

# Chapter 6

## Geological Structure of the Quaternary Sedimentary Sequence in the Klaipėda Strait, Southeastern Baltic

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**Abstract** The Klaipėda Strait is located between the Curonian Spit and the mainland coast of Lithuania. It links the Curonian Lagoon with the Baltic Sea. The Quaternary sequence is represented here by Pleistocene sediments formed during a few glaciations and interglacials. Its uppermost part is composed of Late glacial and Holocene sediments originating from different stages of the Baltic Sea development. One of the main problems of Quaternary geology in the vicinities of the Klaipėda Strait, as well as in the whole Lithuanian Coastal Area, is the reliable geochronology and stratigraphic correlation of sediments. To contribute to the solution of this problem, the infrared optically stimulated luminescence (IR-OSL) dating of the lacustrine inter-till sandy sediments was done during the engineering geological mapping of the Klaipėda Strait. The absolute majority of the IR-OSL ages obtained for the investigated inter-till sediments fall within the age range of marine isotope stages (MIS) 5d-5a. The subsequent more detailed examination of geological setting of Quaternary sequence has led to the assumption that the sampled inter-till sediments occur not in situ, i.e. they are found as blocks (rafts) in a thick till bed that have been formed by the ice advance during the Weichselian early pleniglacial maximum (MIS 4). This conclusion does not support the former standpoint that the till beds beneath the bottom of the Klaipėda Strait were formed during the Warthanian (Medininkai, MIS 6) glaciation.

**Keywords** Klaipėda Strait · Late Pleistocene · Till · Stratigraphy · IR-OSL dating · Glacioidislocations

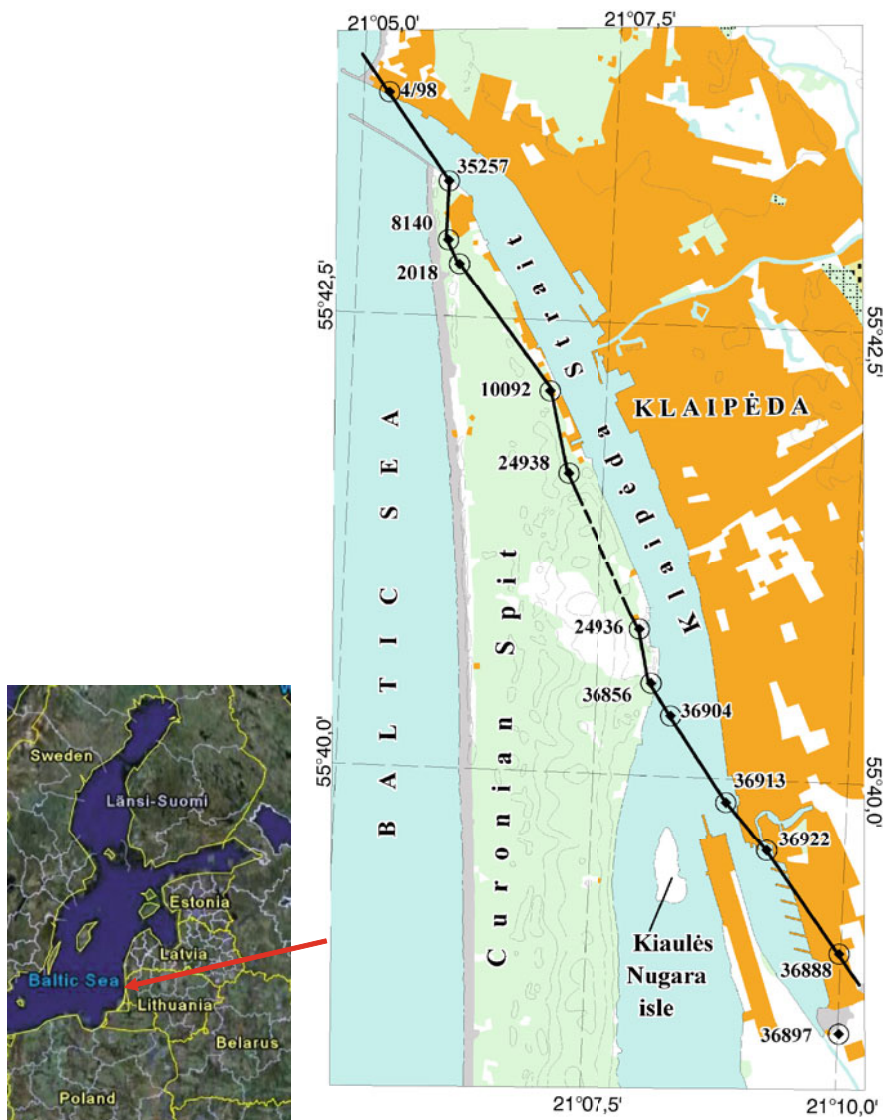
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## 6.1 Introduction

