APPENDIX E

RSDYK2008 – GEOLOGY

1 GEOLOGICAL SETTING

The information about the geological setting of the test sites is summarized from previous works of researchers who worked in the area, from regional studies, and from the general geological history of the Netherlands.

1.1 Regional Geologic history

According to Van Staalduinen, at the end of the early Tertiary, the North Sea Basin developed in northwestern Europe and the later territory of the Netherlands was located at the southern tip of the basin. During the Tertiary and the Quaternary, the basin subsided gradually due to the continuous filling up with sediments (Van Staalduinen et al., 1979; Ten Cate, 1982).

According to Ten Cate (1982), the configuration of the coastline of the Netherlands was determined by the tectonically active area of the Central Graben and Lower Rhine embayment in the southeast in the latest part of the Tertiary. The river Rhine had its course towards the northwest and built a delta in the Central Graben area. In the northeast, delta where built on by North German on ancient Baltic rivers. This indicates that the large part of the deposits has been laid down in a coastal area at the end of the Tertiary. These deposits are referred deposition either in a shallow sea not deeper than ten meters, or in coastal swamps, lagoons and lower river courses. However, at present they are found at considerable depth below sea level, sometimes as low as 400 to 600m. Variations in intensity of tectonic movement, changes in river courses and climatic changes with glacial and interglacial periods have determined the geological genesis of the subsiding basin in the Netherlands during the Quaternary (Ten Cate, 1982).

During the Saalian glaciation (Figure 3.2) the inland ice covered Northern Europe again, as in several glacial periods before Quaternary, but this time it included the northern half of the Netherlands. This event had a profound influence on both the sedimentation pattern and the morphology of the landscape. The rivers Rhine and Meuse were forced into westerly courses. The ice sheet that pushed by pre-glacial and river sediments formed the hills in the central and eastern part of the country.

The Saalian glaciation was followed by the melting of the inland ice during the Eemian interglacial and at the end of the Weichselian (remained in the Per-glacial zone without inland ice) resulted in a rise of sea level and the sea penetrating far more to the east. According to Ten Cate, during the sea level rising at the end of the Weichselian, there were three zones of sedimentation: a littoral sandy zone of coastal barriers and dunes, a clayey zone of tidal flats, salt marshes and brackish lagoons and, at a greater distance from the sea, a zone of peat formation in a fresh water environment. These zones were shifted towards the east as the sea gradually flooded the former dry North Sea floor.

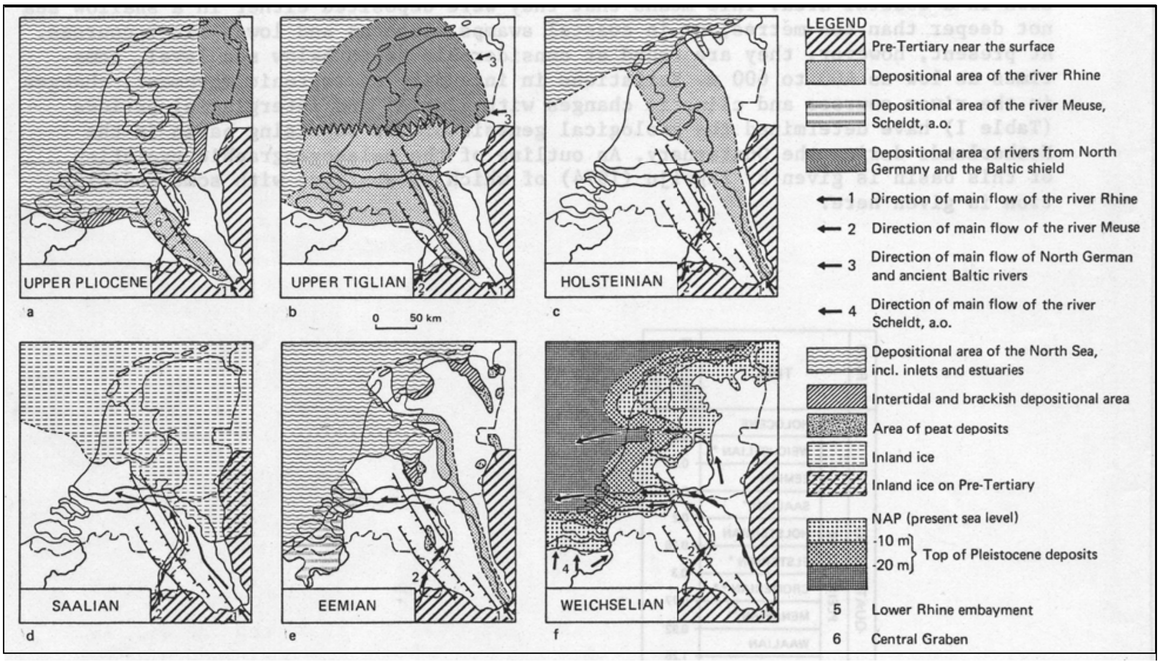

Figure 1. Palaeogeographic map of the Netherlands during the Upper Tertiary and the Quaternary (Ten Cate, 1982)

