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Tectonic control on karst processes in Pasvalys Area, North Lithuania

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Karst processes are active in the northern part of Lithuania and cause different problems for the local community. The activity is related to sub-cropping of the Upper Devonian (Tatula Formation) gypsum-carbonaceous succession under a thin (<25 m) Quaternary cover. The Pasvalys cluster of karst sinkholes is distinct by anomalous density of karst features. The structural conditions and lithological variations were studied in relation to karst processes in Pasvalys Town and vicinities. A close correlation of those processes with tectonic structures was recognised. Pasvalys Town is situated within the Pasvalys uplift that is characterised by intense dissolution of the upper part of the evaporitic-carbonaceous Tatula Formation suggesting intense ground water infiltration within the uplift. Therefore the potential of karst activity is rather exhausted here. By contrast, the adjacent Lėvuo-Mūša depression, located west of the town, shows intense pervasive gypsum dissolution of the lower part of the Tatula Formation that resulted in preservation of the upper (Nemunėlis) gypsum layers from erosion processes. It is associated with the high potential of recent dissolution processes and formation of karst features. A similar scenario is identified north of Pasvalys Town in the Maskoliškės depression. The most intense karst processes occur along the high-gradient boundaries of the aforementioned structures. The Pagojis depression, defined in the south, comprises only little affected by pervasive dissolution Tatula succession that also has the high potential for development of karst features. The regular pattern of some sinkholes along lineaments suggests that the fracture system dissecting Devonian sediments also contributed to the uneven distribution of dissolution processes.

Key words: karst, gypsum, tectonic structure, North Lithuania, Devonian

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INTRODUCTION

Lithuanian territory is subject to only low activity of surface geodynamic processes owing to low tectonic activity and rather flat relief (Česnulevičius, 1999). The central part of North Lithuania is characterised by anomalous surface geodynamic processes that are related to karstification of the Devonian evaporitic-carbonaceous succession (Marcinkevičius, Bucevičiūtė, 1986; 1997). They are covered by a thin (<25 m) Quaternary cover and therefore are exposed to intense hydrodynamic processes leading to selective leaching of gypsum layers (Klizas, Šečkus, 2007).

The karst processes impose significant complications on agricultural and other human industrial activities due to sensitivity of the system to pollution and damage risk. Therefore the understanding of parameters controlling the temporal and lateral variations of karst processes in North Lithuania is of primary importance (Paukstys et al., 1999).

Some periodicity was recognised in activity of karst processes (Skuodis, 1979). It was defined that the temporal variations in karst processes are most closely related to two-year period rainfall intensity changes that in turn correlate with karst rivers discharge (Satkūnas et al., 2007). The rate of sulphate dissolution in 1994–2000 was 30% higher than that registered in 1962–1979 in the karst area of North Lithuania, thus reflecting impact of climate change.

In terms of the lateral distribution, the karst area is confined to the minimum thickness of Quaternary deposits, less than 25 m thick (Narbutas, 1960; Narbutas et al., 2001; Dėnas, Račkauskas, 2005), overlying the Tatula Formation of the Upper Devonian composed of predominant gypsum with dolomite and marlstone interlayers (Paškevičius, 1994). The thickness of the Quaternary cover is therefore considered as the basic factor controlling occurrence of karst processes (Dėnas, Račkauskas, 2005). However, it cannot explain the local variations in karst activity. Some studies suggest that karst sinkholes are often controlled by the fracture system dissecting the Upper Devonian sediments (Eimantaitė, Skuodis, 2001; Šliaupa, Šliaupa, 2003).

It is, however, realised that the uneven distribution of karst sinkholes is a result of a more complex combination of different geological factors (e. g. Nicod, 2003). The present study is scoped on recognition of local tectonic structures and their impact on hydrodynamic conditions and lithology variations of the Tatula Formation in Pasvalys Area that may affect the intensity of gypsum dissolution and karstification in North Lithuania. The controlling role of tectonic structures on the pattern of karst processes and their intensity is well defined in other regions (e. g. Glazek, 1989; Kresik, 1995; Ross et al., 2001; Rubio et al., 2007; Kassa et al., 2012). Some studies indicate that the influence of faulted structures very much depends on the kinematic type of tectonic features (Herold et al., 2000).

GEOLOGICAL SETTING OF PASVALYS AREA

Pasvalys Town is situated in the central part of North Lithuania, in the Middle Lithuanian topographic low that is characterised by the reduced thickness of the Quaternary cover. Two distinct karst clusters, i. e. Biržai and Pasvalys, are defined in North Lithuania (Marcinkevičius et al., 2010).

The Biržai cluster is the largest one, elongated roughly SW–NE (Fig. 1). A particular feature is the predominance of NNW–SSE trending sinkhole chains that parallel the general orientation of major rivers in the region. It is still not clear if those chains are controlled by the fault / joint system or by Quaternary cover features (or combination of both). This lineament system is superimposed by less distinct sinkhole chains trending WSW–ENE. Those lineaments compartmentalize the Biržai karst area to blocks (segments) as large as about 2.5 × 2.5 km (Fig. 1). East of Biržai Town, the north–south striking karst lineaments predominate.

There is no distinct karst lineament network identified in the Pasvalys karst swarm. It is also smaller in size (Fig. 1).

Geophysical studies unravelled that Biržai and Pasvalys karst clusters are located within the NE–SW trending Pasvalys–Biržai tectonic zone well defined in the potential field maps reflecting the structural grain of the crystalline basement (Šliaupa, Šliaupa, 2003). Activity of this zone may lead to increased fracturing of the overlying sedimentary cover, including Upper Devonian evaporitic-carbonaceous succession.

A more detailed inspection of the tectonic structures of the Upper Devonian succession (Fig. 1) indicates that the Biržai swarm is confined to the northern slope of the Daudžgiriai uplift that is complicated by the Pabiržė depression. The Pasvalys swarm is located within the eastern part of the Sindriūnai depression that passes to the Gulbinėnai depression in the east. The boundary between Sindriūnai and Gulbinai depressions in the south and Vaškai and Daudžgiriai uplifts in the north is related to reactivated Lower Palaeozoic Telšiai fault striking roughly west-east.

Pasvalys Town is located at the confluence of Svalia and Lėvuo rivers (Fig. 2). The area of the town is characterised by essentially low activity of recent karst processes, while abundant sinkholes

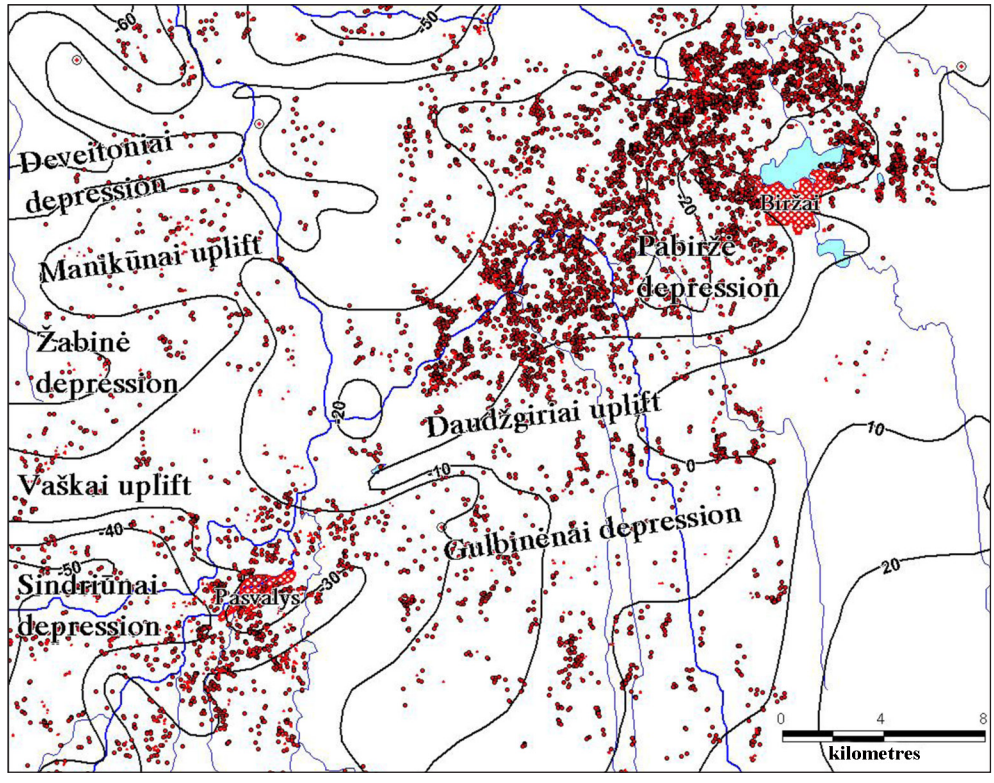

Fig. 1. Distribution of karstic sinkholes (karst data base by S. Bucevičiūtė, an unpublished report) and the structural map of the bottom of the Pliaviniai Regional Stage of North Lithuania compiled based on the drilling data (Pasvalys–Biržai). Major rivers are shown
1 pav. Karstinių smegduobių paplitimas (S. Bucevičiūtės duomenys, nepublikuota). Izolinijos nurodo Pliavinių regioninio aukšto pado gylius pagal gręžinių duomenis, pateikti struktūrų pavadinimai