The Klaipėda Strait links the Curonian Lagoon (Kuršių Marios) with the Baltic Sea, i.e. separates the Curonian Spit (Kuršių Nerija) from the continental part of Lithuania (Fig. 6.1). The only seaport of Lithuania is located in the Klaipėda Strait. The length of the strait from the port gates on the Baltic Sea coast to the Kiaulės Nugara isle in the Curonian Lagoon is 12 km. The strait is 1,500 m wide at its

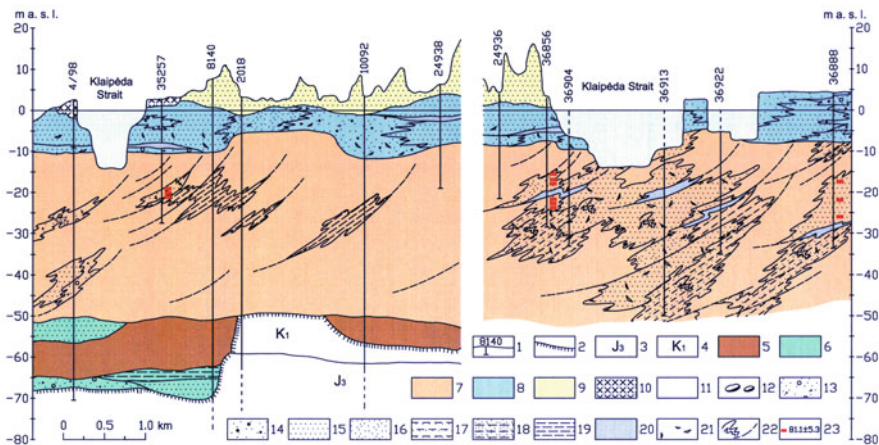


**Fig. 6.1** Map of the study area, location of investigated boreholes and line of geological cross-section

widest point and 385 m at its narrowest. Due to permanent cleaning and dredging of the harbour basin area its depth varies from 8.0 to 14.5 m.

Geological setting of the Klaipėda Strait region is complicated. The lowermost part of the Quaternary sedimentary sequence was formed during the last few glacial–interglacial cycles and is represented by layers of glacial, glaciofluvial, glaciolacustrine, limnic and organogenic sediments, while the uppermost part was formed in the Late glacial and Holocene during a few stages of the Baltic Sea development (Fig. 6.2). The dredging of the strait opens the layers of fine-grained sand filled by groundwater. Some of these layers are under high hydrostatic pressure that causes sub-aquatic suffusion posing a threat to the jetties of the seaport. Thus, the complicated geological structure and hydrogeological conditions were the valid reason to start a detailed (at a scale of 1:5 000) engineering geological mapping of the Klaipėda Strait area. The vast majority of geological information presented in this chapter was collected during this mapping.

