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Vendian sedimentation and low-rate syn-sedimentary tectonic activity in SE Lithuania

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The Vendian deposits represent the basal part of the sedimentary cover of the Baltic sedimentary basin. The sedimentation was restricted to the eastern part of Lithuania that represented the western margin of the vast Moscow basin. The thickness of the Vendian deposits reaches 170 m in the east.

Data of more than 100 wells were inspected to map lithofacies distribution of different stratigraphical units of Vendian in the southeastern Lithuania. An emphasis has been made to standard logging data because stratigraphy of the Vendian deposits is based on lithological criteria. Various authors presented different interpretations of the lithofacies variations that resulted in a non-unique stratigraphical subdivision of well sections. The presented study allowed unification of the stratigraphical subdivision of the southeastern Lithuanian wells.

Five formations, i. e. the Merkys, Jašiūnai, Rūdninkai, Skynimai, and Vilkiškės Fms, are defined up the Vendian succession of Lithuania. They compose individual sedimentation cycles. The sedimentation trend indicates a gradual levelling of the relief and an increasing degree of the chemical weathering of the provenance rocks (exposed crystalline basement).

The lithofacies and isopach maps of the Vendian formation were compiled that revealed sourcing and sedimentation trends as well as the syn-sedimentary tectonic activity of local structures. Three sub-regional structures were defined in the study area, i. e. the Žiežmariai–Maišiagala and Merkys depressions separated by the South Lithuanian elevation striking west–east. Against this background structural pattern smaller-scale structures were recognised that also affected thickness and lithofacies variations, the latter pointing to syn-depositional activity of structures. The South Lithuanian uplift is characterised by deposition of coarser grained sediments compared to the adjacent Žiežmariai–Maišiagala and Merkys depressions. The local structures Šalčininkėliai, Šalčininkai, Pabarė, Kalesninkai, Barčiai, Varėna were defined within the Merkys depression in the south.

The lithofacies distribution was sensitive to the structural grain of the basin bottom. The lithofacies distribution reflects not only local features, but also it is indicative of activity of the uplifts located beyond the basin that were eroded during the Vendian time. A discordant trend of lithofacies belts with respect to thickness changes pursued the presence of the uplifted structure further south that can be related to the Grodno–Mosty basement uplift suggested in the northwest Belarus, that shaded the clastic material to the adjacent basin in southwest Lithuania.

Key words: Vendian, tectonic syn-sedimentary activity, Lithuania, Baltic sedimentary basin, Moscow basin

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INTRODUCTION

The Vendian deposits represent the basal part of the sedimentary cover of the Baltic sedimentary basin. They directly overlay the crystalline basement of the Palaeoproterozoic age marking the first invasion of the marine basin to the Baltic Region. The Vendian sediments were deposited in the eastern part of Lithuania, Latvia, and most of Estonia. They represent the western periphery of the large Moscow basin widely distributed in the east to the Timan foredeep (Fig. 1) (Veretennikov et al., 1986; Vidal, Moczydlowska, 1995; Nagorny, 2008). Accordingly, the thickness of Vendian deposits increases to the east, off the western shore line that extends south–north in middle Lithuania. The largest thickness attains 200 m in the easternmost Lithuania (Fig. 2).

The western part of Lithuania and most of the Baltic Sea area represented the provenance area composed of the exposed crystalline basement peneplain. Further west, another basin was established along the Teissier–Tornquist zone marking the western margin of the East European Craton (Aren, 1988a, b).

There is little known of the tectonic regime that affected the Lithuanian territory. The thickness variations are rather small. Furthermore, the stratigraphic subdivision of Vendian sediments is a quite complex task due to very scarce paleontological evidences and a laterally variable lithological composition.

The southwest Lithuania is the most detailed studied area in terms of drilling material that is related to decades of deep geological mapping targeted at investigation of the crystalline basement that is at the shallowest setting in the Lithuanian territory. The detailed correlation of more than 100 wells was carried out in the presented study. Most of wells were performed with drill coring. Furthermore, the logging data are available in each well. The drill core inspection and logging data provided a good base for consistent lithostratigraphic correlation of wells. It is essentially complicated in the marginal (western) part of the distribution of Vendian sediments due to less contrast lithologies up the section compared to the east.

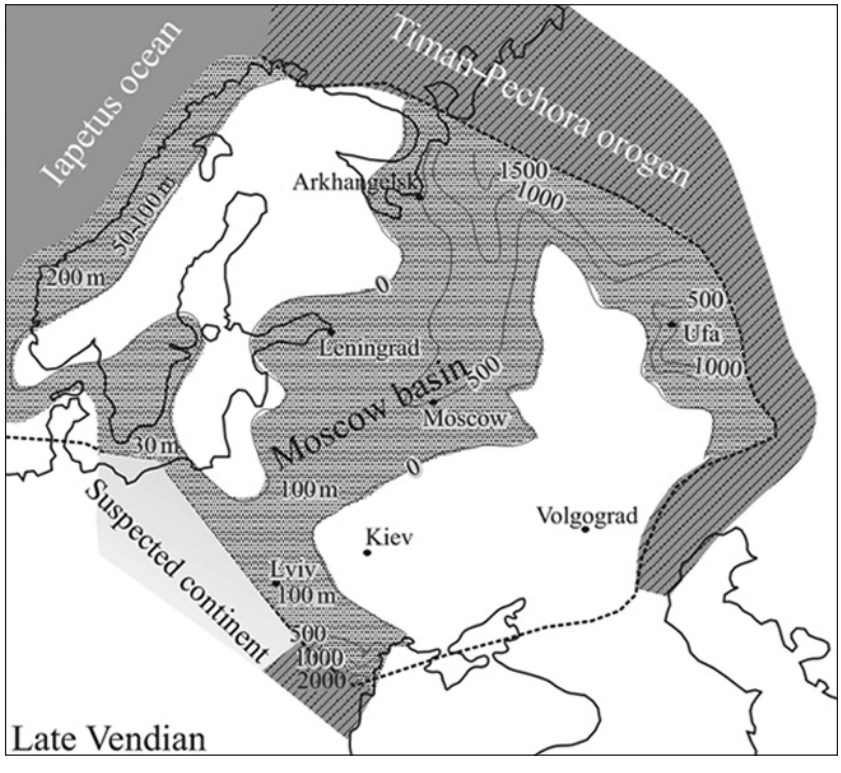

Fig. 1. Late Vendian sedimentary basins of the East European Platform (after Šliaupa et al., 2006)
1 pav. Rytų Europos platformos vėlyvojo vendo sedimentacijos baseinai (Šliaupa ir kt., 2006)

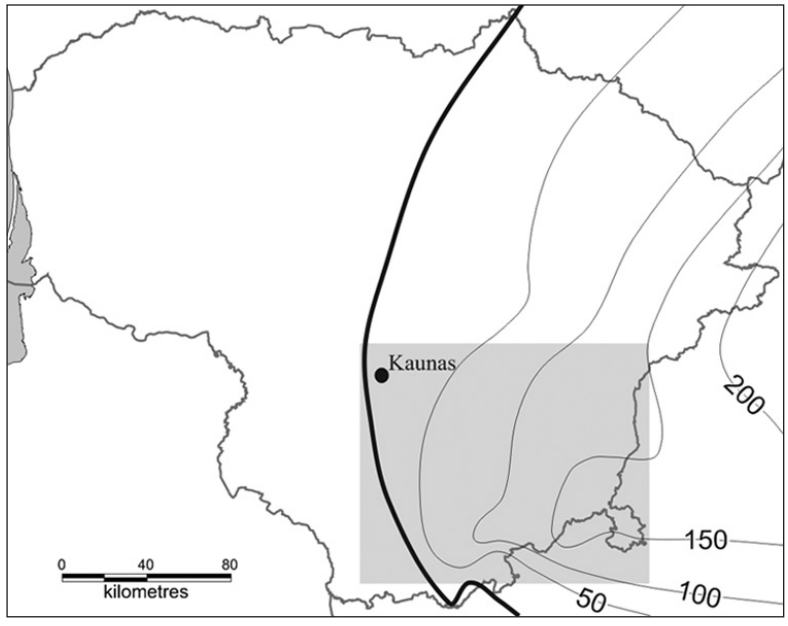

Fig. 2. Isopach map of the Vendian deposits of Lithuania. Grey rectangle indicates the study area
2 pav. Lietuvos vendo nuogulų storių žemėlapis. Pilkas stačiakampis žymi tyrimų plotą

VENDIAN STRATIGRAPHY

The stratigraphic subdivision of Vendian deposits is based on the stratigraphic scheme developed by Sakalauskas (1968; 1976). It was further elaborated by Jankauskas (1994). The Lithuanian Vendian stratigrapic scheme is correlated to the East European platform stratigrapic scheme. Three series are defined in the Vendian succession of the East European platform, i. e. Viltshanskaya, Volyn, and Valday (Machnatsh et al., 1986). The two former series are attributed to the Lower Vendian, while the Valday Series represents the Upper Vendian section (Fig. 3).

