GEOLOGIJA. 2012. Vol. 54. No. 2(78). P. 53–73

Reflection of the Palaeoproterozoic Mid-Lithuanian Suture Zone in the overlying sedimentary cover

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Šliaupa S., Baliukevičius A., Dėnas Ž., Šliaupienė R. Reflection of the Palaeoproterozoic Mid-Lithuanian Suture Zone in the overlying sedimentary cover. *Geologija*. Vilnius. 2012. Vol. 54. No. 2. P. 53–73. ISSN 1392–110X.

The Mid-Lithuanian Suture Zone represents the first-order Palaeoproterozoic tectonic feature defined in the crystalline basement of Lithuania. It crosses the whole territory of Lithuania from the SW to NE. The vast basin sedimentation was established after more than 1.2 Ga years and persisted from Late Vendian to Quaternary. The geodynamic conditions were quite different during different geological periods. Accordingly, the structural pattern of the basin was also variable.

Despite of the varying tectonic situation, the ancient Mid-Lithuanian Suture Zone showed a persisting impact on the sedimentation pattern and structuring of the overlying sedimentary layers. This influence is initially traced in the distribution of the Upper Vendian deposits, the western boundary of which is confined to the Mid-Lithuanian Suture Zone implying the subsidence trend east of the zone and erosion of the basement lithologies exposed on the surface in the west. The sedimentation pattern dramatically changed in the middle Early Cambrian time showing the transgression of the new marine basin from the west. The analysis of the thickness distribution of the trilobitic Cambrian deposits indicates the preservation of the controlling role of the Mid-Lithuanian Suture Zone on the local sedimentation variations. The zone is marked by the distinct depression characterised by increased thicknesses. Furthermore, it controlled the distribution of the lithofacies distribution. Some changes are recognised in the structural pattern during the Ordovician that reflect the changing tectonic situation. The southern part of the Mid-Lithuanian Suture Zone preserved the increased subsidence trend inherited from Cambrian, while the northern part is not discernible in the thickness variations. This can be related to different orientation of the southern and northern parts of the Mid-Lithuanian Suture Zone with respect to affecting tectonic forces. The dramatically increased subsidence and associated sedimentation rates mark the flexuring stage of the Baltic Basin evolution. The Mid-Lithuanian Suture Zone, however, is well defined in the lithofacies and thickness distribution. The zone is marked by transition from deep basin facies in the west to inner shelf shallow sedimentation in the east.

The Mid-Lithuanian Suture Zone is not identified as the controlling feature in the Devonian sediments. However, the Mid-Lithuanian Suture Zone is well defined in the map of local structures. Application of the method of local residuals unraveled the local uplift confined to this zone. It suggests the post-Devonian formation of the Middle Lithuanian uplift. Furthermore, this uplift is well traced in the older Cambrian and Silurian layers. The amplitudes of the uplift are compatible for Cambrian, Silurian, and Devonian sediments that confirm the post-Devonian age of this feature.

The later history of the Middle Lithuanian uplift cannot be restored due to absence of younger sediments straggling along the Mid-Lithuanian Suture Zone. The distribution of the Jurassic sediments makes a hint to persisting activity of the zone.

It is implied that the Mid-Lithuanian Suture Zone represents the important feature of the Earth's crust with specific mechanical properties that resulted in persistent activity under changing tectonic forces.

Key words: suture zone, tectonic inheritance, Baltic, Palaeozoic, Palaeoproterozoic, sedimentary basin

Received 5 September 2012, accepted 15 November 2012

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INTRODUCTION

The Precambrian crystalline basement of Lithuania is overlain by the 0.2–2 km thick scarcely structured sedimentary cover. The studies of other regions show that the heterogeneities in the crust influence significantly its response to deformation. Variations in crustal lithology, lithosphere structure (Snyder et al., 1997) and its rheology (Stephenson et al., 1997; D'Lemos et al., 1997) govern architecture and location of regional and local structures accommodating crustal strains. The basement structures play the crucial role in deformation of the overlying basin sedimentary pile causing inheritance or reactivation phenomena stressed by many authors (e. g. Buttler et al., 1997; Allen, Vincent, 1997; Cloke et al., 1997). The influence of the pre-existing fault zones is essentially distinct. Virtually all crust is dissected by faults and shear zones that are inherently weak and might be easily utilized by subsequent deformations. Causative fault zone weakening mechanisms were reviewed (Holdsworth et al., 1997; Imber et al., 1997). Strain is generally focused into faults (Holdsworth et al., 1997) and sharp basement compositional / rheological boundaries. The pre-existing zones of weakness tend to reactivate repeatedly often in preference of the onset of new discontinuities. The reactivation might exhibit similar or different trends of displacement for successive events (Holdsworth et al., 1997). The World Stress Map project provides convincing data on far-field horizontal stress field transmission into plate interiors affecting recent deformations of the Earth's crust (Zoback et al., 1992).

In view of the facts mentioned above, the reflection of basement discontinuities in the sedimentary cover can be expected. The present paper discusses the impact of the Palaeoproterozoic Middle Lithuanian Suture Zone on development of the sedimentary cover. It is the major basement structure recognised in the Lithuanian crystalline basement.

GEOLOGICAL SETTING

Lithuania is situated in the eastern periphery of the Baltic Sedimentary Basin superimposed on the Palaeoproterozoic crystalline basement. Two major lithotectonic domains are distinguished in the crystalline basement of Lithuania that differs in lithology, history of metamorphism and structuring style, i. e. the West Lithuanian Granulite Domain and East Lithuanian Belt.

The West Lithuanian Granulite Domain belongs to the granulite belt extending along the eastern shore of the Baltic Sea from western Latvia through Poland to the Tornquist-Teisseyre Zone in Poland. Mosaic pattern of gravimagnetic anomalies is a characteristic feature of the domain. The West Lithuanian Granulite Domain is dominated by charnockitic rocks with relict bodies of supracrustals ranging from metabasites to felsic gneisses (Skridlaitė, Motuza, 1997; 2001). Isotopic datings (Claesson, 1994; 1996) demonstrate that the basement is of the Paleoproterozoic age. The main feature of the West Lithuanian Granulite Domain is the Kuršiai massif. It is the polyphase batholith of charnockitic rocks, extending over some 10 000 km^2 with a few smaller plutons (Motuza, Motuza, 2011).

Plutons intruded between 1 850 and 1 815 Ma, and are composed of intermediate and acid varieties of charnockite rocks. Magmatism took place in the later orogenesis period, transitional from synkinematic collisional to post-kinematic extensional phases (Motuza, Motuza, 2011).

The NE and NNE structural trends dominate in the magnetic and gravity anomaly patterns in the East Lithuanian Belt. The supracrustal association is represented by amphibolites and gneisses metamorphosed in amphibolite facies, which occur commonly as the relict bodies hosted by granitoids, granitic gneisses and migmatities. In terms of the original rock composition of the metasedimentary rocks of the East Lithuanian Belt, the predominating felsic biotite-plagioclase-quartz gneisses are metamorphosed grywackes and arcoses, in places with admixture of volcanic mainly pyroclastic material (Motuza, 2005). They are associated with accompanied by mafic gneisses, marbles and metapelites. The oldest supracrustal rocks of the East Lithuanian Belt are dated by the youngest age of detrital zircon at ca 1.91 Ga. The upper limit is indicated by the age of the oldest migmatite neosome – 1.884 Ga (Mansfeld, 2001; Claesson et al., 2001).

