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SURVEYING THE NETHERLANDS: SAMPLING TECHNIQUES, MAPS AND THEIR APPLICATION[1]

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ABSTRACT

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In 1953, under J. D. de Jong's supervision, a new mapping programme was started to meet the expected demand for more detailed information. At that time, the only available method of collecting data was based on rather simple hand-operated sampling equipment. Technical developments as well as the demand for more detail information led to the application of improved sampling techniques and geophysical methods. More information is now presented on the maps whereas other types of maps, such as the offshore geological maps, have been added to the programme.

As expected, the demand for geological information today is great. The present article reviews the surveying methods applied by the Survey and the maps which are in preparation. Some case histories are given to illustrate the application of the results of the mapping programme.

INTRODUCTION

Around 1950 the decision was made to undertake a new geological survey of The Netherlands and to publish a series of maps, embodying the results, on a scale of 1:50 000. The Geological Foundation, predecessor of the present Geological Survey, appointed Dr. J. D. de Jong to supervise the project, which required a considerable expansion of the staff and additional assistants. Under De Jong's direction mapping was started, a legend and mapping system was developed for the lagoonal-marine and peri-marine Holocene areas as well as for the Pleistocene areas of the country, and preliminary sheets were prepared (DE JONG & HAGEMAN, 1960; DE JONG ET AL., 1960; GEOL. STICHTING, 1962; HAGEMAN, 1963a, b). The first official map was published (GEOL. STICHTING, 1964), shortly after De Jong left the Geological Foundation in 1962.

This new mapping programme was considered necessary because the increased demand for gravel, sand and clay, the country's rapid industrialization, and the concurrent development of an infrastructure were expected to create a need for more detailed information. Although surveying or mapping of a country generally means a long-term project, only a thorough investigation can provide sufficient information about the geological outline to permit adequate consultancy services. Systematic mapping that is not based on short-term economic interests yields basic information, which can be used to give any geologic advice in a relatively short period of time with rather limited additional fieldwork to be done.

Time has justified this approach. The data and knowledge collected have proved to be directly applicable in even more fields than anticipated. For instance, the selection of sites for the emplacement of explosives for seismic prospecting in the water-rich lower part of The Netherlands can be made in such a way that no damage is done. Another example is information about the migration velocity of pollutants through the superficial layers, down to the first aquifer, since this velocity is related to the lithological properties of the overlying beds. Relatively recently the increase in not only the scale of civil-engineering structures, but also the amounts of surficial materials like sand and gravel required and problems with respect to water management have made it imperative to collect data from greater depths as well. Gradually a general surveying of the deeper lying strata, was added to the systematic mapping, which meant a substantial expansion of the programme. This

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development was a direct response to the increased demand for information.

Practical questions – with their limited objectives – tend by nature to be more pressing than general demands for systematic investigation. Since the same personnel and equipment perform both consultancy and systematic mapping and the former tends to be given precedence, attention to the latter tends to shrink. To keep the information up to date, a certain rate of systematic mapping has to be sustained. Strict planning schedules must be applied to safeguard the mapping programme.

In the 1960s exploration for oil and gas in the offshore zone and harbour improvement to permit entry of the larger oil tankers implied a demand for offshore data on sub-bottom conditions for the emplacement of drilling rigs and for dredging purposes, respectively. These offshore activities too created a need for reliable geological data. Consequently an offshore mapping programma was considered equally necessary. Moreover, systematic geomorphologic mapping has been undertaken to facilitate the geological and soil investigations. In co-operation with the Soil Survey Institute, these maps are being prepared on a scale of 1:50 000.

To the present Survey staff, De Jong is still known as the former head of the Mapping Department and the man who started the project we are continuing. The scope of the mapping programme has changed and the surveying techniques have undergone a rapid evolution. Our understanding of geological processes has greatly increased, and this has lead to a better interpretation of the data, which is reflected in the new maps with explanation. The introduction of the use of computers in our work enables us to produce special maps and sections in a short time. It seemed worthwhile to review current surveying techniques and mapping activities. Two case histories are presented here to illustrate the general benefits of the systematic approach, which provides basic knowledge for later application.

SURVEYING TECHNIQUES

The first geological maps and sections of the new 1:50 000 series were based solely upon relatively shallow borings, which could be easily performed with hand-drilling equipment or manually operated bailer drilling equipment, but the increasing demand for information pertaining to greater depths, meant a greater effort to collect the necessary data. This trend led to mechanization of all of the drilling equipment. Small motors were to assist occasionally the operation of the hand-drilling equipment, and small tractor-mounted drilling units were also used to facilitate the fieldwork. Wherever possible, the above-mentioned bailer equipment was replaced by more highly mechanized drilling equipment, partially developed within the Survey.

Some years ago SCHOLTENS (1980) reviewed the Survey's sampling equipment, providing technical data as well. More recently the (former) Ministry of Public Works and Environment had a review made of available techniques to sample and study the subsoil. In this latter study (dis)-advantages and sample quality of various drilling systems are brought together (VOMIL, 1981). The reader is also referred to SUBCOMM. SOIL SAMPL. (1981).

Besides improvement of the equipment itself and the introduction of other drilling/sampling techniques, developments in geophysics allowed the collecting, with logging equipment of valuable information about the lithological conditions in boreholes. Geophysical measurements at the surface are made to obtain useful information on the structure and composition of the subsoil. Progress in the field of micro-electronics has resulted in an increase of the sensitivity and a reduction of the weight of geophysical equipment. Both of the factors, together with the possibilities for the elaboration of geophysical data by computer, greatly expanded the usefulness of geophysical surveying techniques for the geological mapping of the soft rocks in The Netherlands. For the mapping of offshore areas, geophysical methods are on the one hand indispensable and on the other hand easier to apply. The reader is referred to DOBRIN (1976) for further information on the geophysical methods.

In more recent years, the application of remote sensing for geological mapping purposes has been investigated. The results showed that in certain areas this method can contribute to improvement of the quality of geological mapping.

The last technique to be mentioned is the soil-mechanical sounding or the Dutch cone-penetration test. The method implies the registration of the mechanical resistance as experienced by a cone, which is pushed into the subsoil. The measurements are made at regular intervals. The results of the soundings carried out as part of site investigations for civil-engineering projects appear to allow accurate lithological correlation. The latter is based on the numerical values as well as on the shape of the logs, the combination being characteristic for certain lithostratigraphic units. Series of soundings are now incorporated into all surveying programmes. The technique will not be discussed here, since methods of interpretation are no part of this paper. Reference is made to a.o. KRAJIČEK & DE LANG (1982), DEPRET (1983).

The following review concerns the capacities of the Survey in the fields of drilling, geophysics and remote sensing.

Drilling equipment

Hand-drilling equipment – Most of the data for the geological map are still being collected with hand-drilling equipment, which is easy to handle and produces high quality samples. It consists of Edelman augers (for sampling sand above the water table or clay and peat above as well as below the groundwater table), gouges (sampling of clay and peat) and Dachnowsky samplers (sampling of peat) (Fig. 1). Adapted to different types of sediment, each of those tools is available in various shapes and diameters (LAMMERS, 1965; SCHOLTENS, 1980). Recently a new and very practical tool, the Van der Staay suction corer, has been developed (VAN DE MEENE ET AL., 1979). This tool, which permits easy and rapid sampling of sandy deposits below the groundwater table to a maximum depth of 10 m, consists of two p.v.c. tubes, one fitting inside the other. The inner one functions as a suction barrel, the other as a suction tube (Fig. 2).

A special version of the gouge is equipped with a motor on top of the sampling tubes (Fig. 3). This method is especially useful in sediments that can otherwise only be sampled with great physical effort, for example boulder clay. The quality of the samples is rather good.

Mapping truck – A simple light-weight rotary drilling unit has been mounted on a tractor, whose motor operates 3 hydraulic pumps which provides the power for the various functions of the equipment. The unit can be used to make borings of the following types:
- *Auger borings,* to a maximum depth of 25 m with an ultimate diameter of 150 mm.
- *Straight-flush borings,* to a depth of about 60 m, the diameter of the hole being 65 mm. Straight-flush means fast penetration, but low quality samples.
- *Counter-flush borings,* to take disturbed samples from accurately known depth (Fig. 4). Incidentally, undisturbed samples of limited length can also be collected. A drilling depth of some 30 m can be reached. Special tubes are being used.

This equipment has been developed by the Technical Section of the Survey. At present, four of such units are operational.

Mechanized bailer drilling units – Two types of mechanized bailer drilling equipment are in use, one being heavier and slightly larger than the other. Hydraulic cylinders push the casing covering the wall of the drill hole over its entire length, into the subsoil. Through the casing the bailer or the (core) sampler is lowered to do the sampling of unconsolidated sediments (Fig. 5). The equipment can be simply adapted to perform drilling with an auger through the casing, for instance when stiff clay layers have to be penetrated. In this way the heavier (Nicoland) unit can drill holes down to 130 m and the lighter (Stihl) to 70 m.

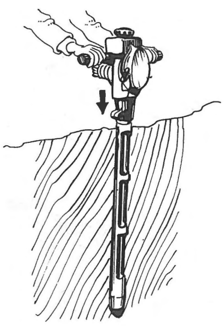


Fig. 3
The Ram gauger.

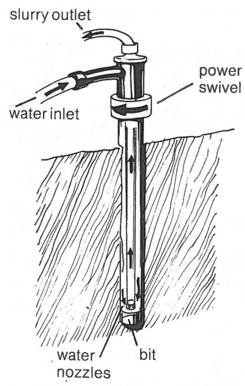


Fig. 4
The counter-flush system.

Rotary drilling units – Two rather different types of rotary equipment are used. The Longyear 24 is a light-weight drill designed for diamondcore drilling-sampling in consolidated rocks. With an AQ wire line corebarrel system (core diameter 27 mm) the unit can drill to depths of up to 200 m.