Five stratigraphic units are defined based mainly on lithological evidences in the Vendian succession of Lithuania. They represent distinct sedimentation cycles. The succession is composed of different terrigenous lithologies that show general grain-size attenuation upwards.

The Merkys Fm composes the basal part of the Vendian section of Lithuania. It is represented by poorly sorted fun deposits that accumulated mainly within isolated depressions. It is attributed to the Volyn Series of the uppermost part of the Lower Vendian. The peculiar feature is a high saturation of detrital sediments by ferric hydroxides which resulted in a specific dark brown colour. The composition varies from quartz-feldspar conglomerates to quartz-feldspar various-grained sandstones and siltstones somewhere. The thickness ranges from 2–3 to 12 m. Analysis of pebble material indicates the local source of detrital material (poorly rounded grains, presence of magnetite iron pebbles sourced from nearby iron ore deposits exposed at the surface of the crystalline basement).

Younger Vendian formations are attributed to the Valday Series of the Upper Vendian. The Jašiūnai Fm is well identified from the underlying Merkys Fm by a somewhat brighter brown colour that is attributed to lower saturation of the Upper Vendian lithologies by ferric hydroxides; also, they are better sorted. The Jašiūnai Fm is composed of conglomerates that grade to coarse-grained sandstones with conglomerates in the east thus reflecting distancing from the shore located in the west. The thickness attains 65 m in the southeast. The upper part of the Jašiūnai Fm is characterised by a finer grain-size composition.

The overlying Rūdninkai Fm is composed of conglomerates and sandstones of a similar composition to Jašiūnai Fm, though somewhat of finer grain-size. Somewhere rare siltstone and mudstone

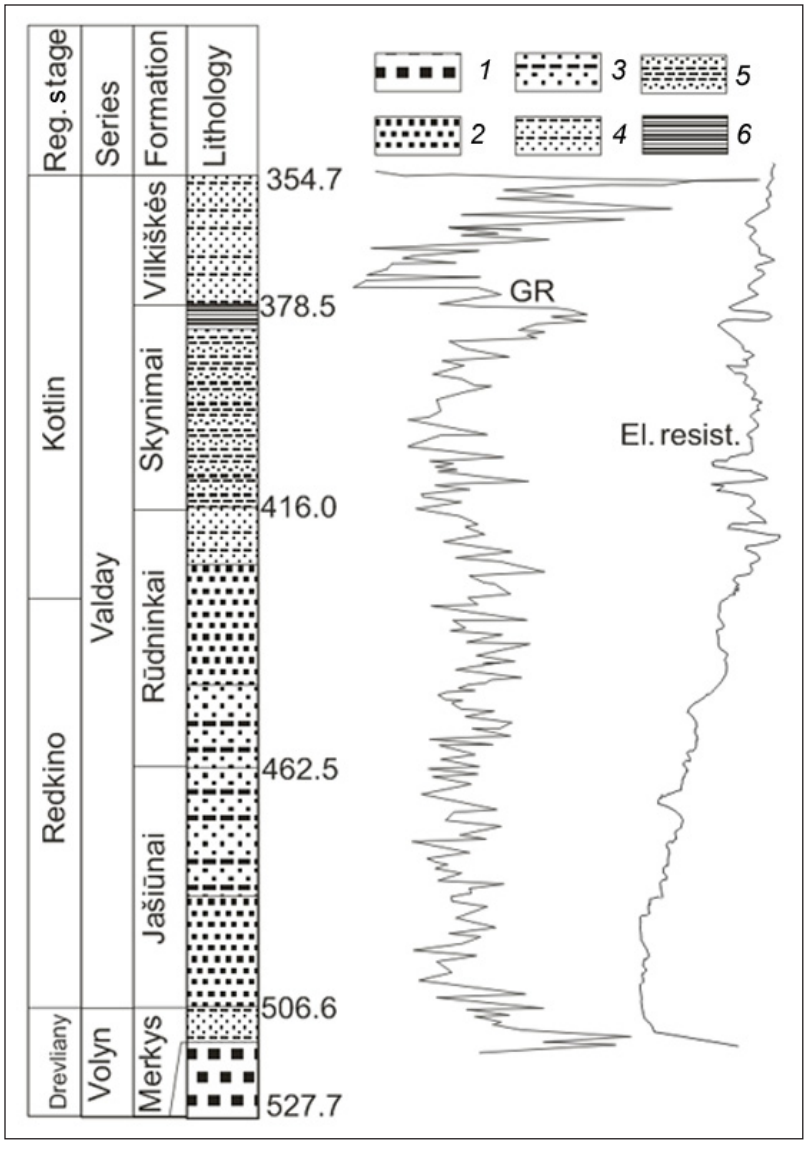

Fig. 3. Geological section of the stratotype well Vilkiškės-68, southeast Lithuania. *1* – conglomerate, *2* – coarse-grained sandstone, *3* – sandstone with siltstone, *4* – conglomerate, sandstone with siltstone, *5* – siltstone with sandstone, *6* – shale. Gamma-ray and electric resistivity logs are shown

3 pav. Stratotipinio gręžinio Vilkiškės-68 geologinis pjūvis (PR Lietuva). *1* – konglomeratas, *2* – stambiagrūdis smiltainis, *3* – smiltainis su aleurolitu, *4* – konglomeratas, smiltainis su aleurolitu, *5* – aleurolitas su smiltainiu, *6* – molis. Parodytos gama diagrafijos ir elektros varžos diagrafijos kreivės

layers are distributed. A distinct ~1 m thick grey coloured layer of weathering is commonly observed in the middle part of the formation that marks either some long termed exposure of sediments above the sea level or temporary change in weathering conditions. It resulted in subdivision of Rūdninkai Fm into Rūdninkai Fm and Pagiriai Fm (Jankauskas, 2002), which, however, was not widely accepted by other researchers. The thickness of the formation reaches 50 m in the south-eastern part of the study area.

The Skynimai Fm reflects significant changes in sedimentation conditions from coarse-grained to fine-grained terrigens. It is characterised by sharp reduction in grain-size composition. The section of the formation is dominated by brown siltstones and fine-grained sandstones of quartz-feldspar composition with rare mudstones that are mainly observed in the upper part of the section. The thickness gradually increases to the east and reaches 50 m.

The Vilkiškės Fm shows sharp change in mineral maturity of terrigens. The fine- to coarse-grained quartz sandstones predominate in the area. They grade to feldspar-quartz sandstones in the east. The high maturity of sandstones marks transition from predominating mechanical denudation to predominating chemical denudation in the adjacent provenance which is likely related to more humid climate conditions. The thickness attains 28 m in the east.

The humid climate conditions established in the Vilkiškės time continued to the Cambrian time. Vendian sediments are overlain by about 100 m thick "Blue Clay" formation of the earliest Cambrian. Similarly to Vendian, those clays were deposited in the western periphery of the Moscow marine basin.

DATA

Data of more than 100 wells were inspected to map lithofacies distribution of different stratigraphical units of Vendian in the southeastern Lithuania (Fig. 4). The wells are essentially abundant in the area between Vilnius and Druskininkai where extensive drilling was carried out with the frames of deep (basement) geological mapping at the scale of 1 : 200,000. In most cases Vendian sediments were drilled with drill core recovery before entering the crystalline basement rocks. Still, emphasis has been made on standard logging data because the drill core recovery is rather poor (30–50%) and the local stratigraphy of Vendian deposits is based on lithostratigraphic criteria. In different years, various authors presented different interpretations of the lithofacies variations that resulted in a non-unique stratigraphic subdivision of well sections. The presented study allowed unification of the stratigraphic subdivision of wells of southeast Lithuania.