The enderbites-charnockites and mafic granulites are reported from the easternmost part of Lithuania representing the western margin of the Belarus–Baltic Granulite Belt extending NE–SE from southern Poland through western Belarus with possible continuation in Estonia. According to the U-Pb and Sm-Nd dating, the East Lithuanian Belt and Belarus-Baltic Granulite Belt are of the Palaeoproterozoic age.

The final intense tectonothermal-magmatic events occurred about 1.5 Ga when numerous granodioritic-granitic rapakivi-like bodies intruded the crust in different parts of Lithuania.

The sedimentary cover of Lithuania is represented by the Upper Vendian–Phanerozoic deposits. The thickness ranges from 200 m in the southeast (Mazury–Belarus High) to more than 2 km in West Lithuania (axial part of the Baltic Basin). A set of faults was documented in the sedimentary cover that is most abundant in the Lower Palaeozoic succession (Stirpeika, 1999). Amplitudes of some faults exceed 200 m in West Lithuania (e. g. the Telšiai, Gargždai faults). Faults are rather rare in younger structural complexes.

MID-LITHUANIAN SUTURE ZONE

The N–S-directed mafic and felsic metavolcanics compose the Mid-Lithuanian Suture Zone (Fig. 1). The age of volcano-plutonic rocks is around 1.84 Ga. This feature is regarded as a subduction-related collisional zone between the West Lithuanian Granulite Domain and East Lithuanian Belt (Motuza, 2005; Wiszniewska et al., 2005; 2007; Linnemann et al., 2008). The mafic metavolcanites predominating in the Inčukalns zone of the Latvian crystalline basement are interpreted (Kirs et al., 2009) as a northern continuation of the Mid-Lithuanian Suture Zone. This correlation still remains a matter of discussion.

The metavolcanics of mafic to felsic and intermediate composition of the Mid-Lithuanian Suture Zone bear a geochemical signature of a volcanic island arc setting (Motuza, 2005; Wiszniewska et al., 2005). The Mid-Lithuanian Suture Zone is considered a volcanic island arc with a mafic fore-arc unit on its eastern side and a felsic-intermediate arc unit on its western side (Motuza, 2004; 2009).

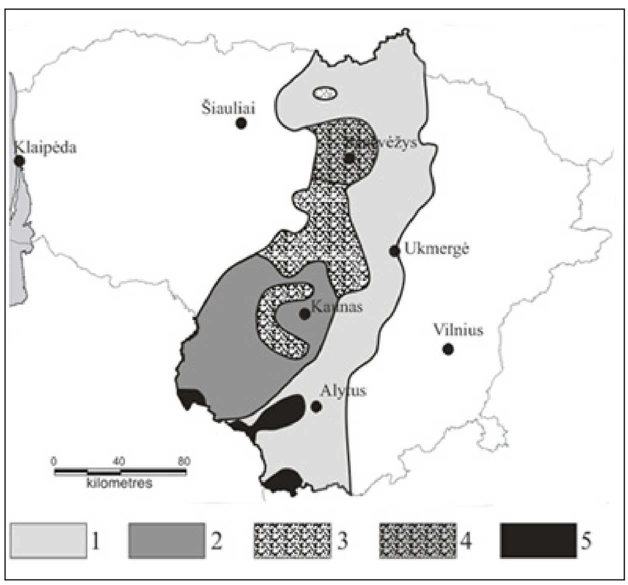

Fig. 1. Geological scheme of the Mid-Lithuanian Suture Zone (after Motuza, 2005). *1* – predominant mafic metavolcanics; *2* – predominant felsic metavolcanics; *3* – granitoid intrusions, amphibolite facies; *4* – charnocitoide intrusions; *5* – cratonic granitoid intrusions

1 pav. Vidurio Lietuvos sandūros zonos geologinė schema (Motuza, 2005). *1* – vyrauja bazinės sudėties metavulkanitai; *2* – vyrauja vidutinės sudėties metavulkanitai; *3* – granitoidų intruzijos; *4* – čarnokitoido intruzija; *5* – kratoninės granitoidų intruzijos

The dismembered belt of pyroxene-biotite-hornblende-feldspar-quartz gneisses with well developed porphyry texture, interpreted as metavolcanics of andesitic-dacitic composition, occurs in the western part of the Mid-Lithuanian Suture Zone. The porphyry texture is formed by idiomorphic and zoned plagioclase phenocrists dispersed in a fine-grained matrix (Motuza, 2005). The amphibolites showing geochemical features of subduction-related magmatic arc volcanics predominate in the eastern part of the Mid-Lithuanian Suture Zone (western margin of the East Lithuanian Belt). The age of the Mid-Lithuanian Suture Zone rocks is constrained by single dating of mafic metavolcanics, andesitic-dacitic metavolcanics and granitoids at 1.87 Ga (Rimsa et al., 2001), 1.842 and 1.836 Ga, respectively (Motuza, 2005).

In the southern part of the Mid-Lithuanian Suture Zone, the rounded zircons of the Lazdijai-32 anatectite granitoids yield ages 2.9–1.5 Ga (Wiszniewska et al., 2005). One detrital grain was dated at 2.91 Ga while the group of faintly zoned grains gave ages of ca. 2.00 and 1.94 Ga. One 1.94 Ga old core is overgrown by a wide ca. 1.50 Ga rim. In the central part of LMSZ (well Blūdžiai-150) different age zircons were distinguished. The oldest, oscillatory zoned two cores grains were dated 3.08 Ga and 2.88 Ga. Numerous zircon cores gave ca. 2.00 Ga, 1.94 Ga and 1.89 Ga ages. Most of cores are surrounded by thick 1.85 Ga rims. It indicates a highly complex history of development of the Mid-Lithuanian Suture Zone.

Deep seismic sounding data (Motuza et al., 2000; Grad et al., 2003) and modelling of potential fields (Sliaupa, Popov, 2007) suggest the western subduction polarity of the Mid-Lithuanian Suture Zone. It is confined to dramatic increase in the Earth's crust thickness from 43 km in the west to 50 km in the east. An abrupt change in other physical parameters of the crust and mantle is also noted. The width of the transitional zone is about 35–40 km.

The Mid-Lithuanian Suture Zone exhibits different geophysical characteristics. The eastern part of the Mid-Lithuanian Suture Zone is confined to the gravity high that associates with the increased magnetic field characterised by high differentiation (Figs. 2, 3). The increased values of the potential fields correlate with the predominant mafic volcanic lithologies. The