The Nordmeyer Mobil drilling rig type OS BI is a more powerful hydraulic universal rig, equipped with three pumps. This unit is suitable for dry rotary drilling and percusion drilling down to 60 m. With the use of a centrifugal pump, straight-flush drilling down to 200 m (Fig. 6) and counter-flush drilling to 60 m can be accomplished. With a piston high-pressure pump, core drillings to a depth of 200 m can be made. Reversed circulation borings (Fig. 7), made with the suction pump or airlift borings can be made to a depth of 150 m. The drilling unit, including the pumps, is mounted on a truck.

Offshore sampling equipment – For the offshore work on the North Sea shelf and the (Atlantic) Ocean, a wide range of sampling tools is available. Besides the well known *Van Veen grab sampler* (Fig. 8, disturbed samples) and *boxcorer* (Fig. 9, undisturbed samples), the latter penetrating 50 cm, used to collect samples from the surface of the seabed, the *Hamon grab sampler* (VAN OOSTRUM, 1973) is applied where the seabed consists of coarse gravelly sediments. The latter sampler is designed such that the sand fraction of this type of sediment

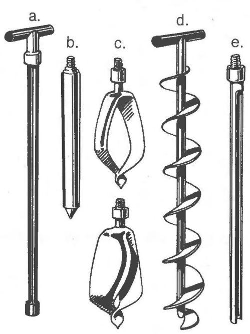


Fig. 1
Hand-drilling tools.

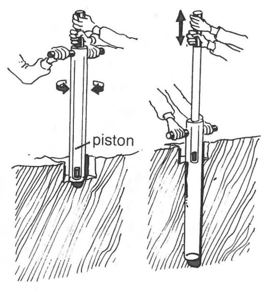


Fig. 2
Van der Staay suction corer.

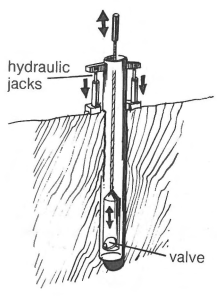


Fig. 5
Principle mechanized bailer system.

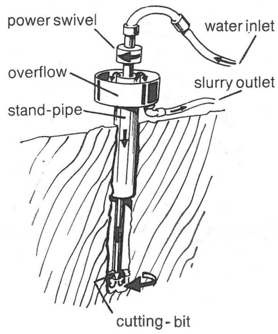


Fig. 6
Straight-flush system.

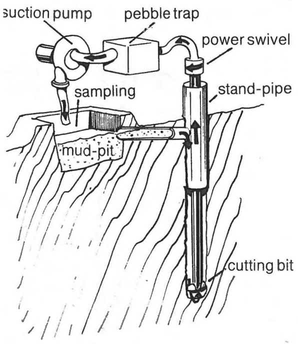


Fig. 7
Reversed-flush system.

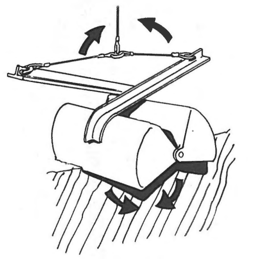


Fig. 8
Van Veen grab.

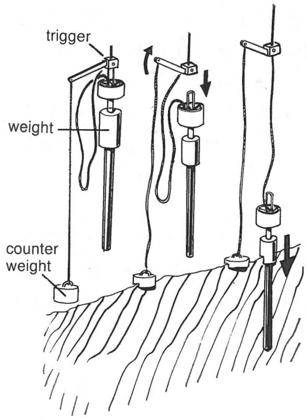


Fig. 11
Gravity- or Pistoncorer.

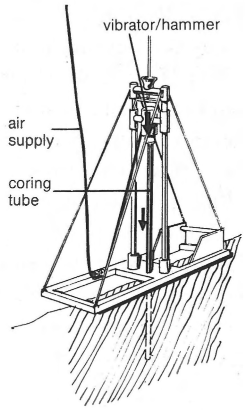


Fig. 12
Air operated vibrocorer developed by the Geological Survey of The Netherlands.

will not be washed out during the sampling operation, as is the case with the Van Veen grab sampler (Fig. 10).

The oceanic floor is sampled by the above-mentioned box-corer and the gravity- or pistoncorer (Fig. 11).

The pistoncorer consists of a 350 to 1000 kg weight on top of a sampling tube. A special device regulates free-fall movement from a certain height above the seabed. The tube penetrates into the seabed. The presence of a piston, preventing the cored material from flowing out of the tube, allows the collection of long cores, the Survey's record being 22.8 m in water 5600 m deep.

The *gravitycorer* operates without a piston, its application being restricted to shelf areas with clayey bottom sediments. Neither of these corers is suitable for sandy sediments like those in the North Sea area.

Offshore drilling equipment – Vibrocorers and *vibrohammer-corers* are available for the collection of relatively undisturbed samples (see also SCHOLTENS, 1980). A core barrel connected to the vibrator is pushed into the seabed by the vibrating force which is increased by the weight of the vibrator. The core barrel is extracted from the seabed by simply hoisting the cable connecting the vibrator head to the boat (Fig. 12). A plastic liner fitting in the core barrel is used by preference. The vibromotor can be electrically driven or operated by compressed air (vibrohammers). The Survey has corers of both types. The relatively small dimensions and light weight (1000 kg) means that the equipment can be handled on board relatively small boats. By means of a simple adaptor, core barrels ranging from 70 to 200 mm can be easily interchanged.

The Geodoff I and *mk II* are drilling units to be emplaced on the seabed developed by the Technical Section of the Survey in cooperation with Conrad Stork. The main differences between them are the higher installed power in the mk II, which can also take wider core barrels (up to 200 mm instead of to 80 mm). The principal difference between the Geodoffs and the vibrocorer is the linking of the vibrator to the core barrel (Fig. 13). For the vibrocorers this is a rigid connection, whereas the vibrator of the Geodoff, which has a hollow shaft and a clamping device, can slide freely along the core barrel or be made stationary. Clamped to the core barrel, the vibrator pushes the core barrel one or two metres down into the seabed; then the vibrator is released and moved upward, sliding along the core barrel, and then again clamped to the

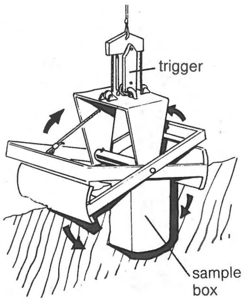


Fig. 9
Boxcorer.

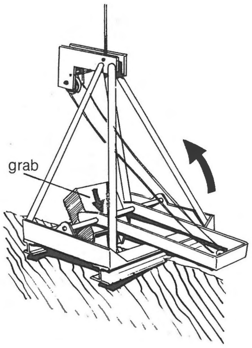


Fig. 10
Hamon grab.

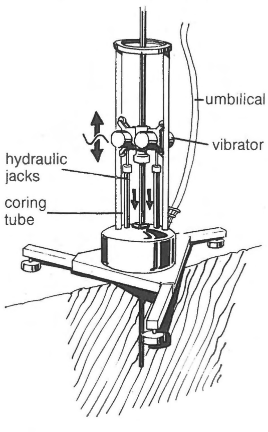


Fig. 13
Geodoff MK II remote controlled vibrocorer.

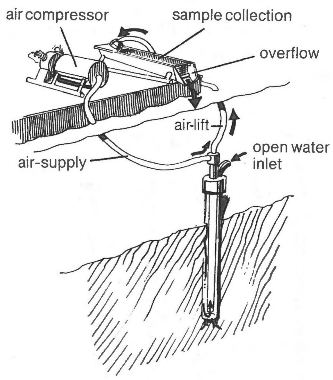


Fig. 14
Airlift counter-flush subsea system.

barrel and lowered again. In this way the core barrel is brought down in stages. This system has two great advantages: in principle an endless barrel can be used, and the reversability allows the unit itself to remove the barrel from the seabed. Designed for penetrating unconsolidated sediments at a maximum water depth of 200 m, the Geodoffs can take undisturbed samples up to 7 m in length when used as vibrocorers. It is also possible, however, to make borings under these conditions with an airlift counter-flush drilling system (Fig. 14). The samples collected in this way are disturbed, but penetration to a depth of 12 m below the seabed in unconsolidated sediments can be guaranteed. Although the sample is disturbed, the original location of the material in the drillhole can be determined with an accuracy of 20 cm or less.

Geophysical methods

Well logging methods – Geophysical measurements made in boreholes provide a detailed picture of the penetrated formations where such measurements are available there is less need of good rock samples, which means that the borings can be executed at a much higher speed. The Survey uses a Mount Sopris series III logging system, with which logs can be made to a depth of 1000 m. After a hole has been drilled, usually one or more of the wireline logging tools are run. These devices are used to measure the electrical, radioactive, or acoustic properties of the formation. Temperature, fluid resistivity, and caliper logs can also be measured.

Electric logs can be run with different types of logging devices. At present, the following logs are available: spontaneous potential single point resistance, and six resistivity curves, i.e., the Normal (two electrodes) with a spacing of 20, 40, 100, and 160 cm and the Lateral (three electrodes) at 110 and 180 cm. Electric logs are extremely useful for the determination of lithological features, porosity and the groundwater composition. Moreover, the resistivity logs provide very valuable data for the interpretation of geoelectric measurements made on the surface.

The natural gamma log serves primarily to determine the lithological picture. It is very sensitive for some specific minerals, such as glauconite or clay minerals, and is also useful for the detection of radioactive pollution of groundwater.

The acoustic velocity log is a good tool for the estimation of porosity and elastic properties. This device measures the acoustic velocity of a sound wave travelling through formations and the intensity of the signal picked up by the receivers. It is also possible to record the full sonic wave train. The sonic log is an aid in the interpretation of seismic data.

The temperature log measures the temperature in the hole and provides information about the geothermal gradient. Small variations in this gradient occur with depth because of differences in thermal conductivity. These differences often correspond with lithological variations.

