced by M. HETTING

to be duc to tectonics. The Danian limestone east of the boundary, as well as the Paleocene beds west of the boundary, have been subjected to glacial erosion during the Quaternary. In this connection, it is interesting that the trend of the subsurface valley in the pre-Quaternary formations south

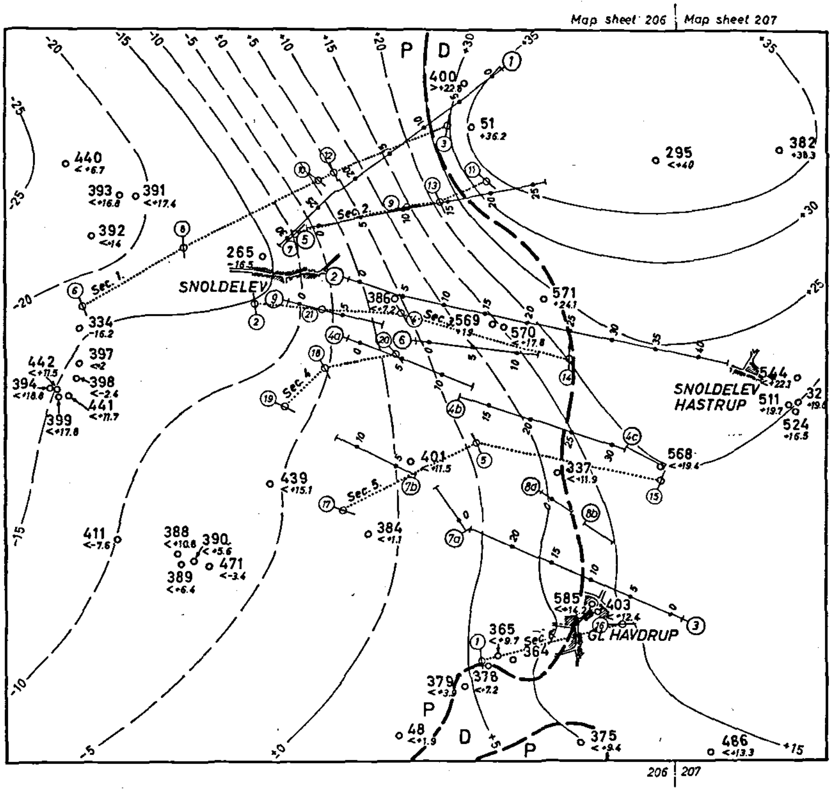

Fig. 2. DANIAN LIMESTONE TOPOGRAPHY

Legend:

524 Well File No.
+16.5 Top of Limestone: elevation in m.
> = Above < = Below
Sec. 6 Section 1-6

Contour interval: 5 m.
P/D Paleocene-Danian boundary
Trenching line

1000 m 500 0 1 Km

Base map:
Geodætisk Institut
M 3327 and M 3328

Compiled by G. LATMIRAL 1962
Traced by M. HETTING

of Snoldelev (see fig.3) is the same as that of the "tunnel valley" at the surface. Stratigraphic data are defective in the central part of the subsurface valley, at Snoldelev. It is, therefore, impossible to decide whether this valley is continuous, or whether it is interrupted in its central part, like the surface valley. The topography of the pre-Quaternary formations differs on the two side of the Paleocene–Danian boundary: it is rather flat

