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The Streif classification system: a tribute to an alternative system for organising and mapping Holocene coastal deposits

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Abstract

The classification system for organising and mapping Holocene coastal deposits as introduced by Streif is highlighted with respect to mapping requirements. Apart from the requirements such as a user-friendly legend and map, the linkage of the classification system with the history of deposition is demonstrated for the tide-dominated lowlands of the southern North Sea and English Channel. The linkage becomes obvious when considering the effect of the changes in the rate of relative sea-level rise. The difficulties that surrounded the lithostratigraphy of Holocene coastal deposits and the principles of the classification system which eventually made an end to the well-known and long-standing debate about the lithostratigraphy are briefly recalled.

1. Introduction

The coastal lowlands of the southern North Sea and English Channel are embanked areas which developed during the Holocene in a meso- and macrotidal setting. The subsoil is characterised by frequent lateral and vertical changes in lithology. Moreover, the deposits are unconsolidated and very sensitive to compaction. Both the spatial variability of the lithologic composition as well as the susceptibility to compaction form the main causes of geotechnical problems and the related high costs of constructing infrastructural elements (Hageman, 1984). Therefore, it is essential to show the vertical and lateral lithological changes on a geological map. Although not all details can be shown on a map, the map provides good information for rural planners and policy makers on a regional level. To civil engineers the maps serve as a warning for the need to undertake site-specific investigations, preferably in cooperation with a locally experienced geologist. The vertical and lateral lithological changes can be shown by using a sequence map representing the entire vertical sequence of the Holocene sediment body in a three-dimensional way with profile types. However, producing a sequence map should meet some requirements. The map should be user-friendly for everyone and thus be constructed on the basis of a simple and easily readable legend. Plain descriptions of the sediments are preferable rather than the classical stratigraphical terms, meaningless to non-geologists. It is also important that the mapping system is not too rigid so that some alteration can be made for local adaptions without violating the principles of the system.

Mapping a coastal plain implies working with cores because the lowlands are flat areas without outcrops. From the point of view of the mapper, it is essential that the mapping units are of practical use and applicable to the entire area. The different sedimentary units in the cores must be correlated in order to understand their three-dimensional distribution or geometry. Correlating involves the understanding of the interplay of all relevant factors and processes that have built the depositional body. Therefore, facies of depositional environments form excellent mapping units. Streif (1972) introduced facies for the description of sedimentary units and called them lithofacies. The latter are very relevant as mapping units. However, using lithofacies deviates from classical lithostratigraphic units.

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Above all, the legend and map must reveal and reflect the geological history or the infill of the plain at first glance. Therefore, it is essential that the organisation of the legend is constructed on a geologically based concept. This is not an easy job while producing sequence maps. It must be avoided that individual profile types are constructed without stratigraphic interrelationships, because this results in a mosaic of many independent coloured areas on the map (cf. De Moor, 2002). Mapping may not be looked upon as a statistical treatment of data. Streif's classification system for organizing and mapping coastal lowland deposits fulfils these requirements.

This paper aims to highlight the ingenuity of the classification system introduced by Streif and, at the same time, to encourage wider use of it. The aim will be addressed by demonstrating how the classification system reflects the depositional history of the lowlands of the southern North Sea and English Channel, in particular the linkage of the classification system with the effect of the changes in the rate of relative sea-level (RSL) rise on the depositional history of a coastal plain. The practical use of the system will be shown with an example of how it can be easily adapted for the purpose of a particular geological situation.

2. The lithostratigraphy of the Holocene coastal deposits and its difficulties

The general character of the Holocene sedimentary sequences in the coastal lowlands bordering the southern North Sea and English Channel is typified by a complex pattern of tidal and fluvial deposits intercalated with peat beds. This paper is not concerned with the origin of the multiple intercalated peat beds, but with the organization of them into a classification system and with the presentation of their complexity on a map.

History teaches us that making a lithostratigraphic correlation of clastic deposits and peat beds is difficult, if not impossible, because the number, lateral extent and elevation of the peat beds are highly variable. Moreover, peat beds were radiocarbon dated and provided a chronology. The latter was then intermingled with the lithostratigraphy, bringing along confusion. An additional, but major, problem was caused by the interpretation of the peat beds as regression phases and the clastic deposits as transgressive phases (see e.g. De Jong and Hageman, 1960; Hageman, 1963; Brand et al., 1965; Jelgersma et al., 1970; De Jong, 1971; Roeleveld, 1974; Zagwijn and van Staalduinen, 1975).