The caliper log measures the size of the borehole. Two probes are available, i.e., for diameters up to 25 and 75 cm.

Caliper and *fluid-resistivity logs* are important aids in the interpretation of the other logs. A combination of several logs permits better interpretation and therefore gives better information about the sequence under study. Different combinations of logs can be run at the same time. The results of the measurements are displayed continuously as a function of depth on a 4-channel tracing and stored digitally on a cassette tape as well.

Software has been developed to elaborate the digital data with an HP 9845 B desk-top computer, after which the logs can be plotted on any scale.

Surface prospecting methods

The geophysical techniques employed at present include the galvanic-resistivity, electromagnetic and seismic methods. The electrical methods are only used on land, seismic methods are used both on land and offshore.

Galvanic-resistivity method – A wide variety of electrodes patterns have been used to measure earth resistivities. The Wenner array is the one most frequently employed by the Survey. In this array, four electrodes are equally spaced along a straight line. The distance between any two adjacent electrodes is called the array spacing a. According to this system, a current (I) is applied to the outer pair of electrodes and the potential (V) established in the ground by this current is measured with the inner pair of electrodes. The quotient of V/I multiplied by $2\varrho a$ gives an apparent resistivity of the sediments.

Apparent resistivities can be measured in two ways, i.e., with a fixed distance or with a gradually increasing separation between the various electrodes. With a fixed separation we measure apparent resistivities along traverse line or on a grid. Results are worked out as resistivity profiles and contour maps, which provide information about lateral variations of geological phenomena. We use an increasing separation of electrodes, with a fixed midpoint of the array, to study variations in resistivity with increasing depth, for example in a layered medium. With larger spacings the effect of the deeper layers on the measurements becomes more pronounced. This type of measurement is called an electrical sounding (ES) or resistivity sounding. Software has been developed for the elaboration and interpretation of resistivity data with an HP B desk-top computer.

The Survey possesses portable equipment in a range permitting measurements to a depth of 300 m and under favourable conditions to 1000 m. Special equipment has been developed to run resistivity surveys from the surface of water by means of multiwired floating cables carrying (21-26) electrodes which are towed behind a vessel to record apparent resistivities continuously.

The equipment is portable and can also be used on land, the operator walking and towing a small 4-conductor cable through water-filled ditches.

Electromagnetic methods – Electromagnetic methods can be used to detect anomalies of the inductive properties of the subsoil. The Survey has two kinds of portable equipment in use, the EM-31 and the EM-34. These instruments work on the principle of electromagnetic induction. A time-varying magnetic field arising from an alternating current in a transmitter coil, induces very small currents in the earth layers. These currents in turn generate a secondary magnetic field which is sensed by the receiver coil. It may be assumed that at any given point the induced currents are linearly proportional to the magnetic field strength and the conductivity. The instruments give a direct reading of these conductivities in millimhos per metre. For uniformity, all conductivities are converted into resistivities.

The EM-31 works with a fixed intercoil spacing of 3.66 m, and the effective depth of penetration is approximately 6 m. The EM-34 works with three intercoil spacings: 10, 20, and 40 m. The maximum effective depth of penetration is approximately 30 m, and unter favourable conditions can reach 60 m. Both instruments are used mainly to map the lateral distribution of lithological phenomena. The advantage of electromagnetic methods is that contact with the earth is not necessary, which makes the conditions of the terrestrial surface become less important.

Seismic methods

Seismic land equipment – At the Survey, a 12-channel Nimbus signal enhancement seismograph is in use. This system is suitable for both reflection and refraction studies. Signal enhancement is used to add the signal of each impact to the previous signals, the sum being stored in a memory. Because seismic noise is random, it is cancelled or limited by repeated signals. Low-pass, band-pass, high-pass, or band-reject filters are selectable for each channel, and a 50 or 60 Hz notch filter is available for elimination of power-line interference. The signal stored in the memory is displayed on the built-in CRT monitor, and a paper record can be made from the signal displayed by a built-in oscillograph. The data stored in the memory can be put on tape by a digital tape recorder, which can also play back information into the seismograph memory for verification or later analysis. Software is in development for an HP 9854 B to elaborate the digital data. The seismic waves can be generated by means of a hammer or a dropped weight. Other sources such as an airgun or dinasource can also be applied. An example of the recording is given on figure 15.

Offshore geophysical equipment

Offshore geophysical methods make use of acoustic signals generated by one or two sources. Due to the acoustic impedancy between seawater and bottom sediments, a large part of the downward-directed signal is reflected and received by one or more hydrophones, the smaller part penetrating into the seabed. The penetration and the resolution are dependent on the main frequency of the signal, the low frequencies penetrate deeper than the high ones and the high frequencies give a better resolution than the lower ones. Theoretically speaking, the resolution is about a quarter of the main wavelength, in practice the penetration and resolution depend heavily on the noise level. The acoustic source is triggered to give the signal at regular intervals lasting between one and ten seconds, depending on the requirements.

Sources – The following sources are used:

1) *Sparker.* A sparker is an elongated frame, triangular in cross-section profile, and containing several electrodes. The Survey possesses a 3-elements and a 9-elements sparker. The energy source of the sparker is a series of condensers which are loaded by a high-voltage source. When triggered, the condensers release a burst of electric current of many kilovolts to the sparker. The electrons travel from the electrodes through the seawater to the frame in the same way as lightning in the sky. The cause of the acoustic signal is also comparable to that of thunder.

The frequency band ranges from about 100 Hz to 1 kHz, implying a wide variation in penetration (max. 1 sec.) and resolution.

2) *Boomer.* The boomer too, has condensers and a high voltage source as an energy source. The electric-current

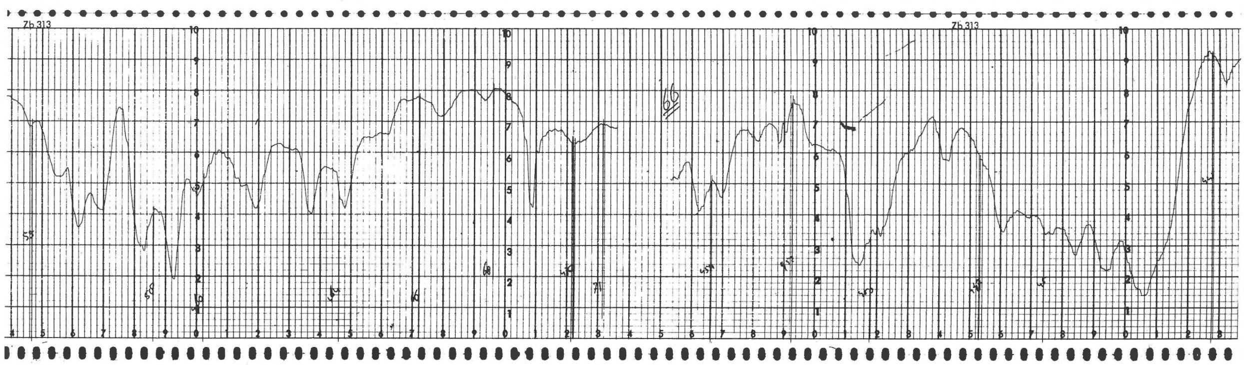


Fig. 15
Example of a field record of a continuously measured resistivity profile (Wenner configuration, a = 20 m).

bursts cause one of two just opposed plates to move suddenly away from the other, which, when repeated, produces a pulse-like signal. The Survey has two boomers differing as to tow depth.

(a) *Catamaran boomer.* The boomer plates lie about a foot below the surface, which means that wave motion can be troublesome.

(b) *Subtow boomer.* This boomer is shaped like a fish and is towed at a depth between a few and approximately 15 m.

The frequency band of the boomer is around several kHz giving a moderate to low penetration (generally not deeper than the first sea bottom multiple) or a resolution down to a few cm.

3) *Watergun.* The watergun produces a signal that radiates in all directions. In this device, an underwater chamber is kept filled with air when a trigger cuts off the air supply briefly, the air escapes and water rushes into the void. This process produces a pulse-like signal. The watergun is therefore an implosive source.

4) *Airgun.* The airgun too uses air, but the trigger opens a chamber kept under high pressure. The air rushes outwards, thus producing a pulsating bubble which is nuisance for the interpreter. The airgun is an explosive source. The resolution of the airgun is, due to bubble oscillations only a few metres while the watergun resolves about one meter. The penetration is in both cases about two seconds.

5) *3.5 kHz Transducer.* This transducer is used in ocean-bottom surveys to assess the upper 100 m, the resolution being about 15 cm.

All of these devices are owned by the Survey except the airgun and 3.5 kHz transducer which can be borrowed from other institutions when required.

Hydrophones – Towed behind the source they lie in series inside a kind of garden hose filled with oil for buoyancy. Such a hose with hydrophones is called a streamer. Since acoustic signals travelling through water form a pressure wave, each hydrophone must convert a pressure signal into an electrical one. All electric signals are added up in the streamer and arrive abord as one signal. The Survey has at its disposal several streamers of various lengths and with different frequency characteristics.

The last phase of the procedure concerns *processing.* Before being graphically recorded, the signal arriving from the streamers is always frequency-filtered, which means that on its way to the recorder the signal passes through a band of frequencies, those not belonging to this spectrum being rejected. This filtration is necessary to remove as much noise as possible without serious loss of useful information.

The signal may also be passed through a TGV and a Swell filter. The TVG is a time varied gain and compensates for the increasing reduction of signals strength. The Swell filter removes the effect of swell on the graphic record, on which the filtered signals are visualized.

The unfiltered signal is usually recorded analogously on magnetic tape. The tape recording can be used to make another picture with – for instance – a different frequency filtering. At present, the signal can be recorded digitally on tape as well, and with a computer the digitized signal can be modified by digital filters, which can be used to shape the signal appropriately. Figure 16 shows the recording of the seabed by a sparker.