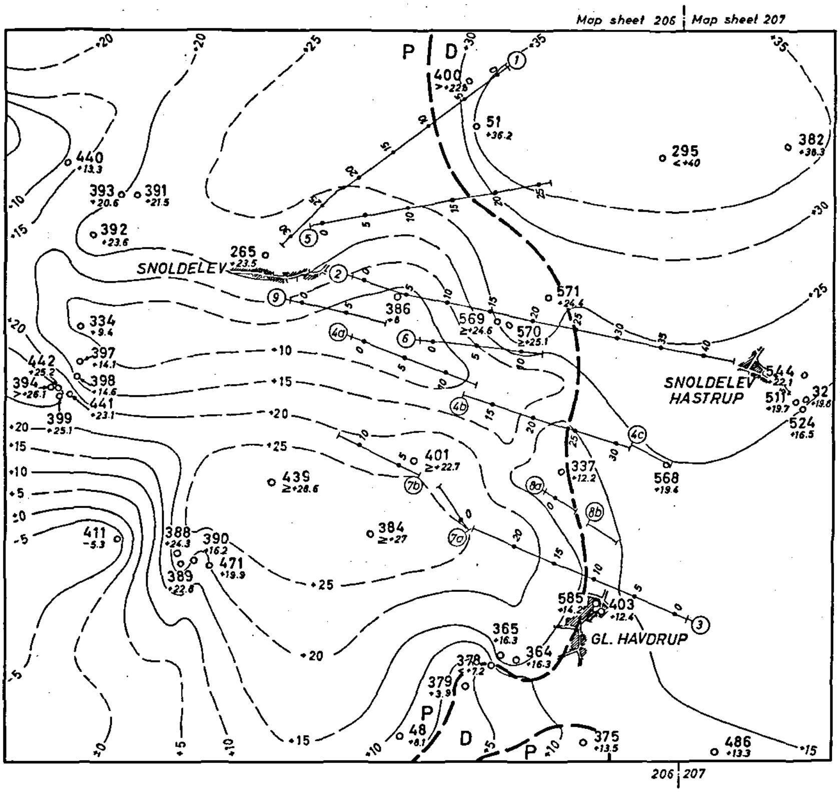

Fig. 3. PRE-QUATERNARY TOPOGRAPHY
(Base of the Glacial Drift)

Legend:

388 Well File No.
+19.9 Top of Pre-Quaternary
> = Above < = Below

Contour interval: 5 m
P/D Paleocene-Danian boundary
Trenching line

1000 m 500 0 1 Km

Base map: Geodætisk Institut M 3327 and M 3328

Compiled by G. LATMIRAL 1962
Traced by M. HETTING

in the Danian area (east of the boundary), and more irregular in the Paleocene area. This difference may be due to the different degree of induration of the relatively hard limestone and the rather soft Paleocene beds.

In accordance with the description of the Paleocene beds in the D.G.U. well file, the composition of the Paleocene "greensand" varies from clay ("grønsandsler" = greensand-clay) through a more or less indurated rock ("grønsandsten" = greensand-stone), to limestone at the very base of the Paleo cene ("grønsandskalk" = greensand-limestone)[1]).

Part of the composition of the glacial drift is shown on fig. 1. The locations of the wells, from which data are available, are plotted on the map. Figures indicating thickness and percentage of coarse materials (sand and gravel) of the penetrated glacial drift column are indicated at each well. Stratigraphic data are lacking in the upper part of the Quaternary interval in some wells. In these cases, the average composition has been calculated as if the unknown part of the column was clay. The nature of the Quaternary interval being completely unknown in several other wells, it is difficult to generalize the few data available. The glacial drift apparently consists mainly of clay. Sand and gravel beds are, however, present in the central part of the surveyed area (wells 206.386 and 206.337 of the D.G.U. file, where the presence of coarse clastics can be related to the tunnel valley)[2]).

Contours of the ground water table are shown on fig.4.

The underground watershed crossing the surveyed area is affected by pumping at the Havdrup "Kildeplads" (pumping area), just south of the mapborder. Another watershed, influenced by pumping at some water works situated west and north-west of the investigated area, is found just outside the north-western edge of the map. But lack of data makes it difficult to define its situation. The ground water contours have been drawn on the basis of the water table levels recorded in a few wells in the area by the Copenhagen Water Supply during the month of June 1962. Shortage of data in the surveyed area has been cured by also considering several wells situated outside the map limits. One well had to be numbered with the Copenhagen Water Supply number (1206), because it was not found in the D.G.U. file. The water table levels available in the D.G.U. file for the other wells drilled in the surveyed area were not used, because measured at different periods.

The resistivity measurements.

Method and working programme

The instrument used was the "Earth Resistivity meter type 766", manufactured by AB Elektrisk Malmletning, Stockholm. The WENNER (1915) method was applied. The measurements were otherwise carried out in the two common ways, as e.g. described by SORGENFREI (1955), viz. measurements with constant electrode spacing along straight lines ("trenchings"), and measurements with expanding electrode spacing around a fixed point (vertical measurements). In each case the apparent resistivity $\varrho = 2\pi aR$ was determined.

The general aims of the geo-resistivity survey were the following:

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[1]) A petrographic description of the Paleocene "greensand" has been given by GRY (1935) for the Tune samples (northern end of the sheets M 3327 and M 3328).

[2]) Tunnel valleys may generally include more coarse materials (meltwater sand and gravel) than the areas of ground moraine.