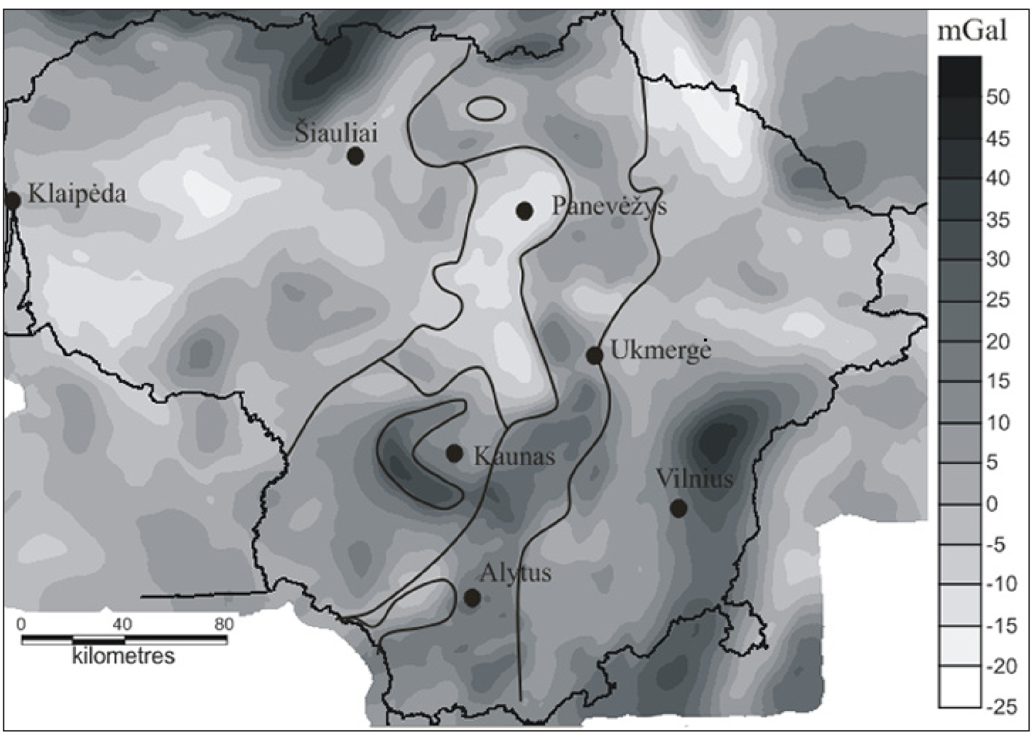

Fig. 2. Map of the Bouguer anomalies (compiled from the digital database of Geological Survey of Lithuania). Contours of the Mid-Lithuanian Suture Zone are indicated for comparison
2 pav. Bouguer anomalijų žemėlapis (sudarytas remiantis LGT duomenų baze). Linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

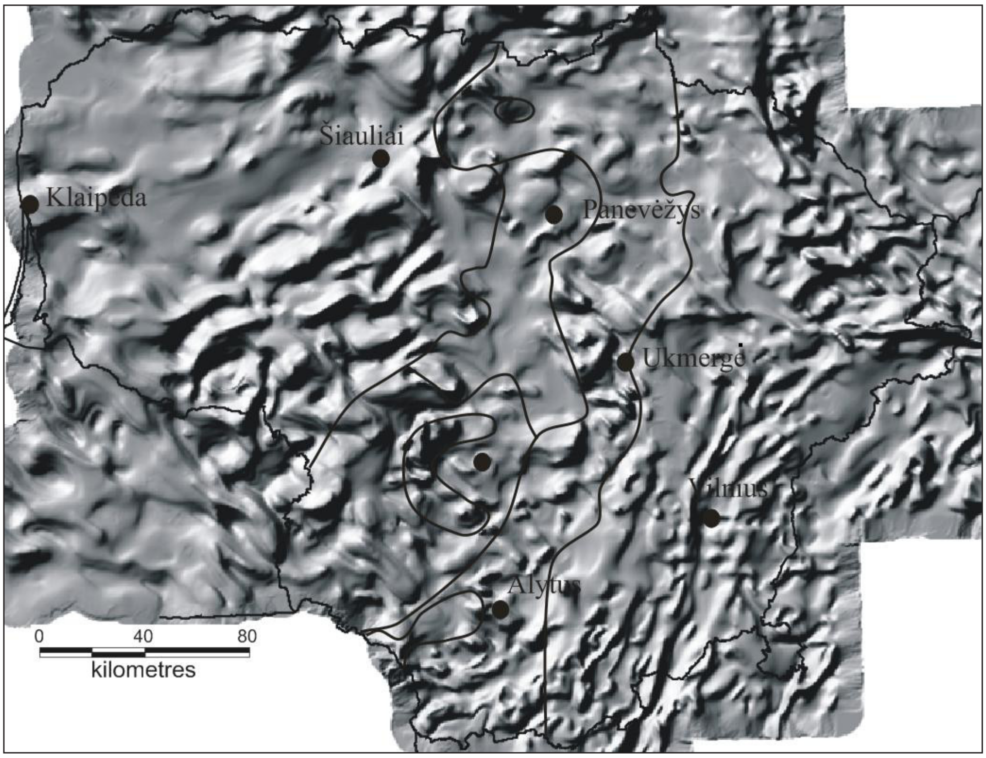

Fig. 3. Shaded image of the magnetic field (calculated from the digital database of Geological Survey of Lithuania). Contours of the Mid-Lithuanian Suture Zone are indicated for comparison
3 pav. Magnetinio lauko šešėlinis žemėlapis (sudarytas remiantis LGT duomenų baze). Linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

gravity anomalies are elongated parallel to the axis of the Mid-Lithuanian Suture Zone, while the magnetic anomalies are rather disordered. The differentiation of the magnetic field is essentially distinct in the central and southern parts of the Mid-Lithuanian Suture Zone, and is quite smooth north of the W–E trending Polotsk shear zone (north of Ukmergė).

The intensity of the gravity field is of lower intensity in the western part of the Mid-Lithuanian Suture Zone. The Panevėžys gravity and magnetic lows are related to the large granitoid intrusion that was formed in the amphibolite and granulite facies in the south and north, respectively. These two "compartments" are well manifested in the magnetic field intensity variations, the granulites characterized by higher field values. The distinct boomerang-shaped gravity high west of Kaunas is of disputable origin. The magnetic anomalies do not show any predominant orientation in the western part of the Mid-Lithuanian Suture Zone.

According to the modelling of the magnetic field, the Mid-Lithuanian Suture Zone extends to the lower crust (Sliaupa, Popov, 2007) that is in agreement with the deep seismic sounding data. The southern and central portions of the suture zone are characterized by the near-vertical angle of dipping of structural elements, while distinct structural dipping to the west is recognized in the northern part.

EVIDENCES OF IMPACT OF THE MID-LITHUANIAN SUTURE ZONE ON FORMATION OF THE SEDIMENTARY COVER

Vendian

The oldest platform sediments of Lithuania are attributed to the Vendian. The deposits are composed of quartz-feldspar fluvial conglomerates and sandstones predominating in the lower part of the section and shallow marine siltstones and shales dominating in the upper part of the section (Paškevičius, 1997). Sediments were deposited in the western periphery of the large Moscow basin extending to the Ural margin of the East European Craton. The thickness of Vendian deposits increases accordingly to the west reaching the maximum value of 140 m in Tverečius area close to the Belarus border.

Vendian deposits are distributed in the eastern half of Lithuania. The western limit of the basin is roughly confined to the Nemunas River in the south and the Nevėžis River in the north (Fig. 4). In terms of the tectonic grain of the crystalline basement, the limit of Vendian deposits marks the axial part of the Mid-Lithuanian Suture Zone. West Lithuanian Domain granulites were exposed to erosion during the Vendian time. The eroded material was transported to the west and deposited in the near-coastal zone of the Moscow basin. It is therefore suggested that the Mid-Lithuanian Suture Zone represented an important transition between erosional and depositional areas in, respectively, the west and the east.

Cambrian

The sedimentation pattern of the Vendian time persisted until the earliest Cambrian (Paškevičius, 1997). The Blue Clays, referred to as the Baltic Series, were deposited in the Moscow marine basin. The eastern part of Lithuania submerged under the western margin of the shallow sea. The section of the lowermost Cambrian is composed of shales with some interlayers of quartz sandstone abundance of which increases towards the palaeoshore in the west. The western limit of distribution of Blue Clays is close to that of Vendian sediments pointing to persistent impact of the Mid-Lithuanian Suture Zone on the sedimentation pattern. The thickness of the Baltic Series increases to the east and reaches up to 115 m (Fig. 4).