TECTONIC STRUCTURES OF VENDIAN DEPOSITS OF SE LITHUANIA

In terms of the tectonic zoning of the Belarus–Baltic Region, southeast Lithuania is situated on the northern slope of the Mazury–Belarus anteclise that plunges towards the Baltic syneclise in the north and west. There is no definite tectonic border between those two largest scale tectonic features. The depth of –500 m of the top of the crystalline basement is conventionally accepted as

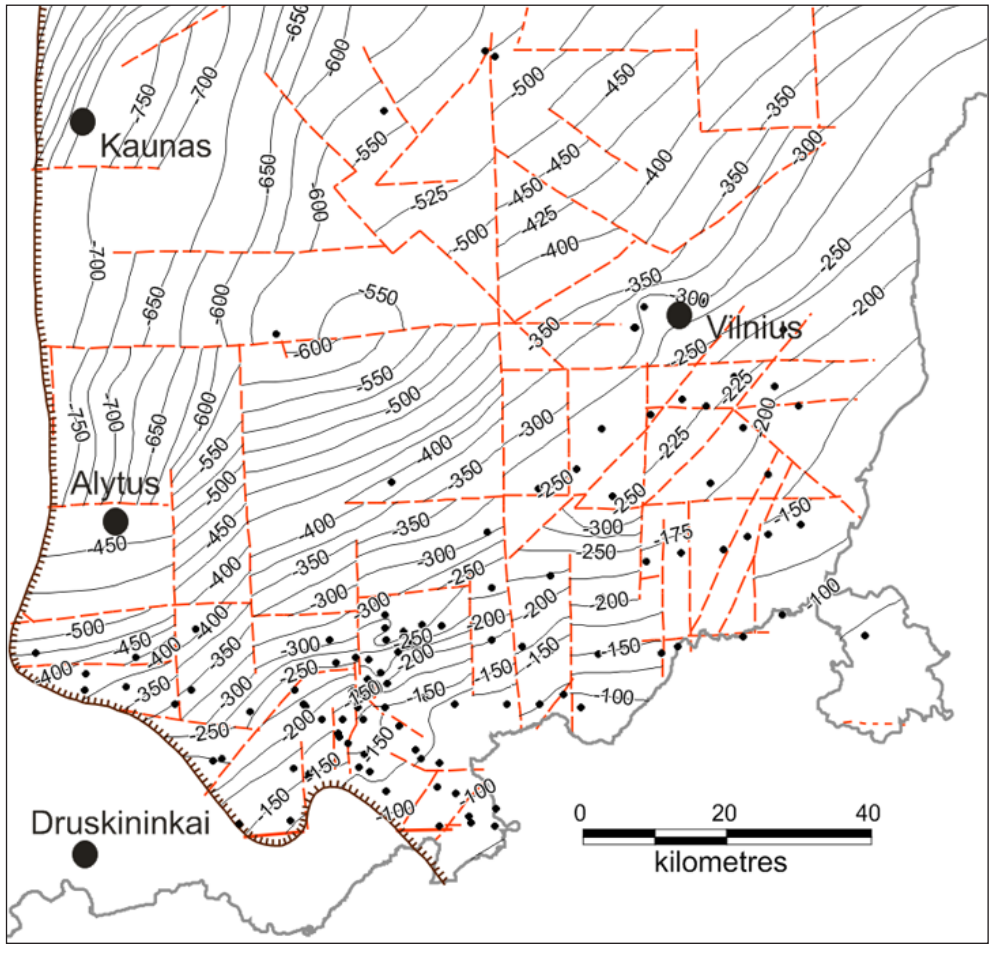

Fig. 4. Depth of the top (m) of the Vendian deposits of southeast Lithuania (after Šliaupa, 1997). Hatchet lines indicate faults. Black dots show wells cutting the Vendian deposits
4 pav. Vendo nuogulų storių žemėlapis (Šliaupa, 1997). Dantyta linija rodo vendo nuogulų paplitimo ribą. Pažymėti gręžiniai, kertantys vendo nuogulas. Raudonos linijos rodo lūžius

the boundary between the Baltic syneclise and the Mazury–Belarus anteclise (Suveizdis, 1979; 2003). Other authors define the limit between those structures along middle Lithuania (Paškevičius, 1997; Stirpeika, 1999) (Fig. 5). It is notable that the western limit of distribution of the Vendian deposits is

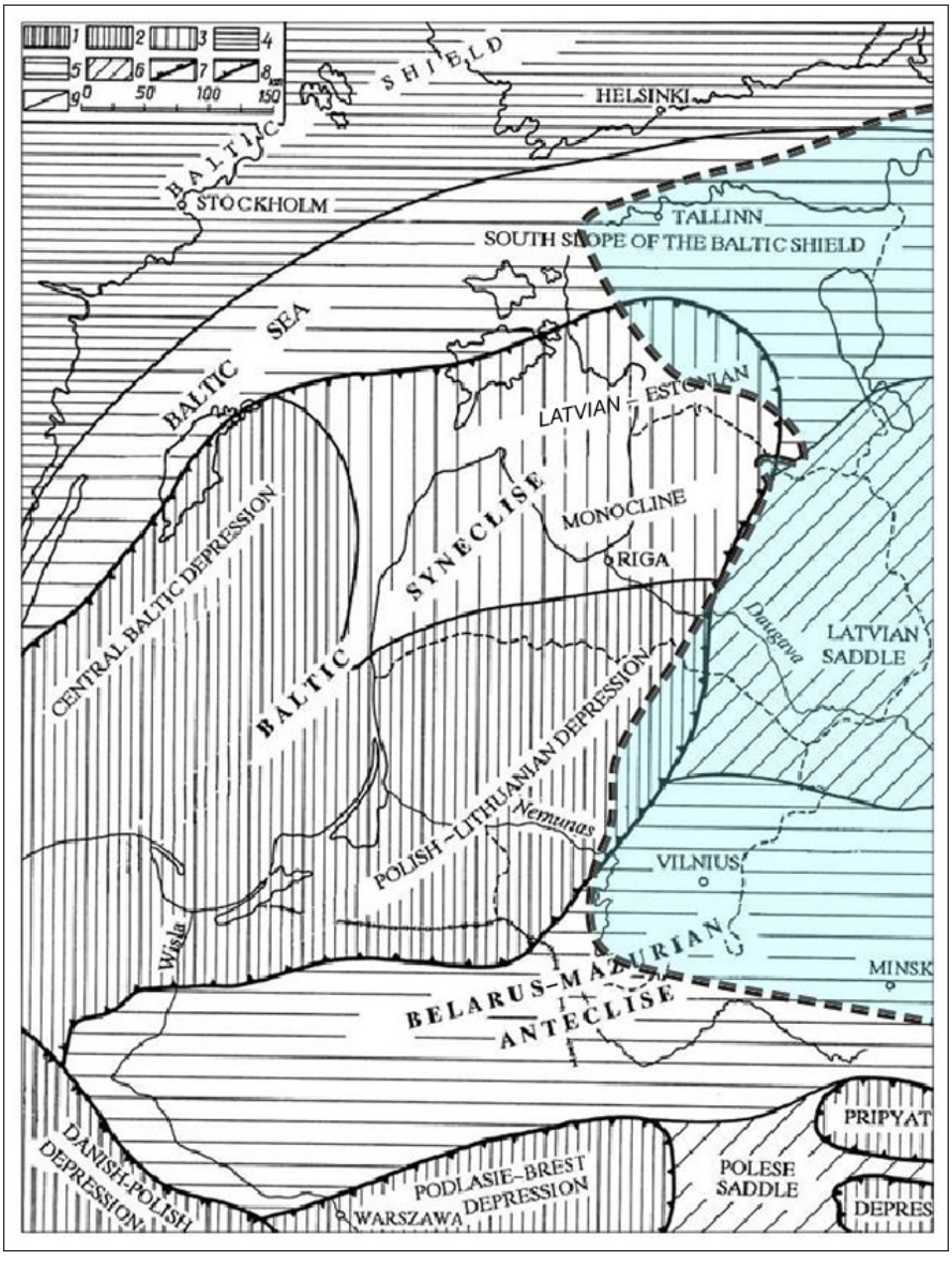

Fig. 5. Major tectonic structures of the Baltic Region (after Paškevičius, 1997; with modifications): *1* – depression at the margin of the platform with a thick sedimentary cover, *2* – syneclise-depression with a thick sedimentary cover, *3* – monocline of the syneclise with a thin sedimentary cover, *4* – shield without sedimentary cover, *5* – shield slope with sedimentary cover, *6* – saddle with a thin sedimentary cover, *7* – boundary of the periplatformic depression, *8* – boundary of the syneclise and / or depression, *9* – boundaries of the structures inside the platform. Thick hatchet line shows the limits of distribution of the Vendian deposits (blue polygon)

5 pav. Pagrindinės Baltijos regiono tektoninės struktūros (Paškevičius, 1997; papildyta). *1* – Danijos-Lenkijos įlinkis, *2* – sineklizė, *3* – sineklizės monoklina, *4* – skydas, *5* – skydas su plona nuosėdine danga, *6* – struktūrinis balnas, *7* – platforminio įlinkio riba, *8* – sineklizės riba, *9* – vidinių struktūrų ribos

confined to this boundary in the latter structural zoning scheme.