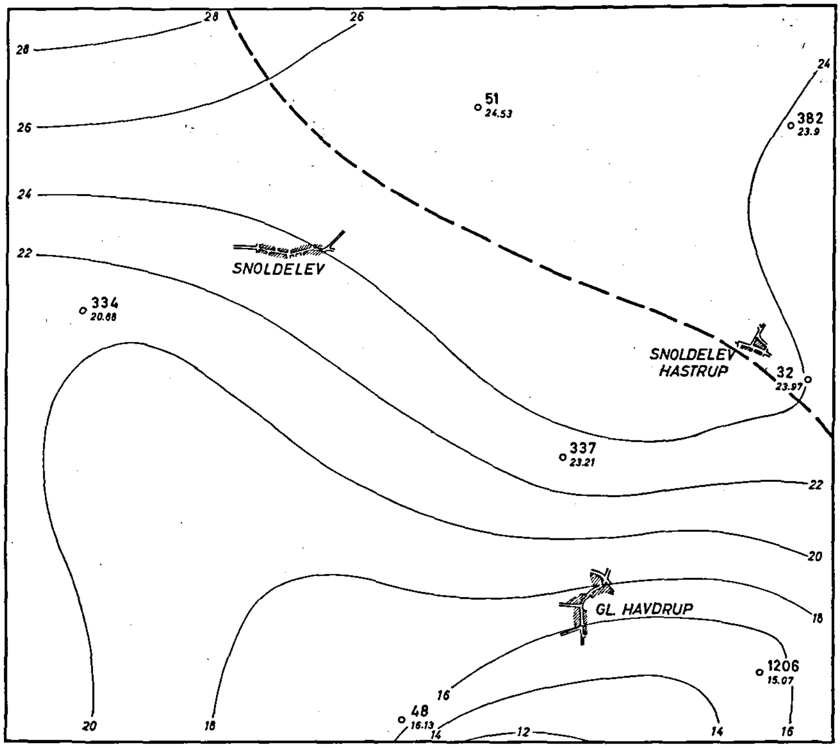

Fig. 4. APPROXIMATE GROUND WATER TABLE

(As of June 1962)

Legend:

48 Well File No.
16.13 Water table m. above sea level

Contour interval: 2 m

Subsurface Watershed

1000 m 500 0 1 Km

Base map: Geodætisk Institut M 3327 and M 3328

Compiled by G. LATMIRAL 1962
Traced by M. HETTING

a) trenchings: survey of the horizontal variations of the Quaternary deposits, the bedrock topography, and potential ascending salt water occurences.

b) vertical measurements: investigation of depths to ground water table and formation boundaries, and determination of the true resistivities of the Quaternary and pre-Quaternary deposits.

The possibility of locating shallow aquifers was particularly interesting. The measurements were, therefore, preferably placed in relation to the tunnel valley, in which the coarse glacial drift was assumed.

The trenching programme was based on an electrode spacing of 50 m, in order to get the apparent resistivity values affected by both the Quaternary and the pre-Quaternary formations. In order to get the maximum variation of the resistivity, the trenching lines were mainly placed in E–W directions crossing the Danian-Paleocene boundary. They were thus, largely speaking, parallel with the regional dip of the Danian-Paleocene partition plane.

The twenty-one vertical measurements were preferably located in the resistivity anomalies. Their electrode systems were approximately parallel to the iso-ohm contours of the resistivity map, in order to carry out measurements in the directions of potential minimum variation of the apparent resistivity. The electrode spacings were adjusted to the variability range of depth to the ground water table and formation boundaries.

Results

The apparent resistivity values of the trenchings and the 50 m values of the vertical measurements have been plotted on a map (fig. 5), and contoured. The resulting apparent resistivity map shows a maximum (up to about 300 Ohm.m) at Allehöj Gd, a relative maximum (up to about 160 Ohm.m) between Snoldelev and Söager, and a minimum near Raanæs Gd.

Curves of the apparent resistivity have been traced for the vertical measurements. Each curve has finally been resolved into a number of intervals[1]) with theoretic true resistivity values, in accordance with the method of quantitative interpretation elaborated by HEDSTRÖM and described by SORGENFREI (1955). The vertical resistivity curves approximately lying on E–W alignments have been grouped in "sections" 1–6 (see fig. 2). Graphic logs of a few wells adjacent to measuring stations are furthermore shown on these sections (plates 1–2).