Remote-sensing methods

Besides normal black and white aerial photographs, red and infrared images taken with two synchronized photogrammetric cameras with sufficient overlap are used to support the geologic mapping. On these pictures, the photo interpreter delimits areas with different characteristics that may reflect different geological conditions in the subsoil.

To avoid the negative influence of presence of a vegetation cover on the quality of the picture, the surveying is done in the period between January and March.

Surface reflectivity – The interpretation is based on tonal differences. These differences on the red-band images correspond with differences in the surface reflectivity, which is determined by certain characteristics of the topsoil. The determining factors are moisture content and the content and composition (i.e., texture and structure) of the organic matter. Laboratory analysis has confirmed that the topsoil characteristics vary according to changes in the composition of the underlying material. The moisture content has a strong influence on the degree of reflection. High moisture levels lead to decreased reflectivity, which results in darker tones. The moisture content itself depends on the permeability of the underlying material, the depth of the groundwater table, and capillary rise.

The organic-matter content plays a dominant role if its percentage exceeds 2. An increase of this content too leads to a lower reflectivity. From measurements on a number of undisturbed soil samples it is known that sediments with a sandy composition have a higher reflectivity than the fine grained sediments do. This is contrary to what one would expect, because laboratory analyses have also shown that fine-grained sediments generally have textures with the characteristics of aggregates coarser than sand. Final differences on the infrared images are due mainly to differences in moisture content.

The relationship between reflectivity and the texture of the surface bed was analysed in several places including an area near Losser. The results are shown in Table I.

Terrain parameters are also taken into consideration in the interpretation of the images. These parameters comprise the morphology and elements of the biosphere in question. Morphological changes can be indicative of geologic changes. Land use (for crops, pasturage, forest, etc.) too may provide additional information about the soil and underlying materials. Remote-sensing images and their interpretation contri-

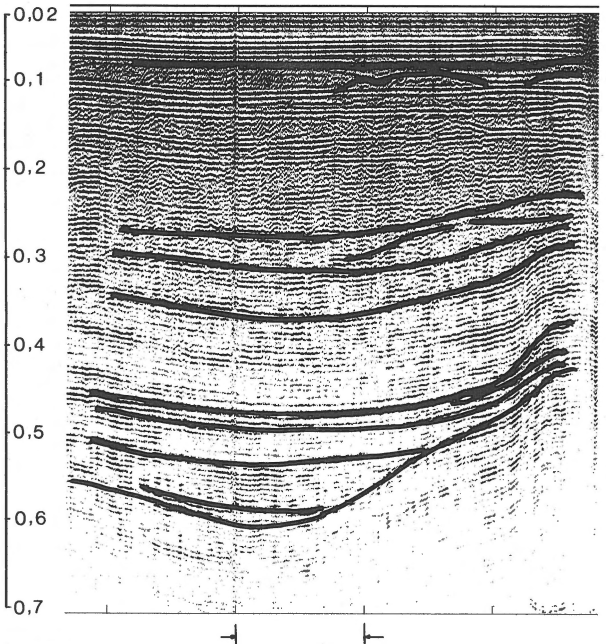


Fig. 16
Example of a seismic record. The record is the output of digitally recorded data. Primary reflections are emphasized by bold lines. Note that every reflection has at least two clearly visible multiples. Vert. scale: two-way travel time in seconds. Hor. scale: distances in nautical miles.

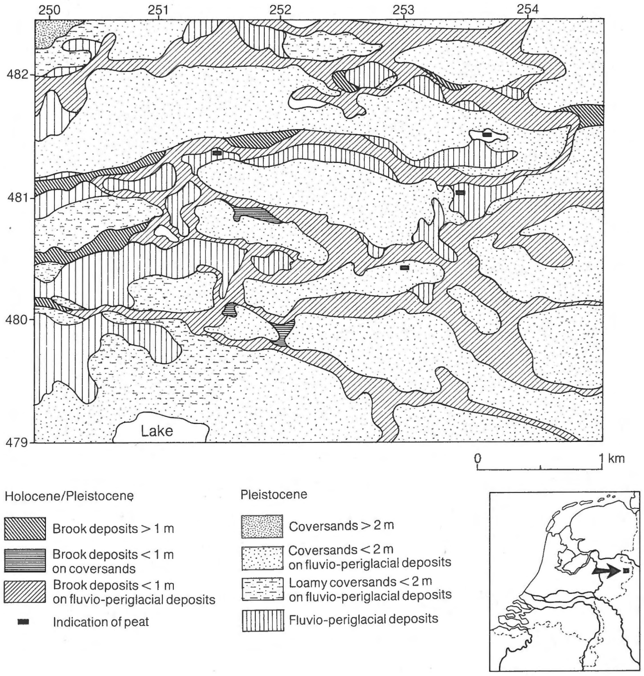


Fig. 17
Geological map of area at Losser, based on remote-sensing data and a field check.

bute to increased accuracy. Figure 17 shows a geological map based on the interpretation of remote-sensing studies and a number of field checks.

GENERAL MAPS

The geological survey of The Netherlands now in progress is the third of its kind (Table II). In the last century the first geological survey was carried out by Staring, – W. C. H. Staring (1808-1877): 'father of the Dutch geology' – who published a map series on the scale 1:200 000 between 1858 and 1867. After its establishment in 1918, the Geological Survey – which between 1938 and 1968 was a Foundation – started a second survey, which took about 25 years; the 1:50 000 sheets were edited between 1925 and 1952. Staring's map was based almost solely on data from outcrops and on surface features. The second or Tesch map series – P. Tesch (1879-1961): first director of the Survey – contained much more information, because of the larger scale and since a system of borings to a depth of 2 m had provided additional basic data. The present survey is collecting data from much more and deeper boreholes. Old, new and planned general geological maps of The Netherlands and the Dutch North Sea sector are listed in Table II. Most of these maps have been designed by, or in co-operation with, the Geological Survey or the related Geological Foundation. In Staring's time, neither of these institutes existed, but he was assigned by the government to make map 2 (Table II). In many ways he was the precursor to the Survey. Map 12 was prepared by J. B. Hol without participation of the Survey, with an influence through the Tesch map.

The Survey's completed and planned general maps are discussed below. Many other kinds of map showing the geology of a certain area or giving thematic information have also been published.

Table I
Topsoil characteristics in the Losser area.

underlying deposits	moisture content %	organic mat. content %	fine & coarse sand %	clay & silt %
Coversand	12	4.75	88.58	11.42
Boulderclay	25	7.00	35.57	64.43

New and planned Survey maps

New Geological Map 1:50 000 (Table II:8) – Each of the new map sheets on a scale of 1:50 000 form a set with explanatory notes. Besides the main geologic map, there are subsidiary maps, mostly on a smaller scale. The latter deal with various subjects such as the thickness of the Holocene strata or distribution of certain beds. Generally, cross-sections are given as well, detailed sections to a depth of some 2-10 m and others of a more general nature to a depth of 50-100 m.

The explanatory notes provide comprehensive information on stratigraphy/lithology, laboratory analyses, hydrogeology, and mineral resources.

Table II
Old, new and near-future general geological maps of The Netherlands and the Dutch North Sea sector (updated until 31-12-82).

Reference number for this paper	Publication dates	Informal designation and scale		Number of planned sheets	Number of mapped sheets: e.g., 17 in print (+11) on file	Adjoining sections	Adjoining subsidiary maps	Adjoining articles etc.
GEOLOGICAL ONSHORE MAPS								
	1st survey							
1	1844	Staring provisional geol. map	1:800 000	1	1	–	–	–
2	1858-1867	Staring geological map	1:200 000	20	20	–	+	–
	2nd survey							
3	1925-1952	Tesch geological map	1:50 000	189	173	++	–	+
4	1936-1954	Generalized Tesch geol. map	1:200 000	19	19	–	–	++
5	1937	Generalized Tesch geol. map	1:800 000	1	1	–	–	+
6	1947	Generalized Tesch geol. map	1:600 000	1	1	–	–	+
7	1951	Modified Tesch geol. map	1:500 000	1	1	–	–	+
	3rd survey							
8	1964-	New geological map	1:50 000	86	17 (+11)	++	++	++
9	1975	New geological map	1:600 000	1	1	+	++	++
9[1]	1979	Enlarged new 600 000 map	1:200 000	Exhibition-map, not to be published				
10	1973-	German new geol. map	1:200 000	Dutch border sheets:				
				4	1 (+1)	+	–	–
11	1986-	New geological map	1:250 000	5	0	++	+	+
GEOMORPHOLOGICAL MAPS								
12	1951	Provisional geomorphol. map	1:500 000	1	1	–	–	+
13	1974	Geomorphological map	1:600 000	1	1	–	–	+
14	1975-	Geomorphological map	1:50 000	49	12 (+2)	–	–	+
GEOLOGICAL OFFSHORE MAPS								
15	1969-1971	Dutch North Sea geol. map	1:500 000	2	2	+	–	+
16	1984-	Dutch North Sea geol. map	1:250 000	11	(1)	++	++	+
17	1987-	Dutch North Sea geol. map	1:100 000	Planned longshore sheets:				
				17	0	++	++	+

legend: – missing none
\+ restricted, one to a few
++ comprehensive, some to many

The main geological map is based almost completely on investigations performed with hand-drilling equipment. Generally, 10 borings/square km are made, the depth ranging from 2 to 5 m in Pleistocene areas and often from 6 to 10 m in Holocene areas. Additional information is collected with the instruments carried by the 'mapping truck'. As already mentioned, geophysical methods and aerial photographs are used to define certain map boundaries.

The deeper sections and some of the subsidiary maps are based on data from other mechanized borings to greater depths and geophysical information. In this connection it is of interest that the Survey shares with the National Water-supply Institute an archive of borehole descriptions. This archive contains descriptions of many of the boreholes drilled in The Netherlands, the most for groundwater surveying. Furthermore, samples of many of these borings have been given to the Survey. Additional information is collected by the Survey's drilling units and geophysical group.