The Vendian deposits are inclined generally to the northwest (Fig. 4). The average gradient is rather low 6.0 m/km. The depths range from –80 m in the southeast to about –800 m in Kaunas area. The Vendian deposits are dissected by a number of faults of prevailing N–S, W–E, NW–SE, and NE–SW directions. The definition of faults is rather tentative as no seismic data is available in the area and the main source on basement (and Vendian) depths is based on drilling. The amplitudes of faults do not exceed 50 m. The faults were established at different stages of the tectonic evolution of the region. The main faulting took place during high-rate uplift of the Mazury–Belarus anteclise in the late Variscan tectonic stage (Carboniferous – Early Permian) and in Permian–Triassic times (Cimmerian tectonic stage).

DISTRIBUTION OF VENDIAN LITHOFACIES AND THICKNESSES IN SE LITHUANIA

Vendian paleo-structures of SE Lithuania

A number of sub-regional and local structures were defined based on thickness variations in southeast Lithuania. They have predominating W–E, less often N–S orientation (Fig. 6A, B). In the north, the Žiežmariai–Maišiagala depression was defined based on increased thicknesses. The southern boundary is controlled by the large-scale Vilkaviškis–Birštonas–Vilnius fault striking W–E. It is essentially well mapped in the Permian–Triassic deposits, the amplitude exceeding 50 m. It separates the depression from the South Lithuanian elevation in the south. The Taučionys and Vokė uplifts are defined within the elevation in the west and east, respectively. The Merkys depression is defined in the south that is subdivided into the Lower Merkys depression and the Upper Merkys depression. In more detail, the local structures were identified, i. e. Subartonys, Barčiai, Pabarė, and Šalčininkėliai depressions and Varėna, Kalesninkai, and Šalčininkai uplifts (Fig. 6B).

Lithofacies and thickness variations of the Merkys Formation

The oldest Vendian deposits, referred to as the Merkys Fm, acumulated within the local depressions. In the south of the study area, they are classified as the fan deposits of highly variable composition, while shallow marine deposits accumulated north of Vilnius (Fig. 7). The Merkys Fm clastic sediments filled in the Subartonys, Barčiai, Upper Merkys, and Žiežmariai–Maišiagala depressions. The general trend of decreasing of sediment grain-sizes to the northeast is recognised. Also, some fining of the grain-size composition is documented up the section of wells. Some lateral sediment differentiation is noted within the depressions.

The Subartonys depression is well delineated by drilling, except the northern boundary (scarce wells). The thickness attains 13.5 m. The depression accommodates quartz-feldspar fine-grained sandstones that grade to conglomerates and breccia along the depression periphery. Some grain finning to the north is recognised. In the south (wells Lazdijai-15, Dzūkija-2) sandstones contain abundant

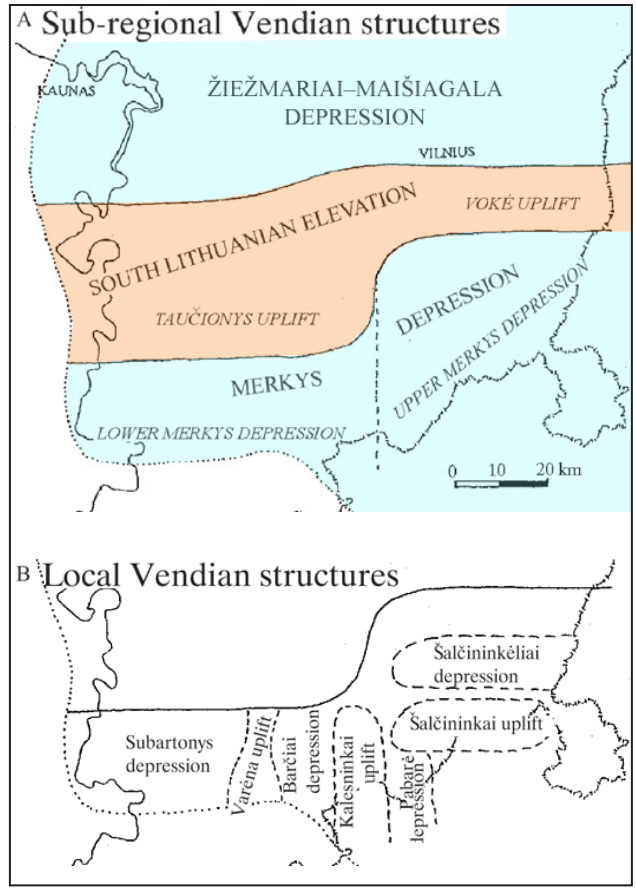

Fig. 6. Vendian sin-sedimentary tectonic structures of sub-regional (A) and local (B) order
6 pav. Subregioninės (A) ir lokalios (B) vendo tektoninės struktūros

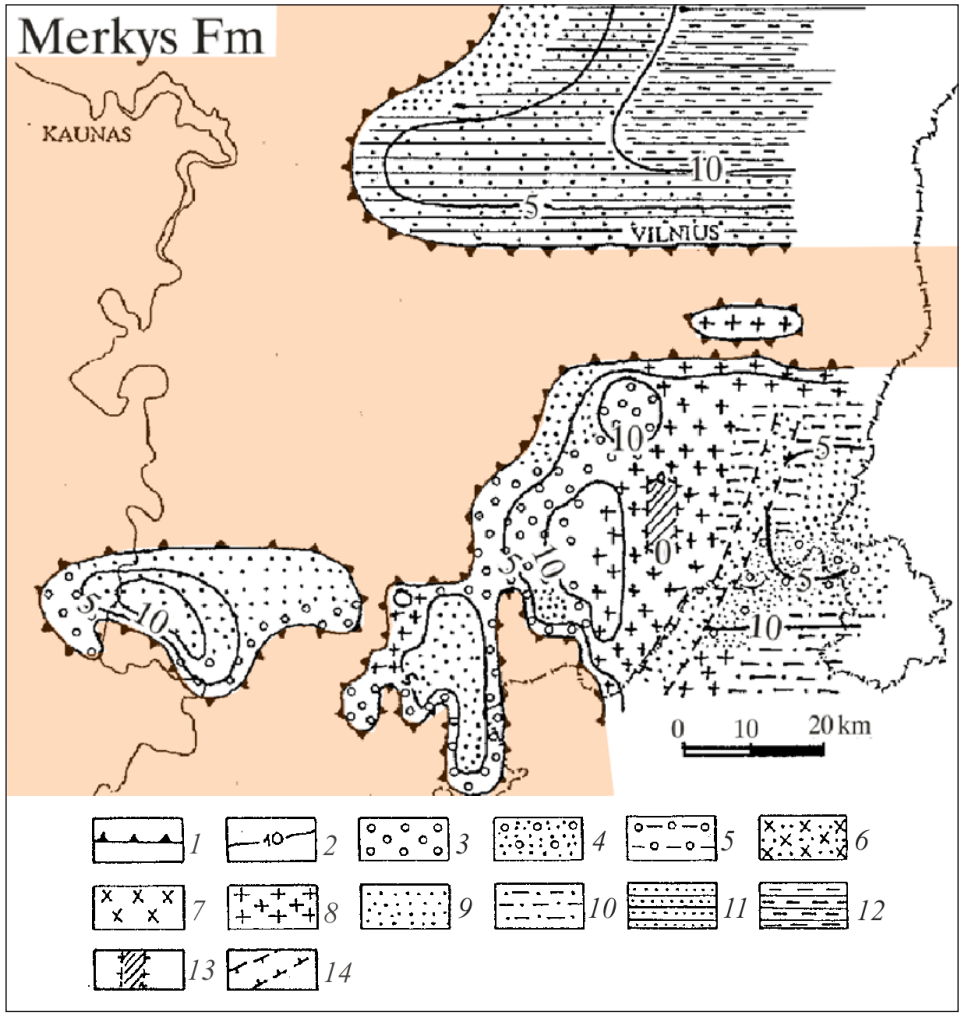

Fig. 7. Lithofacies and thickness distribution of the Merkys Fm of SE Lithuania. *1* – Limit of sediments distribution, *2* – isopach (m), *3–12* – lithofacies zones: *3* – conglomerate, *4* – sandstone-conglomerate, *5* – sandstone-conglomerate with siltstone, *6* – sandstone with conglomerare, *7* – conglomerate, breccias, *8* – breccia-fanglomerate, *9* – sandstone, *10* – sandstone-siltstone, *11* – sandstone-claystone, *12* – siltstone-claystone, *13* – Kernovėlė uplift, *14* – graben-like structure
7 pav. PR Lietuvos Merkio svitos litofacijos ir storiai. *1* – vendo nuogulų paplitimo riba, *2* – storių izolinija (m), *3–12* – litofacijos: *3* – konglomeratas, *4* – smiltainis su konglomeratu, *5* – smiltainis su konglomeratu ir aleurolitu, *6* – smiltainis su konglomeratu, *7* – konglomeratas, brekčija, *8* – brekčija su konglomeratu, *9* – smiltainis, *10* – smiltainis su aleurolitu, *11* – smiltainis su moliu, *12* – aleurolitas su moliu, *13* – Kernovėlės pakiluma, *14* – grabeno tipo struktūra