The apparent resistivity curves belonging to the eastern part of sections 1–3 and 5–6 are similar, by generally showing a rather rapid increase of the values starting few meters below surface. Contrary, in the curves belonging to the western part of sections 1–3 and 5–6 and to the whole of sections 6, this rapid increase, if visible, generally takes place only in the lowest part of the curves, i.e. at considerable depth.

The physical and geological interpretation of the vertical measurements is shown on table 1.

Vagabondary currents rendered readings impossible at a number of stations of the trenching lines and vertical measurements. The curve of vertical measurement no. 10 has not been interpreted, due to its strong irregularity.

The resistances between the potential electrodes and the center at

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[1]) The subdivision into intervals may also be made in a somewhat different way.

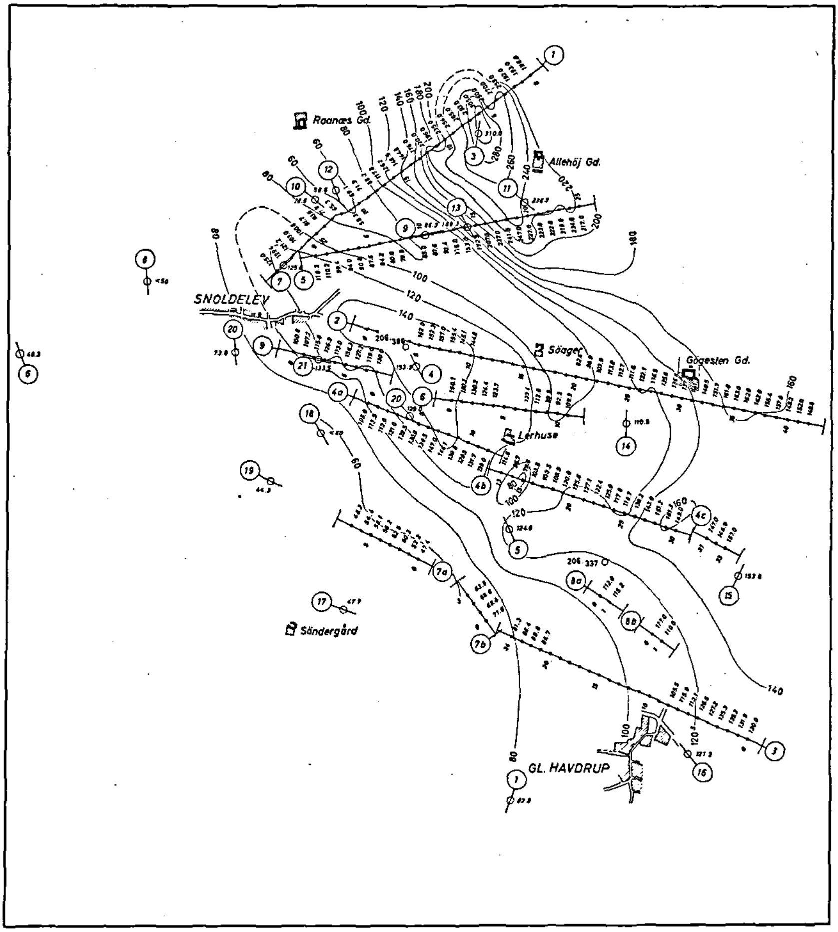


Fig. 5. APPARENT RESISTIVITY, Electrode spacing 50 m

Legend:

Values — No. Trenching line — Stations

403 o Well with File No.

Vertical measurement with No. and direction of electrode system.

Contour interval: 20 ohm m.

0 500 1 Km

Base map: Geodætisk Institut M 3327 and M 3328. Surveyed 8. May–25. June 1962 and compiled by G. LATMIRAL, Traced by M. HETTING

maximum electrode spacing were determined at some of the vertical measurements. The differences between the two values obtained were generally small. This means that the zero-potential point of the Wenner configuration was about coincident with its center.

