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Sequence mapping of Holocene coastal lowlands: the application of the Streif classification system in the Belgian coastal plain

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Abstract

A geological map of the Holocene deposits of a portion of the western Belgian coastal plain is presented. The map differs from a conventional geological map which is of little use for coastal lowlands because of the high lateral and vertical variability in lithology in the subsoil. The method of sequence maps was chosen because these maps allow the representation of the entire vertical sequence of the Holocene deposits. A sequence map is constructed on the basis of profile types consisting of the vertical succession of the various mapping units. In order to produce a user-friendly map, preference was given to lithogenetic units instead of formal lithostratigraphic units for the determination of mapping units. The organisation of the mapping units was established according to the Streif classification system. The application of the system is demonstrated with two different sequence maps each constructed on a different level of the hierarchic system: a general sequence map and a special sequence map showing further differentiation.

1. Introduction

Conventional geological maps represent the geographical distribution of outcropping deposits. Such maps are of little use for the present-day Holocene coastal plains because their sedimentary sequences are characterised by a high lateral and vertical variability. Geological maps of coastal plains are useful only when the entire Holocene sequence is represented and the lithological variability of the subsoil delineated. The need to show in-depth information becomes obvious when considering the geotechnical aspects of the subsoil consisting of deposits which are very sensitive to compaction and liquefaction (Hageman, 1984; Baeteman and Paepe, 1991; Browne and Mc Millan, 1991).

It was Hageman (De Jong and Hageman, 1960; Hageman, 1963) who introduced a method for representing the totality of the Holocene deposits for the renewed geological mapping of the Netherlands. The method consists of constructing a series of profile types each identified by a particular colour or symbol. The representation of the profile types on a map forms a sequence map. In the Netherlands, formal lithostratigraphic units were used to construct the profile types. However, for the Holocene coastal deposits, the use of formal lithostratigraphic units for mapping purposes is not without difficulties (see Baeteman, 2005). Therefore, Streif developed a new classification system and its representation in the form of profile types (Barckhausen et al., 1977; Streif, 1978) which has recently been slightly modified (Streif, 1998).

This paper presents the application of the Streif classification system to Holocene deposits in a part of the Belgian coastal plain (Fig. 1). The official geological map of the area dates back to 1895 (Mourlon, 1895). A map of the Quaternary deposits was published in 1992 (Maréchal, 1992). However, it shows the surficial sediments with a legend inferred from the pedological map of the area. For the Holocene deposits, no official map sheets of the area have been published yet, only fragments as examples in support of the Streif classification system (Baeteman, 1981, 1987). Very recently a

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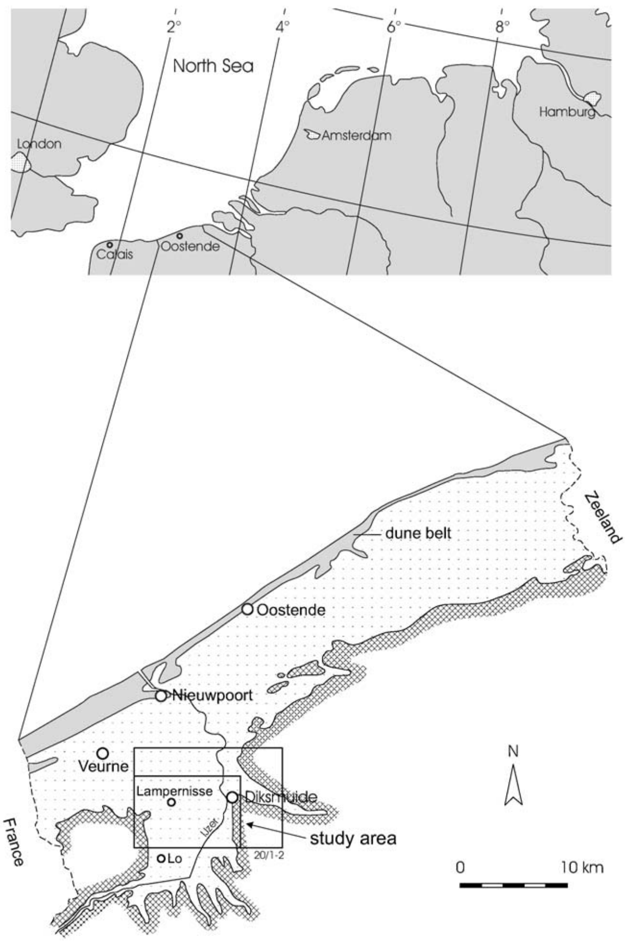

Fig. 1. Location map of the Belgian coastal plain showing the study area as part of the Lampernisse–Diksmuide map sheet (NGI topographical map no. 20/1-2).

sequence map of the area has been published in the framework of the "Quaternary mapping of Vlaanderen", but the map combines the Pleistocene and Holocene deposits applying the Streif system for the Holocene only (Bogemans and Baeteman, 2003).