5–10 cm large moderately rounded quartz pebbles that are missing in the central part of the depression (well 346). The section of the northernmost well Ilgai-54 is composed of very fine- and fine-grained sandstones.

The Barčiai depression is defined to the east of the Subartonys depression; they are separated by the Varėna local uplift. The depression is oriented north–south. The maximum thickness of the Merkys Fm is of 6–9 m in the central part of the depression comprising fine-grained and very fine-grained sandstones (wells 61, 63). The calstic material is coarsening towards the periphery of the depression from fine-grained to various-grained sandstones (wells 977, 971, and 418) and conglomerates, breccia, coarse-grained sandstones (wells 987, 988, 989, 978, 973, etc.) thus reflecting some local lithofacies trends from central to peripheral parts of the depression.

The Barčiai depression is bordered by the Kalesninkai uplift in the east that separates it from the larger Upper Merkys sedimentation locus. It is characterised by distinct variations of thickness and lithofacies. The small-scale Kernovėlė basement uplift, devoid of Merkys Fm sediments, is defined in the central part of the depression (well 722). The amplitude of the basement uplift is of 80 m and basement rocks are directly overlain by the Rūdninkai Fm. Furthermore, about 50 km long narrow (few kilometres) graben-like Zavišonys structure trending NE–SW is mapped to the east of this drape structure (Šliaupa, 1997). It is filled in by 22–47 m anomalously thick sandstones of the Merkys Fm, while it is only 3–14 m thick in adjacent wells. It is interesting to note that this graben-like depression is confined to the boundary between the Balninkai and Roduka formations of the crystalline basement representing, respectively, amphybolite and granulite metamorphic facies units that point to the Proterozoic age of this tectonic boundary. As it was mentioned above, there is highly variable lithofacies distribution in the Upper Merkys depression. Yet, the general trend of grain size fining to the east is noted. The coarse-grained clastic sediments (conglomerates, breccias) accumulated in the central part of the depression that is centred by the aforementioned Kernovėlė basement uplift which likely represented the local source of clastic material. Mostly coarse-grained sandstones and conglomerates were deposited along the western periphery of the depression, while various-grained (mainly fine-grained) sandstones with abundant siltstone interlayers predominate in the east.

The Upper Merkys depression is separated from the Žiežmariai–Maišiagala depression by the Vokė elevation. The Merkys Fm sediments of only 2 m thick (conglomerates) were reported from only well 713. The thickness of the Merkys Fm reaches 8–10 m in the Žiežmariai–Maišiagala depression. It differs from the aforedescribed depression by generally much smaller grain size. The western margin is marked by the belt of very fine-grained clayey sandstones that grade to intercalation of mudstones and sandstones, and alternating siltstones and mudstones further east.

Lithofacies and thickness variations of the Jašiūnai Formation

By contrast to the Merkys Fm the younger Vendian sediments are continuously distributed in Lithuania thus marking significant changes in the sedimentation basin. It is notable that the boundary between Volyn and Valday Series is marked by the weathering crust in the Moscow basin pointing to break in sedimentation that is recognised in most territory of the East European platform (Mens, Pirrus, 1986). The Moscow Valday marine basin was characterised by slightly decreased salinity (Mens, Pirrus, 1986).

The thickness of the Jašiūnai Fm reaches 65 m in southeast Lithuania. It represents the transgressive sedimentation cycle. Three lithofacies zones are defined in the area, showing general decrease of the grain-size to the northeast which is discordant to the thickness pattern (Fig. 8). Conglomerates and coarse-grained sandstones were deposited in the west that grade to sandstones and siltstones in the northeast. The local structures influenced the lithofacies pattern. The Varėna uplift is marked by reduced thickness and deposition of breccias and conglomerates. Similarly, the Vokė uplift is distinct by attenuation in its thickness (9–20 m) and coarse grained sedimentation. The lithological boundary between the South Lithuanian elevation and the Žiežmariai–Maišiagala depression is rather sharp. Various-grained sandstones accumulated in the west and grade to siltstones and sandstones with rare mudstone and conglomerate layers. The main terrigenous material sourcing took place from southwest; the South Lithuanian uplift seemingly provided the bottom topographic barrier for transportation of clastics in the basin.

Lithofacies and thickness variations of the Rūdninkai Formation

The clastic deposits of the overlying Rūdninkai Fm are of somewhat smaller grain-size compared to the Jašiūnai Fm. It also represents the particular thinning upwards the sedimentation cycle. Furthermore, the weathered layer is distinct in the middle part of the formation that separates two smaller-order sedimentation cycles of transgressive type. Three lithofacies zones are defined in southeast Lithuania, i. e. (1) coarse-grained sandstones and conglomerates, (2) predominating sandstones with conglomerates, (3) various-grained sandstones (Fig. 9). The distribution of lithofacies resembles that of the Jašiūnai Fm which points to persistence of the sedimentation

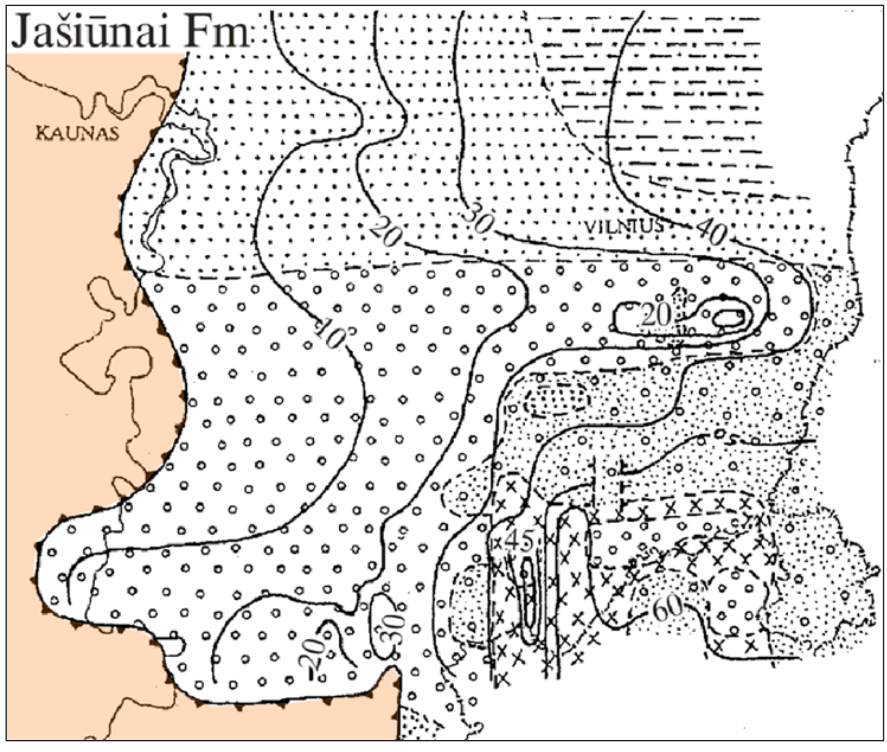

Fig. 8. Lithofacies and thickness distribution of the Jašiūnai Fm of SE Lithuania. See Fig. 7 for the legend
8 pav. PR Lietuvos Jašiūnų svitos litofacijos ir storiai. Legenda pateikta 7 pav.