The mapping is based on the analysis and representation of stratigraphic and genetic units, lithological descriptions of these units too generally being given in the legend accompanying the map. In relation to the geological history, six areas differing in geologic nature are distinguished, each of them requiring a somewhat different approach (Fig. 19). For each of the areas, legend and mapping systems were developed. In many cases, surface data and those of deeper levels are combined on the map; for instance, a sequence of three special units in the lagoonal marine area is expressed by a specific code and colour.

Since the description of the stratigraphy of The Netherlands is in part based on sedimentary petrologic and palynologic analyses, the mapping results are supplemented by laboratory investigation of samples.

New Geological Map 1:600 000 (Table II:9) – This map was published in 1975. It is accompanied by 3 thematic maps on the same scale, three sections on a horizontal scale of 1:300 000 to a depth of 100 to 500 m, and explanatory notes giving a description of the maps, sections and all the units

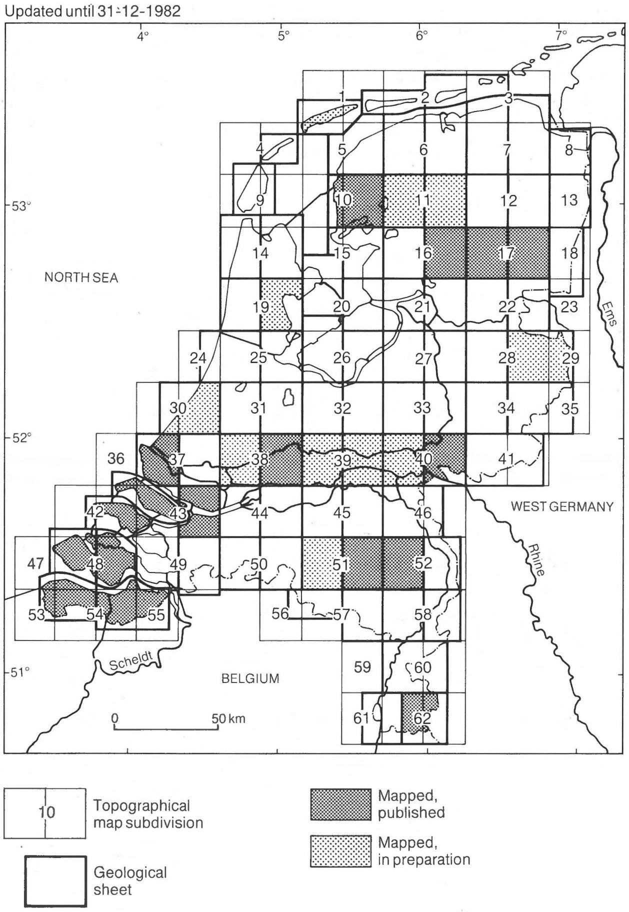
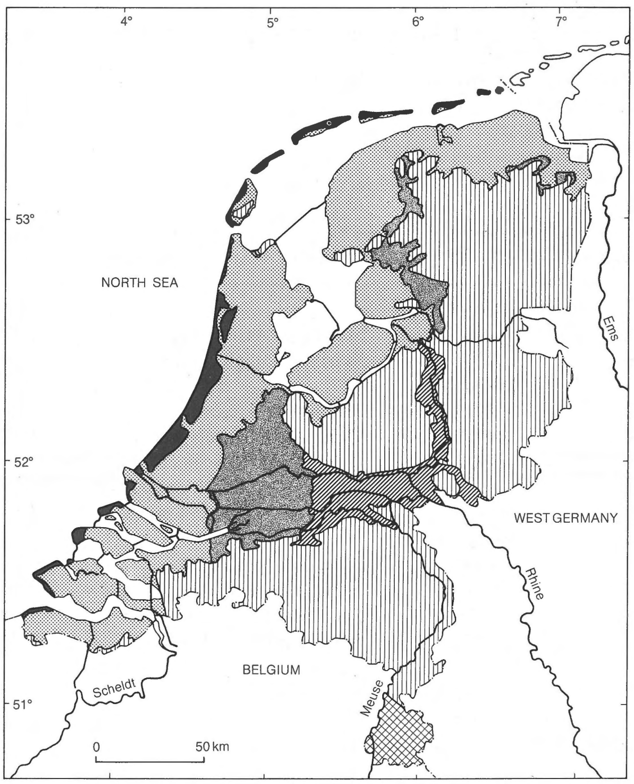


Fig. 18
Index to the New Geological Map of The Netherlands 1:50000 (provisional subdivision). Small overlaps of neighbouring sheets omitted.



Subregions			Types of systems
Littoral areas	HOLOCENE Westland Formation	lagoonal sediments and locally peat	Chrono-lithostratigraphic profile-type system (sequence system.stack-unit system): Based on recognition of successions of strata, as characterized by lithology, origin and age
Lagoonal-marine areas		Estuarine-, tidal flat- and other lagoonal-marine sediments, non-marine sediments and peat	
Perimarine areas		Fluvial sediments and/or peat	
Middle river area	Betuwe F.	Fluvial sediments (extensive, dominant and differentiated), locally some peat	Lithogenetic system: Based on recognition of channel-, bank-, flood-basin deposits etc.
Pleistocene areas		Mainly Pleistocene, further Holocene (fluvial sed., blown sands, peat etc.), locally Tertiary	Lithostratigraphic system: Based on recognition of formal lithostratigraphic units (e.g. Twente Formation) and lithogenetic subdivisions (e.g. loess. Twente Formation), supported by age determinations
Southern Limburg		Holocene, Pleistocene, Tertiary, Cretaceous, Carboniferous	

Fig. 19
New Geological Map of The Netherlands 1:50000; outline of subregions and types of systems, for mapping surveying and legend design.

distinguished. The sheet gives a simplified picture of the data available at the Survey with respect to the Quaternary and Tertiary geology, and is intended as a reference work for both professionals and laymen.

The main map has a generalized legend of the 50000 map, and use was made predominantly of published and unpublished new data, but also sheets of the Tesch map and regional maps prepared by other institutes. One of the thematic maps is a lithological map representing the distribution of materials over the entire country and the adjacent part of the North Sea. Comparison of the sections with those published in 1958 (ZONNEVELD, 1958) illustrates the increase in knowledge. The geological sections were later converted into geohydrological sections (Stichting Wetenschappelijke Atlas van Nederland, 1976).

German New Geological Map 1:200000 (Table II:10) – Geological maps on a scale of 1:200000 are being prepared by the German Bundesanstalt für Geowissenschaften und Rohstoffe in co-operation with the Geologische Landesämtern. A section based in the Palaeozoic accompanies each sheet. The geological boundaries on the Dutch part of the border sheets were drawn by the Survey on the basis of a translation of the available data into the German legend system. The sheets Emden and Lingen (Fig. 20) have been published and prepared respectively.

New Geological Map 1:250000 in preparation (Table II:11) – This map will be published in the second half of the 1980s. Although its design has not yet been finalized, the following scheme is probably a good approximation: five sheets (Fig. 20), one key with a few explanatory notes, 5 to 10 sections ranging in depth from 200 to 500 m. The addition of subsidiary lithological maps and shallow sections is being considered. This publication is intended to bridge the gap

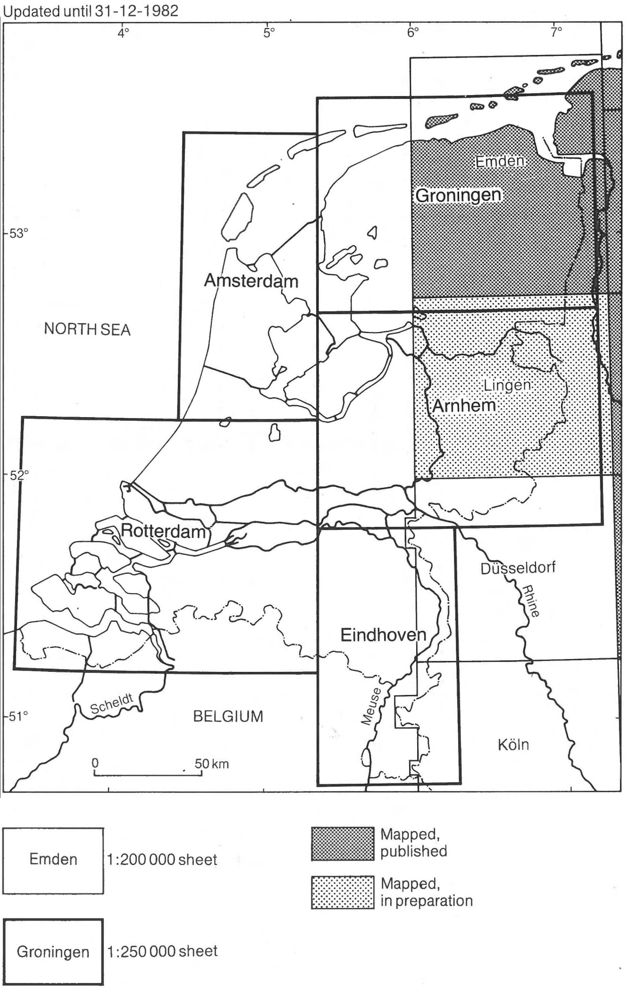


Fig. 20
Index to the Dutch border sheets of the New Geological Map of West Germany 1:200000 and to the future New Geological Map of The Netherlands 1:250000 (provisional subdivision).