2. Study area

The study area is located in the central part of the western Belgian coastal plain (Fig. 1). The coastal plain is part of the lowlands of the southern North Sea which stretch from Cap Blanc Nez in northern France to Skagen in Denmark. The Belgian coastal plain is about 10 km wide with a southern extension in the west along the river IJzer. The plain is an embanked area actually situated about 2 m below present mean high water level. Dunes and dikes protect the area from being flooded. The western coast is characterised by a mean tidal range that varies between 4.7 and 3.8 m in Nieuwpoort (Van Cauwenberghe, 1993). The study area covers about 80 km^2 and is located on the topographic map of Lampernisse–Diksmuide (1:25.000, nr 20/1-2) (Fig. 1).

3. Holocene geological setting of the study area

The subsoil of the coastal plain consists of a compact Eocene clay. It is covered by fluvial and marine deposits of Pleistocene age with thicknesses varying between 5 and 10 m (Baeteman, 1993). The Holocene deposits in general form a wedge which is about 25 m thick in the seaward part and narrows to the south where the Pleistocene deposits are outcropping at the landward limit of the plain.

In the study area, the coastal plain developed in the drainage basin of the late Weichselian predecessor of the river IJzer. The post-glacial sea-level rise affected the area by way of the palaeovalley, which developed into a tidal basin with channels and flats. As groundwater level rose with sea level, basal peat formed as a time-transgressive unit shifting landward (Baeteman, 1999). The initial relative sea level was rising at an average rate of 7 m 1000 yr^{-1} in the period before ca. 7500 cal BP (Denys and Baeteman, 1995). This resulted in a rapid landward shift of the tidal environments together with a significant vertical sediment accumulation. At ca. 7500–7000 cal BP, the rate of the relative sea-level rise decreased to an average of 2.5 m 1000 yr^{-1}. The tidal basin became infilled and peat developed, at first short-lived and locally. However, by ca. 6800 cal BP, peat accumulated on a more regional scale. The sequence deposited in the period between ca. 7800 and 5500 cal BP consists of peat beds alternating with tidal flat deposits. A second deceleration of the rate of relative sea-level rise at 5500–5000 cal BP to an average of 0.7 m 1000 yr^{-1} corresponds with the development of the thickest and most widespread intercalated peat bed. The re-entrance of the tidal system in the late Holocene resulted in the deposition of a 1–2 m thick clay cover, associated with deep and narrow sand-filled tidal channels (Baeteman et al., 2002).

4. Methodology

The mapping has been carried out with a hand-auger gouge providing undisturbed cores. The elevation of the ground level at borehole sites was levelled relative to TAW (Belgian Ordnance Datum, referring to mean low water spring) or inferred from the topographic map. For this investigation, 78 new boreholes were carried out and over 150 boreholes archived at the Belgian Geological Survey were also used, some of them

mechanically cored and penetrating the entire quaternary sequence.

It is always the intention to reach the Pleistocene deposits while coring, independently of the depth. However, the presence of water-saturated sand or the collapse of a borehole, frequently occurring at greater depth, may prevent this. The Pleistocene deposits are easily recognisable in the field since in the study area they consist of fluvial sand and clay. Being relatively consolidated, the Pleistocene deposits are almost impossible to penetrate by hand auger.

In the field, the following characteristics were recorded: depth, lithology, colour, type of boundary, sedimentary structures, macrofossils and other biogenic features. The different lithologies encountered were then interpreted according to the facies of sedimentary environments. In addition to supratidal freshwater marsh peat, the following tidal environments are encountered: mudflat, mixed and sand flats, and tidal channels. In general, these sedimentary environments are easily recognisable with visual inspection in the field on the basis of lithology, sedimentary structures and macrofossils and their determination as such is sufficient for mapping purposes. The interpretation of the field descriptions were then drawn in logs forming the basis to construct cross-sections. Fig. 2 is an example of such a cross-section showing the relief of the Pleistocene subsoil and the associated Holocene infill. The cross-section demonstrates very well that the number of peat beds and their height may vary, the latter being the result of differential compaction. Note that the cross-section is drawn with a significant vertical exaggeration. The cross-sections in turn form the basis for the construction of the profile types and, eventually, the sequence map.