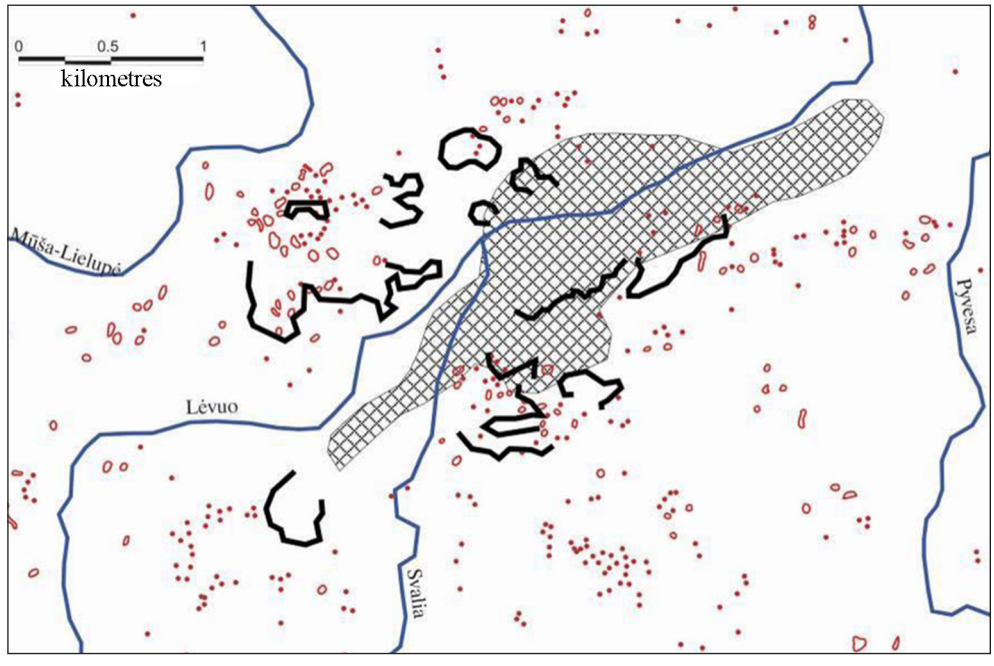

Fig. 2. Distribution of karst sinkholes (after Bucevičiūtė, unpublished report). Bold lines show boundaries of large karst depressions
2 pav. Karstinių smegduobių schema (pagal S. Bucevičiūtę, nepublikuota ataskaita). Storos linijos žymi karstinių muldų ribas

are mapped just in the vicinity of the town. Furthermore, the distribution of sinkholes is rather uneven; some chain clustering is noticed.

The uppermost part of the geological section of Pasvalys Town and its vicinities is composed of glaciolacustrine sediments, mainly clayey, deposited during recession of the last Nemunas ice sheet (Marcinkevičius et al., 2010). The thickness ranges from 0.5 m to 6 m (Fig. 3, 4). It covers Baltija moraine composed mainly of clayey till; sandy layers are mapped somewhere. West and north of Pasvalys Town, older moraine layers are identified. The

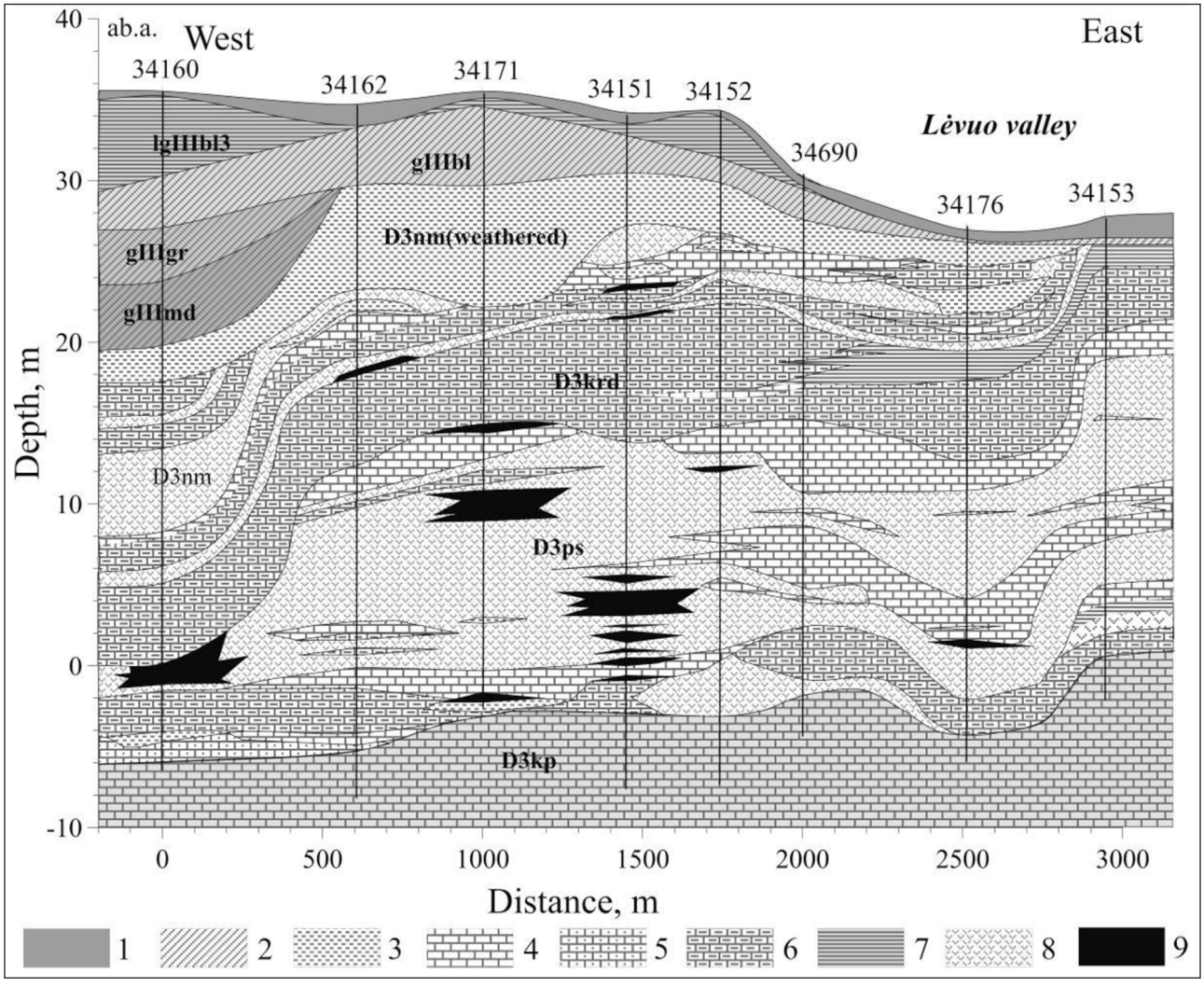

Fig. 3. Geological cross-section, north (see Fig. 7 for location). *1* – Holocene deposits, *2* – moraine, *3* – weathered carbonates, *4* – dolomite, *5* – dedolomite, *6* – dolomitic marlstone, *7* – clay, *8* – gypsum, *9* – karstic cave. Indexing: lgIIIbl – glaciolimnic sediments of Baltija Sub-formation, gIIIbl – glacial sediments of Baltija Sub-formation, gIIIgr – glacial sediments of Grūda Sub-formation, gIIImd – glacial sediments of Medininkai Sub-formation, D3nm – Nemunas Member, Upper Devonian, D3kr – Kirdonys Member, Upper Devonian, D3ps – Pasvalys Member, Upper Devonian, D3kp – Kupiškis Formation, Upper Devonian

3 pav. Šiaurinis geologinis profilis (vieta parodyta 7 pav.). *1* – holoceno nuogulos, *2* – morena, *3* – išdūlėjusios karbonatinės uolienos, *4* – dolomitas, *5* – dedolomitas, *6* – domeritas, *7* – molis, *8* – gipsas, *9* – karstinė tuštuma. Geologiniai indeksai: lgIIIbl – Baltijos posvitės limnoglacialinės nuogulos, gIIIbl – Baltijos posvitės glacialinės nuogulos, gIIIgr – Grūdos posvitės glacialinės nuogulos, gIIImd – Medininkų posvitės glacialinės nuogulos, D3nm – Nemuno sluoksniai, D3kr – Kirdonių sluoksniai, D3ps – Pasvalio sluoksniai, D3kp – Kupiškio svita