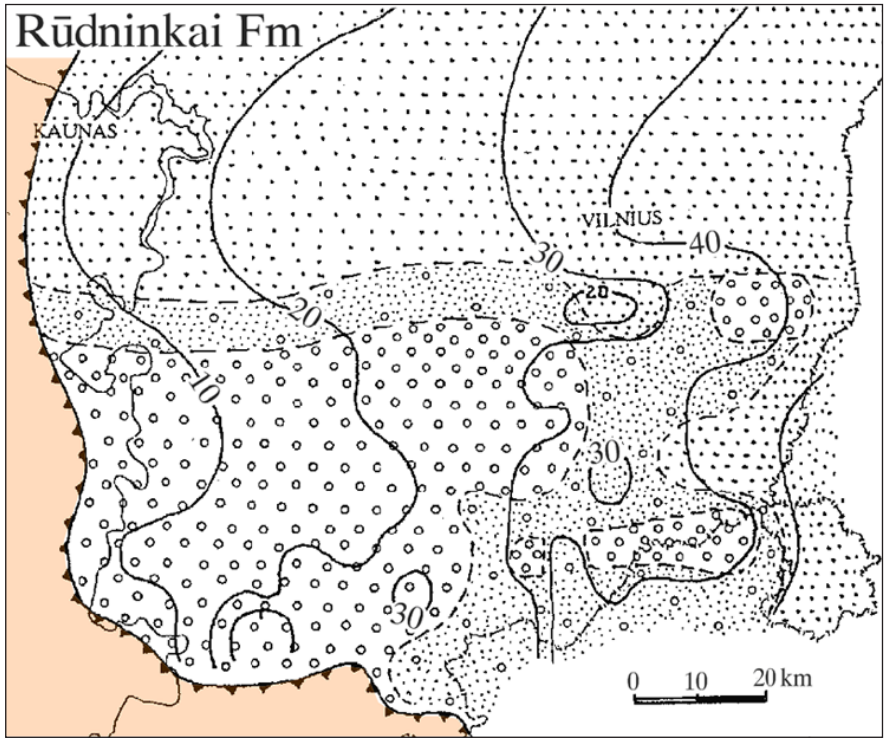

Fig. 9. Lithofacies and thickness distribution of the Rūdninkai Fm of SE Lithuania. See Fig. 7 for the legend
9 pav. PR Lietuvos Rūdninkų svitos litofacijos ir storiai. Legenda pateikta 7 pav.

and structural patterns, except less differentiated lateral distribution of different lithologies. Sediments of the Rudamina Fm show some expansion of the marine basin to the west that is in some conflict with previous stratigraphic interpretations (Sakalauskas, 2002; Jankauskas, 2002). Those lithofacies zones roughly coincide with the Žiežmariai–Maišiagala depression, the South Lithuanian elevation, and the Merkys depression (Fig. 9). The local structures defined in the latter depression exerted some influence on the sediment accumulation. The Šalčininkai uplift is distinct by predominance of conglomerates in the section, while the Pabarė depression is reflected in relative increase of the formation thickness. The thickness is relatively increased and less coarse sediments accumulated in the Šalčininkėliai depression. Siltstone layers are present in the axial part of the depression and wedge out in the proximity of the Vokė uplift in the north.

Lithofacies and thickness variations of the Skynimai Formation

The grain size of clastic deposits is significantly smaller in the Skynimai Fm section that comprises the particular thinning-upwards sedimentation cycle. However, it has no effect on the mineral composition, and feldspars prevail over quartz grains similarly to underlying formations. The lithological boundary between Skynimai and Rūdninkai formations is less distinct in the west that is related to much coarser composition of clastic material which led to misinterpretation of the stratigraphy of western wells by some authors.

There are six lithofacies zones identified in the area, such as (1) conglomerates with sandstones, (2) sandstones and conglomerates, (3) sandstones with abundant conglomerates in the lower part of the section, (4) sandstones and conglomerates with abundant layers of siltstones, (5) sandstones, (6) sandstones and siltstones (Fig. 10). All major structures mentioned above are well discernable in the lithofacies and thickness variations, including the local features (Barčiai, Šalčininkėliai, Šalčininkai, Kalesninkai structures). It is notable that lithofacies are much more sensitive to local structures in comparison to lateral thickness changes. It is partially related to post-depositional denudation of the uppermost part of the Skynimai Fm prior re-establishment of the sedimentation

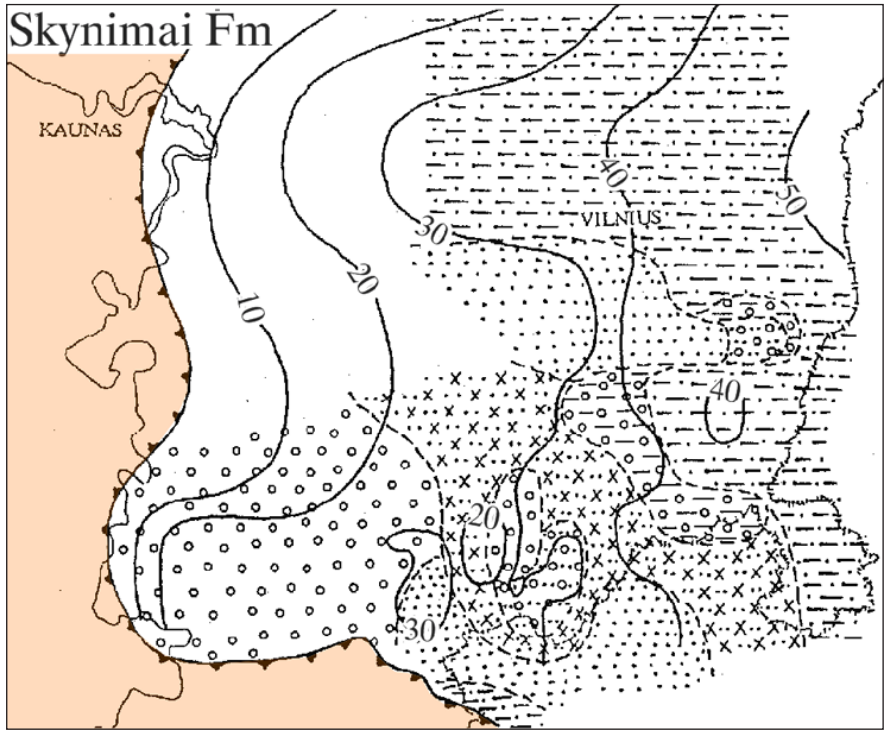

Fig. 10. Lithofacies and thickness distribution of the Skynimai Fm of SE Lithuania. See Fig. 7 for the legend

10 pav. PR Lietuvos Skynimų svitos litofacijos ir storiai. Legenda pateikta 7 pav.

conditions during the Vilkiškės time. Some break in sedimentation is documented at the top of the formation.

Lithofacies and thickness variations of the Vilkiškės Formation

The Vilkiškės Fm overlies the Skynimai Fm clastic sediments with some evidences of the break in sedimentation, as marked by the weathering features and a very sharp change in the mineral composition of sandstones. The underlying Vendian clastic deposits are dominated by feldspar and less quartz grains, while quartz sandstones dominate the section of the Vilkiškės Fm. These changes can be reasonably accounted to establishment of more humid climate conditions. Furthermore, the colour of sediments changes from brown to grey. Yet, reddish colours are common in the easternmost wells that are associated with increased amount of feldspar grains.

No significant changes are noted in the general framework of the lithofacies and thicknesses in spite of significantly changed sediment character. Four major lithofacies zones are defined in southeast Lithuania: (1) medium- and coarse-grained sandstones with fine-grained sandstones, (2) fine- and medium-grained sandstones, (3) fine- and very fine-grained sandstones grading to coarse-grained sandstones in the lower part of the section, (4) fine- and very fine-grained sandstones (Fig. 11). Furthermore, siltstone layers are common in the zones 3 and 4. These zones well correlate with thickness variations reflecting major structures defined in the underlying Vendian sediments. Relatively coarser material was deposited in the relatively uplifted structures, while local depressions are marked by finer grained composition.

DISCUSSIONS

The Vendian succession of southeast Lithuania is composed of three distinct units that correlate with regional-scale geological events reported from the East European platform. The lowermost unit, attributed to the Merkys Fm, marks the incipient stage Early Vendian basin widening, previously confined to the graben-type structures just after cessation of the igneous activity that implies thermal-sag mechanism which involved adjacent areas into wide subsidence (Šliaupa et al., 2006).