Since the introduction of a subdivision of coastal deposits by Dubois (1924), introducing the well-known Calais and Dunkerque deposits, and the further advocating of it in Belgium by Tavernier (1948), the stratigraphy of coastal deposits has been subject of a long-standing debate in Belgium, The Netherlands, England and northern Germany. For overviews of the national and regional debates which surround this particular Holocene lithostratigraphy, see e.g. Streif and Zimmermann (1973); Barckhausen et al. (1977); Baeteman (1981, 1987); van Loon (1981); Berendsen (1984); Wheeler and Waller (1995). From these papers it is apparent that the variability of the deposits and the admixture of chrono- and lithostratigraphy are the main constraints for fitting Holocene coastal deposits into simple, but formal, stratigraphic schemes.

Streif made a clean sweep with all these difficulties and proposed a totally new and ingenious system (Barckhausen et al., 1977). It should be mentioned that the Dutch Geological Survey recently made a complete revision of their Quaternary lithostratigraphy, still following the international stratigraphic guidelines but paying attention in separating lithostratigraphy from bio- and chronostratigraphy (Ebbing et al., 2003; Weerts et al., 2005). The renewed official lithostratigraphy for the Quaternary deposits in Belgium does not show any progress yet. The Holocene coastal deposits are still subdivided into Calais and Dunkerque Members (Bultynck and Dejonghe, 2001).

3. The Streif lithological classification system

The lithological classification system was introduced by Streif in 1977 as a tool for mapping Holocene coastal lowlands in the form of sequence maps (Barckhausen et al., 1977; Streif, 1978). The system has been successfully applied in North Germany (see Streif, 1998) and in Belgium (Baeteman, 1981; Bertrand, 2001; Bogemans and Baeteman, 2003; Bertrand et al., 2003).

The Streif classification system deviates from the formal lithostratigraphic requirements (Hedberg, 1976; Salvador, 1994). The Holocene deposits are subdivided according to a hierarchic system on the basis of the vertical succession and the lateral interfingering of clastic sediments on the one hand, and peat beds on the other hand. The three distinguished hierarchic levels are the complexes, the sequences and the facies units (Fig. 1). The complexes and sequences have well-defined elements, while the facies units are variable in number. The three hierachic levels form the basis for the representation of the following profile types: the main profile types (X, Y and Z), the subordinate profile types (X1,…, Z3) and the special profile types. The sequences are most often used to produce a general sequence map on the basis of subordinate profile types. Fig. 2 is an example of such a general sequence map showing the landward portion of the western coastal plain of Belgium. Further detail of the subordinate profile types, more in particular with respect to lithological differentiations, can be obtained by using facies units and

