4.6. The coastal section of Cape Mamontov Klyk

4.6.1 General profile

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The costal section studied in detail extends from the Nuchcha Dzhiele River mouth 2.2 km to the east to a deep thermo-erosional ravine close to the navigation signal of Cape Mamontov Klyk (Figure 4.4-3 box B and Figure 4.4-4). The coastal relief is characterized by the steep walls of Yedoma, which are interrupted by the wide river valley of Nuchcha Dzhiele with alluvial terraces and by flat several thermoerosional valleys (logs) and smaller deep thermoerosional ravines (ovrages)

The exposure is divided into four main units (A to D). The first three, composing the steep coastal wall, are assigned to the Late Pleistocene (?) and the fourth unit consists of the various Holocene deposits.

The lowest Unit A consists of yellowish-grey, weakly bedded fine-grained sand without visible plant remains. The cryostructure is massive and the gravimetric ice content amounts 25 to 40 wt%. Many stripped ice-ground alternations, so-called polozatic ice wedges, were formed within the unit A. Additionally, the sand unit is penetrated from above by huge ice wedges and a few small ice wedges. A transition zone of about one meter thickness, which contains numerous *in situ* grass roots, covers the organic-free sands. The Unit A is considered as fluvial (?) deposit. The transition zone reflects shallow facies conditions of a flood plain.

The subsequent Unit B consists of an alternation of four cryoturbated peaty horizons and of weakly laminated, dark-grey silty to fine sandy interbeds. The peaty horizons mostly consist of brown moss peat and they are very ice-rich (gravimetric ice content 100 to 200 wt%). The sandy interbeds contain a lot of plant remains like grass roots and twig fragments. They are relatively ice-rich (gravimetric ice content about 80 wt%) and have a banded cryostructure. Various generations of small ice wedges were observed within unit B, which can be assigned to individual peaty horizons (s. chap. 4.6.3). Often the thin ice wedges penetrate into the lower unit A. The sediments of unit B are most probably formed by alternating processes of alluvation in the flood plain.

The transition to Unit C is gradually without a sharp boundary. The unit C represents the Ice Complex deposits with their typical huge ice wedges reaching from about 25 m a.s.l. down below the sea level in some locations. The Ice Complex sequence is composed of many paleosols with peat inclusions and numerous twig fragments. This unit is subdivided into two subunits. The lower horizon of about 0 to 2 m a.s.l. consists of cryoturbated peat soils with silty to fine sandy interbeds (alevrite). The main part of unit C is formed by several weakly developed paleosol horizons and silty to fine sandy interbeds with in situ grass roots and fragments of shrub twigs. The gravimetric ice content of unit C varies between 50 to 100 wt% for interbeds and 100 to 150 % for paleosol horizons. The cryostructure of the segregated ground ice is banded and lens-like reticulated. The Ice Complex deposits are formed on a wide flat alluvial accumulation plain probably extending from the Pronchishchev Range to the Laptev Shelf (Figure 4.4-1). In the studied coastal outcrop the Ice Complex deposits of unit C are exposed from sea level up to 20-25 m a.s.l. between 500 and 1500 m east of the Nuchcha Dzhiele River mouth. This central part of the section is flanked in the West and the East by deposits of the units A and B outcropping up to 10 m a.s.l.. Thus we conclude, the modern coast cuts a former depression in the sandy and peaty-sandy deposits of the first units, which was filled by Ice Complex deposits in the Late Pleistocene. After filling the depression the Ice Complex sediments subsequently covered the whole area.

In places, unit C is covered by a 2 m thick sequence of peat soils representing the filling of small thermokarst ponds a polygonal ponds (so-called Bylary), which have developed on the top of the Ice Complex elevation (Yedoma). They were often observed as peat spots irregularly distributed on the Yedoma surface. These uppermost deposits were assigned to the Holocene Unit D. Additionally, the unit D includes deposits of thermoerosional valleys (logs) and of the river valley. Furthermore, thermokarst deposits, belonging to unit D, were studied in a remote alas depression (about 5 km to the west, see Figure 4.4-3, box B), which is not shown in the coastal profile of Figure 4.6.1-1.

