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GEOLOGICAL, GEOMORPHOLOGICAL AND HYDROGEOLOGICAL HERITAGE IN LITHUANIA

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Abstract. Quaternary deposits are the most spread formations on the territory of Lithuania. They were formed during the Pleistocene glaciations and now they completely cover the territory of the country. Their thickness is up to 315 m. The standard Pleistocene and Holocene outcrops, large boulders, springs and expressive landforms are very typical here and form an essential part of the most picturesque landscapes of Lithuania. The official list of legally protected geological, hydrogeological and geomorphological geosites of Lithuania contains now 183 objects: 122 of them are geological, 32 hydrogeological and 29 geomorphological. The geological objects could be subdivided into 3 groups: erratic glacial boulders, outcrops and depressions. The outcrops are subdivided into 2 groups: Quaternary and Pre-Quaternary type outcrops. The hydrogeological objects (springs) are subdivided by genesis into 2 groups: ascending and descending springs. 29 geomorphological objects established in Lithuania are designed to reserve localities with typical or rare forms of relief bearing a great scientific and educational value. These objects are mostly mounts (5), dunes (5), eskers (5) and steep slopes (5).

Key words: geosites, classification, nature monuments, Lithuania.

Abstrakt. Utwory czwartorzędowe są najbardziej rozpowszechnionymi formacjami na obszarze Litwy. Powstały one podczas zlodowaceń pleistoceńskich. Obecnie pokrywają cały obszar kraju. Ich miąższość dochodzi do 315 m. Wzorcowe odsłonięcia osadów pleistoceńskich i holoceńskich, duże głazy, źródła i pełne ekspresji formy terenu są tu bardzo typowe i stanowią ważny element najpiękniejszych krajobrazów Litwy. Oficjalna lista prawnie chronionych geostanowisk geologicznych, hydrogeologicznych i geomorfologicznych obejmuje obecnie 183 obiekty: 122 geologiczne, 32 hydrogeologiczne i 29 geomorfologicznych. Obiekty geologiczne mogą być podzielone na 3 grupy: eratykowe głazy lodowcowe, odsłonięcia i obniżenia. W odsłonięciach można wydzielić 2 grupy: czwartorzędowe i przedczwartorzędowe. Obiekty hydrogeologiczne (źródła) można podzielić na dwie grupy genetyczne: źródła ascenzyjne i descenzyjne. Obiekty geomorfologiczne wyselekcjonowane na Litwie mają służyć ochronie obszarów z typowymi lub rzadkimi formami rzeźby, o wielkiej wartości naukowej i edukacyjnej. Są to głównie wzgórza (5), wydmy (5), kemy (5) i strome stoki (5).

Słowa kluczowe: geostanowiska, klasyfikacja, pomniki przyrody, Litwa.

The official list of legally protected geological, hydrogeological and geomorphological monuments of Lithuania contains now 183 objects: 122 of them are geological, 32 hydrogeological and 29 geomorphological. Besides, 10 geological and 40 geomorphological reserves have been established for conservation of assemblages of erratic boulders, outcrops and fossiliferous sites, particular landforms and landscapes (Table 1).

Most of the geological heritage objects are represented by large size, interesting composition and otherwise valuable boulders: Puokės (Skuodas district), Vozgeliai (Utena district), Vištytis (Vilkaviškis district) boulders, Banioniai stone (Panevėžys district), "Gaidys" stone (Jonava district), etc. The Puokės stone is the largest erratic boulder known so far in Lithuania. Its height is 3.6 m, length — 13.3 m, width — 7.5 m, and horizontal size — 32 m. Boulders, dragged in Pleistocene by continental glacier from Finland, Aland Islands and Baltic Sea bottom, Sweden, Karelia and elsewhere, bear witness of glaciation, which used to cover the whole Lithuanian territory. They are mostly rubbed smooth blocks of magmatic and meta-

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Table 1

Main types of 183 Lithuanian state protected objects of the geological, geomorphological and hydrogeological heritage

Objects	All objects	Nature monuments
Geological	**122**	**72**
Boulders	93	47
Outcrops	25	21
Quaternary type	17	14
Pre-Quaternary type	8	7
Devonian system	5	4
Jurassic system	1	1
Neogene system	1	1
Devonian and Neogene systems	1	1
Depressions	4	4
Karst funnels	3	3
Thermokarst holes	1	1
Hydrogeological	**32**	**19**
Springs	32	19
Ascending	12	11
Descending	20	8
Geomorphological	**29**	**28**
Cirques	1	1
Depressions	1	1
Ravines	1	1
Ridges	1	1
Hills	5	5
Horns	21	2
Bluffs	5	5
Dunes	5	5
Eskers	5	4
Hillridges	1	1
Offspurs of hills	2	2

morphic rocks (granite, diorite, pophyritic pegmatite, diabase, quartzite, etc.).