The Klaipėda Strait and surroundings, investigated in detail, can be considered as an important key area for the Lithuanian Coastal Area and whole Western Lithuania. During the different stages of the Baltic Sea development – the Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Littorina and Post-Littorina Seas – the paleogeographic situation in the Klaipėda Strait environs was very different and changeable, but this



**Fig. 6.2** Geological cross-section along the Klaipėda Strait: 1 – borehole and its number; 2 – surface of pre-Quaternary sediments; 3 – upper Jurassic sediments; 4 – lower Cretaceous sediments; 5 – middle Pleistocene glaciogenic sediments; 6 – middle Pleistocene glaciofluvial and glaciolacustrine sediments; 7 – upper Pleistocene glaciogenic sediments with glaciotectonized blocks of inter-till limnic sediments; 8 – late glacial and Holocene marine and lagoonal sediments; 9 – Holocene aeolian sediments; 10 – anthropogenic sediments. Lithology of sediments: 11 – till; 12 – boulders; 13 – sand with gravel; 14 – various-grained sand; 15 – fine-grained sand; 16 – very fine-grained sand; 17 – silty sand; 18 – sandy silt; 19 – clay; 20 – gyttja, peat; 21 – fine dispersal remnants of organic matter; 22 – glaciotectonic features (folds, thrust faults); 23 – sampling point for infrared optically stimulated luminescence (IR-OSL); number indicates the luminescence age of sediment (in ka)

issue has been investigated only superficially and is still waiting for solution. A reliable geochronology of Pleistocene deposits and their stratigraphic correlation is another so far unsolved problem: a precise number of glacial advances and their stratigraphic rank have been the objects of intensive scientific discussions until the present time. The petrographic composition of the gravel part of glacial sediments (tills) which has traditionally been applied for stratigraphic subdivision and correlation of Pleistocene tills in Lithuania has proved to be poorly effective (Gaigalas et al. 1987, 1997). Other lithostratigraphic methods and criteria, such as geochemical composition of fine-grained part of tills (less than 1 mm) or variation of well-rounded hornblende grains in tills (fraction  $\varnothing$  0.25–0.1 mm), are more effective, but, unfortunately, also do not give a clear-cut answer (Majore et al. 1997, Bitinas et al. 1999); the fabric measurements of tills are available only in a few cliff sections on the Baltic Sea coast (Bitinas 1997). The only most positive results were obtained by using thermoluminescence (TL) dating of inter-till sediments: the Pamarys Interstadial sediments which were formed at the end of the Medininkai (Varthanian, MIS 6) glaciation (i.e. around 140–160 kyears BP) were identified in the big part of Lithuanian Coastal Area (Satkūnas and Bitinas 2002). The Pamarys stratigraphic unit mentioned separates sediments of the middle and upper Pleistocene, but these sediments have not been used for solution of stratigraphic problems because they are not prevalent in the area of the Klaipėda Strait. Notwithstanding this factor, the methods of absolute geochronology were used in determining the stratigraphy and geological structure of Pleistocene sediments in the Klaipėda Strait area. This chapter presents the results of IR-OSL dating of the lacustrine inter-till sandy sediments. Besides, investigations aimed at finding out the possibilities of till age estimation by the IR-OSL method were also carried out. For this purpose, two till layers from boreholes dislocated along the Klaipėda Strait and three till layers from the Olando Kepurė outcrop (the Baltic Sea cliff), dislocated a few kilometres to the north from the strait, were examined (Molodkov et al. 2010). Additionally, a number of Pleistocene inter-till sections containing organic sediments were examined paleobotanically by pollen and diatom analysis. Identification of mollusc species was carried out.

## 6.2 Geological Setting

The thickness of the Quaternary cover in the Klaipėda Strait and surroundings varies from 60 to 90 m. The upper Jurassic and lower Cretaceous sediments are outcropping beneath the Quaternary sedimentary sequence. The Pleistocene sedimentary sequence is generally composed of alternating till and inter-till sediments. According to the results of previous geological investigations – state geological mapping at a scale of 1:50,000 – the sediments of four different glaciations have been detected in the sequence of Quaternary sediments (unpublished data, report in the archive of Lithuanian Geological Survey). Till layers beneath the bottom of