Figure 4.6.1-1: Photo of the studied coastal section Mamontov Klyk

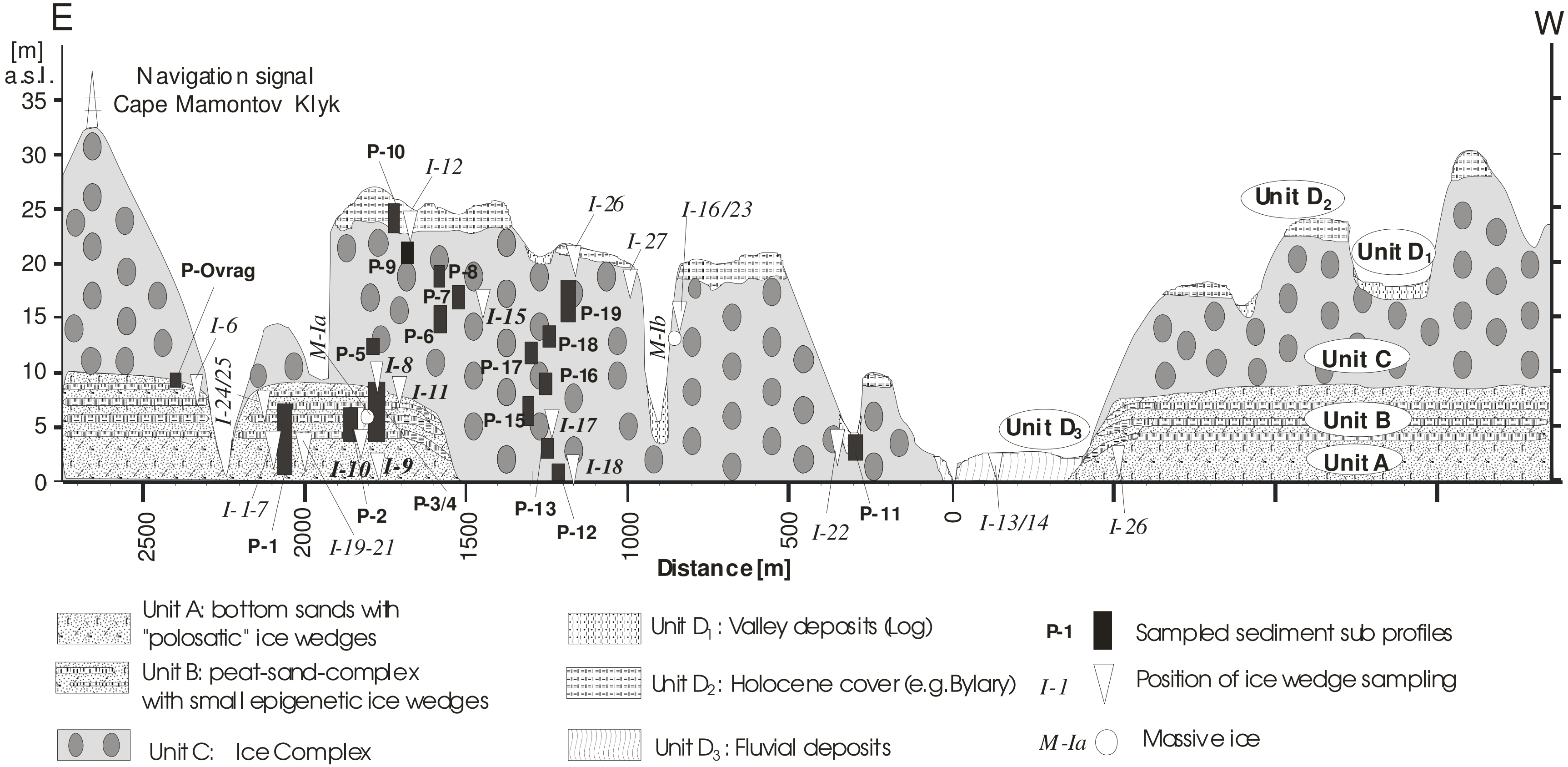

Figure 4.6.1-2: General scheme of the studied coastal section with positions of the sampled sediment: and ground ice profiles

4.6.2 Cryolithological and sedimentological studies of permafrost deposits

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The objectives for investigation of permafrost deposits at the coast section of Cape Mamontov Klyk are the reconstruction of Quaternary paleoenvironmental conditions and landscape history of the lowland north of the Pronchishchev Ridge. For this reason, a description and characterisation of the entire permafrost sequence was necessary concerning its stratigraphical relations as well as the cryolithological, and sedimentological features. In addition, sediment samples were collected for future paleo-ecological, sedimentological and geochemical analysis. Two composite vertical profiles as complete as possible were obtained, which extend from sea level up to the top of the coastal cliff and cover all main stratigraphical units at the site. The composite profiles consist of numerous sub-profiles, mostly exposed on thermokarst mounds (baydzherakhs). The first composed profile covers the unit A to D and the second focused on the Ice Complex deposits of unit C, which were exposed with about 20 m from the sea level to top of the cliff. Additional single sub-profiles of a Holocene thermoerosional valley (log) and of a thermokarst depression (alas) were studied (unit D), which do not belong to these composite profiles. In order to describe the special characteristics of the permafrost deposits, all sub-profiles are presented in this chapter. With this style the outcrop context for all samples becomes clear. For each sample 0.5 to 1 kg of frozen sediment was taken with a hammer and a small axe. Additional samples were collected for ice content measurement in the field lab. The gravimetric ice content is calculated in relation to the dry weight of samples. Therefore, ice supersaturated permafrost samples could have gravimetric ice contents of more than hundred percent. All sediment samples are listed in Appendix 4-5.