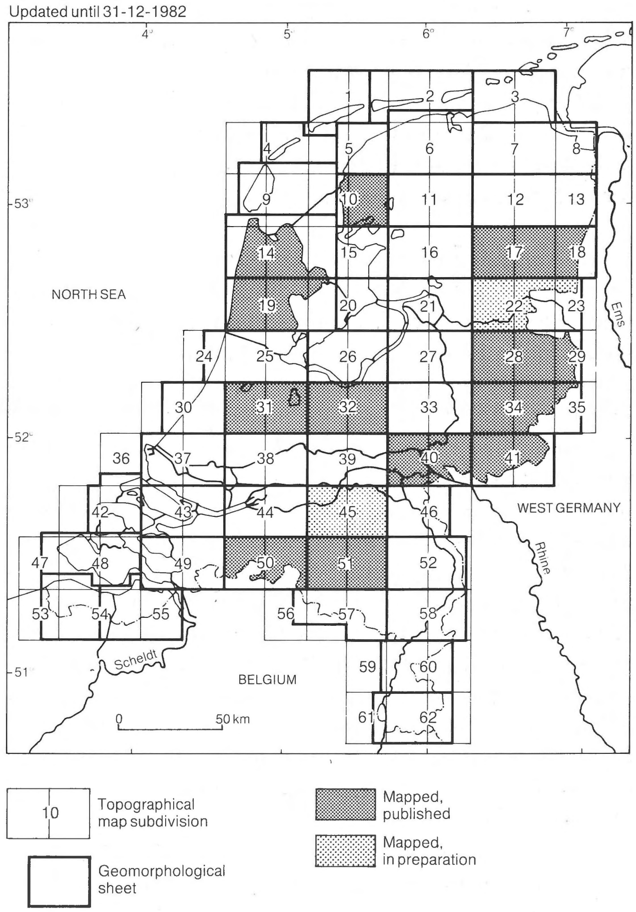


Fig. 21
Index to the Geomorphological Map of The Netherlands 1:50000.

between the published and unpublished survey data well in advance of completion of the 50000 series.

Thematic maps related to the new general survey – There are plans to prepare maps on raw materials, engineering-geologic properties, and environmental geology. It is clear that this kind of map is indispensable for the further development of the country. These maps will in all likelihood be made in co-operation with other institutes.

A few nation-wide thematic and single-value maps published within the last decade can be found listed at the end of this paper.

Geomorphological Maps 1:600000 and 1:50000 (Table II:13, 14) – In 1966, on the initiative and under the direction of G. C. Maarleveld, preparations started for a 1:50000 geomorphological map as a joint project of the Soil Survey Institute and the Geological Survey. After publication of some preliminary 1:50000 sheets, a definitive system was chosen for the whole of The Netherlands. Information on relief, landscape forms and the genesis and age of forms, is combined on the map. The rationale used for the legend has been explained and illustrated by TEN CATE & MAARLEVELD (1977). A simplified form of the legend system was used for a 1:600000 map in 1974.

A map sheet of this kind is to a great extent composed in the office and completed after a limited fieldcheck. A relatively rapidly produced map (Fig. 21) which presents and explains all kinds of geomorphological, geological and topographical features, has proved to be useful for planning and environmental studies.

Dutch North Sea Geological Map 1:1500000 (Table II:15) – The Dutch offshore area has been surveyed systematically since 1968. This work is being carried out in close co-operation with the North Sea Directorate of the Ministry of Transport and Public Works.

Two small-scale maps covering the northern and southern parts were published by OELE in 1969 and 1971, respectively. Use was made of data provided by vibrocorer (3-4 m) samples, rig-site investigations (40 to 70 m), and a geophysical survey. The purpose of the map is to show the geologic units below the young seasand. Most of the stratigraphic units recognized are the same as those mapped on land.

A complementary map on a scale of about 1:1250000 and representing the lithology of the uppermost 50 cm of the seabed was later published by SCHÜTTENHELM (1979). This map is based on analysis of 3000 samples.

Dutch North Sea Geological Map 1:250000 (Table II:16) – Because of the low density of the available data and the relatively shallow sources of information, a closer survey was started in the 1970s. Various types of marine equipment are being used for systematical investigation of geophysical lines. Moreover, the intense activity in the field of oil and gas exploration had yielded an abondance of material from site investigations.

Much attention is being given to the publication of a map on scale of 1:250000, which will be issued on eleven sheets, most of them also covering North Sea areas of neighbouring countries. At the request of the British Institute of Geological Sciences (IGS), one of those, the Flemish Bight sheet, will be published jointly in 1984. The British and Dutch groups have reached agreement on the chronostratigraphic and lithologic stratigraphic units and the mode of presentation. The Flemish Bight region is due to appear on three sheets: one representing the lithology of the Holocene deposits, one giving the Pleistocene formations under the variable Holocene cover, and one on the Tertiary and older formations below the Quaternary deposits. Besides the geological maps, each sheet will carry cross-sections, some subsidiary maps (scale 1:1000000), and explanatory notes. The lay-out designed by IGS will also be used for the other maps of the Dutch sector.

Since the map with the Pleistocene formations is the one which corresponds with the above-described general geological onshore map, a few more details are of interest here. The main map is accompanied by a o.a. seismic section to a depth of 200-500 m. The units represented on the maps and sections are seismostratigraphic units. Because of correlation problems between the onshore lithostratigraphic formations and the seismostratigraphic offshore units, a relatively large number of names have been introduced. The suggested chronostratigraphic correlation is based mainly on pollen analyses, some ^{14}C determinations, and additional paleontologic data.

Mapping as a rule involves for each block (ca. 18 × 22 km): 10 grab samples of the superficial 0.20 m, 5 vibrocorer and 5 airlift borings to 5 and 10 m, and geophysical investigations with boomer and sparker.

Dutch North Sea Geological map 1:100000 in preparation (Table II:17) – The survey for this map had been started when priority was given to the Flemish Bight. The firt phase will comprise 10 near-shore sheets (Fig. 22), each covering at most four blocks. A frew complementary 1:100000 maps of each area are planned, besides a large number of small single-value maps. Basic information is being collected on a denser grid than used for the 250000 map. More attention is being given to lithology, particularly of the upper 10 m. Mapping is progressing most rapidly in the three southermost areas.

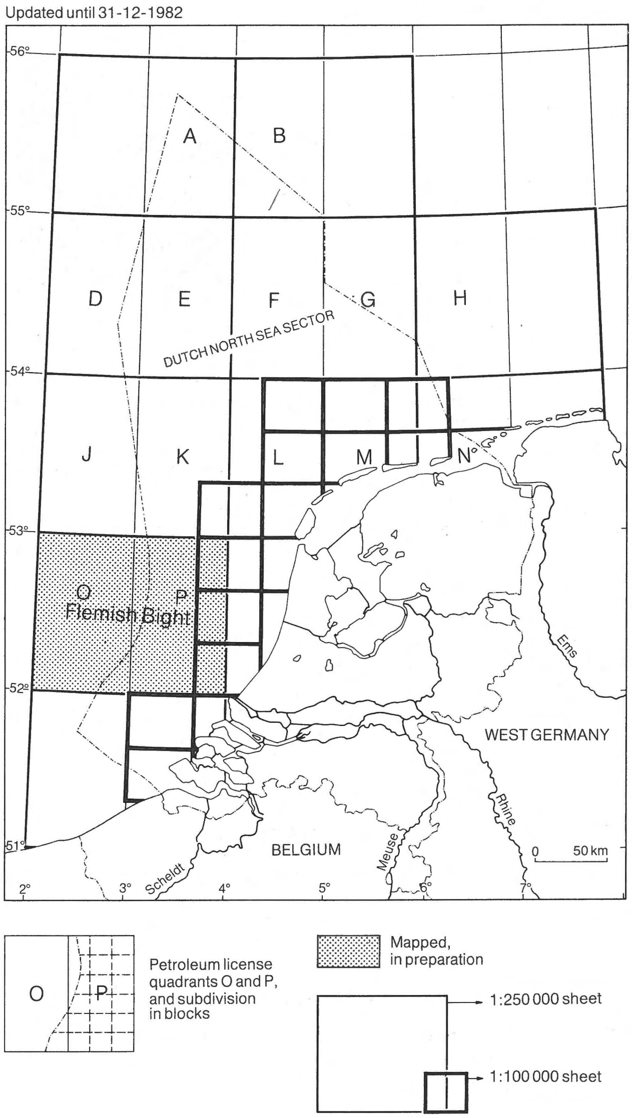


Fig. 22
Index to the Dutch North Sea Geological Map 1:250000 and to the planned first series of sheets of the proposed 1:100000 map.

THE APPLICATION OF THE COMPUTER

Several years ago, computer processing introduced to facilitate the elaboration of the field data and increase the efficiency. Much attention is paid to the storage of the descriptions of borings, which are still the main source for the preparation of the maps. In this section a short outline is given of the application of the computer for handling such data, with three forms of reproduction: print-out, drawn section, or contour map. Although at present use is made of an external computer centre (CDC-Cyber configuration), an in-house computer will be installed soon (DEC-VAX configuration). Terminals have been installed in the regional offices at Nuenen, Oosterwolde, and Alkmaar.

Data entry

Much effort has been given to the input and storage of information in the data-base. To date, some 30000 descriptions of borings present in the Survey's archives have been stored. From now on, descriptions of received material will be typed on an off-line data entry unit, put on diskette, and transmitted to the computer by a telephone-line connection. After inspection and optional revision, the information is stored in the data-base.

The boring descriptions are stored in a non-coded way, i.e., all written text is directly readable. The text constitutes the basic information for further elaboration. Since all borings have a systematic number related to their physical position, any boring can be selected from the data-base. For instance, one or more borings along a geographical line can be selected, or all borings present within a given grid of co-ordinates.

The products

Print-out – All descriptions can be printed out in a neat fashion by using an interactive program on the district's terminal.

Section – A program has been developed within the Survey by which the borelog descriptions can be drawn in small columns along a transect. This exercise takes place in four steps:
Step 1: The descriptions are requested from the data base.
Step 2: The descriptions are screened. This means that they are inspected for completeness, such as the presence of numeric information in numeric columns. If necessary corrections are made.
Step 3: The descriptions, which now meet the computer requirements, are transformed. The wording is translated into a standard wording, and words that have no meaning with respect to the drawing of the section are deleted. The standard wording is then converted into codes for representation and put on intermediate storage. The result can be checked by the user and changed if necessary.
Step 4: The section can be ordered to be plotted on a sheet of paper (measuring 80 to 200 cm) on an arbitrary scale as indicated by the user.