The sedimentation pattern dramatically changed in the middle Early Cambrian that is accounted for breaking apart of the Baltica continent from

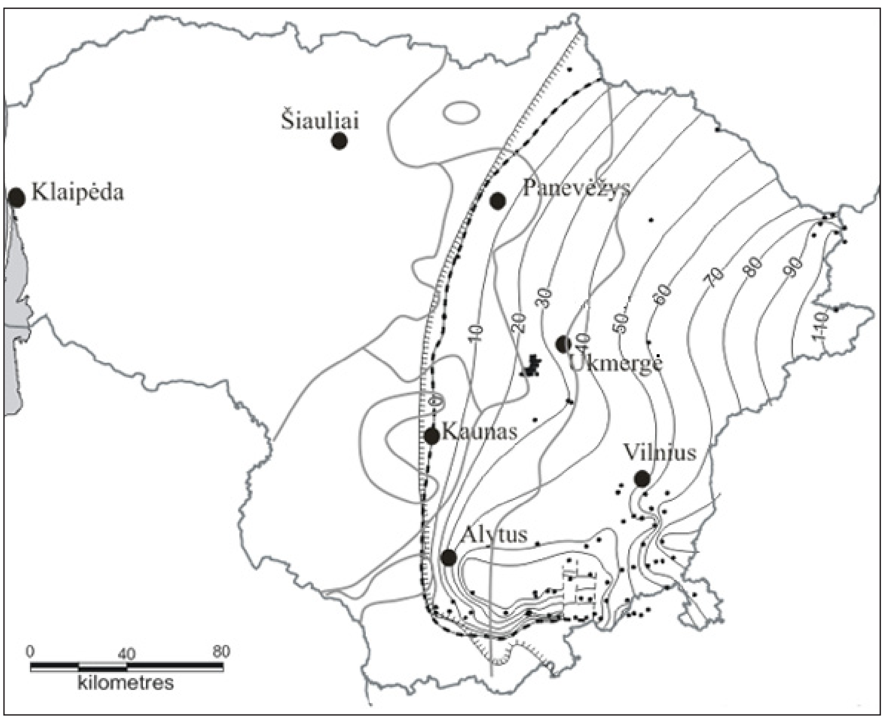

Fig. 4. Isopach map of the Baltic Series of the lowermost Cambrian. Dots show wells penetrating the Baltic Series. Hatchet lines mark faults. Bergstrich line indicates the limit of distribution of Vendian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

4 pav. Apatinio kambro Baltijos serijos storių žemėlapis. Taškais pažymėti gręžiniai, kertantys Baltijos serijos uolienas. Brūkšninė linija žymi nuogulų paplitimo ribą. Plonos brūkšninės linijos rodo uolienas kertančius lūžius. Dantyta linija pažymėta senesnių vendo uolienų paplitimo riba. Pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas suspected landmasses and opening of the Tornquist ocean in the west. The shallow marine basin transgressed all over the territory of Lithuania. The predominantly shaly lithologies were deposited during the upper Lower–lowermost Middle Cambrian times; they mark the maximum extent of the marine basin in the east. The middle Middle Cambrian (Deimena Series) quartz sandstones accumulated in the regressing basin that abandoned the Lithuanian territory since the upper Middle Cambrian.

The Mid-Lithuanian Suture Zone is rather distinct in the trilobitic Cambrian sedimentation. The sediment thickness is systematically increasing to the west (Fig. 5). The first-order residuals of thicknesses were calculated to highlight the local thickness variations against this westward trend (Fig. 6). The distinct NNE–SSW trending depression is identified across Lithuania. The axial part of the depression extends along Alytus–Kaunas–Panevėžys and is clearly confined to the Mid-Lithuanian Suture Zone (Fig. 6). The amplitude of the depression ranges from 1 m to 8 m. The amplitudes of the west Lithuanian and east Lithuanian uplifts attain 15–25 m. It is therefore suggested that the Mid-Lithuanian Suture Zone played

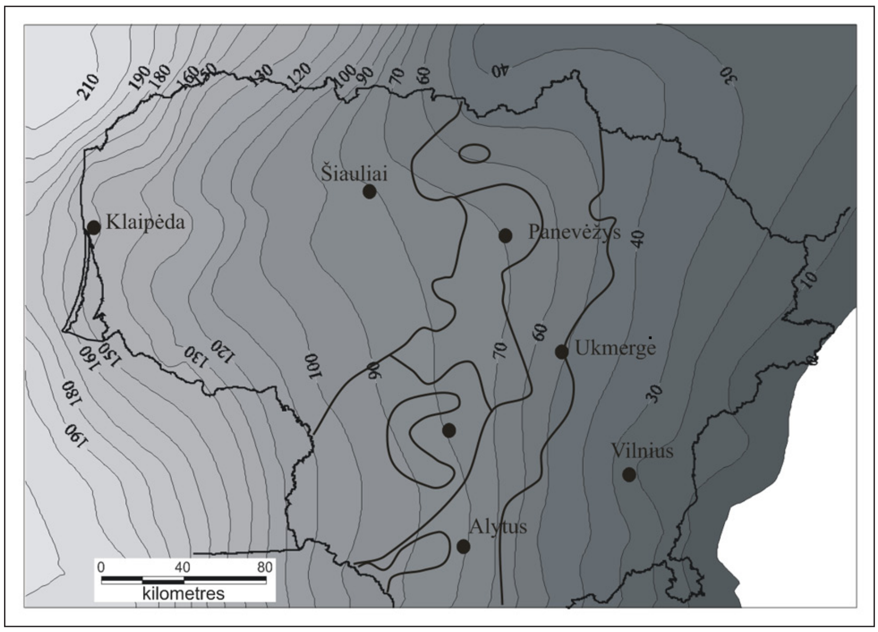

Fig. 5. Isopach map of the trilobitic Cambrian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
5 pav. Trilobitinio kambro nuogulų storių žemėlapis. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

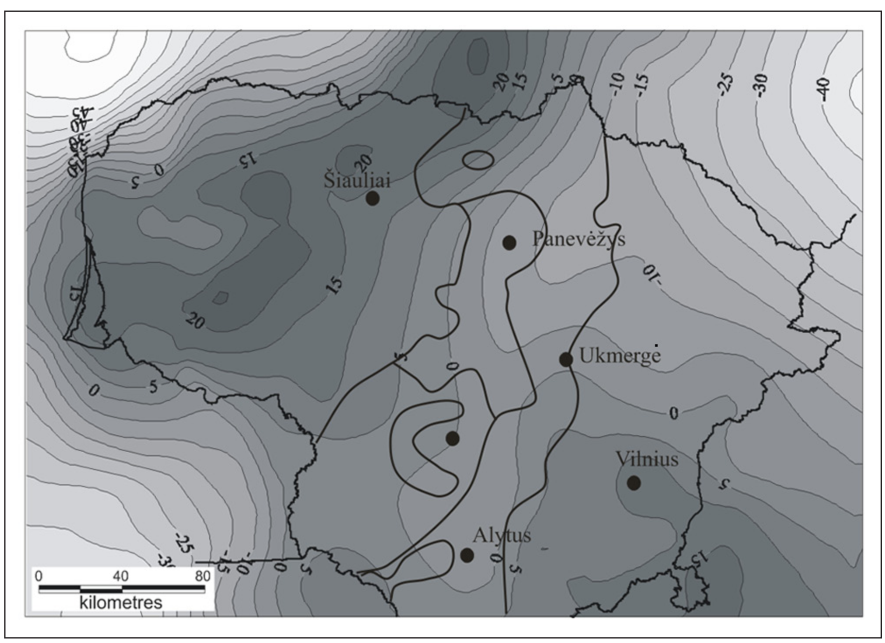

Fig. 6. Map of the first-order residuals of thicknesses of trilobitic Cambrian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
6 pav. Pirmos eilės liekaninės storių anomalijos. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

a major role in the structural evolution of the trilobitic Cambrian basin controlling the local subsidence against the regional westward-dipping basin trend.