4.6.2.1 The first composite profile (Mak 1 to Mak 10)

The lower parts of the sub-profile Mak-1 (Fig. 6.4.2-1) and Mak-2 (Figure 6.4.2-2) expose the sandy deposits of unit A up to 4 m a.s.l.. The grey to yellowish-brown fine sand is irregularly bedded and contains single, thin, light-grey and coarser grained interbeds. No plant remains were visible. The sand seems to be completely free of organic residues. The cryostructure of this sand is massive and the gravimetric ice content is quite high for sand deposits and amounts to 25 to 40 wt %. The thaw consistence is fluid due to excessively high ice content. The samples Mak-1-1 to Mak-1-8 and Mak-2-1 belong to these deposits. In addition, the samples MAK-OSL-1 and MAK-OSL-2 were taken for further geochronological analysis with infrared stimulated luminescence (IRSL).

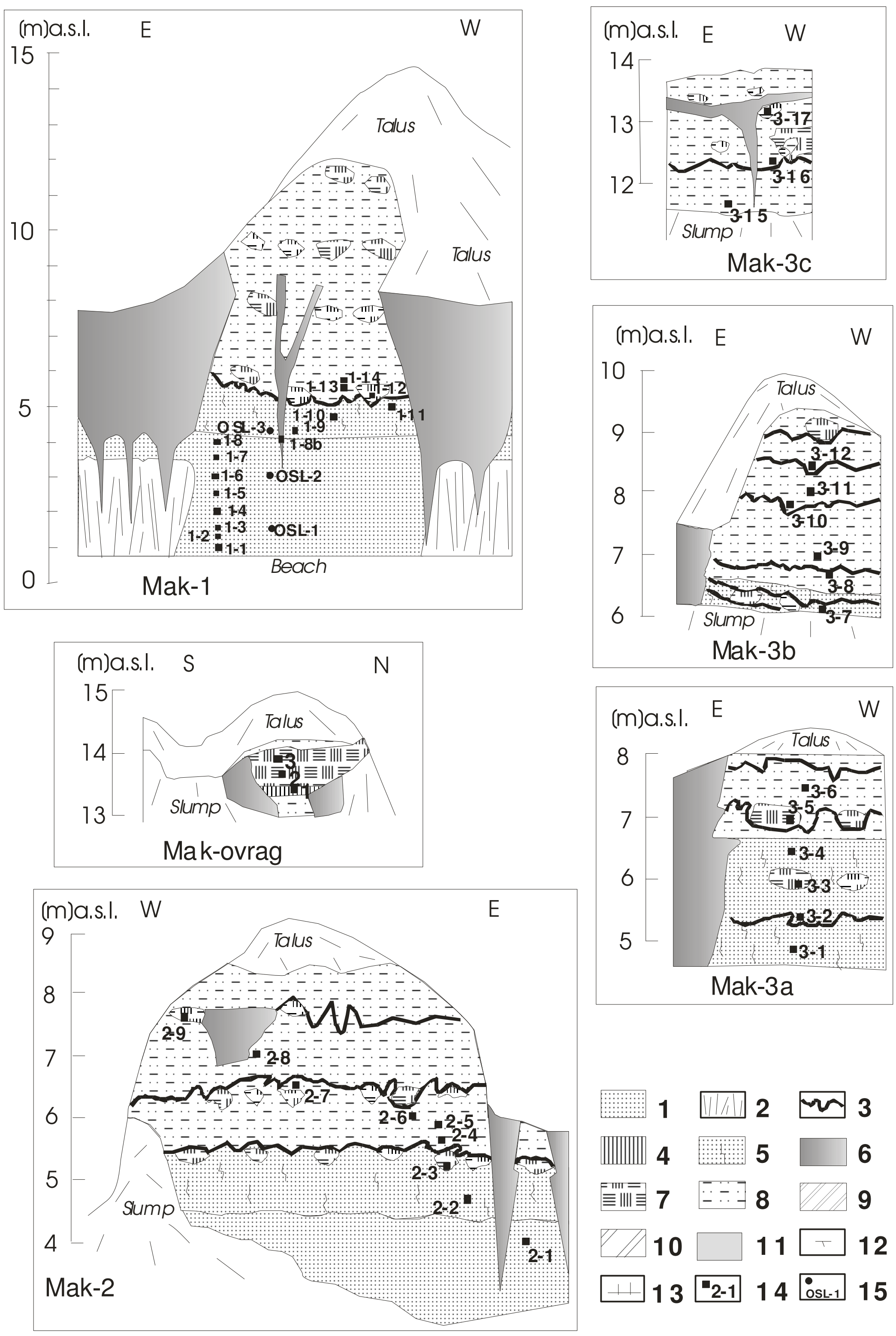

Figure 4.6.2-1: Sub profiles of the lower sands (Unit A) and of the sand-peat complex (Unit B) – lower part of the first composite profile.

A horizon of one meter thickness covers the organic-free sand deposits up to 5 m a.s.l.. It consists of similar fine-grained sand, but is containing numerous vertical *in situ* grass roots. The cryostructure is characterised by individual thin horizontal ice laminae and small vertical ice lenses around grass root remains. This horizon is considered as transition layer between unit A and the sand-peat-complex of unit B. The samples Mak-1-9 to Mak-1-11, MAK-OSL-3 and Mak-2-2 were collected from this transition layer.