Interpretation

It seams reasonable to interprete the resistivity map as follows: The general westward decrease of the apparent resistivity values may be

PLATE 1.-VERTICAL MEASUREMENTS

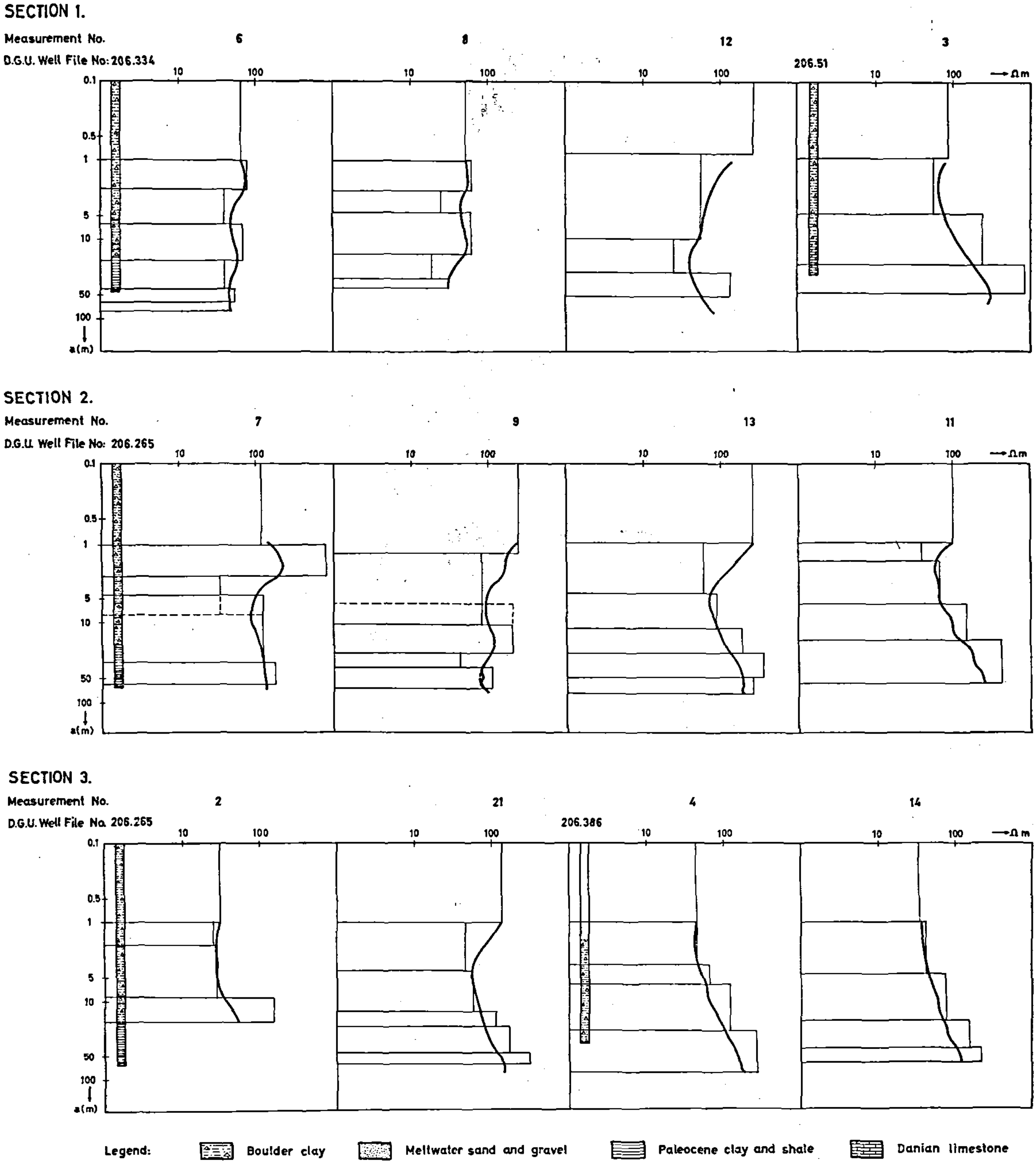
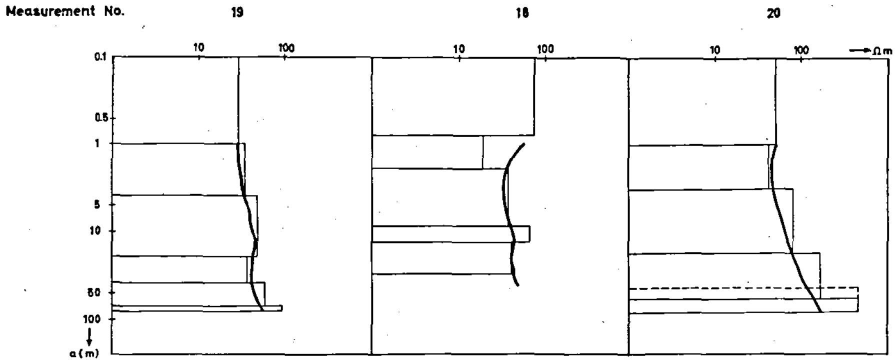
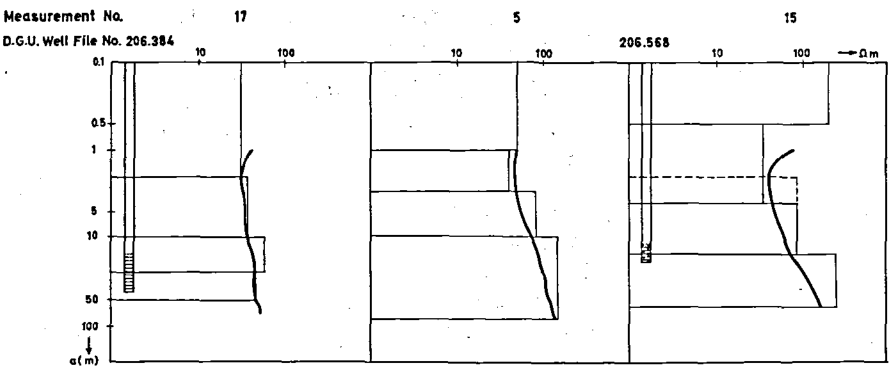