The boulders found on the Lithuania's surface have been brought by glaciers during the last glaciation. Only in the most south-eastern corner of the Republic (Šalčininkai district), boulders brought by glaciers of older glaciations can be found. Some of the boulders are known and valued for their connections with famous persons (A. Mickevičius stone in Kaunas, Napoleon's stone in Zarasai district), for mythological implications (Puntukas stone in Anykščiai district, Laumės stone in Šiauliai district), or as relict attributes of heather worship (stones "Stabo kūlis" and "Šilalės kūlis" in Skuodas district).

The list of geological objects contains by far fewer outcrops of interesting geological composition with fragments of typical and rarer rocks and layers of different age. Seventeen outcrops have sections of Quaternary sediments, only. Outcrop investigations are very informative about moraines of various glaciation layers, their composition and formation conditions, interlayers of interglacial lake, bog and river sediments, their formation conditions (Snaigupėlė outcrop in Lazdijai district, Liškiava outcrop in Varėna district), unique interglacial weathering crust developed on till (Alovė outrop in Alytus district, Škėvonys outcrop in Prienai district), dislocations (Puškoriai outcrop in Vilnius, Pilsupiai outcrop in Kėdainiai district), and activity of glacier melt water flows and character of bottom sediments in periglacial lakes (Balbieriškis outcrop in Alytus district, Rokai outcrop in Kaunas district). Older than Quaternary deposits (dolomite, gypsum, marl, limestones) can be observed in other 8 outcrops with rocks of Devonian, Jurassic and Neogene systems. The Papilė outcrop is one of the most famous outcrops. It has been known to scientists since 1825. Collections of fossils from the Papilė outcrop are available in many European universities.

The list of geological objects also includes three deep karst sinkholes. They have appeared after gypsum dissolution and formation of ample cavities in the layers of Devonian system ("Karvės ola", "Jaronio ola", "Velniapilio ola" in Biržai district). One more sinkhole is located in Trakai district — "Devil's Hole". Scientists have not developed any common opinion as to the origin of this hole, yet. The earliest hypothesis explaining the origin of the "Devil's Hole" was related to the fall of water stream from the ice edge. Another hypothesis was related to the thermokarst process, when after the melting of an ice block buried in sandy deposits, the funnel-like pit with the steep slopes occurred. Our-days capacity of the "Devil's Hole" has developed after transportation of the fine grained sand and silt material to the Škilietai Lakes by underground water flows. The most attractive hypothesis of the Devil's Hole origin is related to a meteorite activity.

29 geomorphological objects established in Lithuania are designed to preserve localities with typical or rare forms of relief bearing a great scientific and educational value. These objects are mostly: mounts — 5, dunes — 5, eskers — 5 and steep slopes — 5.

The geological objects include also 32 springs. Visitors have an opportunity to observe fresh groundwater springs ("Šmito" spring in Skuodas district, "Karalienės liūnas" in Anykščiai district, "Ūlos akis" in Varėna district) and sources, where freshwater carbonates are precipitating (Kavarskas tuff springs in Anykščiai district), or mineral groundwater springs with salty water (Balbieriškis mineral springs, the Nemunaitis mineral spring in Alytus district).