5. The morphology of the pre-Holocene surface

A sequence map does not give any information on the thickness of the deposits under consideration. Therefore, a contour map has to be made showing the elevation of the base of the deposits. For a Holocene coastal plain, the thickness of the deposits can easily be

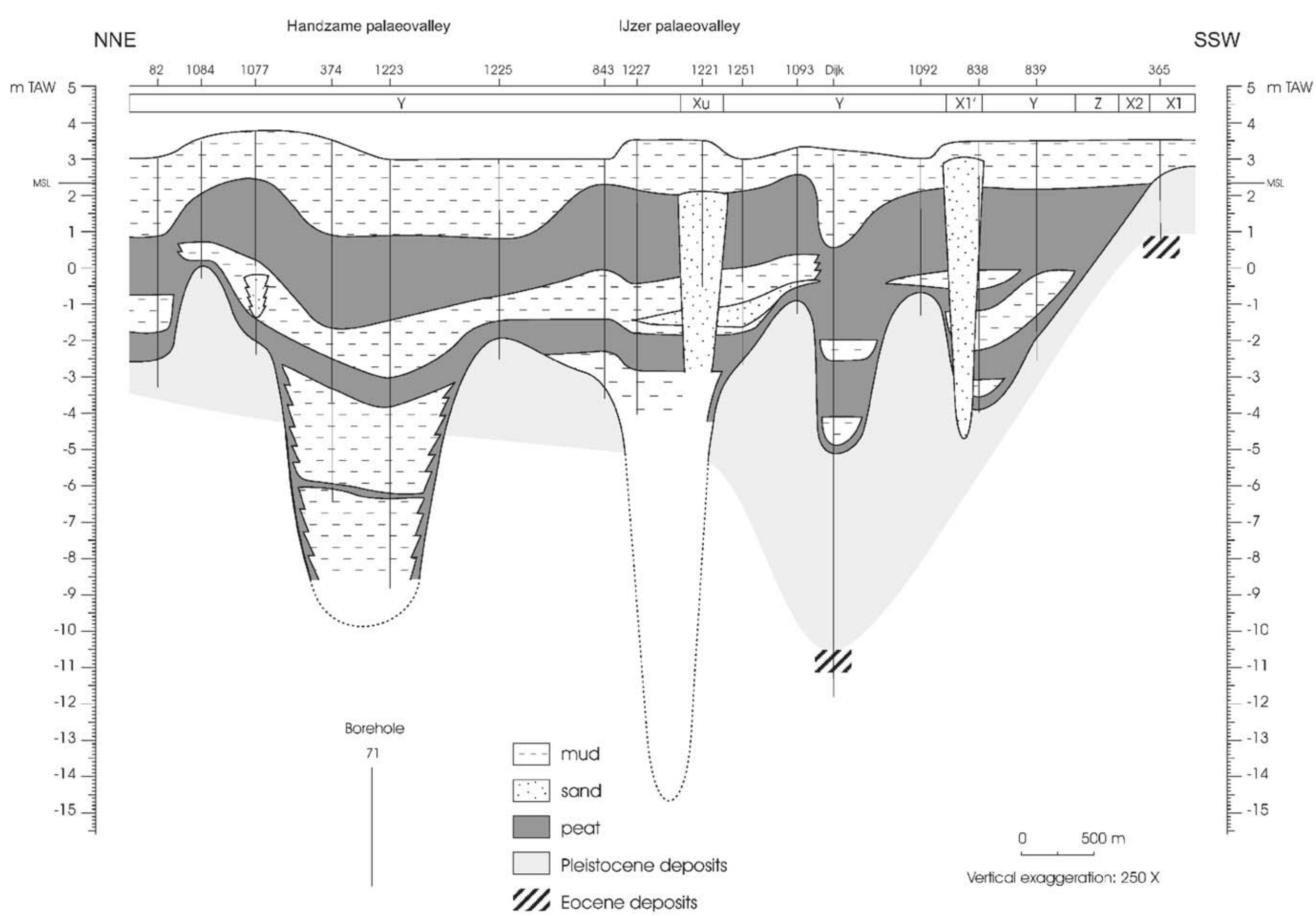

Fig. 2. Cross-section showing the Holocene infill of the IJzer and Handzame palaeovalleys and illustrating the different profile types. Due to the (inevitable) vertical exaggeration in order to show the details, the cross-section gives a wrong impression of the relief of the depressions and palaeovalleys. In reality, they are wide with gentle slopes. The location of the cross-section is shown in Fig. 5.