The unit B, exposed between 5 to 10 m a.s.l., is characterised by an alternation of four cryoturbated peaty paleosols and three also cryoturbated sandy interbeds. This unit is exposed in the upper parts of the sub-profile Mak-1, Mak-2 and in the separately studied sub-profile Mak-ovrag (see Figure 4.6.2-1). The horizons of paleosols contain moss peat inclusions of 0.2 to 0.5 m in diameter (samples Mak-1-12 + Mak 100, Mak-1-14, Mak-2-3, 2-6 + Mak 102/103, Mak-2-9 + Mak 104). The gravimetric ice content of the peaty layer amounts to 160 to 220 wt %. The sediment direct in below the peaty layer is brownish rubiginous-spotty coloured and appears to be a former Go-soil-horizon. The dark grey silty sand interbeds contain a lot of plant detritus. Diagonally oriented black spotty lines of organic residues cross the interbeds perhaps caused by infiltration of organic matter. Special net-like structures were observed in interbed layers of the sub-profile Mak-2 that resemble syn-sedimentary water-escape structures of an instable water-supersaturated sediment. The cryostructure of the interbeds is banded (0.5 to 1 cm thick ice belts). Thin ice laminas occur parallel to the diagonal black infiltration structures. The gravimetric ice content of the interbeds amounts to 26 to 83 wt %. The samples Mak-1-12 to 14, Mak-2-3 to 2-8 and Mak-ovrag-1 to –3 belong to the sand-peat complex of unit B.

The ice wedge profiles MAK-IW-1 to MAK-IW-5 and MAK-IW-7 flank the sub profile Mak-1. The Ice wedge MAK-IW-6 adjoins to the sub-profile Mak-ovrag (see Figure 4.6.1-2 and chapter 4.6.3*)*

An other sand-soil sequence of unit B was studied between 4.6 to 10 m in the sub-profiles Mak-3a to Mak-3c, which were exposed at a large thermokarst mound 20 m west of the sub profile Mak-2. In contrast to the former described sub-profiles, this one does not show such a distinct peaty-sand-complex sequence. Four samples (Mak-3-1 to 3-4) were taken from a 2 m thick greyish-brown fine sand horizon with disturbed bedding, which contains small peat inclusion (1 to 10 cm), shrub root fragments. The cryostructure is massive or dotted and the gravimetric ice content reaches about 25 wt %. The sub-profile Mak-3a was studied on August 14th. One day later, the entire lower horizon was eroded and a massive ice body cropped out. Therefore, the sediment is considered as probably young reworked material. Above the massive ice body the sequence of the both sub-profiles Mak-3a and Mak-3c is the same.

Both sub-profiles continue with a 0.6 to 0.8 m thick cryoturbated paleosol horizon with peat inclusions (∅ 10 to 15 cm), grey to greyish-brown, black spotted silty fine sand (sample Mak-3-5, 3-7 + Mak 108). The cryostructure presents some diagonal irregularly distributed ice lenses. The gravimetric ice content amounts to 21 to 60 wt %. The next horizon of about 1 m thickness consists of alternating bedded grey silt and light-greyish-brown fine sand layers (samples Mak-3-6, 3-8 + Mak 108, Mak-3-9). The single laminae are irregularly bedded and contain sedge remains, roots and wood fragments. The cryostructure of this layer is massive and the gravimetric ice content is of about 21 wt %. It is interpreted as a shallow part of a flood plain area. The second paleosol of the sub-profile Mak-3 is dark coloured, cryoturbated and contains a lot of detritic plant remains (sample Mak-3-10). It looks like a fluvial drift line near the shore. The sandy interbed above of about 1 m thickness (sample Mak-3-11 to 3-13) is similar to the sandy horizon described above. The third peaty paleosol at 10 m a.s.l. is also similar to the already described paleosol horizons (sample Mak-3-14).

A smaller sub-profile (Mak-3c) of only 2 m thickness was exposed near the top of the thermokarst mound between 11.7 and 13.7 m a.s.l. (Figure 4.6.2-1). A yellowish, ice-rich, fine-grained sand (sample Mak-3-14) with fine lens-like cryostructure (gravimetric ice content 50 wt %) is covered by the fourth cryoturbated paleosol with peat inclusions (sample Mak-3-15 + Mak 106, Mak 3-17 + Mak 105,). This sub-profile is penetrated by the ice wedge MAK-IW-11 (see chapter 4.6.3).