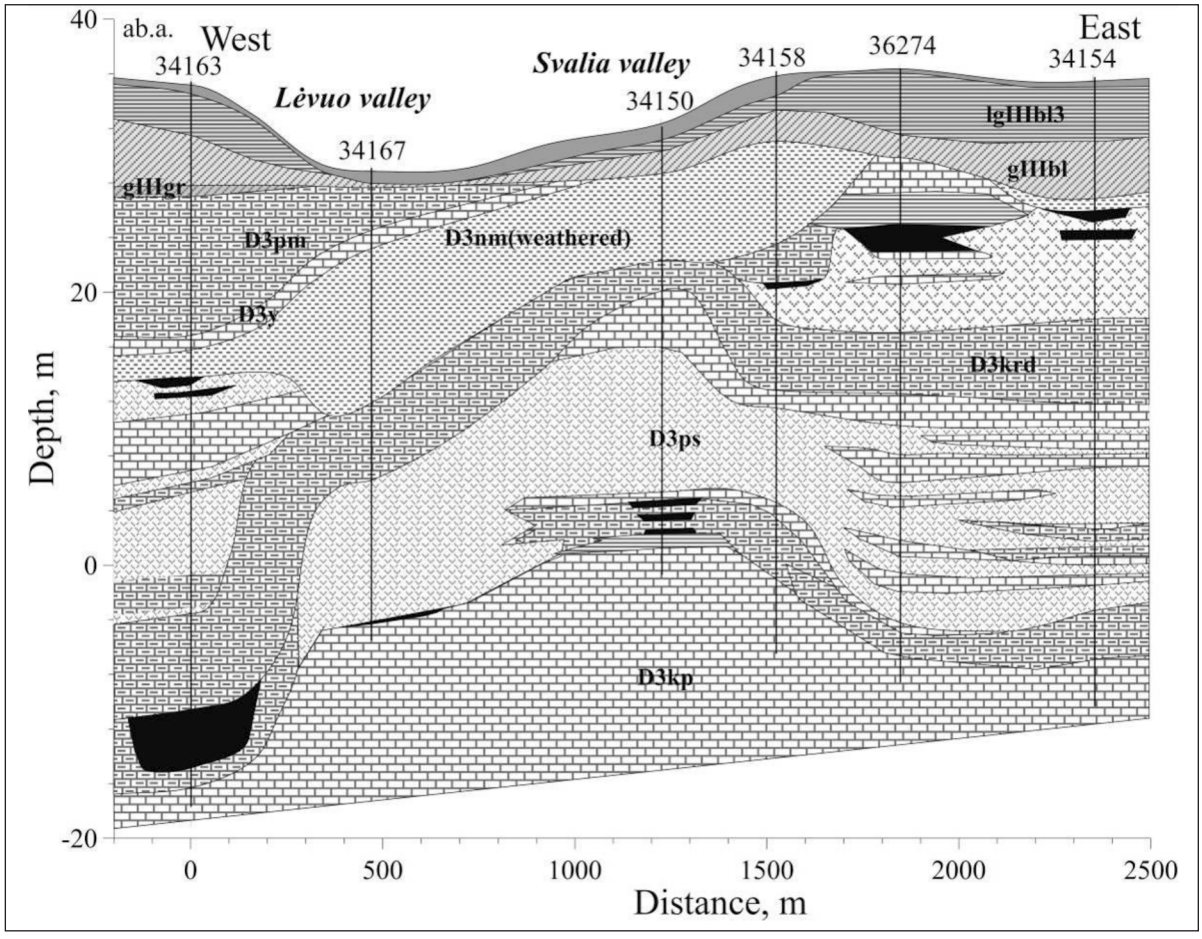

Fig. 4. Geological cross-section, south (see Fig. 7 for location). Legend is in Fig. 3
4 pav. Pietinis geologinis profilis (vieta parodyta 7 pav.). Legenda pateikta 3 pav.

thickness ranges from 0 (river valleys) to 34 m. The predominant thickness of Quaternary sediments is about 8–10 m in the town territory.

The upper part of Devonian sediments is strongly weathered. It is represented mainly by disintegrated dolomite with some selenite and gypsum remnants. The thickness of the weathering zone is variable; it is in the range of 0–17 m.

Three members are defined in the Tatula Formation (Lower Fammenian, Upper Devonian) that is as thick as 15.0–40.5 m. The upper part is attributed to the Nemunėlis Member (D3nm). The thickness is highly variable, mainly in the range of 2–6 m, maximum up to 17.4 m. It is composed of alternating gypsum, dolomite, dolomitic marlstone. The percentage of those lithologies changes dramatically in boreholes and this change is attributed to selective and uneven dissolution of evaporitic lithologies and sin-sedimentary lithological variations. In general, four sedimentation cycles can be defined in the section composed of gypsum at the base and dolomite / dolomitic marlstone at the top. The second cycle comprises the main volume of gypsum. Somewhere the dolomitic and marly layers grade laterally into gypsum containing only minor amount of the latter lithologies that implies sharp variations in sedimentation conditions in the lagoonal basin. Abundant karst caves are mapped in some boreholes indicating progressing dissolution processes.

The Nemunėlis evaporitic-carbonaceous succession overlies 2.3–8.0 m (mainly 5–7 m) thick dolomite marlstones attributed to the Kirdonys Member (D3krd). It contains rare interlayers and laminae of dolomite, selenite, and gypsum. This member has basin-scale distribution and points to a large-scale change in sedimentation conditions in the Baltic Region that resulted in the increased influx of terrigenous material.

The underlying Pasvalys Member (D3ps) is of 5.5–20 m thick, in most cases about 15 m. Similarly to the Nemunėlis Member, it is composed of the triple alternation of gypsum, dolomite, and dolomitic marlstone. Somewhere the layers are weathered, karst caves are also abundant in some boreholes, sometimes filled in by karst breccia. Dedolomite was reported to be present in several wells. The pattern of different lithologies is highly variable, grading from predominant gypsum to intercalations of gypsum and carbonates. The content of carbonates sharply increases in the eastern part of Pasvalys Town. West of Pasvalys Town, gypsum is almost completely dissolved that in turn resulted in preservation of the uppermost part of the overlying Nemunėlis Member. It implies that dissolution took place in the west before the Late Quaternary sedimentation.

The Tatula Formation is underlain by a carbonaceous succession referred to as the Pliaviniai Regional Stage that is about 30 m thick. The lower part is composed of dolomitic marlstones (Jara Member) grading to dolomitic Suosa (D3ss) and Kupiškis members (D3kp) that represent two distinct sedimentation cycles (clayey dolomite and / or dolomitic marlstone at the base grading upwards into dolomite).

The ground water of the Tatula aquifer is of $Ca–SO_4$ type, salinity is about 2 g/l that points to saturation of formation water by dissolved gypsum compounds. The underplaying Pliaviniai dolomitic aquifer contains potable water of about 0.4–0.5 g/l salinity; the water is of $Ca–HCO_3$ type.

DATA AND METHODS

A number of boreholes have been drilled in Pasvalys Town and vicinities. The study area is as large as about 3.5 × 3.5 km. Data of more than 70 wells drilled through the whole Tatula Formation section were collected from industrial (hidrogeological and engineering geological) and mapping reports. The studied boreholes were drilled with core sampling therefore they provide important information on the lithological composition of Upper Devonian and Quaternary sediments. The average well spacing is about 250 m. In some parts of the town dense clusters have been drilled with boreholes spacing up to 10 m (engineering geological drillings).

The detailed inspection study of drilling information of Pasvalys Area enabled identification of smaller scale structures complicating larger structures discussed above. Depth maps of Nemunėlis and Pasvalys members and the Pliaviniai Regional Stage were compiled supplemented with the isopach maps. Also, the percentage of gypsum lithologies was calculated in each well for Nemunėlis and Pasvalys members. The total thickness of Quaternary clayey lithologies covering Upper Devonian sediments was calculated to assess the isolation of evaporites and carbonates from the infiltration of the meteoric waters. The MapInfo Professional GIS programme was employed for data management.

RESULTS

Tectonic framework

The sedimentary cover of the Baltic sedimentary basin is only little deformed. The main deformation phase took place at the end of the Silurian – beginning of the Devonian (Caledonian) Stage (Stirpeika, 1997). Some reactivation and formation of new structures are recognised during succeeding stages, though this activity is classified as minor due to the cratonic setting of the basin and a far distance to active tectonic zones (e. g. Alpine orogenic system).

There is no seismic survey performed in the area. Detailed seismic and deep drilling studies have been carried out about 4 km to the north of Pasvalys Town, owing to exploration of the Vaškai uplift prospective for underground gas storage in the Cambrian siliciclastic reservoir (UGS) (Šliaupienė, Šliaupa, 2011). The seismic lines crossed the large-scale Telšiai fault of more than 200 m amplitude in the Lower Palaeozoic succession and a few dozen meters amplitude in the overlying younger Devonian sediments, including the Tatula Formation. The seismic results were supplemented by electric tomography showing penetration of faulted structures up to the bottom of the Quaternary succession (Šečkus, 2002).

The structural map of the top of the Pliaviniai Regional Stage unravels several local scale low-magnitude tectonic structures affecting Pasvalys Town and its vicinities (Figs. 5, 6). The town is situated within the local uplift (Pasvalys uplift), the depth of the top of the Pliaviniai succession is about –2 m (b. s. l.). The uplift is flanked by