This structural pattern is well manifested in the lithofacies distribution. The Mid-Lithuanian Suture Zone was marked by the transition from mud-silt dominated sedimentation in the west to sand dominated deposition in the east during the Early Cambrian time. The basin regressed during the Middle Cambrian. The distribution limit of the Deimena Series is confined to the Mid-Lithuanian Suture Zone.

The approach of local residuals was also applied to the structural map of the top of Cambrian deposits. The depths pattern of the Cambrian layer ranging from –100 m in the east to –2 200 m in the west (Fig. 7) reflects the long-termed tectonic evolution

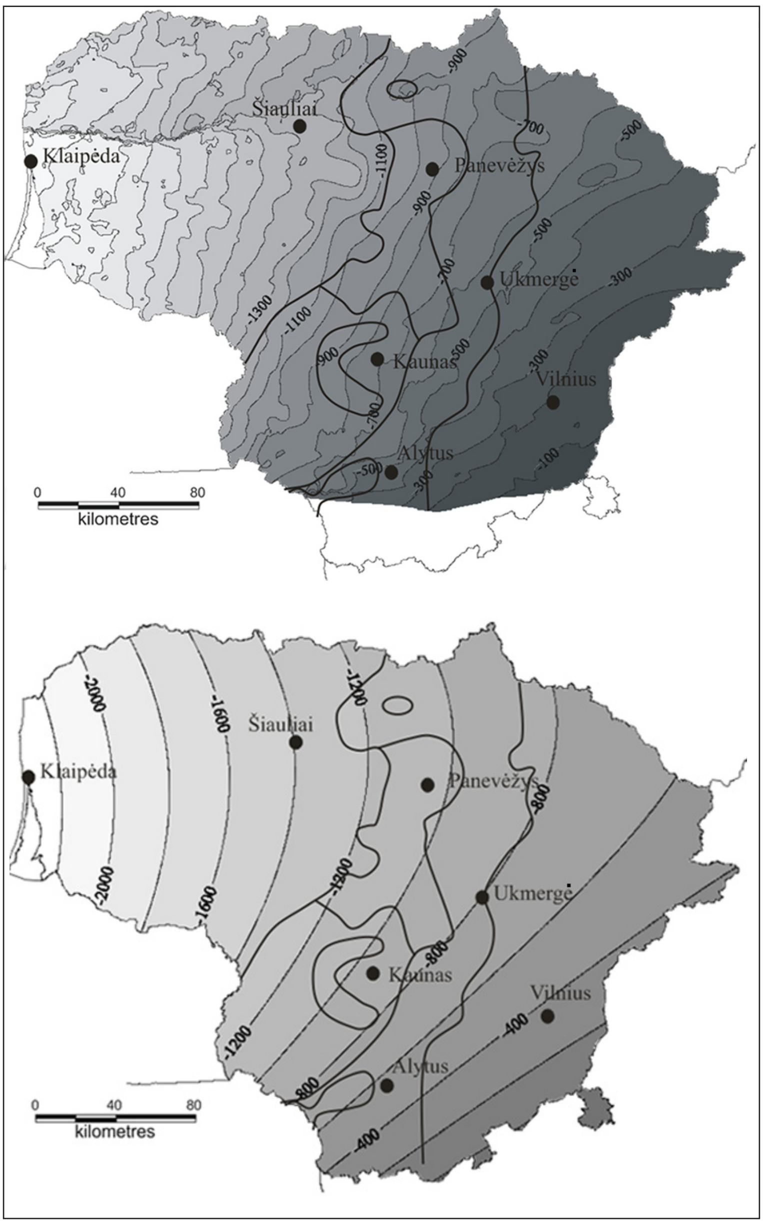

Fig. 7. Upper figure – depths of the top of Cambrian deposits. Lower figure – second-order trend of the top depths of Cambrian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

7 pav. Viršuje – kambro kraigo gyliai. Apačioje – kambro kraigo gylių 2-os eilės trendas. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas of the sedimentary basin throughout more than 500 Ma. The depths of the top of the Cambrian succession were subtracted from the second-order trend (Fig. 7) to identify the local variations. The trend was calculated using the Surfer 8 programme. The distinct uplift was identified in Middle Lithuania. It is well confined to the Mid-Lithuanian Suture Zone (Fig. 8). The amplitude of the Mid-Lithuanian uplift attains +160 m. It implies the tectonic inversion of the Mid-Lithuanian Cambrian depression at some stage of the tectonic evolution of the Baltic sedimentary basin. Furthermore, the west Lithuanian and east Lithuanian Cambrian uplifts were subsided for –150 m and –200 m, respectively.

Ordovician

The structural pattern of sedimentation and local thickness variations changed in the Ordovician time (Fig. 9). The thickness of Ordovician deposits range from 40 m within paleouplifts to 250 m in the axial part of the Jelgava depression in central Latvia north of the Lithuanian border. The Ordovician deposits are represented by carbonates (mainly limestones) intercalating with marlstones and shales the percentage of which systematically increase to the west in the deeper parts of the marine basin. The sedimentation was characterised by persistence, all Ordovician stages are present in the geological section of the Baltic sedimentary basin. Breaks of sedimentation were rather short-termed and restricted mainly to the marginal parts of the basin (Laškovas, 2001). Carbonates are abundant in the basin flanks, while marlstones and shales dominate in the central and western portions of the Baltic sedimentary basin.

The Middle Lithuanian depression is the most distinct structure trending from Southwest Lithuania to Northeast Lithuania (Fig. 9). It is flanked by the western slope of the Belarus high in the east and the Lower Nemunas uplift in the west. The Jelgava depression is defined in the north, the axial part of which is located in central Latvia.

There is no obvious linkage of the structuring of the Ordovician sedimentary basin to the Mid-

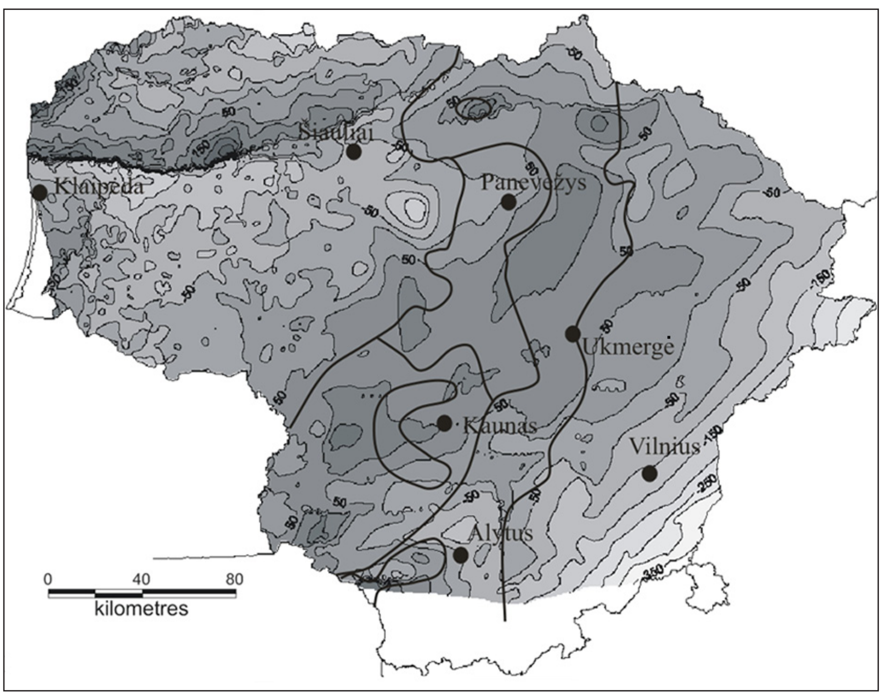

Fig. 8. Map of the second-order residuals of the top depths of Cambrian deposits reflecting local structures. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