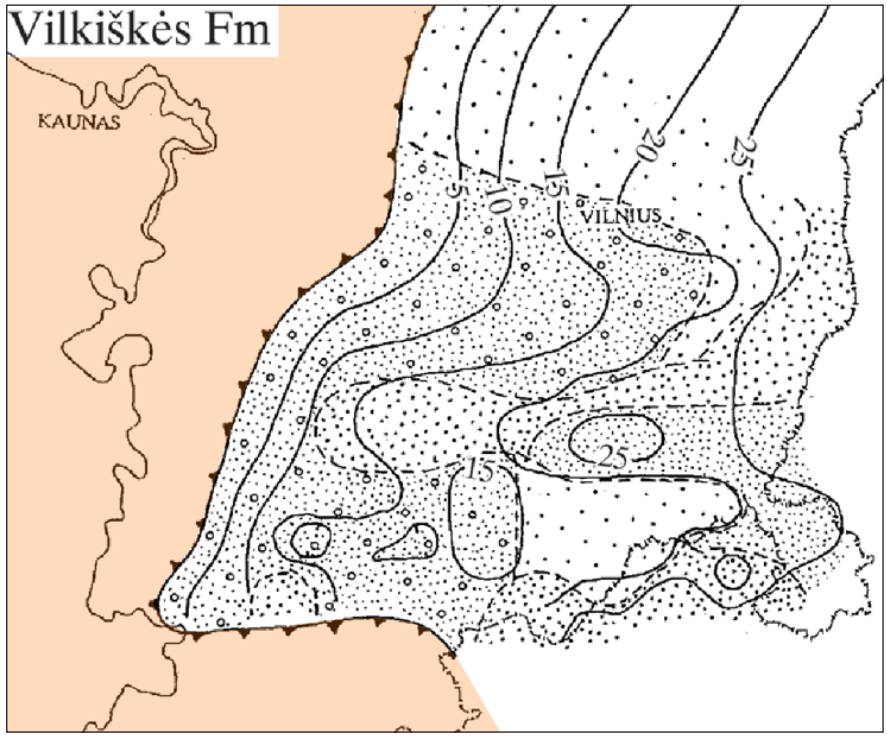

Fig. 11. Lithofacies and thickness distribution of the Vilkiškės Fm of SE Lithuania. See Fig. 7 for the legend
11 pav. PR Lietuvos Vilkiškių svitos litofacijos ir storiai. Legenda pateikta 7 pav.

The latest Early Vendian sedimentation was confined to areas proximal to the graben structures. The southeast Lithuania was affected by subsidence cored by Volyn-Orsha rift in southeast (Veretennikov et al., 1998). The fan deposits were the first to accumulate in the isolated depressions in southeast Lithuania during the Merkys time. A clear trend of fining of clastic sediments from northwest to northeast is distinct. It suggests the influx of the terrigenous material from northwest where the Grodno–Mosty basement uplift is suggested in northwest Belarus.

The Upper Vendian (Volyn Series) sedimentation took place in the vast Moscow basin (Kheraskova et al., 2005) that extended from the Baltic Region to the eastern margin of the East European platform marked by the Timan (or Ural) foredeep (Maslov et al., 2009). Some break in sedimentation is recognised in the Moscow basin between Valday and Volyn Series. The climate conditions were favourable for formation of the weathering crust reaching 37 m in thickness that suggests some increase in weather humidity (Levych, Machnatsh, 1995). In Scandinavia, this weathering crust is of illite-kaolinite composition.

Southeast Lithuania represented the western periphery of this large intracratonic basin that resulted in specific lithologies of marginal deposits. Two parts are defined in the Upper Vendian geological section of the Moscow basin. The lower part is composed of alternating shales and sandstones, while the upper part is represented by intercalating shales and siltstones with minor sandstones. Those parts are referred to as, respectively, Redkino and Kotlin regional stages. The geochemical elements and authigenic mineral association suggests a marine type of the basin with some meteoric water dilution (Mens, Pirrus, 1986; Felitsyn et al., 1998). The increase in river inflow is suggested during the Kotlin time (Mens, Pirrus, 1986). The Upper Vendian succession contains several members of tuff and tuffites. The composition of tuffs is rather different in the eastern and western parts of the Moscow basin. They are predominantly of felsic and acid composition in the east, while mafic composition is characteristic for the western tuffs (Felitcyn, 2004). They differ also in tectonic setting showing affinity to island arcs in the east and rift-related volcanics in the west. The latter imply late stages of igneous activity of the ancient rifted structures underlying the Upper Vendian basin. Furthermore, the western margin was proved to be affected by the extensional regime (Svenningsen, 1995). It points to the persisting extensional regime affecting the western part of the East European craton during the Late Vendian time, including southeast Lithuania. In should be noted that the inversion tectonic processes took place in the eastern and central parts of the Moscow basin during the latter part of the Kotlin RSt (Rovno Fm) that is accounted to initiation of the collision processes along the Timan margin of the Baltica continent (Šliaupa et al., 2006). It also affected the western part of the basin that lead to rearrangement of the deposition pattern, i. e. retreat of the marine basin from Lithuania and flooding of the previously uplifted basement of east Latvia and Estonia.

Redkino and Kotlin regional stages of the Upper Vendian of the Moscow basin are well discernable in the geological section of southeast Lithuania. The Redkino RSt is represented by Jašiūnai and Lower Rūdninkai deltaic sediments that accumulated along the western margin of the Moscow palaeo-sea. The overlying Kotlin RSt starts with basal deltaic sediments at the base (Upper Rūdninkai) and grades to predominating intercalation of marine siltstones and sandstones (Skynimai Fm), and is crowned by mature shallow marine sandstones (Vilkiškės Fm). The boundary between two regional stages is marked by about 1 m thick whitish layer showing intense weathering (bleaching, kaolinization, etc.). This layer can be correlated with the coarse-grained sandstone and conglomerate layer that separates aforementioned two parts of the Upper Vendian section of the Moscow basin (Sokolov, Fedonkin, 1981). It extends from the Black Sea in the south to the White Sea in the north (Makhnach et al., 1986).

It is notable that all major structures defined in the Martkys Fm were active throughout the Upper Vendian time. They affected the thickness and essentially lithofacies lateral distribution. The major NE–SW lithofacies trend recognised in the Merkys Fm is well discernable in the overlaying Vendian formations that implies persistency of sourcing of the terrigenous material, i. e. the main terrigenic influx was derived from the Grodno–Mosty uplift of the basement located further in the southwest.

The uppermost part of the Kotlin RSt (Rovno Fm) of the Moscow basin is absent in Lithuania

that marks a relative uplift of the territory. These rocks are distributed in east Latvia and Estonia that were previously uplifted (Jankauskas, 1994). The marine sedimentation was re-established in the earliest Cambrian (Blue Clay) after some break. It is notable that the major structures defined in the Vendian succession preserved tectonic activity (Šliaupa, 1997) (Fig. 12). The southern part of the area shows an essentially persistent structural framework. The Merkys depression and smaller scale local structures (Varėna, Kalesninkai uplifts, Šalčininkėliai depression) are discernable, while some changes are recognised in the northern part of the study area.

Such persistence of the tectonic structures throughout ~80 Ma can be explained in terms of persistent geodynamic regime. The Early Vendian was marked by high-intensity extensional tectonics affecting the East European craton. The Upper Vendian cratonic basin also developed under the extensional regime, though of lower intensity.