The transition between unit B and the Ice Complex deposits of unit C seems to be exposed in the sub-profile Mak-4 between 11.7 and 12.7 m a.s.l. (Figure 4.6.2). The lowest part of this sub-profile is a weakly distinct, cryoturbated brownish paleosol (sample Mak-4-1). The following layer consists of yellowish-grey fine sand with some plant remains (Mak-4-2). The cryostructure is banded. Diagonal, 1 to 2 cm long fine ice lenses were observed. The gravimetric ice content is 46 to 48 wt %. The cryolithological change of the permafrost deposits is recognisable in the grey fine sandy silty sediment (alevrite) with single small shrub fragments. The cryostructure is banded and fine lens-like with broken ice lenses (samples Mak-4-3, Mak-4-4 + Mak 109). The gravimetric ice content is 64 to 70 wt %. The small ice wedge MAK-IW-8 penetrates this subprofile (see chapter 4.6.3)

The sub-profiles Mak-5 to Mak-9 reflect the sequence of the Ice Complex deposits of unit B between 13.5 and 22.5 m a.s.l.. Largely, these five sub-profiles are composed similar. Therefore, a detailed description of each several sub-profile (Figure 4.6.2-2) is dispensable. The deposits of unit C are characterised by greyish-brown fine-sandy silt (alevrite), which contains shrub wood fragments (Ø 0.5 to 1 cm) and smaller plant residues (e.g. in situ grass roots). Weakly developed paleosol horizons, containing small peat inclusions and more brownish coloured sediment were detected. The cryostructure of these deposits is mainly banded and lens-like (coarse to fine ice lenses). The gravimetric ice content amounts 50 to 90 wt % (max 220 wt%).

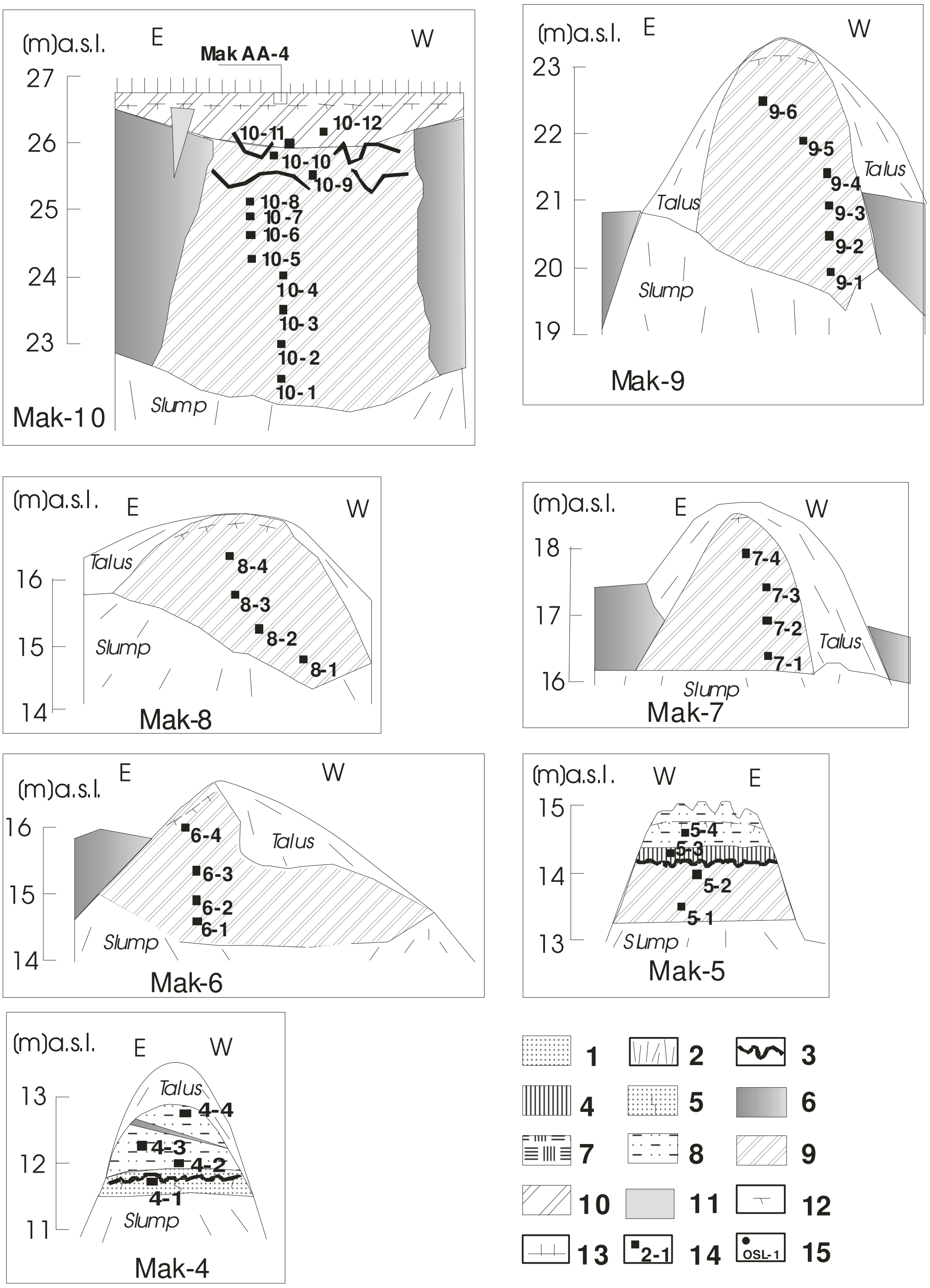

Figure 4.6.2-2: Sub profiles of the of the part of the first composite profile - Ice Complex (Unit C) and Holocene deposits (Unit D).