1.2 Holocene geology of the study area

The regional geological setting of the study area was formed largely in the quaternary by the direct and indirect activities of the river and the sea (Ten Cate, 1982). The Dutch coastal area was drowning due to the melting of the Weichselian glacial ice sheet. The melting of this glacial ice in combination with the tectonic movements resulted in sea level rising. The western Netherlands was gently westward slopping plain at the end of the Pleistocene. This indicates that the geology of the western Netherlands is greatly influenced by the Holocene deposits (Figure 3.3).

At the start of the Holocene, climate change causes a very rapidly sea level rise accompanied by a rise of regional groundwater table. As the result of the rise of the water table, peat growth took place in various places (Ten Cate, 1982). Sedimentation in the Holocene period started with the formation of peat (basal peat). The battle between the land and the water increased as the sea level continued to rise rapidly. As the result, the coastline moved further inward and reached the Dutch territory in about 8000 BP (Bijlsm, 1982). The Palaeo-geographical map above shows that the marine sediments deposited in the coastal area while the fluvial sediments was deposited in the perimarine area (Figure 3.3a). According to Bijlsma, the rate of sea level rise reduced to 27cm/100years during 5000BP (Bijlsma, 1982) and the extension of marine deposit reduced significantly (Figure 3.3b). The sea level rise rate was extremely slow in about 3700BP and more stable river pattern was formed; however, the groundwater level was still high to develop a thick peat layer over the marine and fluvial deposits (Figure 3.3c). This peat forming process continued until 700BP in the central part of the Netherlands (Figure 3.3d). When the peat layer was inundated and/or eroded by the water, the marine or fluvial sediments deposited over it (Figure 3.3e).