PLATE 2.-VERTICAL MEASUREMENTS

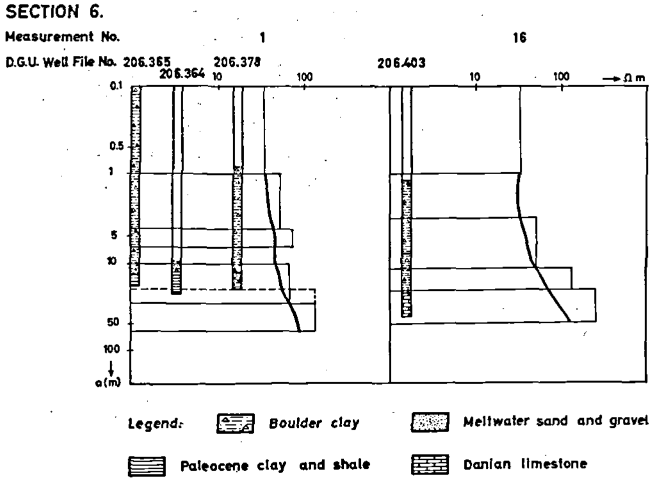
SECTION 4.



SECTION 5.



SECTION 6.



related to increase of clay material in the depth interval covered by the measurements. This assumption is reasonable due to the regional westward dip of the Danian limestone and the corresponding increase in thickness of the more or less argillaceous deposits of the Paleocene and the Quaternary.

The 300 Ohm.m maximum at Allehöj Gd may cheafly be explained by the high resistivity of the shallow limestone, which lies above the ground water table, and by the negligible thickness of the overlying clay deposits.

The areas with resistivity values between 100 and 160 Ohm.m in the eastern and south-eastern part of the surveyed area may also be related to relatively shallow limestone. However, in this area the limestone is undoubtedly below ground water table (at about 20 m depth). Coarse grained glacial drift may, moreover, partly be responsible for the high resistivity values.

D.G.U. well no. 206.386 with significant sand and gravel beds is situated at a resistivity maximum. This maximum is therefore interpreted as an indication of coarse grained, non-argillaceous deposits, probably melt-water sand and gravel, in the glacial drift. The coincidence of the maximum and the tunnel valley is a further support to this suggestion. The Danian limestone is found at about 30 to 40 m depth in this area and could, therefore, not contribute essentially to the resistivity maximum.

The low resistivity values of the south-western area suggest mainly clay in the measured depth interval. This is in agreement with the deep lying Danian limestone. Similarly, the minimum near Raanæs Gd is interpreted as due to argillaceous Quaternary (see vertical measurement no. 12) and rather deep Danian limestone.

Owing to its intermediate true resistivity (see below), the Paleocene beds do not give rise to significant features on the resistivity map.

The resistivity map does not suggest any important salt water occurrence.

Going on to the vertical measurements, the "sections" described in the previous paragraph suggest as a whole a high resistivity bedrock lying near the surface in the eastern part of the investigated area, and becoming deeper westwards, so that its influence on the vertical measurements is progressively replaced in the same direction by that of the superposed formations. The "high resistivity" formation has been interpreted as the Danian limestone. The superposed formations characterized by lower resistivities have been interpreted as Paleocene beds and glacial drift deposits, as shown on table 1.