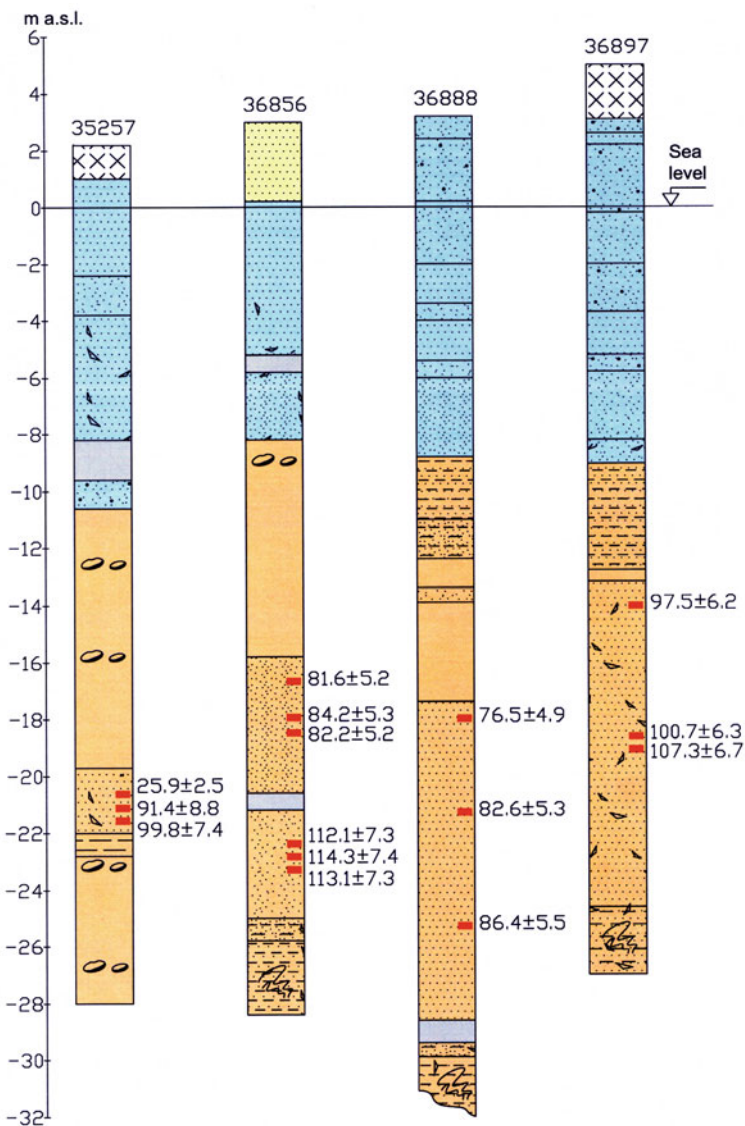
the Klaipėda Strait were generally attributed to the middle Pleistocene Warthanian (Medininkai, MIS 6) glaciation, and in some cases they were attributed to the first glacial advance of late Weichselian (late Nemunas, MIS 2) glaciation. The uppermost part of glacial sediments along the Baltic Sea coast (including the vicinities of the Klaipėda Strait as well) is covered by sediments of the Baltic Ice Lake, Ancylus Lake, Littorina and Post-Littorina Seas and also by recent aeolian sediments (Gelumbauskaitė and Šečkus 2005, Kabailienė et al. 2009).

The boreholes in the Klaipėda Strait and surroundings drilled during the engineering geological mapping generally uncovered only the upper part of the Quaternary sequence to an altitude of 30, in some cases 50 m below sea level (Fig. 6.3). Alternating till and inter-till sediments were established in this part of the Quaternary. According to visual description of borehole cores, two types of till layers were distinguished in the geological sections: brown-grey or grey-brown till and dark grey till (at intervals with a greenish tinge). The inter-till sediments are represented by laminated silt, sandy or clayey silt and fine-grained sand with inter-layers of organogenic sediments – dark grey or black gyttja and dark brown peat. Traces of glaciotectonic disturbances (micro-folds, thrust faults, micro-rafts, i.e. glacioidislocations) were observed in the cores of inter-till sediments (Figs. 6.4 and 6.5). The structure of sediments was possible to establish only in the compact laminated (sand, silt, clay) sediments, because the cores of incompact powdery-like sandy sediments were withdrawn disordered due to drilling technology. This technology does not enable to collect the samples in plastic tubes, so the textures of the sand samples removed from the core barrel are destroyed. The upper part of the borehole sections (to the depth of 2–8 m below sea level) is composed of sandy sediments of the Baltic Ice Lake, organogenic sediments (like gyttja, clayey gyttja, etc.) formed in the lagoons of the Ancylus Lake and the Littorina Sea, as well as layers of marine sand with molluscs formed in the Littorina and Post-Littorina Seas. Recent aeolian sediments are widely prevalent on the western coast of the Klaipėda Strait – the Curonian Spit. In some places, 2–3 m thick layers of anthropogenic sediments occur in the uppermost parts of the borehole sections (Fig. 6.3).