Lithuania has many officially declared objects of natural heritage. Some of them have been given the status of natural monument. From the international point of view, of value are the objects which are preserved as scientific standards (refer-

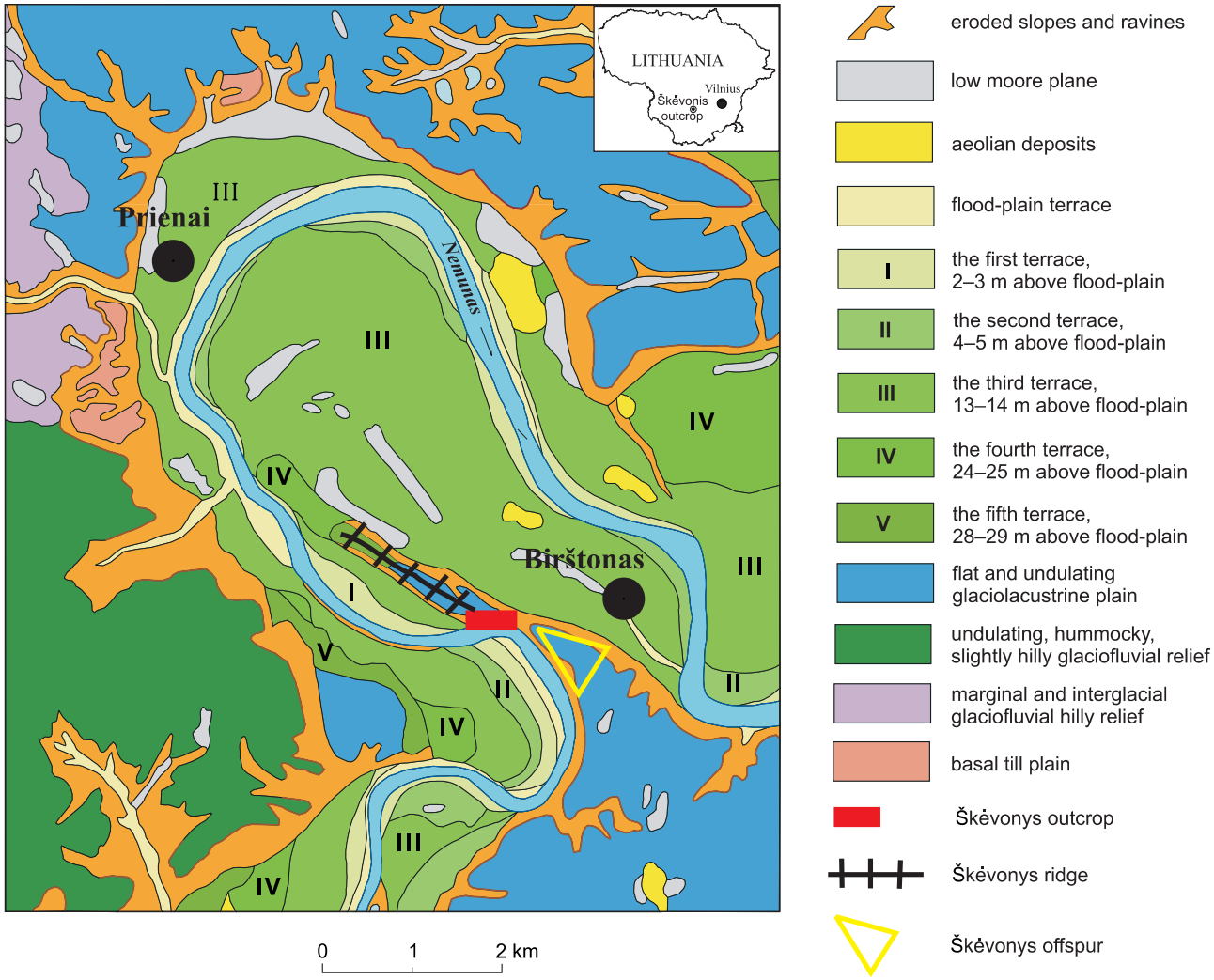

Fig. 1. Geological map of the Nemunas meander between Prienai and Birštonas

ence sections, stratotypes). They include natural monuments associated with little known natural phenomena or with historical or cultural objects and folklore. Of great value are also the objects having a long and important investigation history, which has contributed to the development of natural sciences. Three such natural monuments are discussed below.

Škėvonys outcrop (54136'18"N, 25100'20"E) is located 4.8 km NE of Prienai city centre and 1.0 km WNW of Birštonas town church, in the vicinity of Škėvonys village, on the right bank of the Nemunas River (Fig. 1).