According to the descriptions in the D.G.U. file (see paragraph on "Subsurface geology and hydrology"), the Paleocene beds may occasionally have been mistaken for Quaternary clay and sand. The boundaries between the Paleocene and the Quaternary and between the Paleocene and the Danian deposits are generally difficult to draw on the basis of the resistivity curves. Top and bottom of the Paleocene have been suggested only if the measuring point was close to a well, which made the interpretation more certain. In such cases the resistivity range of the Paleocene is from 30 and 60 Ohm.m.

Several vertical measurements located in the central part of the area (between Snoldelev, Snoldelev Hastrup and Havdrup) show high resistivity materials lying near the surface. These measurements are generally situated in the resistivity maximum around D.G.U. well no. 206.386. The shallow high resistivity material in this region has accordingly been interpretd as sand and gravel. The vertical measurements situated west of the 100 Ohm.m contour of the resistivity map showing low values at shallow depth have been interpreted as indicating mainly clay deposits of the Quaternary, which is in accordance with the well data.

True resistivity ranges of the various formations in the surveyed area have been approximately calculated on the basis of the data of table 1. The results are shown on table 2. It must, however, be emphasized that these ranges comprise layers lying both below and above the ground water table.

Geohydrologic conclusions.

The suggested sands and gravels in the central part of the surveyed area are considered a rather important geo-hydrologic feature. The logs of the D.G.U. wells 206.386 and 206.337 indicate that the coarse deposits may generally lie below ground water table, which means that they may act as good aquifers. The ground water table is only a few meters below surface in the area concerned.

In the south-eastern part of the investigated area (south and south-east of Gl. Havdrup) the Danian limestone, generally water-bearing, lies about 15 m below surface, i.e. below the ground water table. The limestone is accordingly a potential aquifer in this area.

The permeability of the Paleocene beds is supposed to be rather variable. The indurated Paleocene may occasionally be water-bearing.

Some vertical measurements show rather low resistivities in the deeper part of the measured interval (e.g. vertical measurements nos. 3–6–19). This may be due to salt water at depth. However, the salt concentration may not be very high.

ACKNOWLEDGEMENTS

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State Geologist OLE BERTHELSEN, Ph.D., generously permitted the writer to borrow a set of geo-resistivity equipment from the Danish Geological Survey for the field work and to prepare his report at the office of the Survey.

To the Water Supply of Copenhagen which provided data on the hydrology of the area the writer also owes a debt of gratitude.

TABLE 1

Physical and geological interpretation of the vertical measurements

(P = Paleocene; D = Danian; w.t. = ground water table; x = interpretation uncertain)

No.	Depth intervals (m. below surface)	Resistivities (Ohm.m)	Geological interpretation	m. below surface
1.	0 – 1	34	clay	
	1 – 4.2	53.5	clay	
	4.2 – 6.7	72.5	sandy clay (above w.t.)	
	6.7 – 11	46	clay	
	11 – 29(19)	69	sandy clay and P(?)	
	29(19) – 60	13.5	D	
2.	0 – 1	31	clay	
	1 – 1.9	24.4	clay	
	1.9 – 8.8	28	clay	
	8.8 – 18	159 (x)	sand and gravel (partly below w.t.)	w.t. abt. 13
3.	0 – 0.9	86	soil	
	0.9 – 4.4	57.6	clay	
	4.4 19	240	D	
	19 – abt.45	823 (?)	D	
	abt.45 – ?	fall	D with salt water (?)	
4.	0 – 1	44	clay	
	1 – 3.4	45	clay	
	3.4 – 6	66	sandy clay	
	6 – 23	121	sand and gravel (partly below w.t.)	
	23 – 80	270 (average) (x)	?	
5.	0 – 1	50	clay	
	1 – 2.9	41	clay	
	2.9 – 9.2	82	clayey sand (above w.t.)	
	9.2 – 80	151 (average) (x)	gravel above D (?)	w.t. abt. 12
6.	0 – 1	65	sandy clay	
	1 – 2.3	79.3	sandy clay	
	2.3 – 6.4	40	clay	
	6.4 – 18.6	70.5	sand (partly below w.t.)	
	18.6 – 41.5	40.2	P	
	41.5 – 62	57.3	D with salt water (?)	
	62 – 80	50 (x)	D with salt water (?)	
7.	0 – 1.1	115	sand	
	1.1 – 2.6	795 (?)	gravel above w.t. (?)	
	2.6 – 4.5(8)	33	clay	
	4.5(8) – 32	121	sand and gravel (?)	
	32 – 60	165	D (?)	
8.	0 – 1	52	clay	
	1 – 2.4	63.5	sandy clay	
	2.4 – 4.5	24.9 (x)	clay	
	4.5 – 15	63	sandy clay	
	15 30	18.5	clay	
	30 – 40	32	P	