8 pav. Kambro kraigo gylių 2-os eilės liekaninės anomalijos. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

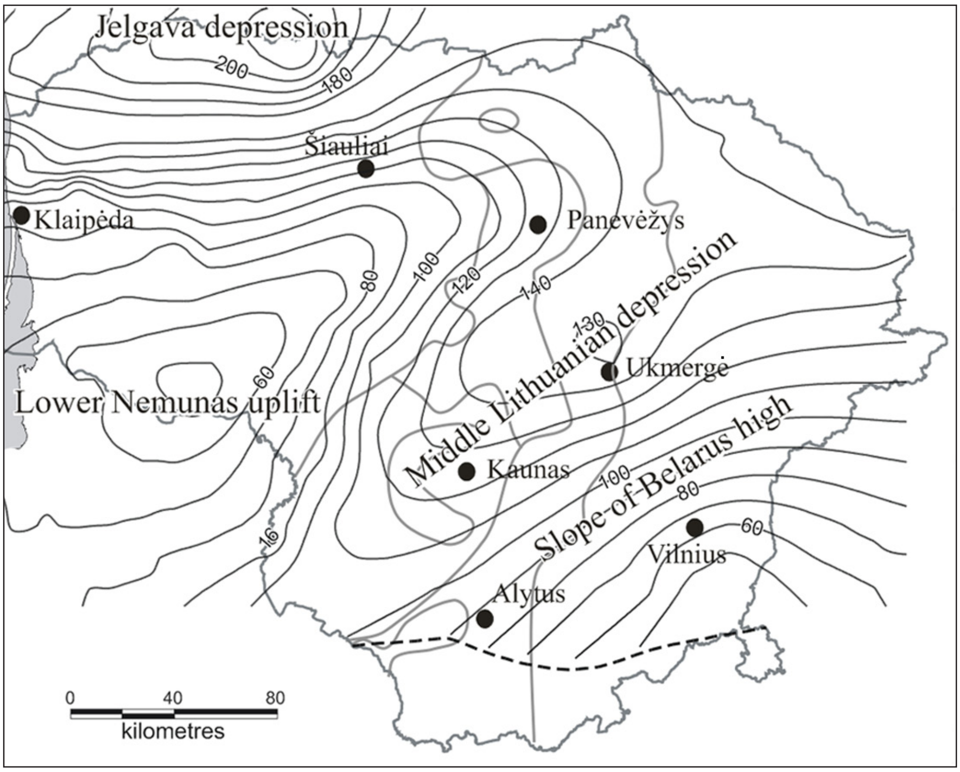

Fig. 9. Isopach map of Ordovician deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison. Hatchet line marks the southern limit of distribution of Ordovician deposits

9 pav. Ordoviko nuogulų storiai. Brūkšninė linija žymi uolienų paplitimo ribą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

Lithuanian Suture Zone. The main structural trend is oriented NE–SW that was likely related to the buckling of the lithosphere induced by convergence of Laurentia and Baltica continents. However, some structural correlation can be discussed. The southern and middle parts of the Mid-Lithuanian Suture Zone overlap the Middle Lithuanian Depression. The amplitude of the depression is about 40 m. It suggests the subsidence trend inherited from the Cambrian sedimentation. The northern part of the Middle Lithuanian depression diverges from the Mid-Lithuanian Suture Zone following the general NE–SW trend. It is suggested that the southern half of the Mid-Lithuanian Suture Zone was reactivated due to favourable NW–SE compression transmitted from the Scandinavian margin of the Baltica continent, whereas the northern part of the zone directed NNE–SSW was less favourably oriented with respect to affecting horizontal tectonic forces.

Silurian

The sedimentation character significantly changed in the Silurian time. The predominance of carbonaceous and shaly lithologies is similar to that of the Ordovician period. However, the sedimentation rates (and subsidence rates) increased dramatically. The thickness of the Silurian succession increases westward exceeding 800 m in West Lithuania and is larger further to the west. The sedimentation was rather persistent in the Baltic Basin during the Silurian. The breaks in sedimentation are only documented in the periphery of the basin caused by the low-amplitude tectonic movements and sea level oscillations. The rate of sedimentation increased in a course of the Silurian.

The sedimentation environment of the Silurian basin deepened towards the western margin of the Baltica continent (Lapinskas, 1997). Graptolite shales dominate in the western and central parts of the Silurian basin. They gradually give way to marlstones, limestones and dolomites in the east. The Llandovery-middle Wenlock sedimentation is considered in terms of the basin starvation stage, which was followed by compensated deposition during the late Early-Late Silurian. Increase in the terrigenous supply, inferred from the sediment thickness, is associated with gradual shallowing of the depositional environment. This is associated with an increase in the carbonate deposition (Musteikis, Kaminskas, 1996).

The low-rate sedimentation of the Baltic sedimentary basin is explained in terms of the passive continental margin during the Cambrian-Ordovician. The acceleration of the subsidence was related to docking of the East Avalonian microcontinent to Baltica that started in the latest Ordovician and climaxed during the latest Silurian. The compressional tectonic regime is implied for the Baltic sedimentary basin that led to rearrangement of the sedimentation pattern and structuring style.

The method of local residuals was applied to unravel the local variations in the vertical movements of the Earth's crust. The map of the local thickness variations of the Silurian succession shows the N–S oriented long-wave (80–100 km) structural pattern to the west of the Mid-Lithuanian Suture Zone (Fig. 10). The amplitudes are in the range of 80–100 m. By contrast, the distinct gradient zone is defined within the Mid-Lithuanian Suture Zone that is of about 200 m amplitude. These thickness variations closely associate with the lithofacies distribution. Based on these lithological variations Stirpeika (1999) defined the Baltic Syneclise west of the Mid-Lithuanian Suture Zone and the Eastern Flank of the Baltic Syneclise east of the Mid-Lithuanian Suture Zone thus stressing the first-order role of this zone in the basin evolution.

Also, the map of local structures was compiled by subtracting the depths of the top of Silurian deposits from the first-order regional depths trend (Fig. 11). The Middle Lithuanian uplift was defined

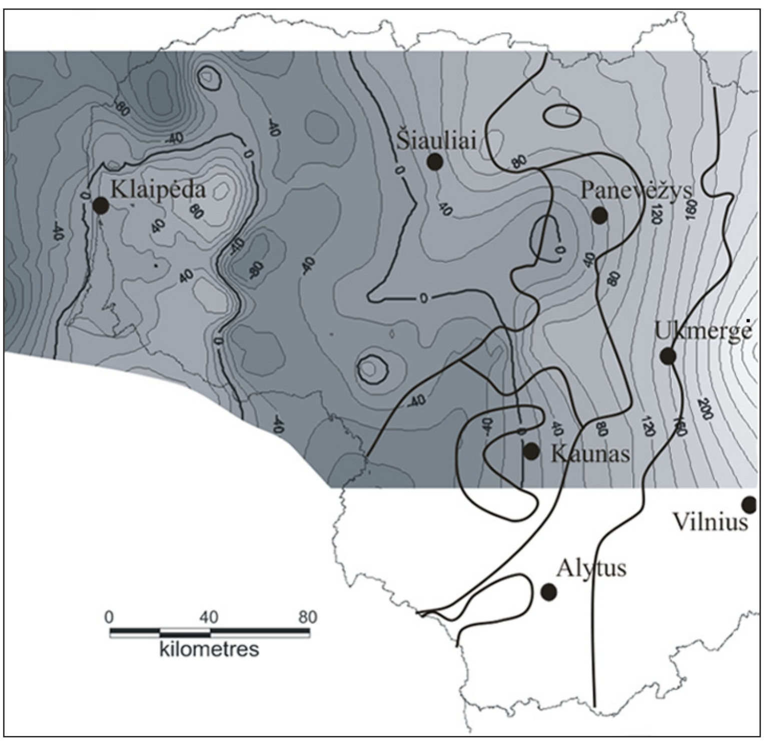

Fig. 10. Map of the first-order residuals of thicknesses of Silurian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