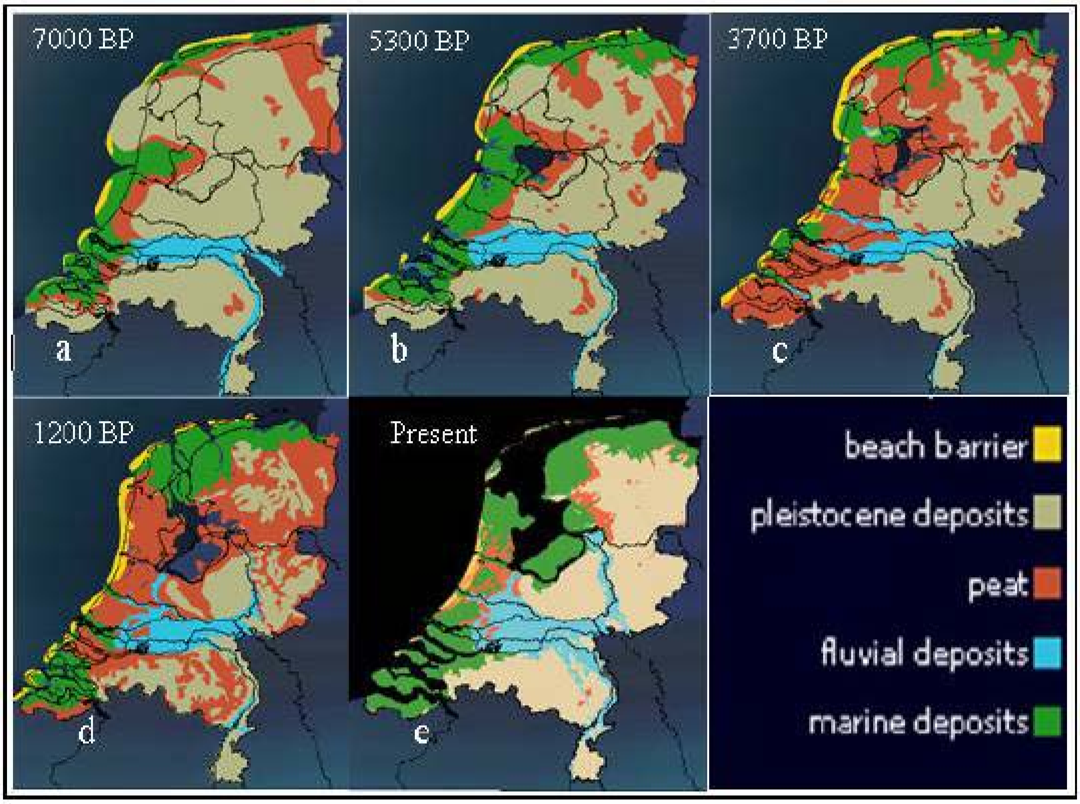

Figure 2. Palaeogeographic map of the Netherlands during the Holocene period (source: took from Mahabubur 2007)

During this Holocene period, the area was located in the perimarine zone, where the deposits were formed under the influence of the sea level rising interacting with river input from the east. Specifically the study area is located on the Holocene deposits of The Netherlands, which are dominated by the thick layers of peat and clay. According to Bosch and Kok, these deposits have two main origins; namely marine and fluvial deposits. In the Netherlands, the Holocene fluvial deposits are named as Gorkum and Tiel depending on their correlation to Calais and Dunkirk marine deposits (Bosch and Kok, 1994).

The marine (Calais and Dunkirk) deposits were formed in a tidal flat depositional environment, normally a plain gently dipping towards the seacoasts with marked tidal rhythms. The deposits comprise very silty and moderately silty, massive clays coarsening upward (Bosch and Kok, 1994). According to the classification made by Reineck and Singh based on the sedimentation process, the fluvial deposits of the area are grouped into three main groups (Reineck and Singh, 1973):

- The channel deposits: are sediment deposits formed mainly from the activity of river channels. It comprises channel lag, point bar deposits, channel bar deposits and channel fill deposits of sand.
- Bank deposits: are riverbank sediments, which are deposited during the flood period. Levee deposits and crevasse splay deposits of sand and clay are included in these deposits.
- Flood basin deposits: are essentially fine-grained sediment deposits formed during heavy floods when river water flows over the levees into the flood basin. They include flood basin deposits and marsh deposits.

The Holocene deposits of the study area belong to Westland and Kreftenheye Formation and both formations being mainly formed by river deposits (Bosch & Kok, 1994).

Different layers are distinguished within the westland formation. This formation overlies the Kreftenheye Formation comprises the fluvial sediments (Gorkum and Tiel deposits) together with the clastic marine deposits and intercalated peat layers (Bosch & Kok, 1994). In the Reeuwijk, area the formation consists predominantly of complex alternations of floodplain clay deposits with Holland peat. Lenses of sandy clay levee and sand channel deposits occasionally interrupt these deposits. Abrupt changes of the soil type in short distances complicate the geology of the area in general.

The Kreftenheye deposits mainly consist of gray, coarse sand and gravel with plant remains. The silt-less sand contains calcareous material. Locally the sand is intercalated with organic clay layers. The lower boundary is located at approximately 20 m below NAP; however, it may reach 10m deeper at channel infill locations (Bosch & Kok, 1994).

The Geological Map of Reeuwijk (1:50000) (Bosch & Kok, 1994) is shown in Figure 1.

Legend (Holocene deposits):

G0: Holland peat

rC2: Holland peat on an alternation of Gorkum (flood-plain and levee deposits) and Holland peat on Gorkum deposits (channel deposits)

rG2: Holland peat on an alternation of Gorkum deposits (flood-plain and levee deposits) and Holland peat

C2: Holland peat on Callais III Deposits (tidal flat deposits) on an alternation of Holland peat and Gorkum deposits

C2..: Holland peat on Callais III Deposits (tidal flat deposits) on Gorkum deposits (channel deposits)

rC0: Holland peat on Gorkum deposits (channel deposits)

rBd2g: Tiel deposits (channel deposits) on an alternation of Holland peat and Gorkum deposits (flood-plain and levee deposits)

rD0g: Tiel deposits (channel deposits, locally covered by levee deposits)

rA0k: Tiel deposits (flood-plain deposits) on Holland peat on Gorkum deposits (channel deposits)

rD0k: Tiel deposits (flood-plain deposits on channel deposits)