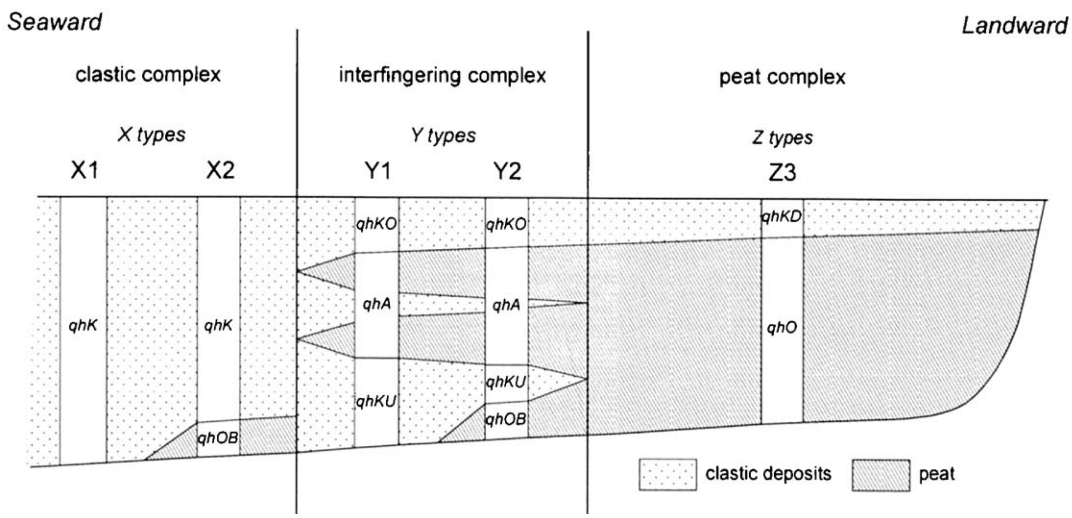

Fig. 1. Schematic cross-section showing the first and second hierachic levels of the Streif classification system including the well-defined elements, i.e. the complexes with principle profile types (X, Y and Z) and the sequences with subordinate profile types (X1,…, Z3). The labels for the sequences are: q: Quaternary, h: Holocene, K: clastic, A: splitting-up, O: organic, KO: upper clastic, KU: lower clastic, KD: clastic cover. The facies units at the lowest hierachic level showing detailed lithologic information are variable and only represented in the special profile types (Redrawn from Streif, 1978).

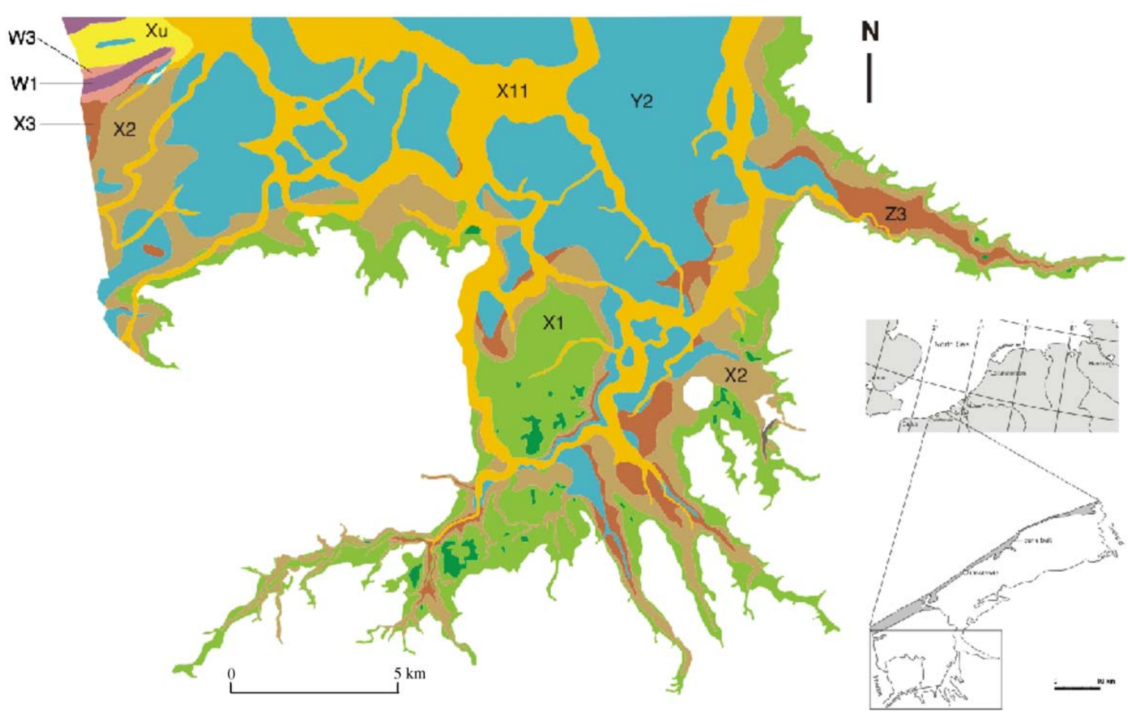

Fig. 2. General sequence map of the landward portion of the western Belgian coastal plain. The inset map shows the entire coastal plain with indication of the mapped area. See Fig. 4 for the explanation of the profile types.

producing a special sequence map on the basis of special profile types to be selected individually according to the prevailing local situation (see e.g. in Bertrand and Baeteman, 2005). However, even at the level of the sequences, the interrelationship between the clastic layers and the peat beds is quite well demonstrated.

4. The relationship of the Streif classification system with the depositional history of tide-dominated coastal lowlands

Although initially not meant as such, the classification system reflects well the depositional history of the

coastal lowlands bordering the southern North Sea and the English Channel. This becomes clear when considering the effect of the changes in the rate of RSL rise on the processes of coastal change. Each coastal plain has its own depositional history with punctuated coastal changes that occur locally. However, the general framework of infill is identical and is governed by the following controlling factors: rate of RSL rise, sediment budget, morphology of the pre-existing landscape, accommodation space, sediment compaction and, in some areas, neotectonic setting (Baeteman, 1998; Beets and van der Spek, 2000). During the Holocene infill of the tidal basin, initially caused by the RSL rise, the relative importance of the individual factors changed in the course of time. The interrelation between the controlling factors will be discussed with respect to the changes in the rate of RSL rise.