## 6.3 Methods

### 6.3.1 Sampling

Fine-grained inter-till sand, in some intervals with minor inclusions of tiny particles of organic matter (limnic sediments), was sampled for IR-OSL analysis in four borehole sections (Fig. 6.3). It was very important to establish the absolute age of organic (gyttja and peat) sediments. Therefore, three samples beneath and three samples above them were taken for IR-OSL dating in borehole 36856. Sampling of sand layer only above the organic sediments was available in borehole 36888. In the other two boreholes (35257 and 36897) where the samples were taken from sandy sediments, the borehole sections did not contain inter-layers of organic sediments. All



**Fig. 6.3** Geological sections of key boreholes from the Klaipėda Strait surroundings, showing the location of the IR-OSL sampling points and luminescence ages of inter-till sediments. For conventional signs, see Fig. 6.2

**Fig. 6.4** Glacioidislocated inter-till sediments represented by deformed micro-layers of fine sand, silt and clay in the core of borehole 36888 (depth 33.5 m)



the inter-till sandy sediments sampled for IR-OSL dating were very similar in terms of geological setting and lithological composition. Drilling technology, despite the fact that it does not allow to remove the undisturbed core samples of sand, is quite suitable for correct sampling for IR-OSL dating.

### **6.3.2 IR-OSL Measurements**

All samples were prepared for the luminescence analysis according to standard laboratory procedures (see, e.g. Molodkov and Bitinas 2006). Briefly, alkali feldspar grains of 100–150  $\mu\text{m}$  size were extracted from the sediment under subdued filtered light in the laboratory by a procedure including wet sieving, heavy liquid floatation (collecting 2.54–2.58  $\text{g}/\text{cm}^3$  fraction) and treatment by 10% HF for 15 min and finally etching by 20–40% HCl. The IR-OSL measurements were carried out with an Ingrid-Type SLM-1 reader using 860 nm stimulation by short laser pulses. Detection was in the 380–430 nm wavelength range using a combination of 3 mm SZS-22

**Fig. 6.5** Glaciodislocated inter-till organogenic sediments in the core of boreholes 36917 and 36922



(blue-green), 3 mm PS-11 (purple) and 2 mm FS-1 (violet) colour glass filters manufactured by the LZOS, JSC (Lytkarino Optical Glass Factory), Russian Federation. For laboratory irradiation a calibrated  $^{60}\text{Co}$  source delivering  $6.5 \times 10^{-2}$  Gy/s of gamma radiation was used. After irradiation all samples were kept for about 1 month at room temperature to allow the decay of post-irradiational phosphorescence and to eliminate some anomalous fading-like effects (Jaek et al. 2007).

The paleodose  $D_e$  was determined by extrapolating the dose–response curves to zero IR-OSL intensities using the multiple-aliquot additive dose (MAAD) technique (up to 66 aliquots, 15 mg/aliquot, 11 dose points). Dose rate data are based on a laboratory NaI (TI) gamma spectrometry (for details see, e.g. Molodkov and Bitinas 2006) taking into account the in situ water content and the contribution from cosmic rays. The internal beta dose from the decay of potassium and rubidium within K-feldspar grains was obtained from the concentration estimates reported by Huntley and Baril (1997) and Huntley and Hancock (2001).