10 pav. Silūro nuogulų storių 1-os eilės liekaninės reikšmės. Paryškinta nulinė storių izolinija. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

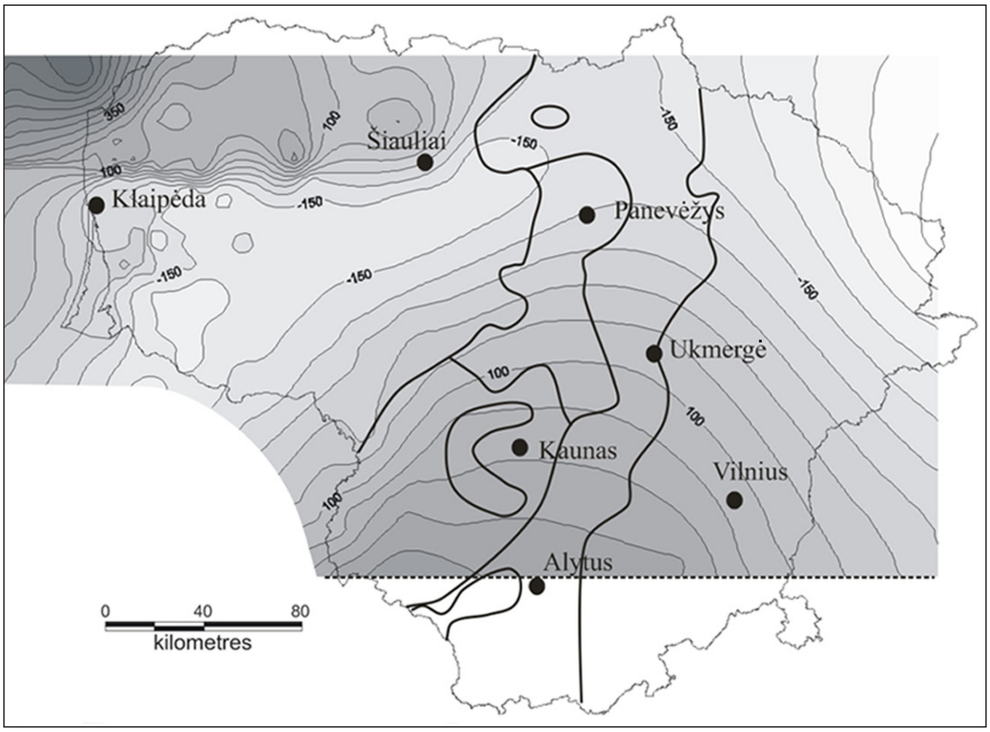

Fig. 11. Map of the first-order residuals of base depths of Silurian. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
11 pav. Silūro nuogulų kraigo gylių 1-os eilės liekaninės anomalijos. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

similarly to that recognised in the Cambrian layer. The amplitude of the uplift is of about 30 m. This event seemingly took place after the Silurian sedimentation and affected the Lower Palaeozoic layers.

The thickness distribution is closely related to the lithofacies variations. The Mid-Lithuanian Suture Zone was the distinct controlling feature during the Early Silurian and lowermost. Comparison of the Mid-Lithuanian Suture Zone to the structural-facies map of Llandovery–Ludlow deposits compiled by Lapinskas (2004) shows that the zone of Sutkai eastern palaeoflexures of the eastern margin of the Baltic palaeosyneclise overlaps this major basement tectonic zone (Fig. 12).

In particular, the Mid-Lithuanian Suture Zone is distinct in the lithhofacies distribution of the Gėluva Regional Stage (Fig. 13). It separates two distinct sedimentation areas, i. e. the deep basin sedimentation in the west and the intertidal deposition in the east. The predominating shales accumulated in the west, while carbonaceous rocks mainly deposited in the east. The latter accumulated in the basin periphery of highly variable environment changing from low- to high-salinity (Lapinskas, 2004). The Mid-Lithuanian Suture Zone is confined to the transition zone dominated by wave activity in the east and storm activity in the west.

A similar facies distribution is defined in the Jaani and Jaagarahu RSts (Figs. 14, 15). Only minor shifts of major lithofacies zones are recognised implying persistence of the sedimentation environment despite of the changing relative sea level (regression). Such persistence is explained by the controlling role of the structural features of the underlying basement.

The lithofacies shifted to the west for about 80 km during the Dubysa time (Gorstian–Lower Ludfordian) (Fig. 16). It was related to progressing regression of the basin. The regression was essentially distinct in the early part of the Dubysa time; the sedimentation limit in the east was confined to the Mid-Lithuanian

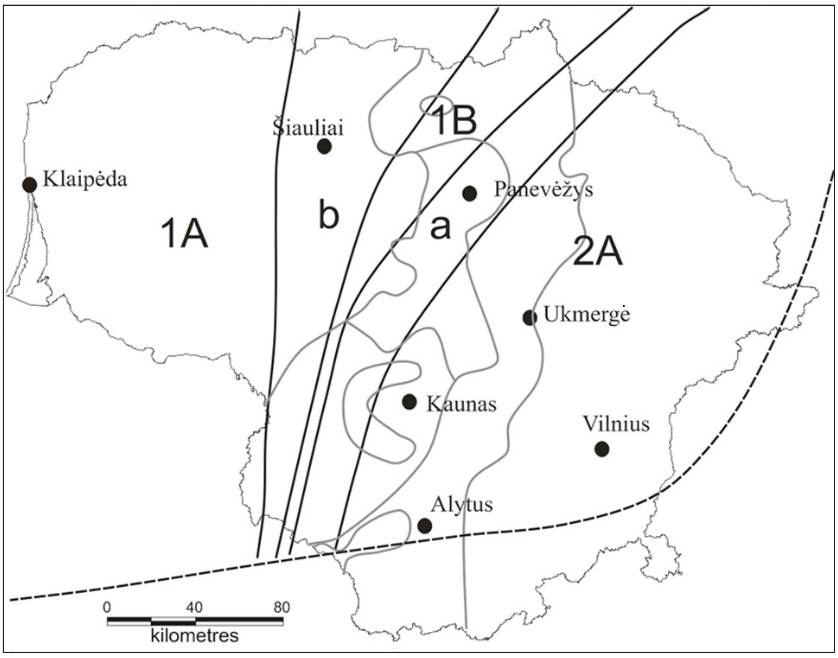

Fig. 12. Llandovery–Ludlow structural-facies distribution (according to Lapinskas, 2004): *1A* – middle marginal region of the south-eastern part of the Baltic palaeosyneclise; *1B* – eastern marginal region of the south-eastern part of the Baltic palaeosyneclise; *a* – zone of Sutkai eastern palaeoflexures; *b* – zone of Sutkai western palaeoflexures; *2A* – north-western slope of the Belarusian–Lithuanian palaeoanticlise. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