Genetically, Škėvonys outcrop is related to the Škėvonys ridge where it occupies part of the SW slope. The ridge has a form of a rampart. Its axis has a NW–SE bearing. An absolute altitude ranges from 54.1 to 87.1 m at the highest point of the crest. A relative height reaches 33 m. The length is 2.3 km, the base width at the foot is 250–350 m. The slopes are rather steep and the slope angle ranges between 221–301. The slope parts at the crest and near the foot are usually flat. The cross-section of the ridge crest is not sharp; it is rather rounded, in some places even flat and comparatively wide (up to 200–250 m). The longitudinal profile of the ridge crest is wavy and lowering in the NW direction. The crest has three subhorizontal planes. Their absolute altitude is 67–69, 79–81 and 84–87 m respectively. The ridge area between the steep slopes of the outcrop and the gullies are overgrown with a dense mixed forest. Fifty years ago the ridge was almost bare, an intensive slope erosion took place in the SE part of the ridge and in the third flood plain terrace. Birštonas offspur, extending to the SE from Škėvonys ridge, is its continuation.

The upper part of the outcrop beneath the steep slopes is covered with talus and fallen trees. The flat part of the slope is in some places overgrown with grass and shrubs. The slopes of erosional gullies are not so steep as in other sectors. The Nemunas stream washes the lower part of the outcrop during tides. Its surface is covered with stones and gravel and waterlogged in some areas due to the presence of groundwater sources. The foot of Škėvonys outcrop is represented by a springy and water saturated 10 m wide flood plain, covered with luxuriant grass, or merely by a flat lower part of the valley slope.

Škėvonys ridge and Birštonas offspur are interesting and rare erosional forms of the Nemunas valley relief which were

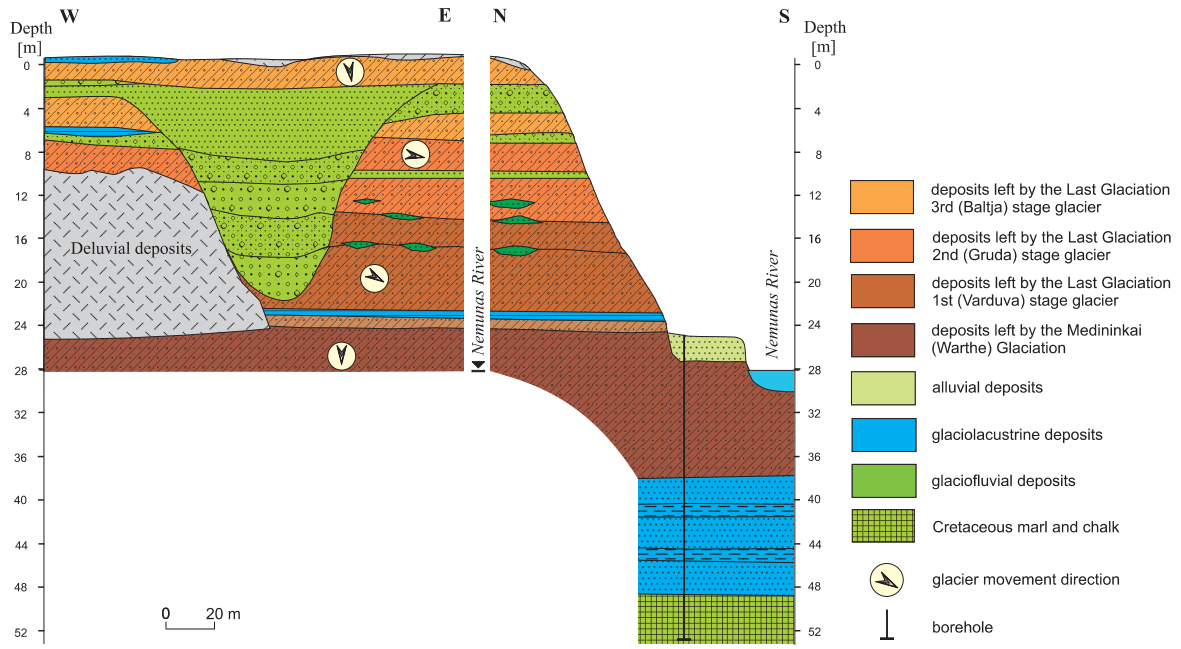

Fig. 2. Geological cross-section of the Škėvonys outcrop

carved in a clay plain 12–11.8 ky BP (Older Dryas) by the Nemunas stream at a height of 13–15 m above the present stream level. The Nemunas waters also deposited the third flood plain terrace. In later periods of time the Nemunas waters eroded only the south-eastern end (at the outcrop) of Škėvonys ridge and "sharpened" the Birštonas offspur. The slow degradation of these forms of relief, composed of solid tills and covered with limnoglacial clay is enhanced by newly developing ravines and gullies, falling steep slopes, surface water erosion and human economical activity.