4.1. The changes in the rate of RSL rise and its effect on the infill of the tidal basins

A comparison between the Holocene sequences of these coastal lowlands shows similarities in the general tendency of infill (see Table 1 for the regions and references). However, not all the sea-level histories give data prior to 7000 cal BP. A rapid RSL rise (at a rate of 7–5 m/ka) in the early Holocene resulted in a rapid lateral expansion of tidal impact in the coastal plain (Fig. 3). This is expressed by considerable vertical sediment accumulation if sufficient sediment was available. Intertidal flat and low salt marsh environments developed, however, without any peat formation. Insufficient sediment supply resulted in the origin of lagoons. This period is mainly governed by the direct impact of the RSL rise and the effect of the other controlling factors is subordinate.

The rate of RSL rise declined between 7800 and 7500 cal BP, resulting in a slower landward shift of the tidal environments and a more or less stable position of the coastal barrier. Sediment supply now outpaced the accommodation space created by the (reduced) sea-level rise and the tidal basin was rapidly filled in by sediment. This period is characterised by the transition from dominant tidal sedimentation to a beginning of peat growth, first locally and short-lived and in landward areas. Slightly different rates of RSL rise in different areas have been calculated for this period: 2–4 m/ka (Waller et al., 1999), 2.5 m/ka (Denys and Baeteman, 1995) and 2 m/ka (Haslett et al., 2000). In the period following the first decrease in the rate of RSL rise, the direct impact of the RSL rise is subordinate to the impact of sediment budget and the effect of local variations in the distribution of sediments (Baeteman, 1999).

A further decline in the rate of RSL rise to an average of 1 or 0.7 m/ka occurred at about 5500–5000 cal BP. Sea level was close to its maximum and sediment supply exceeded the creation of accommodation space.

Table 1
Age of the oldest recorded intercalated peat bed in the lowlands of the southern North Sea and English Channel

Region	^{14}C years BP	cal BP	References
N. Germany			
Ostlichen Wesermarsch	5995±40	6800	Preuss (1979)
Ostfriesland–Woltzeten	5265±55	6000	Streif (1972)
Emsmunding	4790±80	5500	Streif and Zimmermann (1973)
Niedersachsen	6500	7375	Caspers et al. (1995)
Sylter marsch–Schleswig-Holstein	5115±200	5900	Willkomm (1980)
The Netherlands			
Groningen	6460±145	7400	Roeleveld (1974)
Friesland	6200±45	7150	Griede (1978)
NW Friesland	5045±60	5750	Ente et al. (1975)
N. Friesland	5540±40	6300	Ente (1977)
S. Holland	5890±80	6750	van der Valk (1996)
Zeeland	5455±40	6306–6181	Vos and van Heeringen (1997)
Belgium			
Western coastal plain		7790	Baeteman (1991)
France			
Northern France	6500	7400	Sommé (1995)
England			
Southeast England	7050±100	7790	Devoy (1982)
Fenland Embayment		7180	Brew et al. (2000)
Romney Marsh		6800	Waller and Long (2003)
Solent		5700	Waller and Long (2003)
Somerset levels		6700	Haslett et al. (2000)