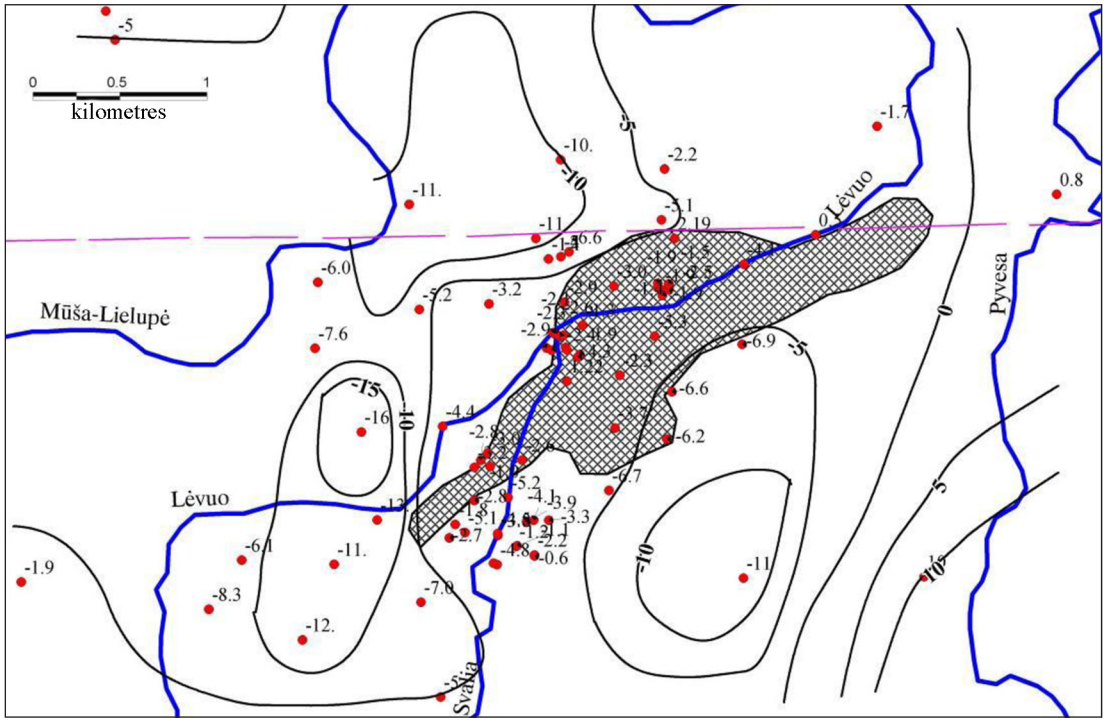

Fig. 5. Structural map of the top of the Pliaviniai Regional Stage. Boreholes and depths are shown. Dashed line indicates the neotectonic zone (after A. Šliaupa, 2001)
5 pav. Pliavinių regioninio aukšto kraigo struktūrinis žemėlapis. Nurodyti gręžiniai ir gyliai, brūkšnine linija pažymėta neotektoninė zona (pagal A. Šliaupą, 2001)

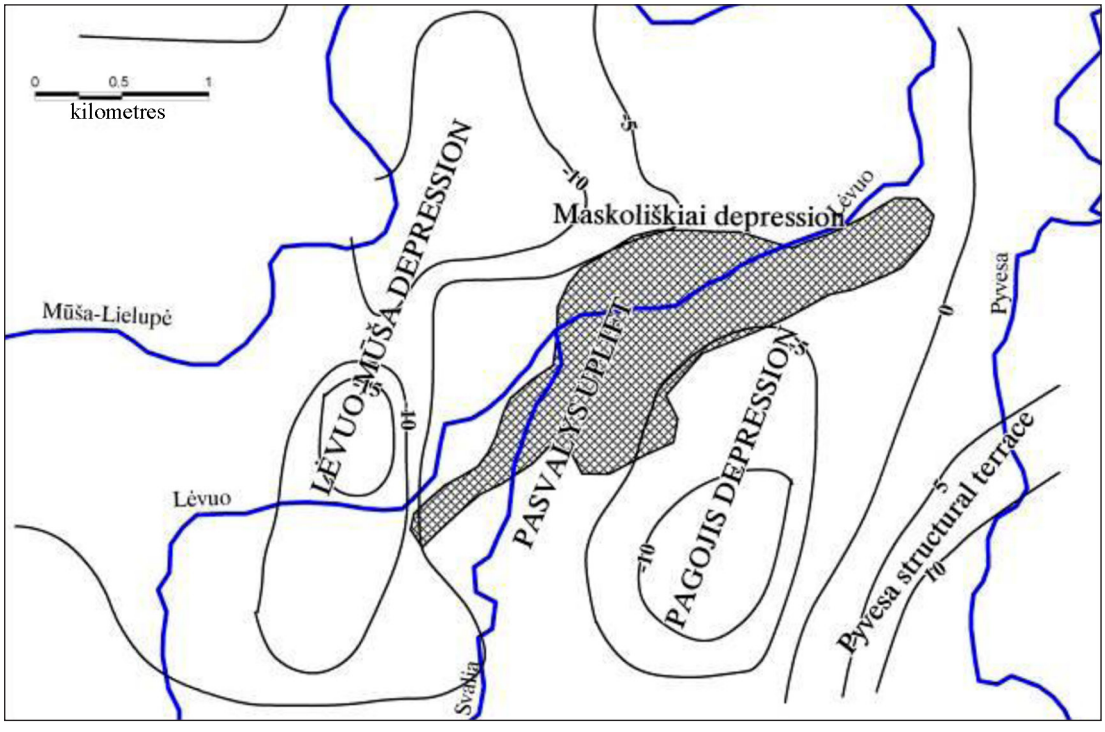

Fig. 6. Structural map of the top of the Pliaviniai Regional Stage. Tectonic structures are defined
6 pav. Pliavinių regioninio aukšto kraigo struktūrinis žemėlapis. Išskirtos tektoninės struktūros

north–south trending Lėvuo-Mūša (two connected depressions, i. e. Lėvuo in the south and Mūša in the north, separated by minor uplift) and Pagojis depressions in the west and the east, respectively. The depth of the top of the Pliaviniai Regional Stage is about –10 to –15 m (b. s. l.) in depressions. A 5 m amplitude structural terrace trending west-east is defined along the northern boundary of the town. The northern flank of the terrace is associated with the minor Maskoliškiai depression. This terrace is confined to neotectonically active lineament of the Meškuičiai–Juodupė zone (Šliaupa, 2001). Those local structures are situated within the larger-scale (about 5 km wide) depression trending west–east.

The depth variations of the bottom of the Nemunėlis Member are more pronounced; this is attributed to the combined effect of tectonic deformations and selective dissolution of sulphate layers (Fig. 7), as suggested by preserved structural grain recognised in the Plaiviniai Regional Stage superimposed by complicating structural features. Lėvuo and Maskoliškiai depressions become essentially pronounced in the overlying Tatula Formation. The new distinct feature is the Paberžėliai terrace of about 10 m magnitude. It is notable that it controls the straight segment of the Lėvuo River. Also, the local uplift separating Lėvuo and Mūša depressions becomes more distinct. Larger amplitudes of structures defined in Nemunėlis beds compared to those in the Pliaviniai Formation are accounted for selective dissolution of gypsum layers.

The structures defined in the depth map are well recognised in the thickness map of Nemunėlis and Pasvalys members (Figs. 8, 9). However, they have reverse trends.

The thickness of the Nemunėlis Member decreases to the east (Fig. 9) that is explained in terms of increasing truncation by the Quaternary cover (Devonian layers are generally tilted to WNW in Lithuania). The thickness variations of the Nemunėlis Member are very closely correlated with depth variations of the bottom of the member.

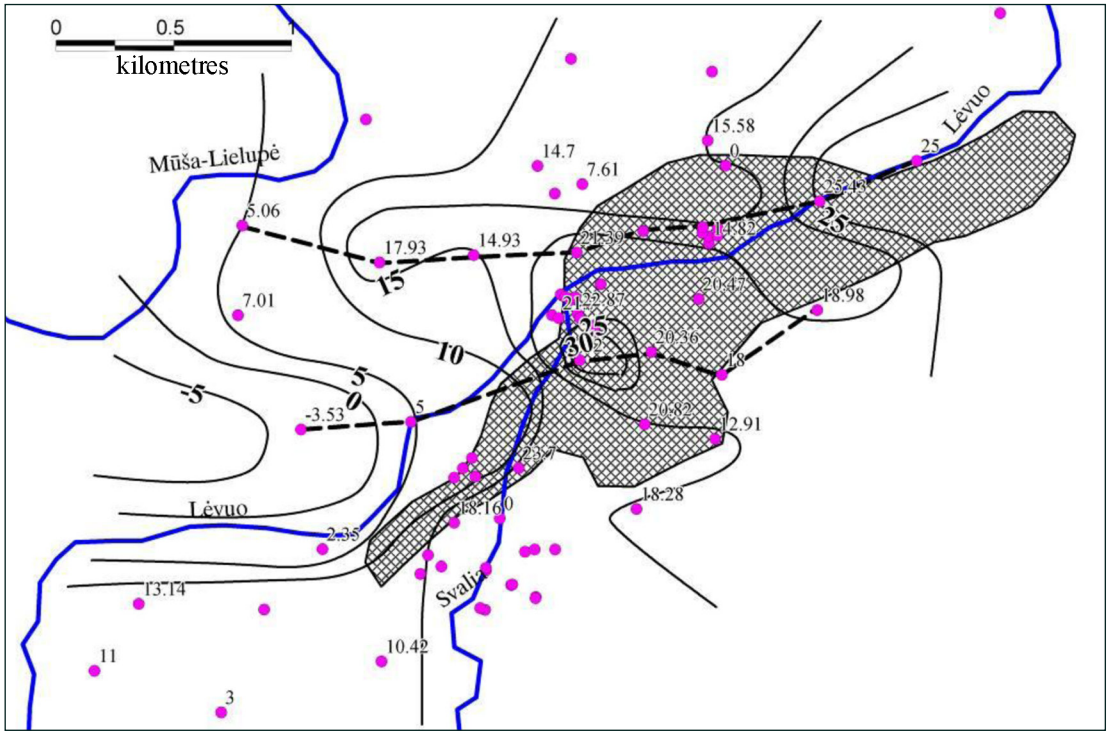

Fig. 7. Depth map of the bottom of the Nemunėlis Member. Boreholes and depths are shown. Bold dashed lines indicate lines of geological profiles (Figs. 3, 4)

7 pav. Nemunėlio sluoksnio pado gylių žemėlapis. Nurodyti gręžiniai ir gyliai, brūkšninėmis linijomis pažymėtos geologinių profilių linijos