Škėvonys outcrop is distinguished for the layers of the next to the last (Saalian) and last (Weichselian) glaciations and a rare weathering crust (the upper part of the outcrop section interval 24.25–26.5 m) developed in an interglacial period (Fig. 2).

The identification of the weathering crust facilitates the determination of the boundary between the Middle and Upper Pleistocene layers and the reconstruction of palaeographical conditions of the ancient relief (Baltrūnas, 2002). The scientific importance of the studied outcrop increased even more when a borehole, reaching the old Cretaceous (135–65 million years BP) calcareous rocks, was made at its foot.

The upper part of moraine of the next to the last glaciation (24.25–26.5 m) has been affected by physical weathering processes of the last (Merkinė, Eemian) interglacial period (117–130 ky BP). This 1–2.5 m thick weathering crust represents a gradual alternation of many features of till. Upwards, the initial brown till attains a pinkish and yellowish tint, the portion of sand increases, the content of weather-proof minerals (quartz, zirconium, magnetite, *etc.*) increases, the content of weather sensitive minerals decreases, among the gravel and shingle debris the content of marls, limestones, dolomites, and gneisses decreases, whereas the content of weather-proof rocks — garnets, porphyries, flints, *etc.* — and secondary carboniferous concretions increases.

A funnel-shaped body containing sand and gravel occupies the central part of the outcrop. It is bedding between the till and sandy loam layers. It represents a glacial palaeoincision (buried valley), which has been filled by glaciofluvial sandy, and gravel sediments. This layer, with gravel, slantwisely stratified, upwards widening, downwards narrowing and getting more coarse-grained, reaches a thickness of 20 m and is an important evidence of a rapid development of the outcrop. Being dry (located on the slope of a narrow ridge) and friable in its upper part, this layer is responsible for the continuous falling and sliding of till blocks. The lower part of the layer not abounding in water, accelerates the accumulation of deluvial scree. An intensive, though not continuous, side erosion by the Nemunas waters takes place at the outcrop, washing away the slope scree into the stream bed.

The "Devil's Hole" one of the most interesting natural monuments, was declared a geological monument in 1964. It is located in southern Lithuania, on the Dzūkų Highland, in the picturesque environs of Aukštadvaris town (54°36'42''N, 24°30'56''E). The diameter of this hole is 200–220 m, depth 40 m (except a 9.5 m thick peat layer on the bottom).

This landform is located within the area of marginal moraines of the Late Weichselian Glaciation, Grūda stadial (Fig. 3). A lot of mystical stories are related to this pit — an impressive mythological and distinct geological-geomorphological object of study.

Deep boreholes (depth 38–40 m) were drilled on the slope of "Devil's Hole". The lower part of the indistinctly bedded sand is dense in comparison with the upper part (Fig. 4).