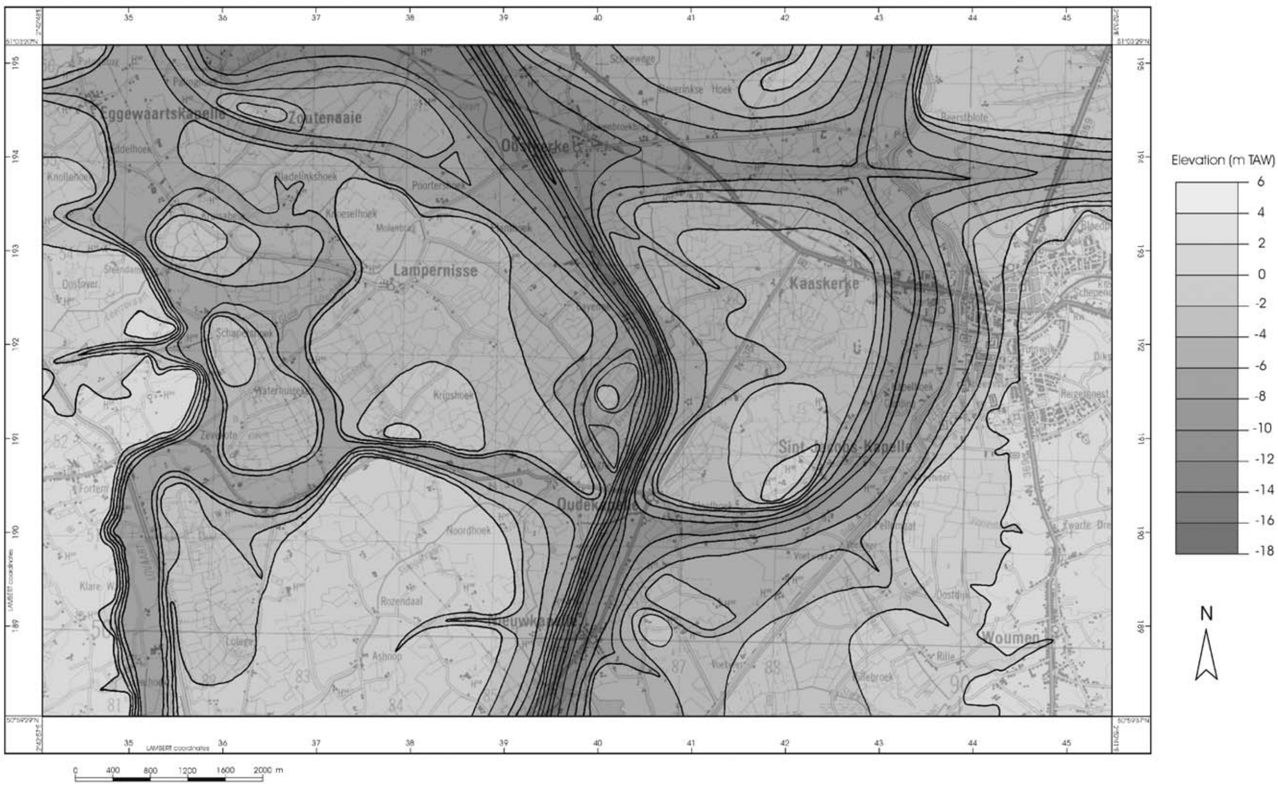

Fig. 3. Contour map of the base of the Holocene deposits at 2 m intervals relative to TAW.

inferred from that map, because the surface is almost flat. From a geotechnical point of view, it is more significant to produce a map indicating the base of the deposits, rather than the thickness.

Since numerous cores do not reach the Pleistocene/Holocene boundary, but indicate that the boundary is at least deeper than the end of the core, it is essential that such a map is hand-made and not constructed by means of an interpolating software (Baeteman and Declercq, 2002). The use of software for the construction of a contour map in areas characterised by a highly variable relief leads to an unrealistic morphology (cf. Streif, 1998; Brew et al., 2000).

The contour map of the base of the Holocene deposits in the study area was constructed at 2 m intervals relative to TAW (Fig. 3). The surface shows a north–south depression which reaches a maximum depth of about −16 m TAW. This depression is interpreted as a former palaeovalley of an ancient IJzer river system which, in the south, has been modified and overdeepened by late Holocene tidal channels. In the NE corner of the map, an east–west aligned depression reflects the palaeovalley of the Handzame River. The presence of basal peat indicates that the palaeovalleys existed prior to the Holocene inundation. All the other overdeepened areas are the result of vertical scour by late Holocene tidal channels (Baeteman, 1985). Apart from these depressions, the contour map reflects the topography at the beginning of the Holocene inundation. As will be demonstrated below, this relief had a significant control on the distribution of the Holocene deposits.

