A GEOLOGICAL INTRODUCTION

The Dutch Sector of the North Sea

The North Sea directorate of the Ministry of Public Works and the department of Geo-Marine & Coast of The Netherlands Institute of Applied Geoscience-TNO jointly carried out a geological mapping programme and the assessment of industrial sand deposits in the Dutch sector of the North Sea. A brief outline of the methods used and the knowledge obtained is given.

The Dutch part of the North Sea (NCP) occupies an area of 57,000 km2 which is larger than the mainland of The Netherlands (Figure 1). In addition to traditional activities, like fishery and shipping, since the 1960s there have been new activities such as oil and gas exploration and exploitation, and extraction of sand from the seabed. New plans for installation of wind turbines and coastal extensions are in progress. In addition the area forms part of a valuable marine ecosystem. Knowledge of the morphology of the seafloor and the sediment properties is important, both to understand the ecosystem as well as for developing infrastructural activities.

Data-acquisition Using a Range of Equipment and Methods
To collect data from the upper few metres of the seabed, a device producing a wavelet in dual-frequency mode is used. The setting at 12 and 250 kHz is suitable for investigating the upper layer with a vertical resolution of centimetres. For deeper penetration, a single short pulse of 3.5 kHz and 1 to 3 ms duration or a dual-frequency wavelet as produced by the parametric acoustic source, can be used. A device frequently used is the chirp sub-bottom profiler. It emanates a long wavelet sweeping from the low end of the frequency range to the high end (Figure 2). Compressing this wavelet to a sharp pulse has the advantage that more control on the energy, frequency content and shape of the pulse is possible than with some other devices. This facilitates estimating the type of seabed material from the reflection strength of the acoustic signal. Calibration is per-formed using seabed samples. Except for the above direct measurement of the reflection coefficient of the seabed, other devices for seabed classification take advantage of other aspects of the wavelet like the duration and amplitude of the secondary pulses which follow the main reflection pulse.

Processing Methods
Processing by computer of acoustic data is part of the normal procedure in the field of oil and gas surveys. Software exists for 3D seismic surveys and 4D (i.e. 3D + time) surveys. Parts of this software are re-used in shallow seabed surveys. Examples of single channel data are time-variant gain and frequency filtering, wavelet shaping, signal-to-noise ratio enhancement, etc. Nearly â€˜real-timeâ€™ processing is also increasingly performed. Multibeam and sea-floor mapping systems can produce a detailed picture of the seafloor almost immediately after the data input has ended (Figure 3). So more processing is done on-board rather than onshore. To extract geological data from acoustic profiles seabed samples are needed, but simple â€˜physicalâ€™ interpretation can be performed on the computer screen, producing a quasi-3D picture of the subsurface. Integrating sample data into this data and into the data from a seafloor mapping or a multibeam system, can produce a 3D model of the (sub) surface. From such a model it is relatively easy to extract the total volume of exploitable sand.
The seismic records are physically interpreted using computerised systems and together with the cores and borehole information, the seismic profiles are then interpreted geologically. 3-D fence diagrams are prepared in order to facilitate construction of geological maps showing the different lithological units.

Sea Bed Sampling
Grabs are used for sampling the upper 25 cms of the seabed. For deeper sampling, coring systems are used. A corer consists of a rectangular base frame on which two vertical guide poles are mounted and a vibrator head which can move up and down. Two electrical vibrators are mounted in the vibrator head each having a frequency of 1,500 rev./min. At the base of the vibrator head a steel barrel with a diameter of 7 or 10 cm and a variable length of between 3 and 6 metres is mounted. High air pressure within the barrel acts to prevent sea water from entering the tube. During coring the air pressure increases even further due to the sampled material entering the barrel. Release of pressure facilitates further penetration of the core barrel into the seabed. The average penetration is only 3 to 4 metres. However, the core quality is usually only moderate and in most cases however sedimentary structures are destroyed partly due to the vibrator frequency and partly to the high percentage of water in the core because some sea water is always sucked in.
A hydraulic corer has a vibrating frequency of 1,750 revs/min and a penetration time of only 20 to 30 seconds. The diameter of the barrel can be varied from 7 to 10 cm, and the length from 5 to 6 m. The average penetration is 4 to 5 metres, and the quality of the core is excellent.

Counterflush/airlift Systems

Drilling systems for deeper sampling operate with the counterflush/airlift method. During drilling air under pressure is fed into the inner tube changing the specific gravity of the water. The introduction of air results in a powerful water stream through the annular space. Water then passes through small holes in the core bit thereby loosening the sediment. Subsequently water enters the inner tube and a mixture of both water and loosened sediment passes through the barrel to the surface. The end of the inner tube is connected to a flexible hose through which the sediment-loaded water is transported to the shipâ€™s deck.
Samples up to 20 metres below the seabed can be collected in only 90 to 120 minutes. These samples are disturbed, but for geological reconnaissance studies counterflush bulk samples of relative good quality can be collected.