CONCLUSIONS

The Vendian deposits represent the basal portion of the sedimentary cover of the Baltic sedimentary basin. The sedimentation was restricted to the eastern part of Lithuania and further east relating to the post-rift widening of rift-related structures (Volyn–Orsha rift in Belarus). The Late Vendian was characterised by relative stability of local structures that were identified in southeast Lithuania on the basis of thickness and lithofacies variations. Geological sections of more then 100 wells were inspected. An emphasis was made on standard logging data that were effective in unifying the stratigraphic subdivision of the studied wells, which was of primary importance taking into consideration the fact that the local stratigraphy of the Vendian deposits is based on lithostratigraphic criteria, and different authors interpreted lithological features in different ways using different approaches that resulted in non-unique stratigraphic subdivision of

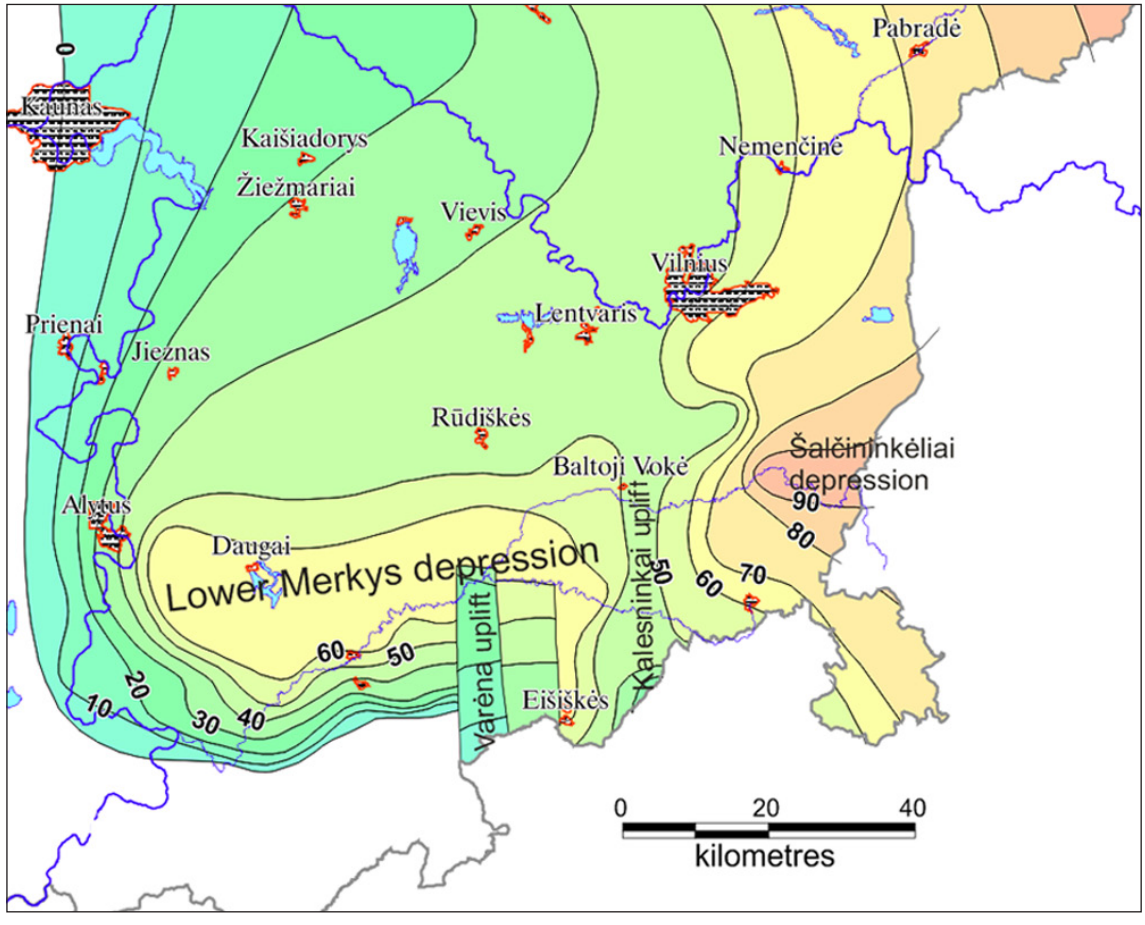

Fig. 12. Isopach map of Baltic Series of the lowermost Cambrian of SE Lithuania
12 pav. PR Lietuvos Baltijos serijos storiai

well sections during decades of drilling activities in south-eastern Lithuania.

Five formations (Merkys, Jašiūnai, Rūdninkai, Skynimai, and Vilkiškės) defined in the Vendian succession of Lithuania represent individual sedimentation cycles. The Merkys Fm is representative of the oldest Volyn Series, it is composed of poor-sorted quartz-feldspar conglomerates, sandstones, and mudstones. Its thickness ranges in the order of 1–13 m.

A general upward fining of the grain size is reported in the overlying Valday Series. The two lower cycles of 30–65 m thickness are dominated by deltaic quartz-feldspar sandstones and conglomerates (Jašiūnai and Rūdninkai formations), while the overlying Skynimai Fm (20–35 m thick) marks a significant change to predominating sedimentation of fine-grained sandstones and siltstones. Westwards, sandstones give way to conglomerates. The Vilkiškės Fm crowning the Vendian succession shows the highest maturity of clastic sediments, i. e. quartz sandstones were deposited with some mudstones. In lithological terms, the Vilkiškės Fm is more close to the overlaying Baltija Series of the lowermost Cambrian. This sedimentation trend reflects increasing chemical weathering from the Volyn time to the earliest Cambrian. It is associated with gradual cessation of the local tectonic movements as it can be inferred from decreased differentiation of thicknesses.

The local structures were of low tectonic activity in southeast Lithuania. Still, this activity was of rather persistent character. The structures that originated in the oldest Volyn time are traced in the Valday time. Three sub-regional structures were defined in the study area, i. e. the Žiežmariai–Maišiagala and Merkys depressions separated by the South Lithuanian elevation striking west–east. Against this background structural pattern the smaller-scale structures were recognised that affected thickness and lithofacies variations, the latter pointing to syn-depositional activity of the defined structures.

The lithofacies were highly sensitive to the structural grain of the basin bottom. The lithofacies distribution reflects not only the local features, but also is indicative of activity of some structures located beyond the present distribution of Vendian sediments that were eroded during later periods. A discordant trend of lithofacies belts with respect to thickness change pursued the presence of the uplifted structure further south that can be related to the Grodno–Mosty basement uplift suggested in northwest Belarus.

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Saulius Šliaupa

VENDO SEDIMENTACIJA IR TEKTONINIS AKTYVUMAS PIETRYČIŲ LIETUVOJE

S a n t r a u k a

Vendo nuogulos sudaro pačią apatinę Rytų Lietuvos nuosėdinės storymės dalį ir reprezentuoja seniausias platforminio etapo nuogulas, kurios užklojo kristalinio pamato uolienas. PR Lietuvos teritorija (piečiau Kauno platumos) tyrimams pasirinkta neatsitiktinai, kadangi čia buvo išgręžta daugiau kaip šimtas gręžinių, įsigilinusių į vendo uolienas. Ir nors gręžimo medžiagos yra daug, išsami vendo laikotarpio paleostruktūrinių sąlygų analizė yra sudėtinga problema. Pagrindinė to priežastis – komplikuota atskirų gręžinių pjūvių koreliacija. Vendo stratigrafija remiasi litologiniais požymiais, kurie plote yra labai kaitūs. Pagrindinis uždavinys, prieš atliekant išsamius paleostruktūrinių sąlygų tyrimus, yra stratigrafinė pjūvių koreliacija. Efektyviai tai leidžia atlikti gręžinių diagrafijos kreivių koreliacija atsižvelgiant į geologinius pjūvių ypatumus. Pietryčių Lietuvoje išgręžtų gręžinių pjūviai buvo suskirstyti ir koreliuojami iki svitų ir posvičių lygio, ir tai leidžia detaliai rekonstruoti vendo–kambro laikotarpio struktūrinių sąlygų raidą. Gręžinių vendo stratigrafinio suskirstymo schema rėmėsi V. Sakalausko pateiktais Lietuvos vendo stratigrafijos principais.

Tyrimai rodo, kad PR Lietuvos teritorija pasižymėjo stabiliu lokaliu struktūriniu planu. Ankstyviausiame, Voluinės, laikotarpyje išskirtos įvairaus rango struktūros aiškiai pasireiškė ir vėlesniais vėlyvo vendo laikotarpiais. Remiantis nuogulų storių ir litofacijų analize, pietrytinėje Lietuvos dalyje buvo išskirtos trys stambios struktūros – Žiežmarių-Maišiagalos ir Merkio įlinkiai bei juos skirianti Pietų Lietuvos platuminė pakiluma. Tektoniniu stabilumu pasižymėjo ne tik šios subregioninio rango struktūros, bet ir smulkesni struktūriniai elementai. Nepaisant konservatyvių lokalių struktūrų baikaliniame etape, galima konstatuoti ir kai kuriuos evoliucijos bruožus.

Facijų pasiskirstymas atspindi ne tik lokalias struktūras baseine, bet ir už jo ribų. Nuogulų sudėties lateralinio kitimo tendencija, diskordantinė storių kaitos trendui, leidžia prognozuoti stambią aukštai iškilusią denudacinėje zonoje Gardino-Mostų kristalinio pamato pakilumą.

Raktažodžiai: vendas, tektoninis aktyvumas, Lietuva, Baltijos sedimentacinis baseinas, Maskvos baseinas