Contour map – The surface-2 programme of R. J. SAMPSON (1975) is used to make contour maps, fishnet plots (mono or stereo), and posted maps. Simplification of the link between the descriptions in the data base and the contour map has been completed.

Besides the above-mentioned products, others are under study, e.g. for the presentation of borings with one or more characteristic layers. A start has been made on the processing of soil-mechanical soundings.

CASE HISTORIES

The main purpose of the third systematic mapping program is to collect information which could be used for practical purposes. The direct application of geological information collected during the survey or the use of the geological outline obtained by general mapping can be illustrated on the basis of two case histories. Besides the surveying techniques described in the second paragraph of this article, soil-mechanical soundings or cone-penetration tests also provide valuable information. Recently, much attention has been paid to the correlation of such soundings with geological sequences (KRAJIČEK & DE LANG, 1982).

Geological study on the consequences of the proposed reclamation of the Markerwaard

Reclamation of the Markerwaard (SW part of the IJsselmeer, in the north-central part of The Netherlands) could cause changes in the groundwater regime and would therefore have an impact on the soil-mechanical parameters of the lithological units in the uppermost 10 to 20 m of the region surrounding the reclaimed area. A reduction of the groundwater potential in the uppermost aquifer could cause first compaction of the compressible Holocene deposits and then subsidence of the land surface and the groundwater table. This might reduce the stability of buildings present in the area, some of which have shallow foundations.

The Geological Survey was to participate in an integrated study on this problem, to be supervised by the Ministry of Transport and Public Works, District North of the Directorate for Water Management and Water Movement). The area to be investigated lies in the eastern part of the province of North-Holland, roughly between Amsterdam and Medemblik. The results of many thousands of borings and cone-penetration tests were available for this study, since by far the largest part of the areas had already been mapped geologically.

The main objectives of the geological investigations were:
1) to construct a geological model of the strata involved in the hydraulic system, in particular the Pleistocene sediments, and
2) to construct a detailed geological model reflecting the composition and distribution of the overlying Holocene deposits.

The results of the first part of the investigation were used by an engineering consultant (IWACO BV) to calculate the expected reduction of the groundwater potential in the uppermost aquifer, which consists of Late Pleistocene sands lying just below the Holocene deposits. No attention will be paid here to this part of the study.

On the basis of the results of the second part of the study and on the calculations on the local reduction of the groundwater potential in the first aquifer, the Heidemij Nederland BV and the Delft Soil Mechanics Laboratory calculated the expected subsidence of the groundwater table and the degree of compaction in the various sedimentary sequences distinguished in the area. The Holocene deposits (Westland Formation) in this area consist of tidal deposits with intercalation of peat layers. They can be divided roughly into two types of sediment succession: 1) areas beyong the range of former tidal channels, and 2) areas influenced by the former tidal channels. From its base to its top, the sediment succession in the area consists of Lower Peat (or Basal Peat) covered with marine clays. These impermeable beds are overlain by sandy clays, frequently alternating with thin sand beds. Upwards, this succession grades into more clayey deposits capped by an often thick peat layer (Holland Peat). In the main reclaimed polders in the southern part of the area, this peat bed is absent due to later erosion. In the northern part, Holland peat is overlain by a clastic succession of clays, sandy clays, and clayey sands with intercalated thin peat beds. In the region to the south, Holland peat is sometimes covered or intercalated by a thin clay bed. The total thickness of this series of sediments is between 10 and 20 m.

The above-mentioned succession may have been eroded partially or completely in places where tidal channels have cut through the underlying strata. The former channels are filled mainly with fine grained sand, often alternating with discontinuous clay seams.

For the purposes of the study, the different sequences of Holocene layers had to be classified in a way giving optimal expression to the succession of geohydrologically and soil-mechanically relevant lithologic units. This led to the design of a geotechnically significant classification of successions of Holocene deposits, based on the presence or absence of not more than five lithological units.

The highly impermeable lower Peat (= Basal Peat) bed is considered as the first level of this classification, and the relatively permeable Holocene sand accumulations as the second. The Holland Peat and overlying clay beds constitute respectively the third and fourth levels, either of which can be subdivided on the basis of relative thickness and the occurrence of intercalated peat beds. The fifth level is formed by a geotechnically important clay bed intercalated in the Holland peat and occurring only in the southern part of the study area.

A certain succession of Holocene strata classified according to this scheme is called a soil type. Figure 23 gives a schematic cross-section including all of the soil types distinguished in the study area. The distribution of these soil types is shown on maps (scale 1:25000), a fragment of which is shown in Figure 24. Additional maps on the same scale show the depth of the top of the Pleistocene, the depth of the top of the Holocene sands, the depth of the base of the Holland Peat, and the thickness of the clay bed on top of the Holland Peat.

Exploration of seepage-susceptible areas in relation to seismic subsurface investigation

At present the shallow shothole method is frequently used for seismic exploration for oil and gas in the subsurface of the western part of The Netherlands. In the past, deeper shotholes were used and the heavy charges were placed in the Pleistocene sands which form the first aquifer, but this caused local perforation of the overlying rather impermeable Holocene deposits and subsequent seepage of generally brackish to saline groundwater into the fresh surface waters, and thus led to damage to agriculture. To solve this problem, the shallow shothole method was introduced and this approach has been increasingly favoured recently. Since a number of light charges are places in shallow positions, the surrounding acquicludes are much less disturbed, as shown by soil-mechanical and geohydrological studies. A distance of 4 to 5 m from the shotpoint is taken as safety criterion, which means that no permanent damage will be done to clay or peat layers beyong that radius. The Geological Survey was requested to compile all data necessary to describe the composition of the Holocene deposits in part of the province of Zuid-Holland to maintain this safety criterion. For the major part of the area, borehole data of the recently mapped but not yet published sheet Gorinchem West (38 West) were available. More than 150 shallow (6-8 m) hand-drilled and a number of mechanically drilled deeper borings were performed for this project, and several thousands of cone-penetration tests made in urbanized areas were interpreted geologically.

The genesis and composition of the Holocene deposits in the western part of the study area are comparable to those of the sediments of the tidal flat/tidal channel complex described above in the first case history. The Holocene sediments in the eastern part of the area (Alblasserwaard, Hoekse Waard) were, however, deposited in a perimarine environment, and consist of fluvial clay beds alternating with (predominantly wood) peat beds (Holland Peat). On a regional scale this clay/peat succession is dissected by a narrow spaced pattern of former river courses. In many cases these rivers maintained the same course for long periods, and thus many of them eroded the Pleistocene sands as well. The channels are filled with medium grained riversands.

Another phenomenon is the occurrence of the river dunes which are geohydrologically important in the perimarine area. The river dunes are dome-like structures consisting of coarse grained, well-rounded Pleistocene sands (Kreftenheye Formation), occasionally cropping out at the surface. The river dunes generally overlie an often discontinuous clay or loam bed which lies above the Pleistocene sands (Hochflutlehm of PONS, 1957). Because of the discontinuity of this clay or loam bed, it must be assumed that the groundwater in the river dunes is in direct contact with the groundwater of the first aquifer. Since there is an overpressure in this aquifer, the

code	I	code	II	code	III	code	IV	Type	code	V	Type
A	Basal Peat present	z	Holocene sand	2	peat<1m, with clay cover >1m	v	intercalated peat beds	Az2v			
						o	without intercalated peat beds	Az2o			
				1	peat>1m	k	thin clay cover >0,25m	Az1k	s	intercalated clay beds	Az1ks
						o	without thin clay cover	Az1o	s	intercalated clay beds	Az1os
				0	peat absent			AzO			
		o	Holocene sand absent	2	peat<1m, with clay cover >1m	v	intercalated peat beds	Ao2v			
						o	without intercalated peat beds	Ao2o			
				1	peat >1m	k	thin clay cover >0,25m	Ao1k	s	intercalated clay beds	Ao1ks
						o	without thin clay cover	Ao1o	s	intercalated clay beds	Ao1os
				0	peat absent			AoO			
B	Basal Peat absent	z	Holocene sand	2	peat<1m, with clay cover >1m	v	intercalated peat beds	Bz2v			
						o	without intercalated peat beds	Bz2o			
				1	peat>1m	k	thin clay cover >0,25m	Bz1k	s	intercalated clay beds	Bz1ks
						o	without thin clay cover	Bz1o	s	intercalated clay beds	Bz1os
				0	peat absent			BzO			
		o	Holocene sand absent	2	peat<1m, with clay cover >1m	v	intercalated peat beds	Bo2v			
						o	without intercalated peat beds	Bo2o			
				1	peat>1m	k	thin clay cover >0,25m	Bo1k	s	intercalated clay beds	Bo1ks
						o	without thin clay cover	Bo1o	s	intercalated clay beds	Bo1os
				0	peat absent			BoO			

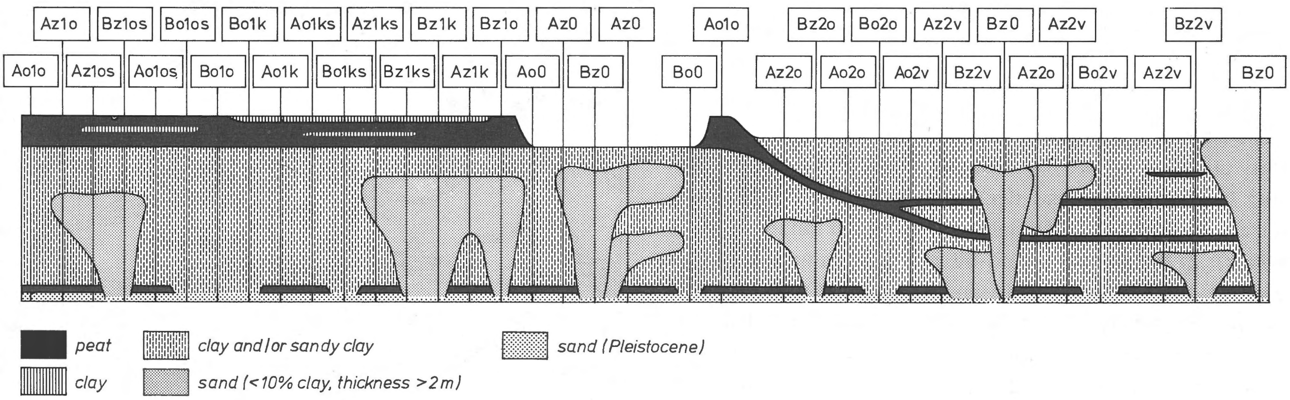


Fig. 23
Classification of the Holocene lithological succession and schematic cross-section with all classification types indicated.