Core Logging

Before opening the cores core logging takes place with a multi-sensor core logger. Gamma radiation is used to determine the sample density, the magnetic susceptibility in order to determine the presence of magnetic minerals and the P-wave velocity. After logging X-ray photographs are taken to study the internal stuctures of the core such as lamination, bioturbation etc.
In the laboratory the cores are visually described together with advanced PC-operated techniques for determination of the grain size, sphericity, grain texture, gravel types, and the content of molluscs. Subsamples are taken for laboratory analysis such as the determination of grain size, calcium carbonate, organic matter content, and the microfloral and faunal content.

Subsiding Basin

The development of the North Sea basin started during the Tertiary period about 60 million years ago and has been subsiding in a SE-NW direction. From the adjacent land areas this basin has been filled by sediments brought by rivers, glaciers and the wind, with gravel, sand and clay that thickens in a NW direction. The last 2.6 million year period is characterised by an alternation of cold (glacial) and relative warm (interglacial) stages. During glacial stages the sea level fell because of the growth of glaciers which, during their coldest phases, covered large parts of the northern hemisphere. The NCP became dry land at several times and the sediments deposited in the basin were of glacial and fluvial (river)origin. During the interglacial stages high sea level stands occurred and marine conditions prevailed. The marine processes reworked the older sediments and marine sediments were deposited.
During the maximum of the last glacial stage, sea-level was about 125 m lower than today due to the enormous amount of land-ice on the continent. At the start of the Holocene period, about 10,000 years ago, sea level rose again and a rapid transgression took place drowning the entire southern North Sea within about 4000 years. This transgression caused changes in the existing bed forms and sediments. Nevertheless, the pre-Holocene morphology and sediments are locally still recognisable at the present sea floor.
Most striking is the influence of the former glaciations on the bed forms in the northern part of the NCP. Both glacial morphological features, such as moraines and (fluvial)glacial melt water valleys, as well as glacial sediments such as boulder clay, are present.
In the southern part of the NCP the morphology has a more marine-induced character with sand waves and linear ridges consisting of reworked fluvial sediments.

Surficial Sediments

The sea floor of the NCP consists mainly of fine to medium sand. Small gravelly areas occur in the northern part. In the central-northern part, silt and clay has been deposited. In general the grain size of the surficial sands decreases from south to north. In the south, median sand with mean grain sizes between 250 - 500 Âµm dominate. Further north fine sand (125 - 250 Âµm) or even very fine sand (63 - 125 Âµm) occurs. In the areas with very fine sand, the content of silt and clay is rather high. (Figure 4).
Gravel deposits are found in places were glacial features such as moraines are near, or at, the seabed. The Cleaver Bank is the only area on the NCP with a substantial amount of gravel and cobbles. Locally gravel is found at the so-called Vlieland Rough, northwest of the island of Texel.
Marine sands of the NCP are of good quality for coastal nourishment and landfill uses. There is enough marine sand to fulfill the need for these purposes for decades or even centuries. More problematic is the sourcing of marine sand for construction. For the manufacturing of concrete a coarser and less sorted sand is needed. These sands, mixed with gravel, are present at the surface near the Cleaver Bank. In the southern part of the NCP they are present in former fluvial deltas at a depth of 5 to 10 metres below the sea floor.

Natural Heritage in the Sea Bed

Some features have an intrinsic geological or geomorphological value. They are a good example of a feature produced by a specific geological process or are important as part of the geological archive in the subbottom. These features are found on the NCP as visual elevations or depressions or as geological layers in boreholes or seismic profiles. A good example is the occurrence of a pock mark due to the escape of gas from older layers in the subbottom (Figure 5).

Tidal Channels

Below the sea floor off the central coast of The Netherlands, relicts of a former barrier island coastline are present. With the aid of seismic profiles tidal channels have been mapped (Figure 6). These channels are filled with fine sand with a high silt content. Along the Dutch coast several major activities are planned, such as the construction of an airport island and the building of wind turbines. For the extraction of large amounts of sand for an island the location of these gullies is of importance. A high silt content is not desirable from an ecological point of view, as it gives rise to a high turbidity during sand extraction. For the building of wind turbines the location of the gullies is important because of the stability of the foundation.

Availability of Data

Data collected as digital maps, bathymetry, and core and borehole information is available at the websites www.nitg.tno.nl and www.eu-seased.net.