6. The sequence map of the Holocene deposits

6.1. The principle of the Streif classification system

A new classification system for coastal Holocene deposits and their representation in the form of profile types was developed by Streif and applied to the mapping of Niedersachsen, Germany (Barckhausen et al., 1977; Streif, 1978). Streif also introduced the use of lithogenetic units for describing the sedimentary units (Streif, 1972) which later on were successfully used as mapping units.

The classification system is applicable to tidal areas, marshes and coastal fens which all occur in the lowlands of the southern North Sea. The system has a hierarchic subdivision and is based on the vertical and lateral interfingering of sedimentary and sedentary units (Streif, 1978). At the first hierarchic level, the deposits are subdivided into three complexes (Fig. 4a): the clastic complex (only clastic sediments with no intercalated peat layers), the interfingering complex (clastic sediments and intercalated peat layers) and the peat complex (dominance of organic material). The com-

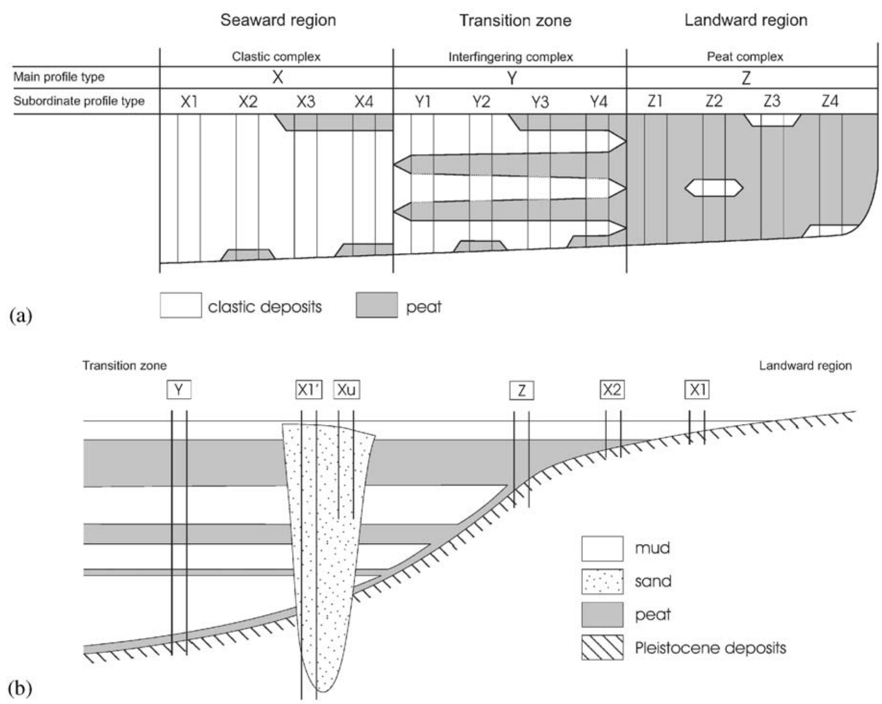

Fig. 4. Schematic cross-sections illustrating the complexes and sequences. (a) The 12 theoretical profile types as developed for the setting in N. Germany. (Redrawn from Streif, 1998). (b) The profile types encountered in the central part of the Belgian coastal plain and used for the construction of the general sequence map (Fig. 5). Note that the landward region in the Belgian and N. German plain differs significantly.