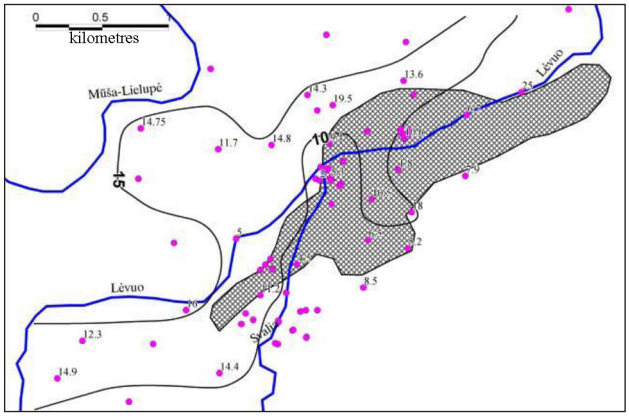

Fig. 8. Thickness map of the Nemunėlis Member. Boreholes and thickness are shown
8 pav. Nemunėlio sluoksnio storių žemėlapis. Nurodyti gręžiniai ir storiai

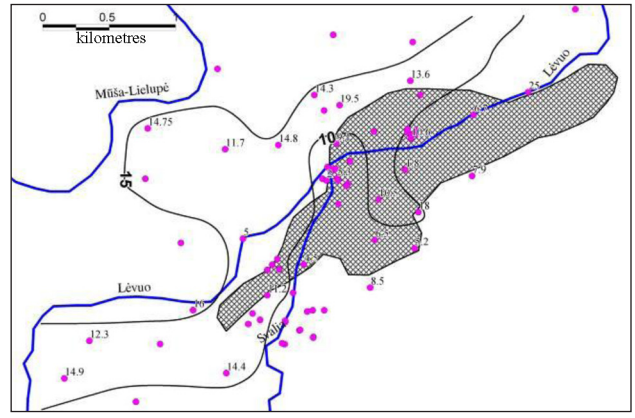

Fig. 9. Thickness map of the Pasvalys Member. Boreholes and thickness are shown
9 pav. Pasvalio sluoksnio storių žemėlapis. Nurodyti gręžiniai ir storiai

The thickness of the Pasvalys Member is about 18–19 m in Pasvalys Town. It dramatically decreases to about 8 m in the west and the north (Fig. 9). Those changes are closely related to depth variations of the top of the Pliaviniai Regional Stage, i. e. depressions are associated with dramatic decrease in thickness of the overlying Pasvalys Member. As indicated in the geological profiles (Figs. 3, 4), sharp thickness reduction is accounted for pervasive dissolution of gypsum layers that are almost absent within depressions. Such correlation leads to a conclusion that structural grain strongly controls gypsum dissolution processes. As it has been mentioned above, the reduction in thickness of the Pasvalys Member is associated with preservation of the upper part of the overlying Nemunėlis Member.

VARIATIONS OF GYPSUM VOLUME

Nemunėlis and Pasvalys formations contain gypsum layers that predominate in the geological section not affected by pervasive dissolution.

The percentage of gypsum layers of the Nemunėlis Member varies from 2% to 52% (Fig. 10). The

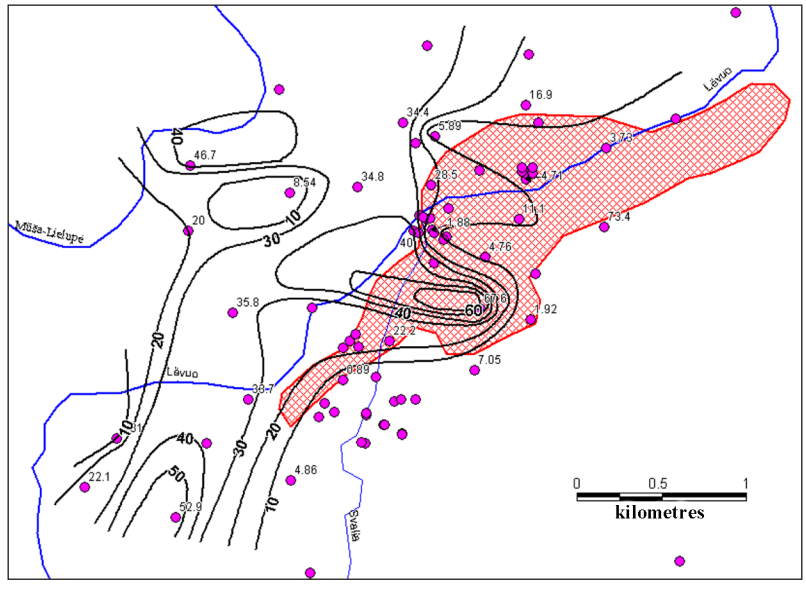

Fig. 10. Percentage of gypsum layers in the Nemunėlis Member. Boreholes are shown
10 pav. Nemunėlio sluoksnio gipsingumo schema. Nurodyti gręžiniai

maximum volumes (35–52%) of gypsum are identified in the Lėvuo-Mūša depression. The local maximum of 67% is identified in the southern part of the town. However, this maximum is not conclusive, as the Nemunėlis Member is considerably eroded here (7.5 m thick) and only the lower (gypsum containing) part of the sedimentation cycle is preserved. The Lėvuo-Mūša maximum is related to a combination of two factors: (1) the upper part of the member is preserved due to pre-Quaternary dissolution of the underlying Pasvalys Member, and (2) much less intense weathering (dissolution) of the upper part of the Nemunėlis Member within depression compared to the Pasvalys uplift (Figs. 3, 4). Those effects are also well recognised in the Maskoliškės depression in the north. It is notable that even minor structural features are well reflected in gypsum percentage variations, e. g. the local uplift separating Lėvuo and Mūša depressions is marked by sharp decrease (8% vs 35%) in the gypsum content in the Nemunėlis Member.

The content of gypsum systematically increases to the east (Fig. 11). It shows a reverse correlation with the gypsum percentage of the Nemunėlis Member. In the town of Pasvalys, the percentage varies from 45% in the west to 60% in the east. Some local anomalies of sharp decrease in the gypsum percentage (3–20%) are mapped that are related to local increase in dolomite sedimentation.

Gypsum layers are considerably dissolved within Lėvuo-Mūša and Maskoliškės depressions, the content of gypsum sharply decreases to 5–25%.

QUATERNARY COVER

The Quaternary succession is an important factor that controls isolation of Tatula evaporites from infiltrating meteoric waters. Pasvalys Area is characterised by a thin Quaternary cover that is in the range of 2–9 m (thickness increases up to 16 m in karst sinkholes) (Fig. 12). Moreover, Devonian sediments are outcropping in the Lėvuo valley. The thickness of the Quaternary cover dramatically increases to more than 30 m about 1.5 km to NW and SW of the town.

The total thickness of clayey lithologies (clay, clayey and sandy loam) of the Quaternary cover was compiled (Fig. 13). The NE–SW trending

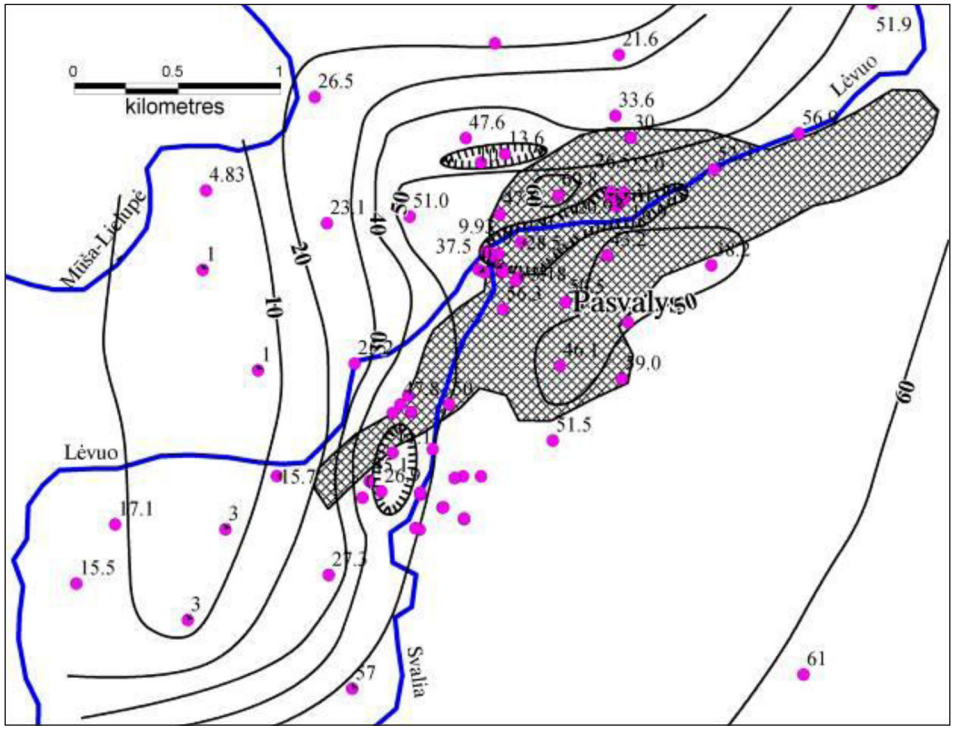

Fig. 11. Percentage of gypsum layers in the Pasvalys Member. Boreholes are shown. Hatched lines mark areas of sharp decrease in gypsum percentage
11 pav. Pasvalio sluoksnio gipsingumo schema. Nurodyti gręžiniai. Dantytomis linijomis pažymėti plotai, kuriuose staiga sumažėja gipso kiekis