The transition from Unit C to Holocene deposits, which cover the Ice Complex sequence in places, is well shown by the sub-profile Mak-10 between 23 and 26.7 m a.s.l. (Figure 4.6.2-2). The lower part (samples Mak-10-1 to 10-6) of this sub-profile consists of the similar greyish-brown, ice-rich fine sandy silt as already described. The upper part of 1.5 m thickness discordantly covers the Ice Complex deposits and contains two well-developed cryoturbated peat soil horizons with loamy interbeds (samples Mak-10-7 to 10-11). The entire sub-profile was sampled additionally for pedological analysis (samples Mak 112 to 120*, see chapter 4.6.4*) The horizon is very ice-rich (gravimetric ice content 84 to 136 wt %) and the cryostructure is ice-banded and lens-like. This sub-profile exposes peaty loamy fillings of a small depression. These forms of depressions and their fillings were frequently observed in form of peat patches (10 to 50 m in diameter) on the surface of Yedoma elevations. The filling of this small thermokarst-like depression contains thin white ice wedges (MAK-IW-12, see chapter 4.6.3) probably of Holocene origin.

4.6.2.2 The second composite profile (Mak-12, -13 and 15 to 19)

The second composite profile covers the Ice Complex deposits of unit C from the sea level to the top of the cliff at 20 m a.s.l. (Figure 4.6.1-1). The lowest sub-profile Mak-12 exposes two cryoturbated peaty paleosols with a silty interbed between 0 and 2 m a.s.l. (Figure 4.6.2-3). The cryostructure of this interbed is banded and lens-like. Apart from these peaty horizons all other sub-profiles situated above (Mak-13 and Mak-15 to Mak-19) are more or less similar in cryolithology and sedimentology. Therefore its description will be briefly summarized only. The individual sub-profiles as well as the sample positions are presented in Figures 4.6.2-3The Ice Complex sequence is composed of greyish-brown ice-rich fine sandy silt (alevrite) and includes weakly developed paleosol horizons with some plant remains like shrub fragments, leaves and detritic organic matter. The cryostructure is banded and dominantly lens-like, sometimes with broken ice lenses. The gravimetric ice content varies between 70 and 115 wt %. The uppermost part of the sub-profile Mak-19 probably belongs to the Holocene cover (unit D), as more sandy sediment and peat inclusions occur, and the position is directly below the Yedoma surface.