IR-OSL dating was performed in the Research Laboratory for Quaternary Geochronology, Institute of Geology, Tallinn University of Technology.

### 6.3.3 Other Investigations

In the Klaipėda Strait and surroundings, inter-till organogenic sediments were found in 10 boreholes. Paleobotanical analysis was carried out in the Department of Quaternary Researches of the Institute of Geology and Geography, Vilnius, Lithuania. The pollen content of seven borehole sections was identified by O. Kondratienė (including boreholes 36856, 36922 and 36888 shown in the geological cross-section, Fig. 6.2). V. Šeirienė analysed the diatoms in three borehole sections (not included in the presented geological cross-section).

In seven borehole sections, remnants of mollusc shells were found inside the layers of organic sediments. Identification of mollusc species was carried out in the Lithuanian Geological Survey by A. Damušytė.

The adaptation of other methods of absolute geochronology for determining the absolute age of organogenic inter-till sediments was unsuccessful: the sediments were too old for the radiocarbon ( $^{14}\text{C}$ ) method, whereas the uranium–thorium (U–Th) method was unsuitable due to the very low content of organic matter in the sediments.

## 6.4 Results

The results of IR-OSL analysis in the four dated borehole sections fall into a relatively narrow time span: from  $76.5 \pm 4.9$  to  $114.1 \pm 7.3$  ka (Table 6.1, Fig. 6.3). The average ages in the five inter-till layers are as follows:  $95.6 \pm 8.1$  ka in borehole 35257,  $82.7 \pm 5.2$  and  $113.2 \pm 7.3$  ka in borehole 36856,  $81.8 \pm 5.2$  ka in borehole 36888 and  $101.8 \pm 6.4$  ka in borehole 36897. Each result presented here is an average of three dating obtained on samples taken from three different sedimentary levels. The single young data of  $25.9 \pm 2.5$  ka in borehole 35257 is probably an anomaly due to mistakes in sampling or labelling or due to the influence of some uncontrollable factor. Therefore, this date can be regarded as an outlier and omitted from consideration.

The results of the investigations aimed at finding the features of glacial tills which allow to temporally constrain Pleistocene tills in the Klaipėda Strait region are discussed in our companion article (Molodkov et al. 2010). The data of the pollen analysis of organogenic inter-till sediments show that the sedimentation of the examined deposits took place under interglacial conditions (Kondratienė and Damušytė 2009).

The results of diatom analysis of inter-till organogenic sediments indicate that these sediments accumulated in a freshwater basin: for example, in borehole 36917 (depth 14.2–15.0 m) freshwater planktonic species like *Aulacoseira granulata* and *Aulacoseira ambigua* prevail.

Molluscs were very poorly preserved. They were represented only by shell fragments. As a result, in all investigated borehole sections it was possible to identify only two species – *Pisidium* sp. and *Bithynia tentaculata* (Linnaeus 1758). Both species are of freshwater origin.

**Table 6.1** IR-OSL results and radioactivity data for inter-till sand samples from boreholes along the Klaipėda Strait

No.	Laboratory code	Borehole no.	Sample no.	U (ppm)	Th (ppm)	K (%)	$D_e$ (Gy)	IR-OSL age (ka)
1.	RLQG 1667-065	35257	2	0.31	0.23	0.87	44.7	25.9 ± 2.5
2.	RLQG 1669-065	35257	3	0.23	0.33	0.55	123.7	91.4 ± 8.8
3.	RLQG 1670-065	35257	4	0.08	0.63	0.65	139.1	99.8 ± 7.4
4.	RLQG 1786-028	36856	1	0.03	1.50	0.74	126.0	81.6 ± 5.2
5.	RLQG 1787-038	36856	2	0.08	0.51	0.58	114.3	84.2 ± 5.3
6.	RLQG 1788-038	36856	3	0.01	1.08	0.69	118.5	82.2 ± 5.2
7.	RLQG 1789-038	36856	4	0.49	2.12	1.15	231.0	112.1 ± 7.3
8.	RLQG 1790-038	36856	5	0.31	1.21	1.14	229.5	114.3 ± 7.4
9.	RLQG 1791-038	36856	6	0.33	2.24	0.96	214.5	113.1 ± 7.3
10.	RLQG 1792-038	36888	1	0.00	0.48	0.66	109.5	76.5 ± 4.9
11.	RLQG 1793-038	36888	6	0.15	1.42	0.71	129.0	82.6 ± 5.3
12.	RLQG 1794-038	36888	10	0.01	0.87	0.72	128.3	86.4 ± 5.5
13.	RLQG 1784-028	36897	1	0.30	1.72	0.85	169.1	97.5 ± 6.2
14.	RLQG 1785-028	36897	4	0.37	1.13	0.68	154.4	100.7 ± 6.3
15.	RLQG 1783-028	36897	6	0.24	1.23	0.67	161.4	107.3 ± 6.7