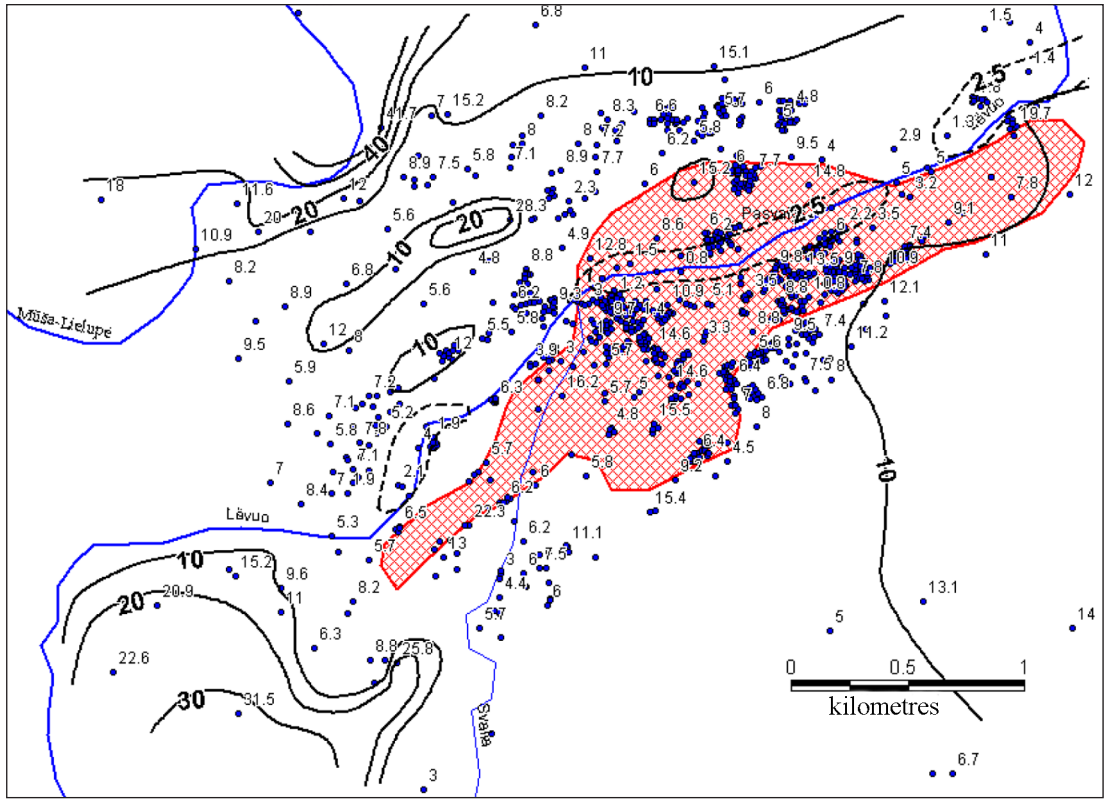

Fig. 12. Thickness of Quaternary deposits. Boreholes and depths are indicated
12 pav. Kvartero dangos storių žemėlapis. Nurodyti gręžiniai ir storiai

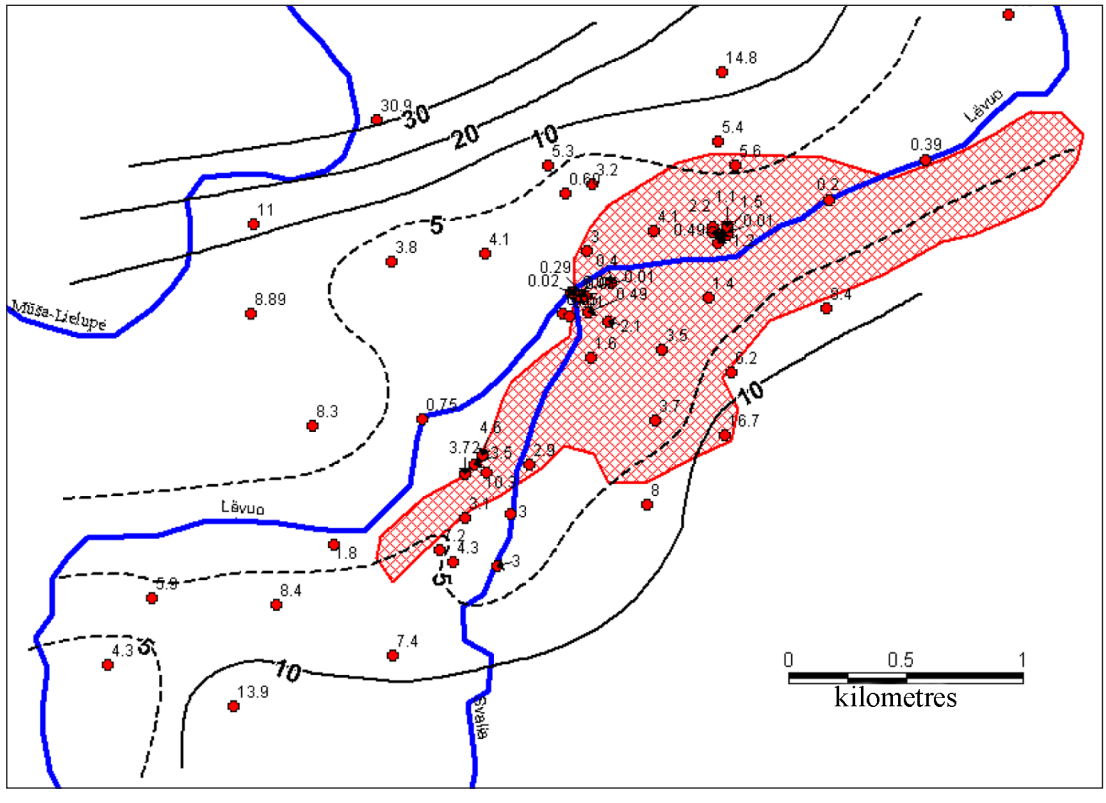

Fig. 13. Total thickness of clayey lithologies of the Quaternary succession. Boreholes and thickness are indicated
13 pav. Kvartero molingų sluoksnių bendras storis. Nurodyti gręžiniai ir storiai

minimum, cored by the Lėvuo River, is defined; the total thickness varies from a few dozen centimetres to 3.5 m. The town of Pasvalys is situated within this minimum. The total thickness of clayey layers increases south and north of the town to 14 m and 31 m, respectively.

The surface lithologies are composed of predominantly clayey sediments deposited in glaciolacustrine basin, dissected by alluvial deposits accumulated in river valleys (Fig. 14).

DISCUSSION

The Pasvalys karst swarm shows the uneven pattern of sinkholes. A comparison of the sinkhole distribution to Upper Devonian tectonic features shows a close correlation (Figs. 15, 16).

The town of Pasvalys is characterised by negligible recent karst activity. The town is situated within the Pasvalys tectonic uplift of about 10 m amplitude in the Pliaviniai Regional Stage and is even more contrasted in the overlying Tatula Formation. Analysis of boreholes indicates that the Nemunėlis Member, representing the upper part of the Tatula Formation, is intensely weathered. The weathered zone contains only minor remnants of selenite and gypsum that explains no or miserable recent karst activity. It implies that the uplift was subject to intense infiltration of meteoric waters that dissolved gypsum and desintegrated carbonate layers.

The Pasvalys uplift is bordered by Lėvuo–Mūša, Maskoliškės and Pagojis depressions in the west, north, and east, respectively. They are associated with the active formation of karst sinkholes. The two former depressions show very intense dissolution of the Pasvalys Member that resulted in two-three fold reduction in total thickness. The dissolution took place before sedimentation of Upper Quaternary glacial sediments. The dissolution