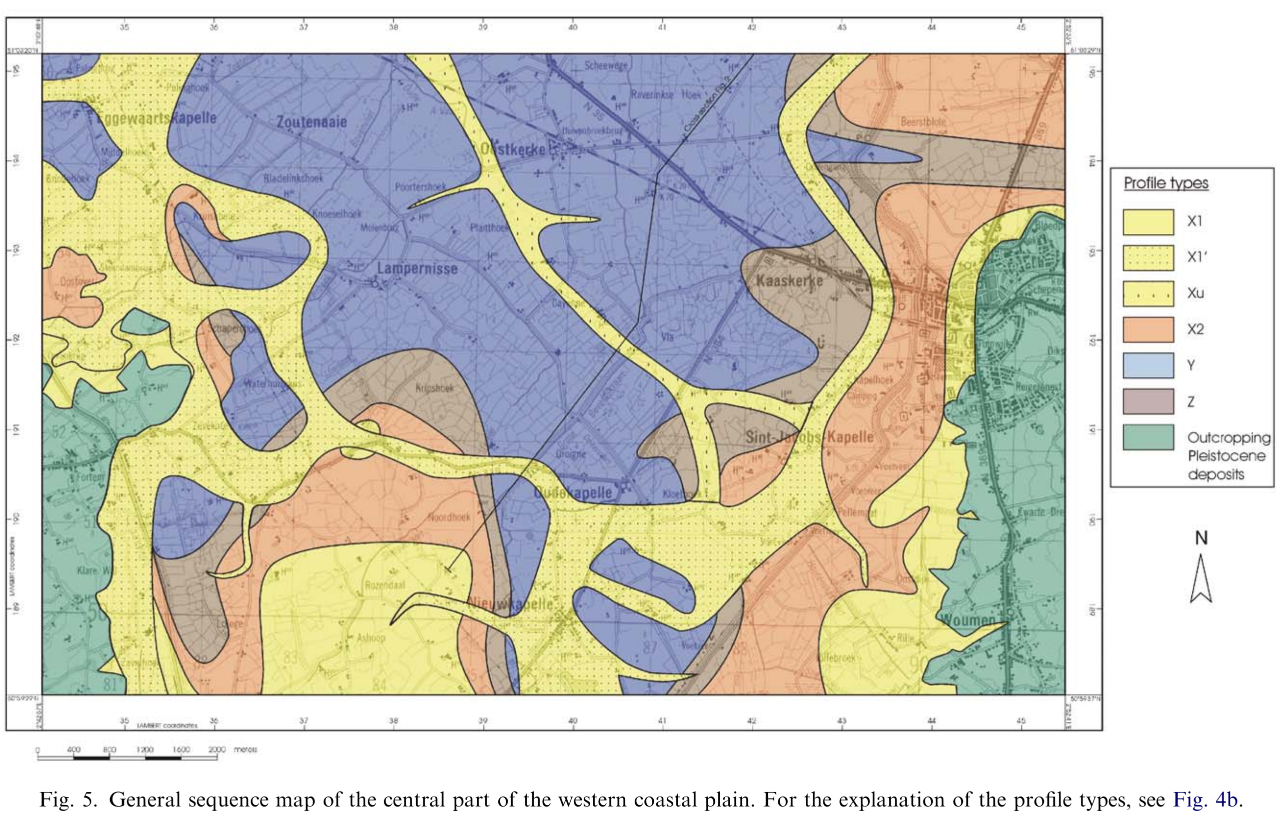

Fig. 5. General sequence map of the central part of the western coastal plain. For the explanation of the profile types, see Fig. 4b.

plexes are represented by three main profile types: X, Y and Z, respectively. The use of the main profile types is limited to maps at a large scale. A further differentiation can be obtained at a lower level of the system by using sequences and facies units, represented as subordinate and special profile types, respectively. The latter are then

used to construct the general and special sequence map, respectively.

6.2. *The subordinate profile types and the general sequence map (Figs. 4 and 5)*

A sequence is defined as a single layer or a group of sediment layers or peat distinct from surrounding lithologies (e.g. clastic sequence, organic basal sequence, clastic cover sequence) (Streif, 1978). The possible combinations of the sequences build up the 12 subordinate profile types (X1,…, Z4) (Fig. 4a). The labels 1 and 3 added to the main profile types X and Y stand for the absence of basal peat; 2 and 4 for the presence of basal peat. The same principle applies for the absence or presence of a cover peat. Not indicated on the schematic cross-section, but foreseen in the system, is the label u to be added to the main profile types for boreholes not penetrating the entire Holocene sequence (see Fig. 2 as an illustration of the profile types).

In the study area, not all the 12 subordinate profile types are encountered. Therefore a simplified model was made according to the prevailing situation (Fig. 4b). Of all the Z subordinate profile types, only Z3 is found; of all the Y-types, only the Y2. For these situations the subordinate profile types have been replaced by the main profile type. In contrast, an extra subordinate profile type X1′ has been introduced to indicate the sand-filled channels which developed during the late Holocene. Without this differentiation, no distinction would be shown on the map between these channels and the mud covering the high-lying Pleistocene subsoil, represented by X1 (Fig. 4b).

The general sequence map for the Holocene deposits is constructed on the basis of six profile types (Fig. 5). Along the limit of the coastal plain and in a restricted part in the south, the X1-type occurs, i.e. only a thin cover of Holocene mud is present reflecting the morphology of the Pleistocene subsoil. Above about +2.5 m TAW, basal peat did not develop (Baeteman, 1999). From the limit of the coastal plain towards the centre of the map, a typical (lateral) succession of the following profile types is seen: X1, X2, Z and Y. The presence of the palaeovalley of the IJzer and Handzame rivers is at the origin of this particular distribution. The depressions of the pre-Holocene surface were flooded by the post-glacial transgression as from the early Holocene (Baeteman, 1999; Baeteman and Declercq, 2002). This led to continued accumulation of mud in the tidal flats and sand in the tidal channels. After ca. 7800 cal BP, intercalated peat beds developed alternating with mud. These areas are represented by the Y-type. However, where the Pleistocene surface gradually rises, all the peat layers merge to form a sequence composed entirely of the peat facies (with a thin clastic cover), represented by the Z-type (compare Figs. 2 and 5). The