No.	Depth intervals (m. below surface)	Resistivities (Ohm.m)	Geological interpretation	m. below surface
9.	0 – 1.4	250	gravel (above w.t.)	
	1.4 – 11(6)	82.5	clayey sand	
	11(6) – 25	209	gravel (partly above w.t.)	w.t.abt. 18
	25 – 38	43	P	
	38 – abt.60	114 (x)	D	
	abt.60 – ?	increase	D	
11.	0 – 1	100	soil	
	1 – 1.7	40	clay	
	1.7 – 6	67	sandy clay	
	6 – 17	150	sand and gravel (above w.t.)	
	17 – 60	420 (average)	D	w.t.abt. 25
12.	0 – 0.8	270	gravel (above w.t.)	
	0.8 – 9.4	56	clay	
	9.4 – 25	25.4	clay	
	25 – abt.50	128	D	
	abt.50 – ?	increase	D	
13.	0 – 1	260	soil	
	1 – 4.4	59.5	clay	
	4.4 – 12	88	clayey sand (above w.t.)	
	12 – 25	191	gravel (partly below w.t.)	
	25 – 50	346	D	
	50 – 80	262	D	
14.	0 – 1	34	clay	
	1 – 4.5	41.5	clay	
	4.5 – 17.5	74.5	clayey sand	
	17.5 – 39	144	gravel (below w.t.)	
	39 – 60	207	D (top of D abt. 25)	
15.	0 – 0.5	200	soil	
	0.5 – 4(2)	35.1	clay	
	4(2) – 15	86	sand (partly below w.t.)	
	15 – 60	265 (average) (x)	D	
16.	0 – 1	33	clay	
	1 – 3.2	32	clay	
	3.2 – 12	49.5	clay	
	12 – 21	133	sand and gravel (partly below w.t.)	
	21 – 50	244	D	
17.	0 – 2	31	clay	
	2 – 9.6	37.8	clay	
	9.6 – 24	59.3	P	
	24 – abt.50	47	D	w.t.abt. 24
	abt.50 – ?	increase	D	

TABLE 1 (continued)

No.	Depth intervals (m. below surface)	Resistivities (Ohm.m)	Geological interpretation	m. below surface
18.	0 – 0.8	75	soil	
	0.8 – 1.9	18.8	clay	
	1.9 – 8.6	37.8	clay	
	8.6 – 13	67	sandy clay (above w.t.)	
	13 – abt.30	43	clay	
	abt.30 – ?	increase	?	
19.	0 – 1	29	clay	
	1 – 3.9	35.4	clay	
	3.9 – 19	49.5	clay	
	19 – 38	36.9	clay or P(?)	w.t.abt.20
	38 – 70	60	P	
	70 – 80	96	D (with salt water?)	
20.	0 – 1	51	clay	
	1 – 3.2	41.7	clay	
	3.2 – 17	80	sand (partly below w.t.)	
	17 – 56(42)	163	gravel (?)	
	56(42) – 80	460	D	
21.	0 – 1	135	soil	
	1 – 4	46.3	clay	
	4 – 13	68.4	sandy clay	
	13 – 20	115	sand and gravel (partly below w.t.)	
	20 – 43	170	gravel (?)	
	43 – abt.60	315 (x)	D	
	abt.60 – ?	abt. 145	D	

TABLE 2

Effective resistivities (approximately)

		(Ohm.m)	
Quaternary (glacial drift)	clay	18– 55	
	sand and gravel	70–210(?)	(the upper limit is very uncertain)
Paleocene shales		30– 60	(resistivity range include only some of the vertical measurements)
Danian limestone		135–460	(sometimes the resistivity may be lower than 135 Ohm.m, probably due to salt water in the deeper parts of the limestone)

Færdig fra trykkeriet den 17. oktober 1963.

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