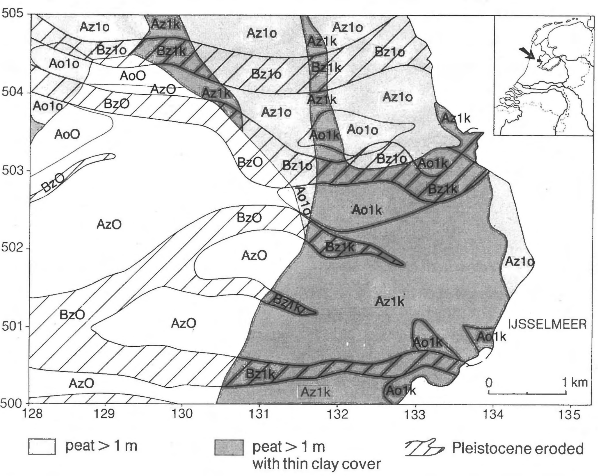


Fig. 24
Fragment of classification-type map.

groundwater level in the river dunes will be rather high, i.e., close to the surface. The same holds for the sand-filled fossil river channels, which reach into the Pleistocene sands. Almost all of the river dunes and filled rivers are covered by clay and peat beds of variable thickness determined mainly by the age of the river fills.

For the purposes of this study, a special classification was developed for the indication of the lithological succession in the former river channels and river dunes on a map (Fig. 25). The former river channels are subdivided into a group which cut through the Pleistocene sands and a group of shallower channels still underlain by impermeable Holocene beds. Both types can be divided into several categories according to the depth of the top of the sand-filled channels (Fig. 26).

Overlaps between shallow and deeper channel fills are indicated separately. Not indicated on the map are the at least 8 m thick clay and peat successions occurring between the river dunes and the river courses.

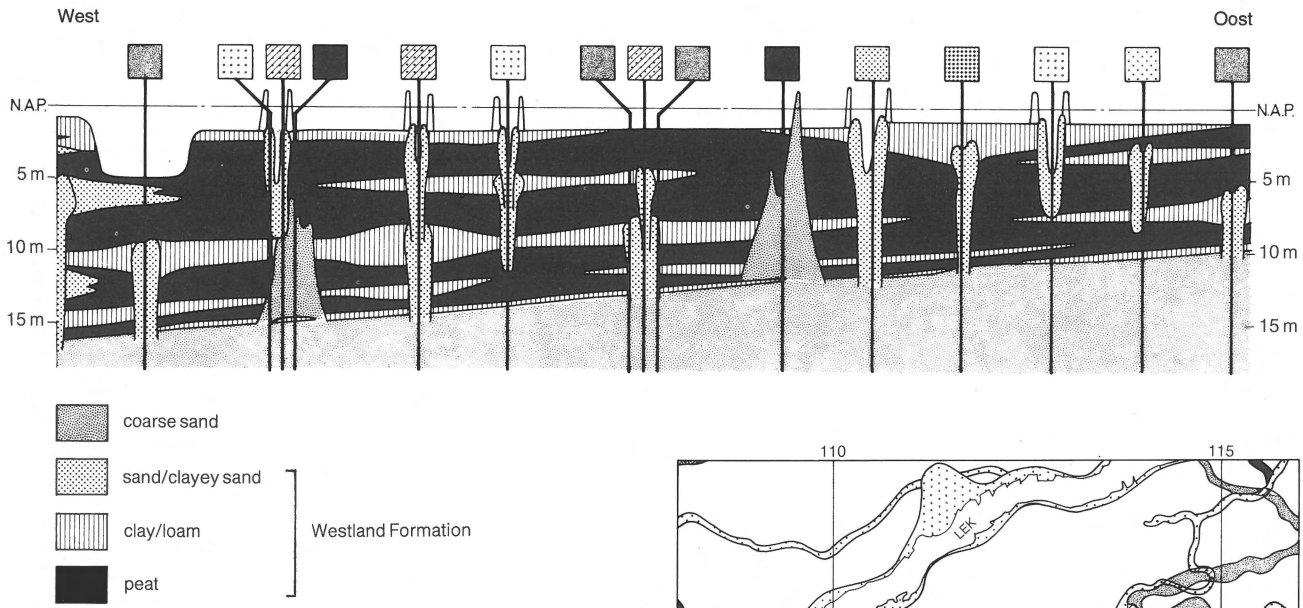


Fig. 25
Schematic cross-section illustrating the legend types shown in figure 26.

The shothole depth of 2 m below the surface satisfies the safety criterion on the following types of lithological succession: 1) river dunes and deeper sand-filled river channels (surface of the sand body deeper than 6-7 m below the land surface); 2) the shallow, sand-filled river channels overlying impermeable Holocene beds; and 3) the clay and peat successions beyong the river dunes and fossil river channels. Moreover, the safety criterion is also considered to be met for lithological successions lacking impermeable beds between the phreatic water and the groundwater of the first aquifer, since the blow will not cause any permanent change in the water balance. The latter successions certainly include the outcropping river dunes and the river channels filled with sand up to the surface level.

The remaining potentially seepage-susceptible areas comprise those places where the top of the donk sands or of the deeply eroded channel fills lies between the surface and at 6 to 7 m depth. Designation of these risky areas, as a result of geological mapping activities, has proved to be of vital importance to both the polder boards and oil companies in the past few years.

SUMMARY

A wide range of sampling equipment is available to collect samples of high quality for closer investigation and also samples of lower but adequate quality to support the interpretation of data collected geophysically. In addition to the standard equipment, special tools have been developed to sample appropriately the unconsolidated subsoil of The Netherlands. Geophysical methods, employing e.g. geoelec-

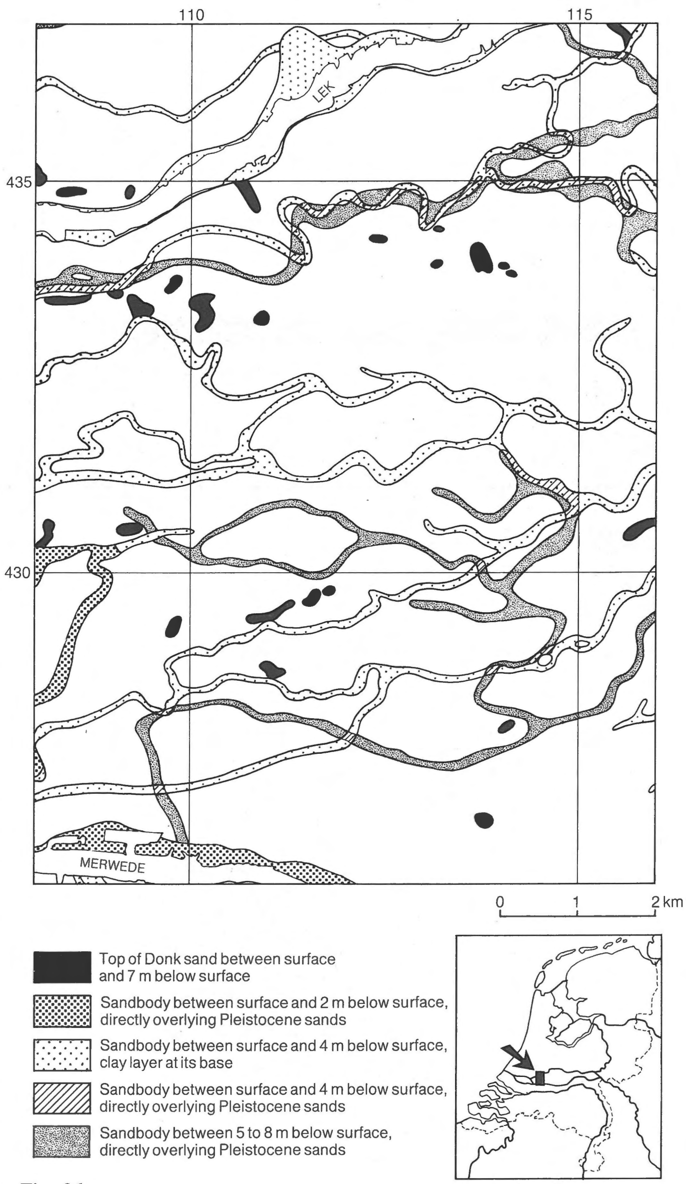


Fig. 26
Map showing various categories of river courses and the distribution of mainly buried riverdunes (donken) in part of the Alblasserwaard area. For legend, see figure 25.

tric, electromagnetic, and seismic techniques, provide the necessary supplementary data. Together with remote sensing, all these surveying techniques permit accurate mapping of the country and its offshore area.

The mapping programme was started to meet the expected demands for geological information pertaining to mineral resources and agricultural projects. The case histories presented draw attention to an unforeseen application of the information: calculation of compaction in the upper 20 m due to empoldering and the impact of seismic exploration for oil and gas with the use of explosives at very shallow depths. The required information could be provided by the Survey only because the mapping programme had once been started as a routine project and much attention had been paid to make it a high quality enterprise.

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