*Notes:* U, Th and K content in sediments are determined from laboratory gamma-ray spectrometry; water content corrections, calculated cosmic ray contribution and internal feldspar dose rate were taken into account on calculation of the IR-OSL ages.

## 6.5 Discussion

One of the main problems of Quaternary geology in the vicinities of the Klaipėda Strait and in the whole Lithuanian Coastal Area is the reliable stratigraphic subdivision and correlation of sediments. The problem is that there are no reliable criteria for stratigraphic correlation, especially for glacial sediments (tills). The colour of tills is very changeable and cannot serve as a correlative. According to the experience of large-scale geological mapping of Quaternary sediments in the Lithuanian Coastal Area, other indicators, such as the petrographic composition of gravel part

tills or other lithological components, are also very changeable and not suitable for the above-mentioned purposes. Thus, indirect methods are to be used to solve the problems of stratigraphic correlation of tills.

The results of IR-OSL studies show that the inter-till sediments investigated in the Klaipėda Strait were formed during the ice-free interval MIS 5d-5a. The sampled inter-till sediments are occurring not in situ but as blocks (rafts) in the till bed (Fig. 6.2). This opinion is confirmed by an abundance of micro-glacioidislocations observed in borehole cores (Figs. 6.4 and 6.5). Based on the geotechnical properties of sediments, some additional conclusions about till age could also be drawn. It was established that the geotechnical properties of the lowermost complex of tills both in the Klaipėda Strait area and in the whole Klaipėda City region at altitudes close to zero or below sea level significantly differ from those of the relief-forming tills situated at higher altitudes (Gadeikis 1998). There are some differences in the density of tills ( $1.96\text{--}2.20\text{ g/cm}^3$  for the younger and  $2.21\text{--}2.24\text{ g/cm}^3$  for the older ones, respectively), but the biggest distinction is the module of deformation, which varies from 16 to 74 MPa for the beds of relief-forming tills and reaches up to 100–110 MPa for older till beds. A big difference is observed in the values of cone resistance, which are 1.1–5.0 and 5.0–14.0 MPa, respectively. According to the presented geotechnical properties, the above-mentioned separate group of tills was in different conditions of consolidation – the older one was additionally influenced by compression from the glaciers and long-lasting lithification processes, i.e. this till was formed significantly earlier than the relief-forming till beds that belong to the late Weichselian (late Nemunas). This difference is very obvious in the above-mentioned Olando Kepurė section (Molodkov et al. 2010).

Hence, we may conclude that the till containing these incorporated inter-till sediments could be formed only during the Weichselian (Nemunas) glaciation. Some other indications corroborating this hypothesis are also reported (*ibid.*).

The limnic sediments – sand alternating with silty-clayey or organogenic sediments – are widespread in the Klaipėda Strait area where they have been established in tens of boreholes. Thus, it is possible to presume that during the MIS 5d-5a time span a quite big freshwater sedimentary basin (or basins) existed within our study area – very likely in the depression of the Baltic Sea; lately it served as a source of terrigenous material for till formation during the Weichselian glacial advances.