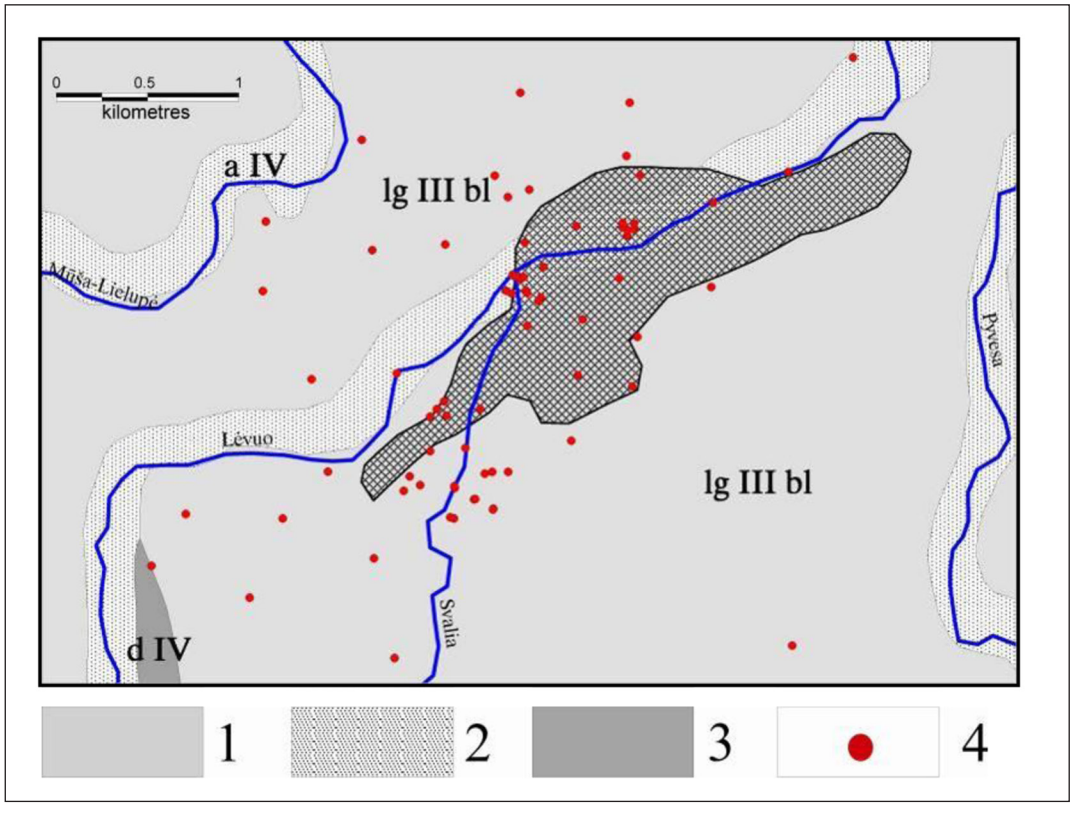

Fig. 14. Quaternary geological map (after Guobytė, 2002). *1* – clay, *2* – sand, *3* – deliuvial sediments, *4* – boreholes analysed in the study area
14 pav. Kvartero geologinis žemėlapis (pagal Guobytę, 2002). *1* – molis, 2 – smėlis, *3* – deliuvis, *4* – darbe analizuoti gręžiniai

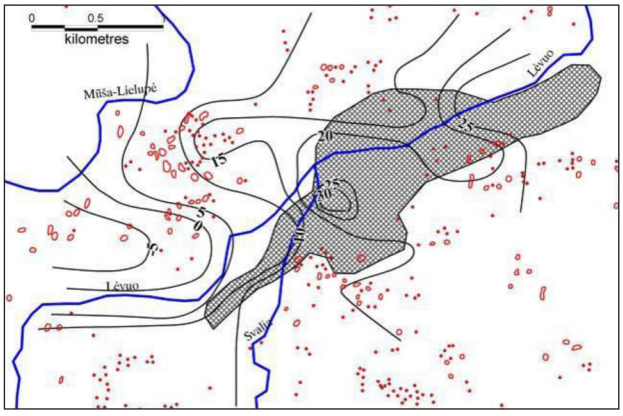

Fig. 15. Depth map of the bottom of the Nemunėlis Member. Karst sinkholes are shown
15 pav. Nemunėlio sluoksnio pado gyliai. Nurodytos karstinės įgriuvos

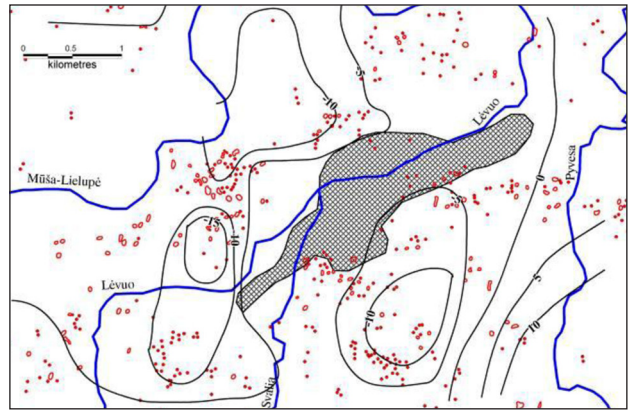

Fig. 16. Structural map of the top of the Pliaviniai Regional Stage. Karst sinkholes are shown
16 pav. Pliavinių regioninio aukšto gyliai. Nurodytos karstinės įgriuvos

of the lower member resulted in preservation of the upper (Nemunėlis) member that contains abundant gypsum layers prone to dissolution and karst activity. The aforementioned Lėvuo-Mūša and Maskoliškės depressions likely represented the path-way for water flow dissolving gypsum in the lower part of the Tatula Formation. Karst processes are most intense along the high-gradient border (transition) zones. The gradient zone is likely more fractured, as can be suggested by intense karstification, thus providing the pathway for migration of ground water down the section to the lower part of the Tatula Formation which leads to intense dissolution of gypsum layers (Fig. 17). Some anomaly of karst processes is reported also from the local uplift separating Lėvuo and Mūša depressions. The uplift likely caused intensification of local water infiltration.

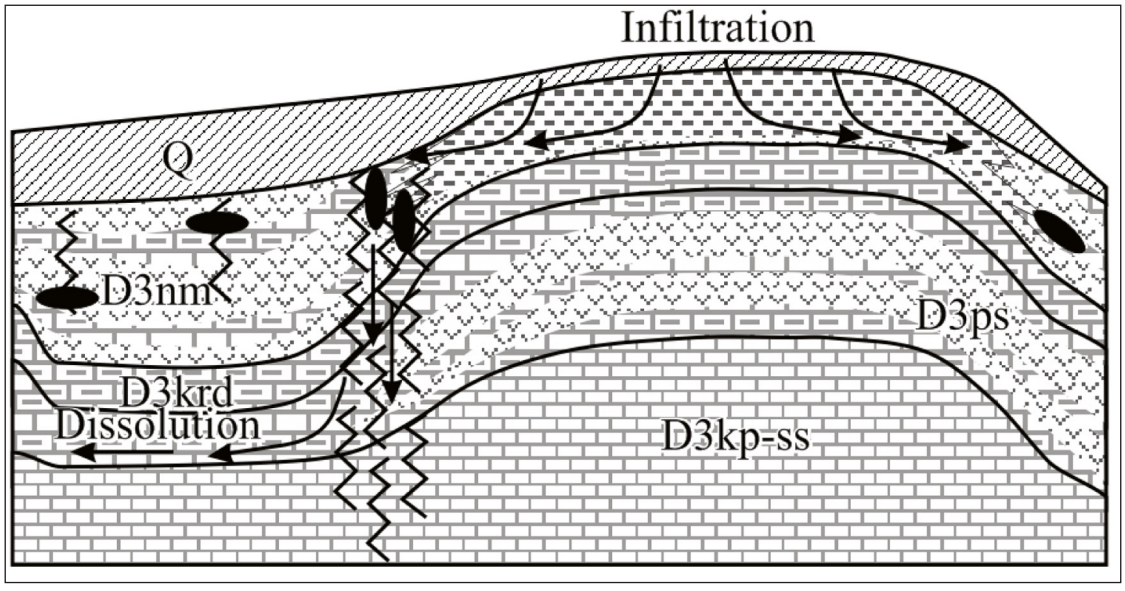

Fig. 17. Infiltration-dissolution model of Pasvalys Area. See Fig. 3 for the legend. Bold lines show fracturing zones
17 pav. Pasvalio ploto infiltracijos-tirpinimo modelis. Legenda pateikta 3 pav. Storos zigzaginės linijos žymi plyšiuotas zonas

The Pagojis depression does not show any anomalous dissolution of the Pasvalys Member gypsum. It is likely related to close contours of the depression that prevented intense migration of ground water and associated dissolution, in contrast to the Lėvuo-Mūša depression that is open to the west. Furthermore, the Nemunėlis Member is also subject to only minor or no weathering and pervasive gypsum dissolution. Therefore this feature is characterised by the high potential of recent karst activity.

There is no detailed analysis of the fracture system in Pasvalys Area due to the Quaternary cover. However, some chaining of sinkholes, defined as karst lineaments, suggests that the fracturing of the Devonian sediments can be accounted for the local uneven distribution of dissolution (Fig. 18). Pasvalys Town seems to be affected by the NW–SE trending lineaments zone as wide as 1.3 km. The lineaments trending NE–SW are less abundant. Also, some lineaments trending N–S and W–E are recognised.

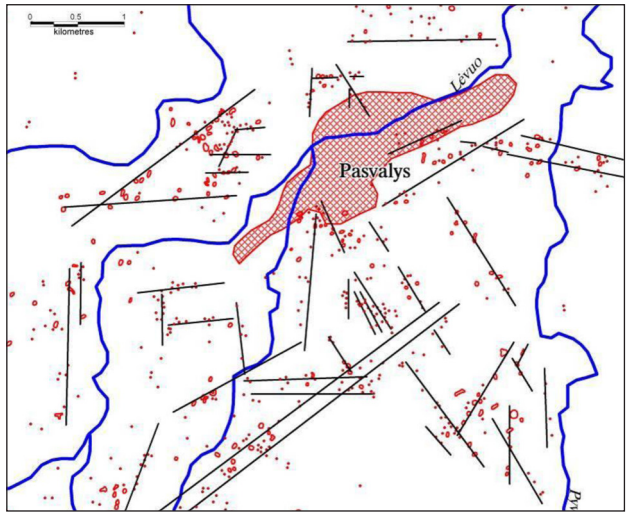

Fig. 18. Distribution of karst sinkholes and defined karst lineaments (black lines)
18 pav. Karstinių įgriuvų paplitimas ir išskirti karstiniai lineamentai (juodos linijos)

CONCLUSIONS

The Pasvalys swarm of karst sinkholes shows the uneven distribution of recent karstification. A close correlation of those processes with tectonic structures was recognised. Pasvalys Town is situated within the Pasvalys uplift that is characterised by intense weathering of the upper part of the evaporitic-carbonaceous Tatula Formation suggesting intense ground water flow in the uplift. Therefore the potential of karst activity is rather exhausted in the town territory.