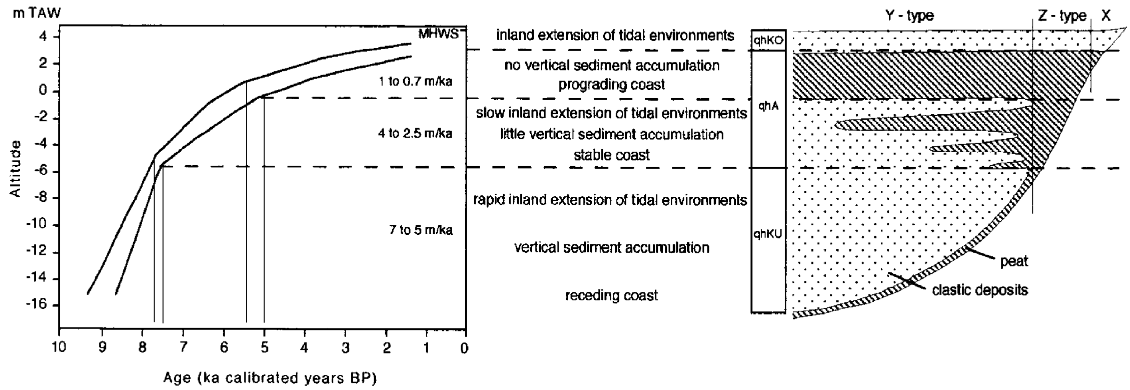

Fig. 3. Schematic representation of the linkage of the Streif classification system with the effect of changes in the rate of RSL rise on the Holocene depositional history and coastal processes. The sea-level curve is drawn as an envelope between the maximal level of the lowest mean high water and the upper mean sea level limit (MHWS: mean high water spring tide; sea-level curve redrawn from Denys and Baeteman, 1995; Baeteman and Declercq, 2002).

Landward migration of the tidal sedimentary environments stopped completely, the stabilization of the shoreface has shifted to shoreface accretion and the shoreline prograded beyond the present-day position. Periods of peat growth lasted longer and the lateral extension of the freshwater marshes became more widespread. This period corresponds well with the development of the uppermost and most widespread intercalated peat bed (e.g. Streif and Zimmermann, 1973; Roeleveld, 1974; Van Der Woude and Roeleveld, 1985; Vos and van Heeringen, 1997; Baeteman, 1999; Waller et al., 1999; Brew et al., 2000; Waller and Long, 2003). This almost uninterrupted peat accumulation which lasted about 3000 years in most of the areas could keep pace with the slow RSL rise.

The thick peat bed is covered with clastic deposits as a result of the re-entrance of the tidal system which was accompanied by deep tidal channel incisions, shoreface erosion and a landward shift of the coastline in the late Holocene. The widespread inundations and the return to tidal sedimentation were not caused by a RSL rise but are the result of an imbalance of sediment supply and accommodation space (Beets et al., 1994; Baeteman, 2005).

Long et al. (2000) also recognised this typical coastal evolution for southern England. The authors suggested a tripartite model of estuary development characterised by an early and late Holocene phase of lateral and vertical expansion, separated by a significant phase of estuary contraction during the mid-Holocene when the lateral extent of intertidal environments reduced significantly to the advantage of peat formation. The expansion in the late Holocene as described in the model, however, was of greater lateral than vertical importance, because the reduced RSL rise did not create significant accommodation space.

After the first decline in the rate of RSL rise, RSL rise is no longer the driving force when filling the basins with sediments. Sediment supply then gradually catches up with RSL rise. This coincides with the beginning of the period that the tidal basins were filled and the first intercalated peat beds developed. The comparison, however, shows that the timing of the formation of the first intercalated peat varies in the different lowlands. This is mainly a result of the shape and elevation of the pre-Holocene surface (Baeteman and Declercq, 2002; Baeteman et al., 2002), the availability of sufficient sediment for the sedimentary surface to silt up until supratidal level (Baeteman, 1999) and the existence of locally determined freshwater conditions. It should be mentioned that when searching for early Holocene organic sediments or deep-seated peat beds in the literature, it was not always clear whether the basal peat or an intercalated peat was meant, because of the lack of stratigraphical information (e.g. Devoy, 1982; Waller and Long, 2003). Therefore, only peat beds from reed swamps or salt marshes have been considered and woody peat has been excluded, because the intercalated peat beds originated as supratidal peat growth and were short-lived (Baeteman, 1999; Baeteman et al., 1999). Woody peat of early Holocene age is most probably associated with the basal peat or peat which developed closely linked with valley systems under eutrophic conditions and independently of sea-level rise.

The comparison between the Holocene sequences of the lowlands clearly shows that the formation of intercalated peat beds started not earlier than 7800 cal BP (Table 1). Of course, the question arises whether older intercalated peat beds could not develop because of a too high position of the pre-Holocene surface or whether they have not been recorded yet. The latter is most unlikely in the areas under consideration, because the age of the basal peat and the elevation of the pre-Holocene surface, as shown in the stratigraphical cross-sections, indicate that the areas were not yet affected by the Holocene transgression prior to 7800 cal BP.