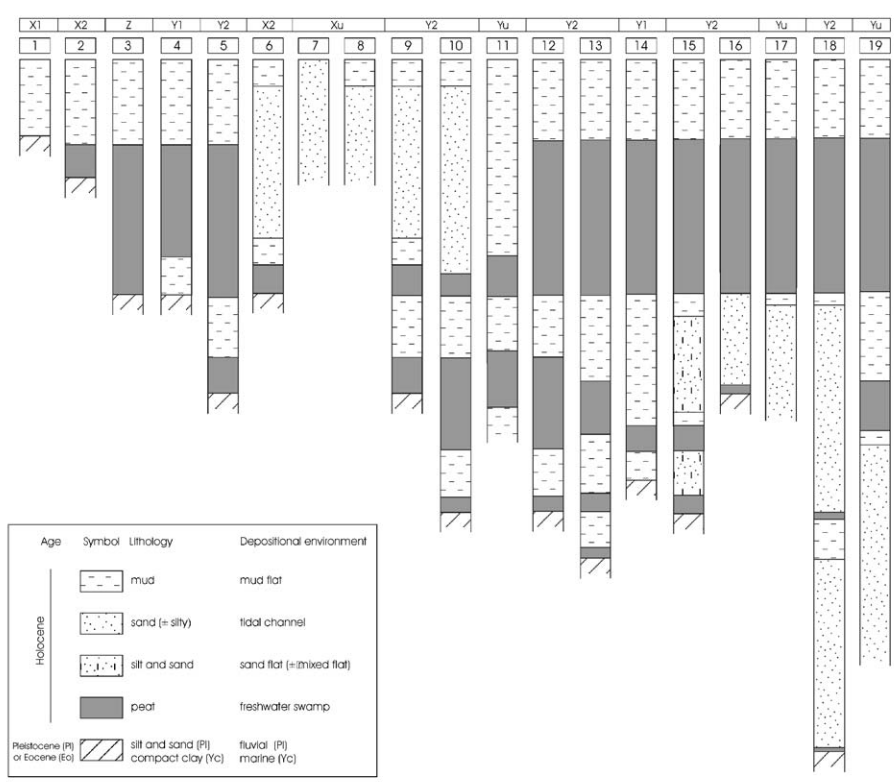

Fig. 6. Explanation of the 19 special profile types used for the construction of the special sequence map (Fig. 7).