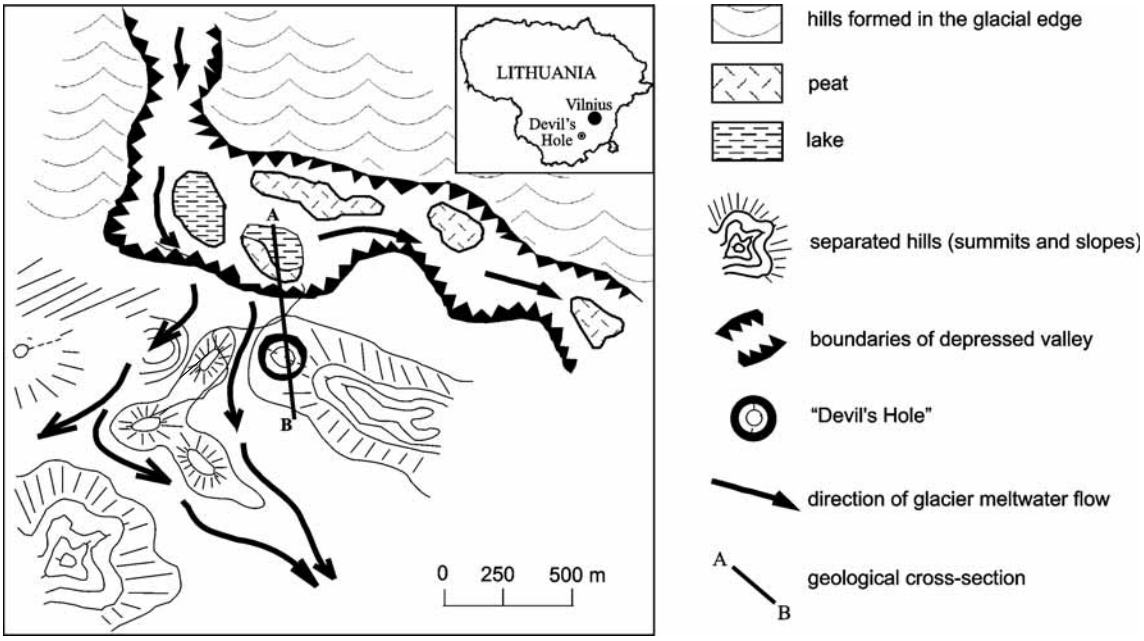

Fig. 3. The geomorphological situation of the "Devil's Hole" environs

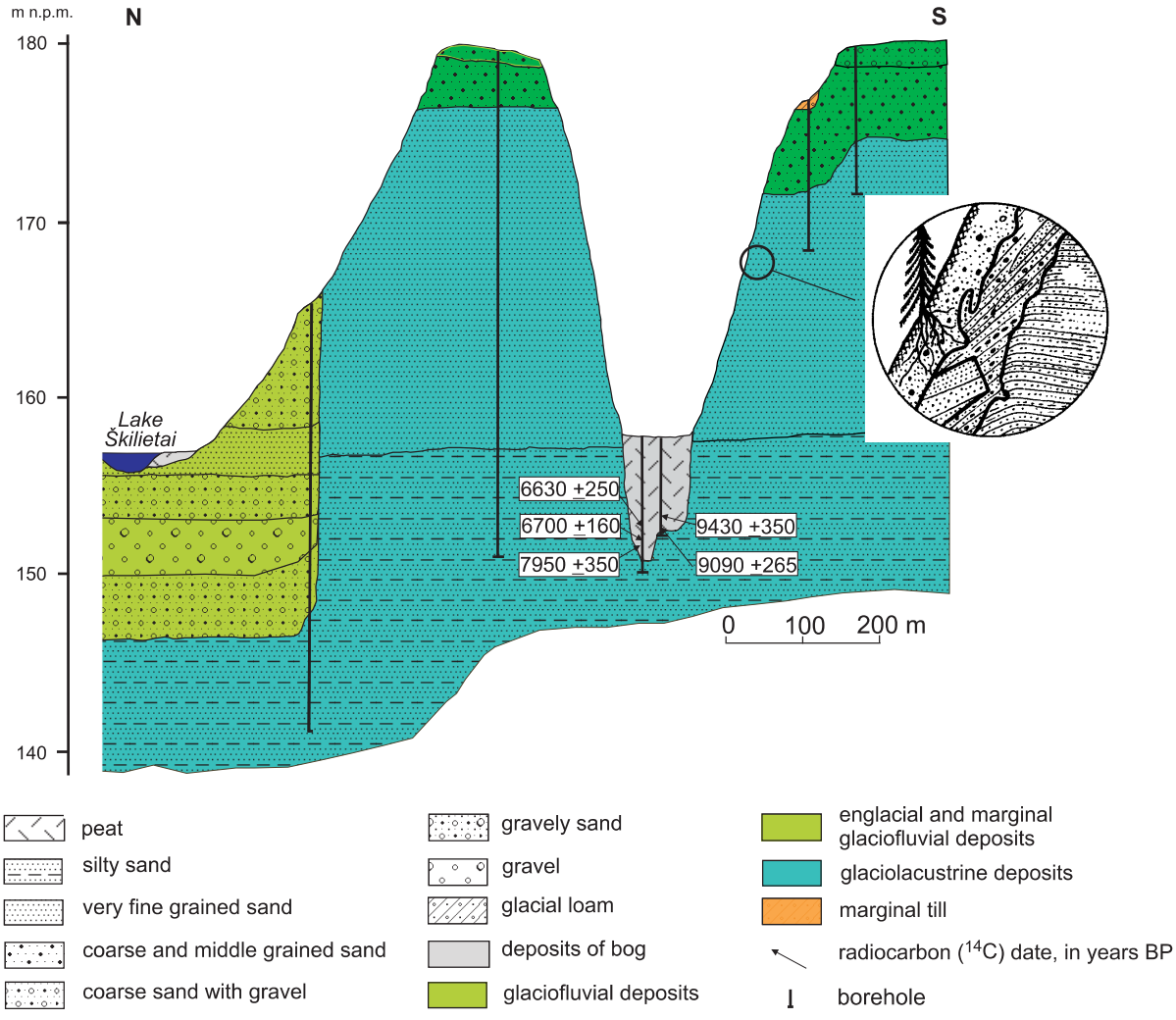

Fig. 4. Geological cross-section of the environs of the "Devil's Hole"

Fig. 5. Spring Smardonė (Photo by V. Mikulėnas)

Table 2

Uncalibrated ^{14}C dates from the bottom of the "Devil's Hole"

Drilling	Depth [cm]	Sediment	Uncalibrated ^{14}C years BP	Laboratory code
1	790–800	peat	9430 ±350	Vs-1156
1	808–810	peat	9090 ±265	Vs-1155
2	916–926	peat	6630 ±250	Vs-1242
2	926–936	peat	6700 ±160	Vs-1244
2	936–946	peat	7950 ±370	Vs-1243

The drilling and analysis of pollen from peat indicated that sand occurring below peat is of the Younger Dryas age. The accumulation of the peat started in Preborel period.

The data obtained testify that lime and elm predominated in the environs of the hole. Hazel and alder were also abundant. Dating by the radiocarbon method in laboratory of the Institute of Geology and Geography showed that the lower part of the peat was formed 9000–9400 ^{14}C year BP (Table 2).

The earliest hypothesis connected the origin of the "Devil's Hole" with the fall of the water stream from the ice edge. Another hypothesis was related to the thermokarst process, when after the melting of the ice block buried in the sandy deposits, a funnel-like pit with steep slopes was formed. The hole obtained its present capacity after groundwater flow had transported fine-grained sand and silt to the Škilietai Lakes. The most attractive hypothesis ascribes the formation of the "Devil's Hole" to meteorite activity.

Spring Smardonė is located in North Lithuania (56°11'55''N, 24°37'55''E), Likėnai spa of Biržai district (Fig. 5).

The curative properties of Smardonė spring have been known since 1587, and were mentioned in 1791, 1855, 1882, 1884, 1892, 1897, 1909, and in later (Linčius, 1991). Physicist and chemist Th. Grotthus obtained and published first results of the spring chemical analysis in 1816 (Grotthus, 1816). Likėnai has been known as a spa since 1890. At present, the mineral water is extracted from a bore well.