On the basis of this comparison, it is suggested to put the beginning of the estuarine contraction of the model described by Long et al. (2000) as early as 7800 cal BP. This date might be suggested as well for the first deceleration of the Holocene RSL rise (recorded onshore). Apart from the sea-level curve, the age for the first decline in the rate of RSL rise can also be inferred from the age of the earliest intercalated peat bed under the condition that sediment supply is in balance with the rate of RSL rise. However, if the pre-Holocene surface of the tidal basin is not deep enough for a sequence to be deposited as from the beginning of the Holocene, early Holocene changes could not be recorded in the sedimentary sequence due to the lack of accommodation space. This is the case in most of the lowlands in southern England.

This general pattern of coastal deposition in relation to the rate of RSL rise is somewhat different in microtidal coastal lowlands. This is the case for Holland (The Netherlands) characterised by more wave-dominated conditions. Sediment supply was insufficient in relation to the size of the tidal basin to be filled and the area remained largely subtidal (lagoonal) in the period prior to 6850 cal BP. After the second decline in the rate of RSL rise (6300–6100 cal BP), parts of the basin were rapidly filled in and changed into a peat swamp together with the beginning of the progradation of the coastal barriers (Westerhoff and Cleveringa, 1990; Beets et al., 1992; Van der Valk, 1996; Beets and van der Spek, 2000). Tidal activity was also limited in the back of the Zeeland basin (The Netherlands) in the period between about 8650 and 8000 cal BP, and the rapid RSL rise together with a low sedimentation rate due to limited supply of sediment and low transport capacity resulted in a shallow permanently submerged lagoonal environment (equivalent to the Velsen Layer; Vos and van Heeringen, 1997).

4.2. The Streif classification system and the linkage with the effect of changes in the rate of relative sea-level rise

The linkage of the classification system with the effect of changes in the rate of RSL rise becomes obvious at the level of the sequences in the interfingering complex (Y-profile types, Figs. 1 and 3) which is occurring in the major part of the plains. Apart from the basal peat, the sequences in the Y-types are the lower clastic, the splitting-up and the upper clastic sequence. The lower clastic sequence (qhKU) consists of only clastic deposits and is underlying the lowermost intercalated peat bed. The splitting-up sequence (qhA) consists of intercalated peat beds (only one in a special case) alternating with clastic layers. The upper clastic sequence (qhKO) consists of only clastic deposits and overlies the uppermost intercalated peat bed.

This tripartite subdivision in the lithological classification system corresponds well with the tripartite model of development controlled by the changes in the rate of RSL rise together with the above-discussed factors for tide-dominated coastal lowlands. The lower clastic sequence corresponds with the period prior to about 7800 cal BP when the infill was characterised by only deposition of sediments due to the dominant impact of the rapid RSL rise. The splitting-up sequence reflects the two retardations in the rate of RSL rise. The first one resulted in a sedimentary sequence consisting of peat beds alternating with tidal flat deposits in the period between about 7800 and 5500 cal BP. The second one resulted in the development of the thickest and uppermost intercalated peat bed. The upper clastic sequence represents the re-entrance of the tidal system.

The close relationship between the sequences and the periods of different rates of RSL rise form a linkage which in this way indirectly reflects time of deposition.

5. The application of the Streif classification system in the Belgian coastal plain

In view of the aim to link a mapping system closely with the history of deposition, additional sequences have been added to the classification system in the course of the systematic mapping of the Belgian coastal plain. The examples also demonstrate how easily the system can be altered. The original schematic cross-section from Streif (Fig. 1) has been slightly changed according to the prevailing geological situation in the Belgian plain (Fig. 4).

The X1 profile type of Streif's system stands for clastic deposits directly overlying Pleistocene (or older) deposits. However, in the Belgian plain, three distinct areas can be recognised, although all being of X1 type. One area is a rather narrow zone located along the landward limit of the coastal plain where the Pleistocene deposits are occurring at a relative high elevation, hence covered only by a thin layer of Holocene tidal deposits (see Figs. 2 and 4). The second area spans the seaward portion of the plain where the basal peat and early Holocene deposits have been eroded by tidal scour. These two areas are never adjacent, and therefore there is no need to make a further differentiation at this hierarchic level. In the special sequence map on the basis of facies units, however, further differentiation is represented. Moreover, the thickness of the Holocene deposits can be inferred from the contour map of the base of Holocene deposits, which should always accompany a sequence map. A quite contrasting situation is the sand-filled tidal channels, which eroded deeply into the Holocene and Pleistocene deposits during the late Holocene. In order to represent explicitly the sand-filled channels, a X11 type has been introduced (Bertrand, 2001). The advantages of representing the sand-filled channels as X11 type are many and this