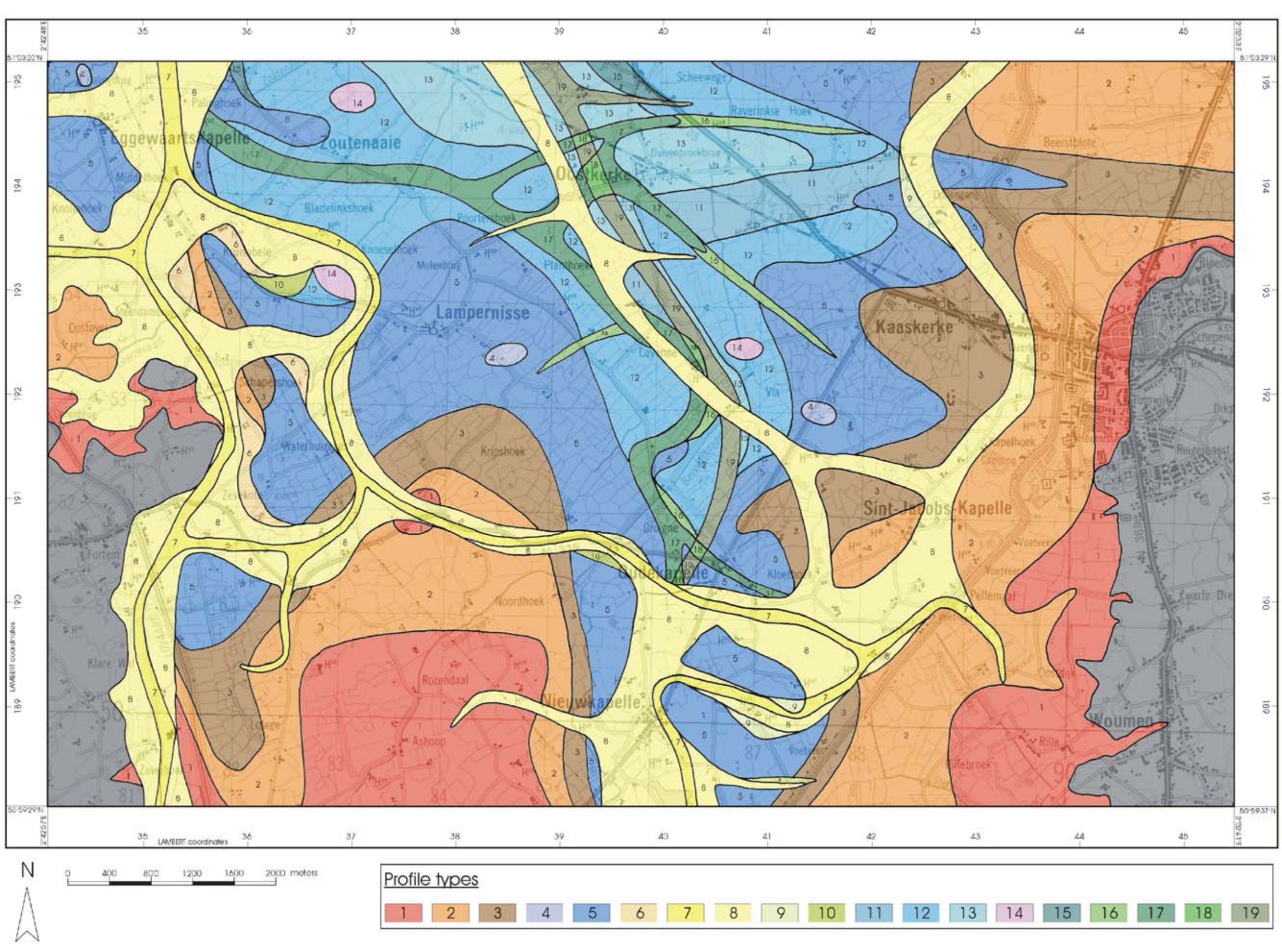

Fig. 7. The special sequence map constructed with the 19 profile types illustrated in Fig. 6. The grey shaded areas are outside the Holocene coastal plain.

profile types X1′ and Xu represent the late Holocene sand-filled channels.

6.3. The special profile types and the special sequence map (Figs. 6 and 7)

The facies units allow a more detailed subdivision of the sedimentary units (at the lowest hierarchic level of the classification system). The facies units form the basis for the special profile types. The latter are not stipulated beforehand in the system and for that reason they are variable in number. The special profile types are constructed according to the prevailing situation and/or the objective of the map. The present application aims to show the lithological characteristics of the Holocene deposits. Therefore facies of depositional environments (see above), also called lithogenetic units, were chosen.

For this application, further differentiation has been carried out for the Y-type in particular. The profile types 1, 2 and 3 are identical to X1, X2 and Z, respectively, from the general sequence map. Profile type 3 differs from profile type 2 in that the thickness of the peat is larger than the thickness of the overlying clastic deposits. In the Y-type special profile types were selected to distinguish the number of intercalated peat beds. Areas with only one intercalated peat bed are represented by profile types 4, 5, 9 and 16; with two intercalated peat beds by profile types 10, 12, 14, 15 and 18; and with three intercalated peat beds by profile type 13. The highest number of intercalated peat beds occurs where the Holocene sequence is thickest (except where it consists of tidal channel deposits).

The selected profile types also reflect very well three phases of tidal channel deposition. The early Holocene tidal channel deposits are found in profile types 18 and 19; the mid-Holocene in profile types 16, 17 and 18. The proximity of a channel is reflected by the presence of silty sand intercalated between peat beds in profile type 15. Finally, the deposits of the late Holocene channels are shown in the profile types 6, 7, 8, 9 and 10. These three phases of channel deposition are found together in the central part of the map where the palaeovalley of the IJzer River is located (cf. Fig. 3). In profile type 7 channel sand is found up to the surface. Here the channel did not silt up into an inter- and supratidal

environment, but was most probably active until the area was embanked.

7. Conclusion

The use of sequence maps allows the representation of the entire Holocene sequence of the coastal plain in a way that considerably exceeds the potential of a conventional geological map. The sequence map together with the contour map of the base of the Holocene deposits provide detailed information on the variability of the lithology, and at the same time, on the history of deposition.

The classification system as developed by Streif is easy to apply and makes it possible to construct and select profile types according to the prevailing situation of the area. Moreover, in the progress of mapping, additional profile types can be constructed. The use of lithogenetic units as mapping units makes the map user-friendly, in particular for non-geologists and for planners.

Acknowledgments

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