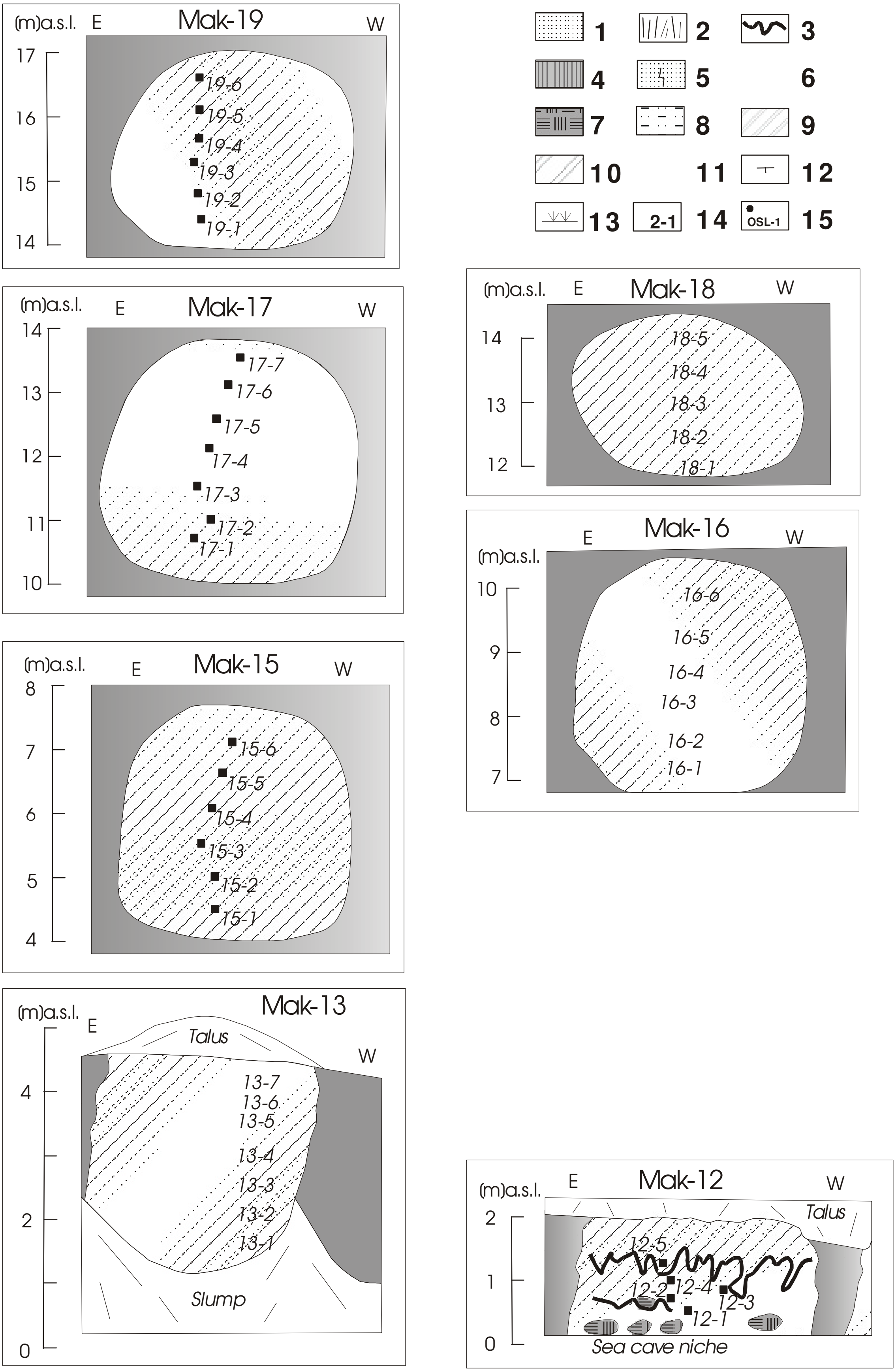

Figure 4.6.3-3: Sub profiles of the second composite profile – Ice Complex (Unit C) and Holocene deposits (Unit D)