C0: Tiel deposits (flood-plain deposits)

rD1k: Tiel deposits (flood-plain deposits) on Gorkum deposits (flood-plain and levee deposits) on Gorkum deposits (Channel deposits)

rF2k: Tiel deposits (flood-plain deposits) on an alternation of Holland peat and Gorkum deposits (flood-plain and levee deposits)

rA2k: Tiel deposits (flood-plain deposits) on an alternation of Holland peat and Gorkum deposits (flood-plain and levee deposits) on Gorkum deposits (channel deposits)

rF0k: Tiel deposits (flood-plain deposits) on Holland peat

F3k: Tiel deposits (flood-plain deposits) on an alternation of Holland peat and Gorkum deposits (flood-plain and levee deposits)

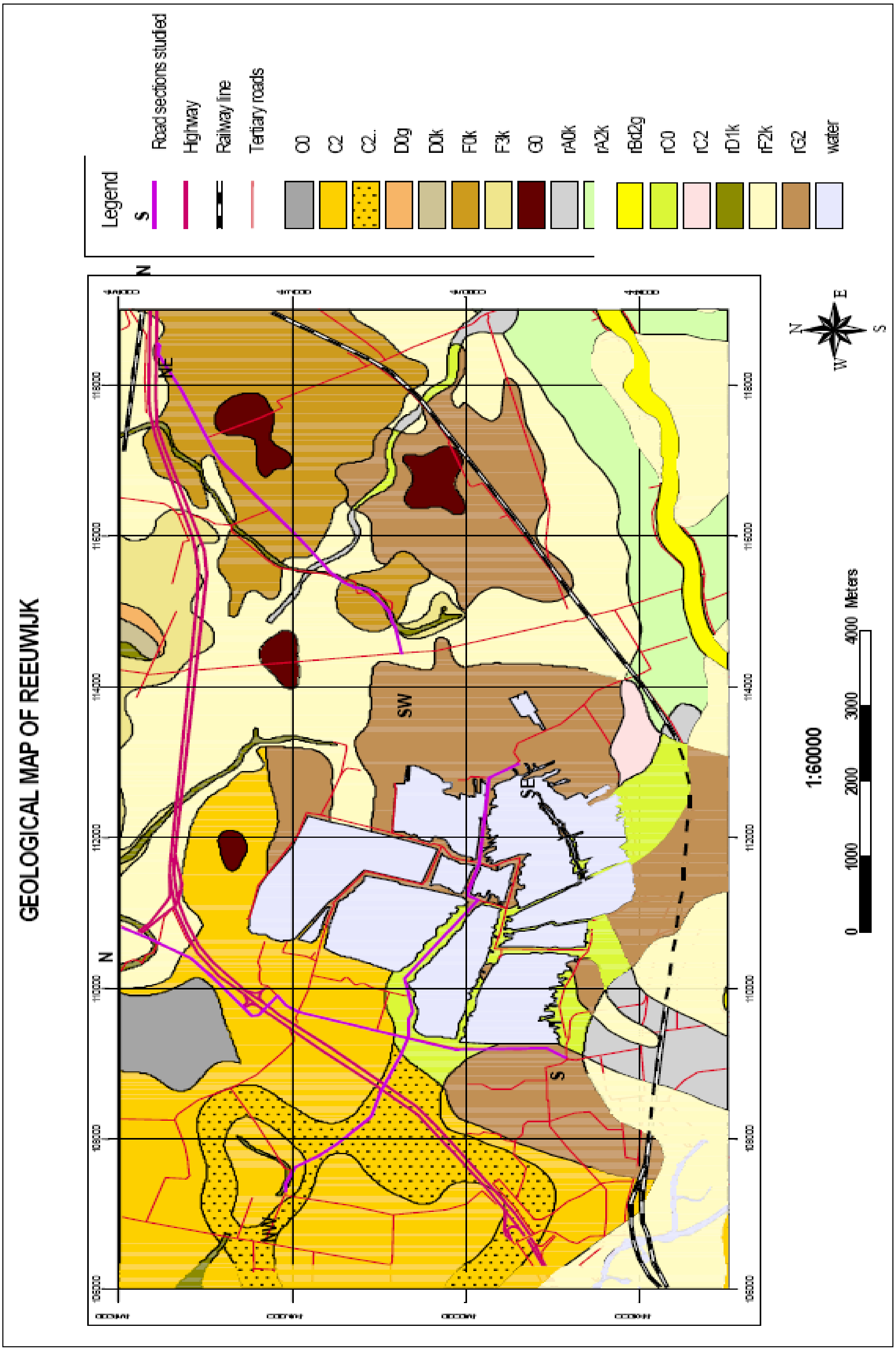

Figure 1. Geological map of the area around Reeuwijk (after Bosch and Kok, 1994) (Legend see page before).