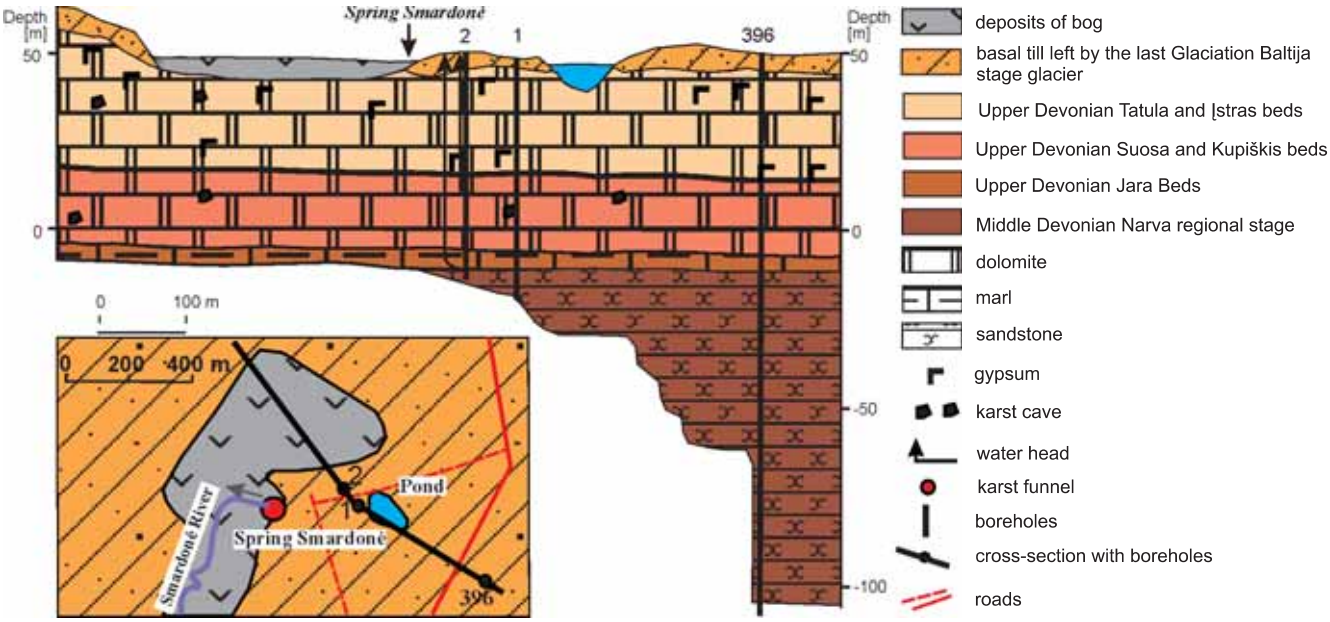

Fig. 6. Hydrogeological cross-section in the environs of the Smardonė Spring. (After Kondratas, Vaitiekūnas, 1990)

Spring Smardonė as one of the most interesting natural monuments, was declared a hydrogeological monument in 1985. It flows across a wavy morainal plain and flows out from the karst funnel 15–17 m in diameter (Fig. 6).

The karst funnel is in the Tatula suite of the Upper Devonian (gypsum, dolomite, marl, *etc*.). The depth of the funnel under the water is up to 3 m. The height of the slope above the water is 1.5 m. The water of Smardonė River is flowing out from a funnel on its western slope. The yield of the spring is 130–540 l/s. In 15.07.1989 the yield was 122.6 l/s. Water is colourless, transparent, with an odour of sulphuretted hydrogen. The temperature is 7–7.5°C. The total mineralisation is 1856.79 mg/l. The main components (mg/l) are CL^- — 24.82; HCO_3^- — 366; SO_4^- – 1020; Na^+ – 10.7; K^+ – 3.7; Ca_2^+ – 581.16; Mg_2^+ – 29.18. The hardness (mg-ekv/l) is 31.43.

Hydrosulphuric waters are widely spread in the northern part of Lithuania, in the environs of Likenai spa. They are connected with gypsum deposits of the Tatula suite of the Upper Devonian, in this part of the Republic deposited not deeply from the surface, over the basis of erosion. Due to this, the streaks and lenses of karst craters, gaps and vacuums are formed. Some of these vacuums are filled with subterranean sulphate or sulphate-hydrocarbonate calcium, magnesium-calcium waters, enriched from 10 to 15 mg/l with sulphuretted hydrogen in some places (Kondratas, Vaytekunas, 1990).

Sulphuretted hydrogen in this district is formed in a biochemical way. The reduction of sulphates takes place owing to the activity of sulphates–reducing bacteria. The maximum concentration of sulphuretted hydrogen occurs in peat. Concentration of sulphuretted hydrogen in water sharply decreases up to several miligrams in a litre in the districts where sediments rich in gypsum were deposited under morainal loamy and sandy soils (Kondratas, Vaytekunas, 1990).

CONCLUSIONS

Lithuania has many legally declared objects of natural heritage. Some of them have been given the status of natural monument. From the international point of view, of value are objects which are preserved as scientific standards (reference sections, stratotypes). They include natural monuments associated with little known natural phenomena or with the historical or cultural objects and folklore. Of great value are also the objects having a long and important investigation history, which has contributed to the development of natural sciences.

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