According to the interpretation of results of pollen analysis, the pattern of the vegetation development including the immigration of particular tree species is different from those typical for Holsteinian (Butėnai) and Eemian (Merkinė) interglacials, but is in good agreement with the biostratigraphical records of the Drenthe-Warthe (Snaigupėlė, Lubavian, Schöningen) interglacial, late middle Pleistocene that suggest the similar age of the investigated inter-till sediments (Kondratienė and Damušytė 2009). However, such interpretation is in disagreement with our IR-OSL data.

Taking into account all the above-mentioned factual data, it is possible to maintain that the till bed beneath the bottom of the Klaipėda Strait was most probably formed by a glacier advance during MIS 4, i.e. during the Weichselian early pleniglacial. This till bed can be correlated with the lowermost till complex in the

Olando Kepurė outcrop that also was most probably formed by a glacier advance during MIS 4 (Molodkov et al. 2010). According to fabric measurements in the Olando Kepurė outcrop, this till was formed by a glacier advancing from the north (Bitinas 1997). All these data are in good agreement with a reconstruction made by Svendsen et al. (2004) according to which part of the southwestern margin of the Eurasian ice sheet could have been situated in the Lithuanian Coastal Area or in the whole Western Lithuania during the Weichselian early pleniglacial maximum (MIS 4). The till bed formed during the early pleniglacial has been distinguished in the neighbouring Western Latvia: in stratigraphic schemes it has been identified as Talsi Stadial (Zelčs and Markots 2004). In the more southern region – territory of Poland – the till bed of the same age has been identified as Świecie Stadial (Lindner and Marks 1995, Ber 2006). According to the assumptions of some former researchers, the glacial advance could reach Lithuania during the early Weichselian – the corresponding till bed was distinguished as Varduva Stage in the stratigraphic scheme of Lithuania (Vonsavičius 1984). Later this opinion was not confirmed by factual data and the mentioned stratigraphic unit was rejected from the stratigraphic schemes (Gaigalas 2001, Satkūnas et al. 2007). The results of geochronological investigations presented in this chapter suggest that the Quaternary stratigraphic scheme of Lithuania should be supplemented by a new stratigraphic unit (for instance, it could be named as Melnragė Stadial) valid for Western Lithuania.

Thus, the evidence reported in this study does not support an opinion that the till layer beneath the bottom of the Klaipėda Strait and those at the same altitudes in the surroundings formed during the Warthanian (Medininkai) glaciation (MIS 6). The till layers in the northern part of the Klaipėda Strait, lying between the above-mentioned middle Weichselian till and pre-Quaternary sediments (Fig. 6.2, boreholes 4/98, 8140, 10092), most probably belong to the middle Pleistocene.

## 6.6 Conclusions

The results obtained in this work show that the absolute majority of the IR-OSL ages of investigated inter-till sediments beneath the bottom of the Klaipėda Strait fall within the age range of MIS 5d-5a, i.e. these sediments were formed during the early Weichselian. The sampled inter-till sediments are occurring not in situ, but as blocks (rafts) within the till bed formed during the Weichselian (Nemunas) glaciation. According to a reconstruction by Svendsen et al. (2004), the latter most probably can be associated with the ice movement during MIS 4 – part of the southwestern margin of the Eurasian ice sheet could have been situated in the Lithuanian Coastal Area and, probably, in the whole Western Lithuania during the Weichselian early pleniglacial maximum (MIS 4). This conclusion does not support the standpoint that the till beds beneath the bottom of the Klaipėda Strait were formed during the Warthanian (Medininkai, MIS 6) glaciation.

**Acknowledgements** We are grateful to colleagues Tatyana Balakhnichova and Marina Osipova for their contribution to IR-OSL dating laboratory work reported here, to Helle Kukk for checking

the English text and to Eglė Šinkūnė and Donė Gribytė for help in preparing the illustrations. This research was supported by grant no. 6112 from the Estonian Science Foundation, by Estonian State Target Funding Project No. 0320080s07, by grant no. LEK-10005 from the Research Council of Lithuania by Klaipėda State Seaport and Lithuanian Geological Survey.

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