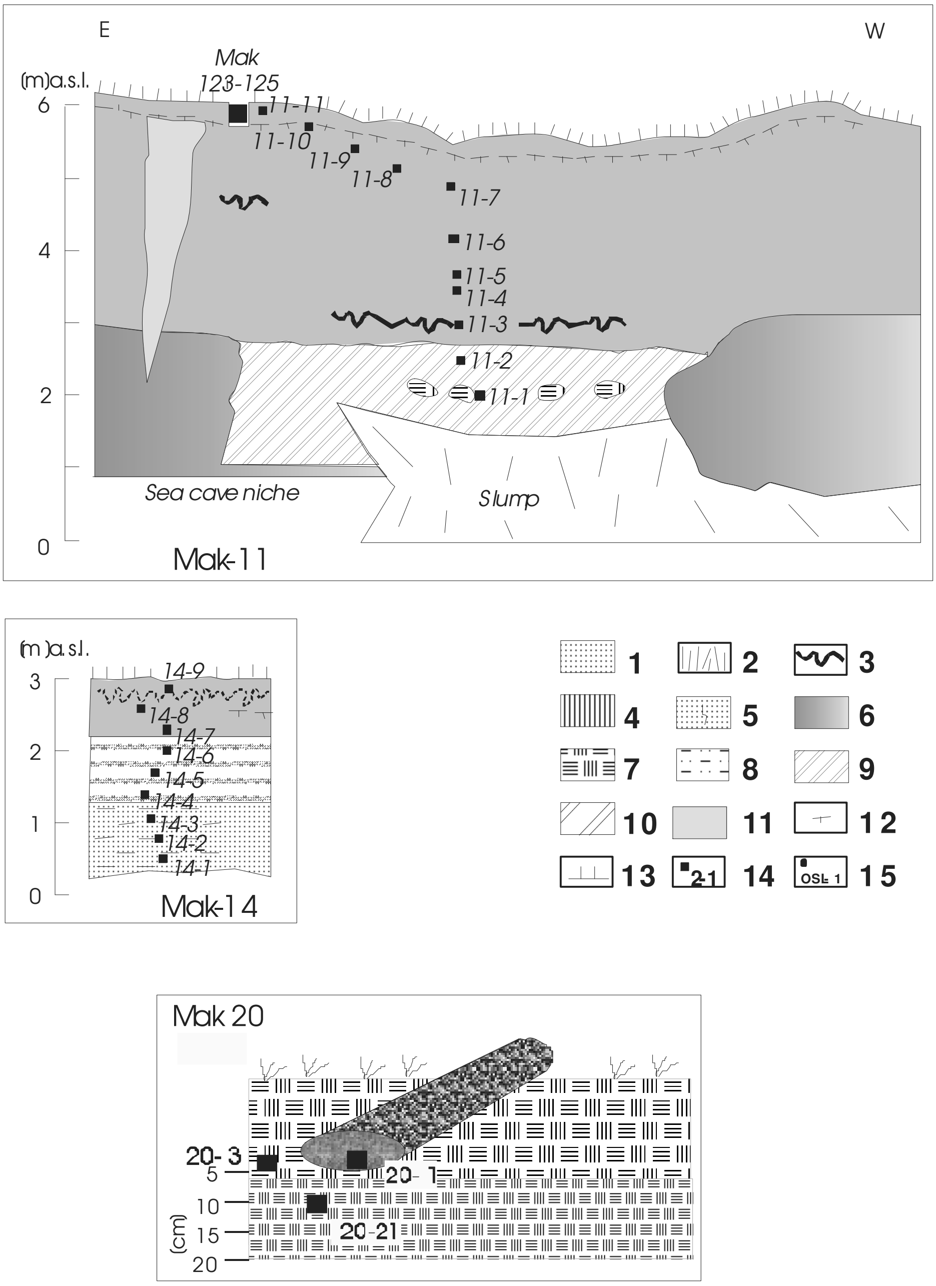

Figure 4.6.2-4: Additional sub profiles of Holocene thermokarst deposits and of a marine terrace

4.6.2.3 Additional sampled sub-profiles (Mak-11, Mak-14, Mak-20/21)

The sub-profile Mak-11 is located about 300m east of the mouth of the Nuchcha Dzhiele River (see Figure 4.6.1-2). It exposes deposits of a thermoerosional valley (unit D) between 0 and 6 m a.s.l., probably covering Ice Complex deposit (unit C). The sub-profile is flanked by ice wedges, which were especially studied (e.g. MAK-IW-22, see chap. 4.6.3). The lower part contains two greyish-brown paleosol horizons with peat inclusions (samples Mak-11-1 to 11-3. The cryostructure is banded, partly massive or lens-like reticulated. The gravimetric ice content amounts to about 50 wt %. Small ground wedges of about 10 cm length were observed 3 m a.s.l.. The upper part of the sub-profile consists of greyish-brown, well-bedded silty fine sand, with some vertically oriented grass roots. It contains additional wood fragments and peat inclusions. The cryostructure is banded with fine ice lenses, sometimes broken ice lenses (gravimetric ice content 46 to 130 wt %). The uppermost 0.5 m was sampled additionally for pedological analysis (samples Mak 123 to 125, see chapter. 4.6.4).

Deposits of a thermokarst depression (alas) were studied about 8 km west of the Nuchcha Dzhiele river mouth due to the absence of such sequences at the coast of Cape Mamontov Klyk(Figure 4.4-3, box B; Figure 4.4-5. The profile Mak-14 is composed of three different parts (Figure 4.6.2-4). The lowest meter consists of clayish fine-sandy silt with plant detritus and is partly brownish coloured. The cryostructure is coarse lens-like and the gravimetric ice content of about 30 wt %. This part is covered by a horizon of interbedding of 2-3 cm thick peat layers and sandy silt layers. Thin ice bands occur. The gravimetric ice content varies between 45 and 110 wt %). A cryoturbated peaty paleosol completes the sequence. The cryostructure is characterized by thick ice belts and vertical ice veins (gravimetric ice content 165 wt %).

Two more profiles are very small and include buried driftwood covered by moss peat. Both profiles are located at the marine terrace of the Bay Kuba Betyuene about 5 km east of Cape Mamontov Klyk (Figure 4.4.-3*)*. The dating of the buried driftwood possibly gives a clue on the genesis of this vast marine terrace e.g. by supposed neotectonic uplift.

1 Fine-grained quartz-feldspar sand; brownish-grey (thawed), light-grey (frozen); horizontal, flaser and cross bedded; without visible plant remains, frozen; with ice cement; fluid after thawing

2 Sand-Ice wedge (polosatic), close alternation (mm to cm) of sand and ice veins, 2-3 m wide

3 Cryoturbated frozen paleosol horizon, no to scale of the profile

4 Cryoturbated frozen paleosol horizon, to scale of the profile

5 Silty fine-grained quartz-feldspar sand; brownish-grey; weakly bedded; with vertical in situ grass roots, frozen, with ice cement, in places with short ice belts near ice wedges

6 Ice wedge grey, compact

7 Autochthonous brownish peat, grass and moss remains, in places with roots and twigs of dwarf shrubs, frozen, ice-rich, formed nests (inclusions) of various diameters and several lenses

8 Fine-grained quartz-feldspar sand; brownish-grey; with loamy (alevrite) interbeds and lenses; with vertical in situ grass roots, in places with roots and twigs of dwarf shrubs; frozen, fine lens-like cryostructure, some bended ice belts

9 Dark grey loam (alevrite); alternate bedding (silt, fine sand); with vertical in situ grass roots; frozen, fine lens-like cryostructure, sequent concave bended ice belts

10 Dark grey loam (alevrite); with peat inclusions; bedded; with vertical in situ grass roots; frozen, horizontal ice belts

11 White ice wedge; less compact; with small silty parts,:on the top of giant, compact grey ice wedges

12 Active layer boundary

13 Vegetation cover of subarctic tundra

14 Sediment sample position and sample number (2-1)

15 Sample position for luminescence dating and sample number (OSL-1)

Figure 4.6.2-5: Legend to the Figures 4.6.2-1 to 4.6.2-4