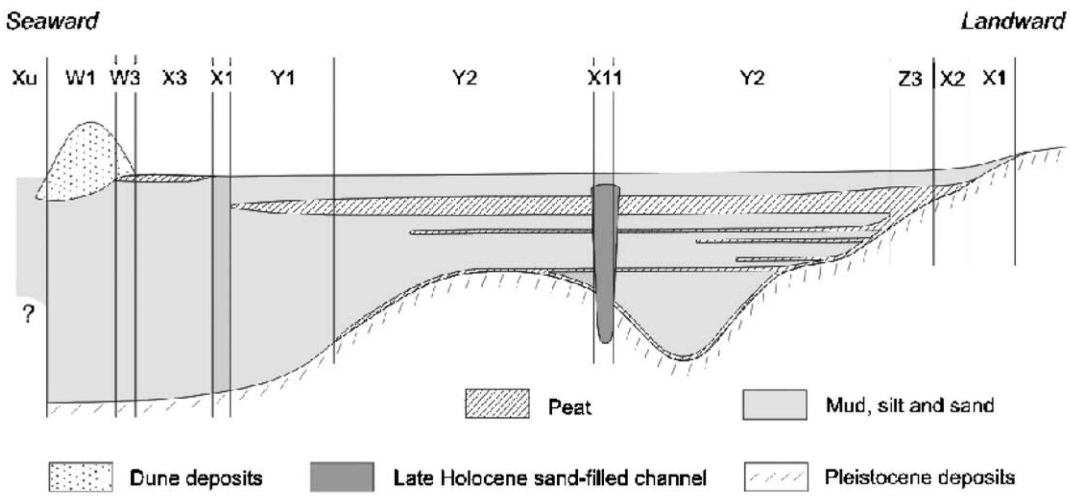

Fig. 4. Schematic cross-section adapted for the Belgian coastal plain with explanation of the profile types. The absence of basal peat in the seaward area suggests an erosive base.

demonstrates the user-friendly aspect of the map. In the central and landward part of the coastal plain, the channels are the only areas which are not sensitive to compaction and land subsidence. Therefore, the X11 type represents the areas suitable for building roads or small houses. The sand-filled channels are also fresh-water aquifers and one of the typical characteristics of the late Holocene sand-filled channels is their potential for liquefaction. Therefore, it is essential to know exactly their location when infrastructural works are planned.

Coastal dune deposits are not explicitly indicated in the Streif classification system but included in the X type (clastic complex). Because the dunes in the Belgian coastal area represent a rather important region together with the presence of coastal inland dunes, an extra principle profile type W was introduced. A further differentiation was made according to the absence or presence of a peat bed underneath the eolian deposits. This is represented as profile type W1 and W3, respectively (Fig. 4).

The classification system as such can also be used for computerisation. All borehole data of the western Belgian coastal plain are currently being transferred into a database designed in Microsoft Access. The structure of the database is based on the three hierarchic levels of the Streif classification system. This structure easily allows various ways of data retrieval. Data queries of the borehole descriptions can be done according to the main profile types, the sequences and the facies units. The results can then be exported into Excel for processing or visualisation in a GIS. The latter forms the basis to produce the sequence map. The system also allows a map showing an individual sequence or the occurrence of a particular profile type to be produced with little extra work.

6. Final considerations

In view of the very practical aspects and ingenuity of the Streif classification system, it is surprising that it is not yet widely applied. One reason may be that the system significantly deviates from classical lithostratigraphy. Alternatively, there is no sufficient interest to map coastal lowlands. The system satisfies all the requirements to make user-friendly sequence maps in a simple and easy way. Moreover, it reflects the development of Holocene coastal deposition in tide-dominated coastal lowlands.

The philosophy of the Streif classification system is based on the alternation of peat beds and clastic deposits. The same concept could be applied to wave-dominated coastal lowlands, including barrier deposits and back-barrier deposits, or to river-dominated coastal lowlands, including the interfingering of fluvial and coastal deposits. The main characteristic of the classification scheme is that it reflects the depositional history of the basin to which it is applied. Although originally intended for mapping purposes, the classification system should also be regarded as useful for palaeogeographical reconstructions or sea-level histories, e.g. to discriminate between basal peat and intercalated peat beds. Applying the system helps to obtain a better view of the sedimentary sequences and their interrelationship, and it furthers understanding of the coastal evolution.

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