The adjacent Lėvuo-Mūša depression shows intense pervasive gypsum dissolution of the lower part of the Tatula Formation that in turn resulted in preservation of the upper (Nemunėlis) gypsum layers from erosion processes. It is associated with the high potential of recent formation of karst features within the depression. A similar scenario is suggested north of Pasvalys Town in the Maskoliškės depression. The most intense karst processes occur along the high-gradient boundaries of those structural features.

Pagojis depression, defined in the south, comprises only little affected by pervasive dissolution Tatula succession that also has high potential for development of karst features.

Some chains of sinkholes, defined as karst lineaments, suggest that the fracture system dissecting Devonian sediments possibly also contributed to the uneven distribution of dissolution processes. Additional methods should be applied in future studies for defining this relationship.

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REFERENCES

1. Česnulevičius A. 1999. *Geodynamic Processes and Problems of Relief Investigations*. Geomokslai. Vilnius.
2. Dėnas Ž., Račkauskas V. 2005. Compilation and analysis of GIS layers of the Map of Cover Thickness and Petrographical Composition of Karstified Rocks (North Lithuanian Karst Area), scale 1:50000. *Geologija* **50**: 48–58.
3. Eimantaitė B., Skuodis V. 2001. Distribution of karst sinkholes and relationship to fracture system in Biržai Region. *Geologija* **35**: 29–33 [in Lithuanian].
4. Glazek J. 1989. Tectonic conditions for karst origin and preservation. In: P. Bosak, D. C. Ford, J. Glazek, I. Horacek (eds.). *Paleokarst. A Systematic and*

Regional Review. Elsevier-Academia. Amsterdam, Praha. 569–575.
5. Herold T., Jordan P., Zwahlen F. 2000. The influence of tectonic structures on karst flow patterns in karstified limestones and aquitards in the Jura Mountains, Switzerland. *Eclogae Geologicae Helvetiae* **93(3)**: 349–362.
6. Kassa S., Pierson B., Chow W. S., Talib J. B. Ab. 2012. Identifying the link between lineament and cave passage trends to comprehend fractures continuity and influence on the Kinta Valley karst system. *International Journal of Speleology* **41(1)**: 59–73.
7. Klizas P., Šečkus R. 2007. Filtration and geoelectrical investigations in the karst region of North Lithuania. *Geologija* **59**: 77–81.
8. Kresic N. 1995. Remote sensing of tectonic fabric controlling groundwater flow in Dinaric karst. *Remote Sensing of Environment* **53(2)**: 85–90.
9. Marcinkevičius V., Bucevičiūtė S. 1986. Geological and hydrogeological conditions for the development of sulphate karst in North Lithuania. *Geologija* **7**: 104–121 [in Lithuanian].
10. Marcinkevičius V., Bucevičiūtė S. 1997. Sulphate karst of North Lithuania. *Proceedings of International Symposium on Engineering Geology and the Environment, organized by the Greek National Group of IAEG, Athens, Greece, 23–27 June 1997*. A. A. Balkema. Rotterdam, Brookfield. 247–252.
11. Marcinkevičius V., Mikulėnas V., Karmazienė D., Bitinas J., Šečkus R., Minkevičius V., Vaičiūnas G., Stankevičiūtė S., Satkūnas J. 2010. *Engineering Geological Conditions of Biržai Town*. Geological Survey of Lithuania. Vilnius. 111 p. [in Lithuanian].
12. Marcinkevičius V., Guobytė R., Kačinskaitė S., Stankevičiūtė S., Minkevičius V., Vaičiūnas G., Bukauskienė V., Jaroševienė L., Šečkus R., Satkūnas J. 2010. *Engineering Geological Conditions of Pasvalys Town* (summary of report). Geological Survey of Lithuania. Vilnius. 63 p. [in Lithuanian].
13. Narbutas V. 1960. The ancient karst phenomena in Devonian Deposits of North Lithuania. In: V. Gudelis (ed.). *Collectanea Acta Geologica Lithuanica*. Vilnius. 329–334.
14. Narbutas V., Linčius A., Marcinkevičius V. 2001. *Karst of Devonian Rocks and Environmental Problems of North Lithuania.* Monograph. AGORA. Vilnius. 191 p. [in Lithuanian].
15. Paškevičius J. 1997. *The Geology of the Baltic Republics*. Geological Survey of Lithuania. Vilnius. 387 p.
16. Paukstys B., Cooper A. H., Arustienė J. 1999. Planning for gypsum geohazards in Lithuania and England. *Engineering Geology* **52(1)**: 93–103.
17. Ross J.-H., Rieg A., Leibundgut Ch. 2001. Tracer study on the tectonic control of the drainage system in the contact karst zone of Lake Voralp (Swiss Alps). *Acta Carsologica* **30(2)**: 203–213.
18. Rubio J. C., Simón J. L., Soriano M. A. 2007. Interacting tectonics, hydrogeology and karst processes in an intramontane basin: the Jiloca graben (NE Spain). *Hydrogeology Journal* **15**: 1565–1576.
19. Satkūnas J., Marcinkevičius V., Mikulėnas V., Taminskas J. 2007. Rapid development of karst landscape in North Lithuania – monitoring of denudation rate, site investigations and implications for management. *GFF* **129**: 345–350.
20. Skuodis V. 1979. Comments on distribution of karst processes and identification of karst cycles in Lithuania. *Geologinis metraštis* **XVI**: 5–8 [in Lithuanian].
21. Stirpeika A. 1999. *Tectonic Evolution of the Baltic Syneclise and Local Structures in the South Baltic Region with Respect to their Petroleum Potential.* Geological Survey of Lithuania. Vilnius. 112 p.
22. Šečkus R. 2002. Basic principles of application of electric tomography for solution of geological problems. *Geologija* **38**: 49–60 [in Lithuanian].
23. Šliaupa A. 2001. *Lietuvos ir gretimų teritorijų neotektoninės struktūros*. Vilnius.
24. Šliaupa S., Šliaupa S. 2003. Tectonic map of the North Lithuanian karst area. In: *Geological Survey of Lithuania. Annual Report 2002*. Vilnius. 25–27.
25. Šliaupienė R., Šliaupa S. 2011. Prospects of CO_2 geological storage in deep saline aquifers of Lithuania and adjacent territories. *Geologija* **3(75)**: 121–133.

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PASVALIO MIESTO IR APYLINKIŲ (ŠIAURĖS LIETUVA) KARSTINIŲ PROCESŲ TEKTONINĖ KONTROLĖ

S a n t r a u k a

Šiaurės Lietuva pasižymi aktyvaus karsto formavimosi procesais, susijusiais su viršutinio devono (Tatulos svita) gipsingos karbonatinės storymės, atsidengiančios po plona kvartero danga (<25 m), tirpinimu. Šioje srityje intensyvesniais karstiniais procesais pasižymi Pasvalio ir Biržų plotai. Pasvalio plote karstinės smegduobės pasiskirsčiusios labai netolygiai. Miesto teritorijoje šiuolaikiniai karstiniai procesai yra mažai aktyvūs, o apylinkėse dažnai formuojasi naujos smegduobės, reljefą vagoja gausios karstinės daubos.

Gręžimo duomenimis, Pasvalio miestas yra Pasvalio tektoninėje pakilumoje, kuri ribojasi su Lėvens-Mūšos, Maskoliškių ir Pagojo įlinkiais atitinkamai vakaruose, šiaurėje ir pietuose. Nustatyta, kad pakilumos ribose po kvarteru atsidengiančios Nemunėlio sluoksnio uolienos yra stipriai išdūlėjusios, gipso sluoksniai ištirpdinti. Be to, pakilumos ribose Pasvalio sluoksnyje padaugėja dolomito. Tai lėmė mažą karstinių procesų potencialą miesto teritorijoje. Vakariau ir šiauriau miesto nustatyti Lėvens-Mūšos ir Maskoliškių įlinkiai. Skirtingai nuo Pasvalio pakilumos, čia stipriai ištirpdinta apatinė Tatulos svitos dalis (Pasvalio sluoksniai) – tai siejama su didesniu požeminio vandens srautu išilgai įlinkusių struktūrų. Požeminio vandens aktyvi infiltracija į apatinę Tatulos svitos dalį vyko išilgai įlinkių pakraščių, kur prognozuojamas didesnis devono uolienų plyšiuotumas, – tai liudija karstinių smegduobių grandinės, žyminčios struktūrų kontaktus. Apatinės svitos dalies išplovimas apsaugojo viršutinius gipso sluoksnius (Nemunėlio) nuo erozinio nupjovimo, todėl čia Tatulos svitos viršutinė dalis pasižymi karstiniams procesams vystytis palankiomis litologinėmis sąlygomis.

Pietiniame Pagojo įlinkyje, matyt, dėl lėtesnio hidrodinaminio režimo (įlinkis yra uždaro kontūro) gerai išliko tiek viršutinės, tiek apatinės Tatulos svitos dalies gipsingi sluoksniai, todėl ši dalis taip pat turi didelį sukarstėjimo potencialą.

Kitas svarbus veiksnys, galimai lemiantis netolygų karstinių smegduobių pasiskirstymą, yra devono uolienų plyšiuotumas. Išskirti karstiniai lineamentai (grandinės). Stambiausia, apie 1,3 km pločio, karstinių lineamentų zona yra orientuota ŠV–PR kryptimi ir kerta Pasvalio miestą, taip pat išryškinti karstiniai lineamentai, orientuoti V–R, Š–P ir ŠR–PV kryptimis.

Raktažodžiai: karstas, gipsas, tektoninė struktūra, Šiaurės Lietuva, devonas