12 pav. Landoverio–ludlovio struktūrinės-facinės zonos (Lapinskas, 2004). *1A* – Baltijos paleosineklizės pietrytinės dalies vidurinis periferinis regionas; *1B* – Baltijos paleosineklizės pietrytinės dalies rytinis periferinis regionas; *a* – Sutkų rytinių paleofleksūrų zona; *b* – Sutkų vakarinių paleofleksūrų zona; *2A* – Baltarusijos-Lietuvos paleoanteklizės šiaurės vakarinis šlaitas. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

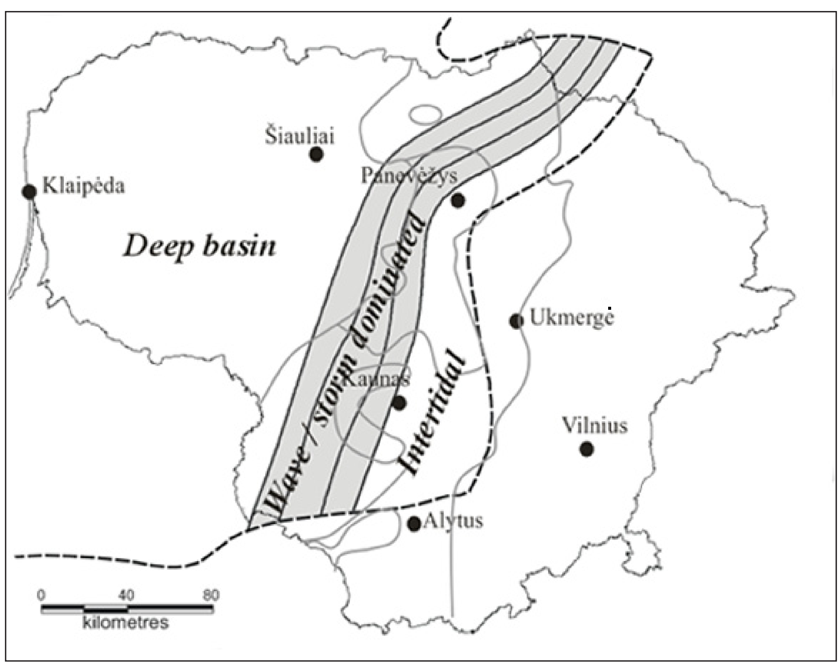

Fig. 13. Lithofacies distribution of the Gėluva RSt of Lower Silurian (Upper Llandovery). Bold lines indicate boundaries of lithofacies zones (after Lapinskas, 2004). Hatchet line shows the distribution limit of deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

13 pav. Apatinio silūro Gėluvos regioninio aukšto (viršutinis landoveris) litofacijos. Storos linijos žymi litofacijų ribas (Lapinskas, 2004), brūkšninė linija – nuogulų paplitimo ribą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

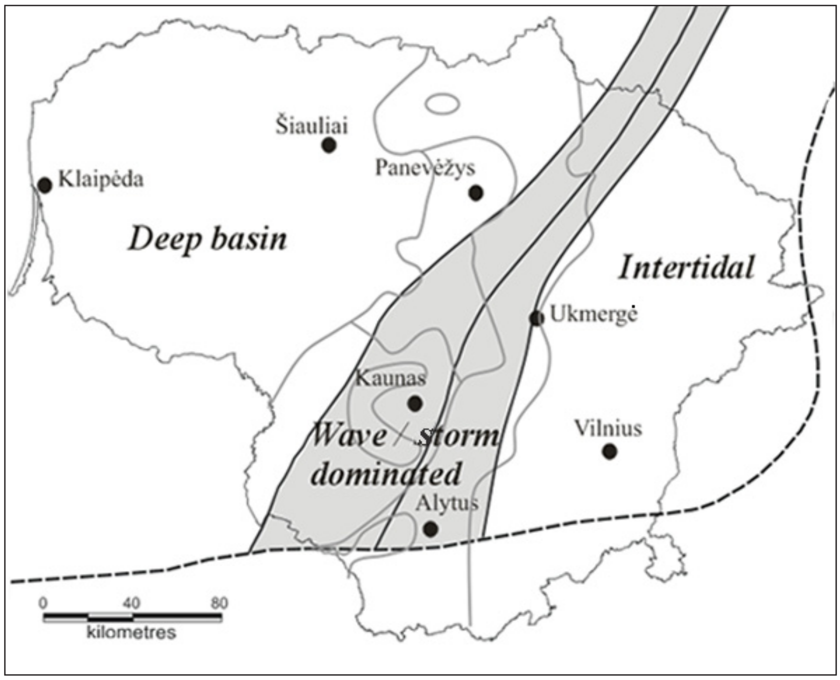

Fig. 14. Lithofacies distribution of the Jaani RSt of Lower Silurian (Lower-Middle Sheinwoodian, Wenlock). Bold lines indicate boundaries of lithofacies zones (after Lapinskas, 2004). Hatchet line shows the distribution limit of deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

14 pav. Apatinio silūro Jaani regioninio aukšto (venlokis) litofacijos. Storos linijos žymi litofacijų ribas (Lapinskas, 2004), brūkšninė linija – nuogulų paplitimo ribą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

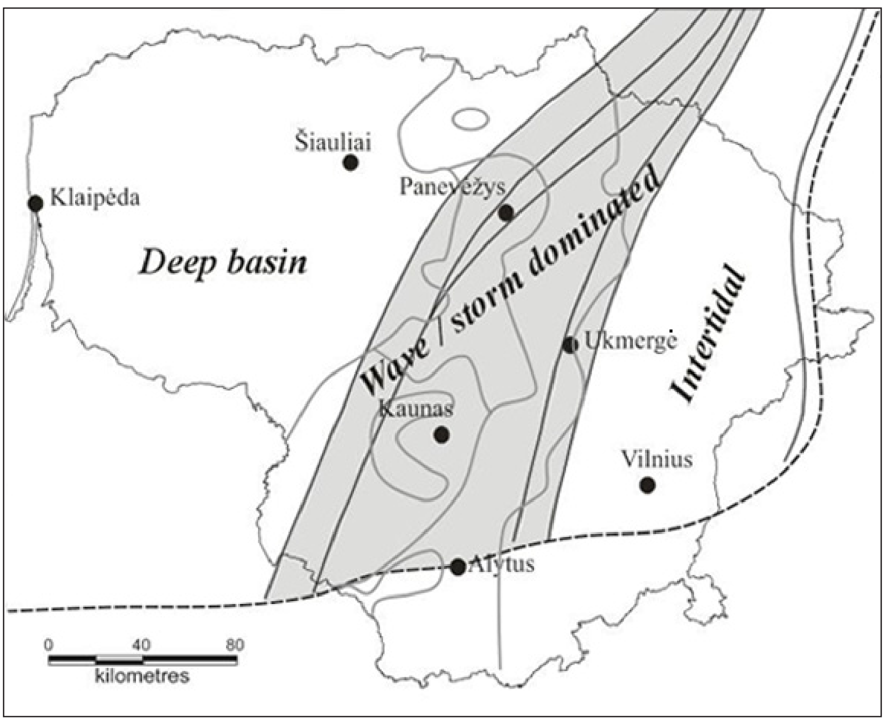

Fig. 15. Lithofacies distribution of the Jaagarahu RSt of Lower Silurian (Upper Sheinwoodian–Lower Homerian, Wenlock). Bold lines indicate boundaries of lithofacies zones (after Lapinskas, 2004). Hatchet line shows the distribution limit of deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

15 pav. Apatinio silūro Jaagarahu regioninio aukšto (venlokis) litofacijos. Storos linijos žymi litofacijų ribas (Lapinskas, 2004), brūkšninė linija – nuogulų paplitimo ribą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

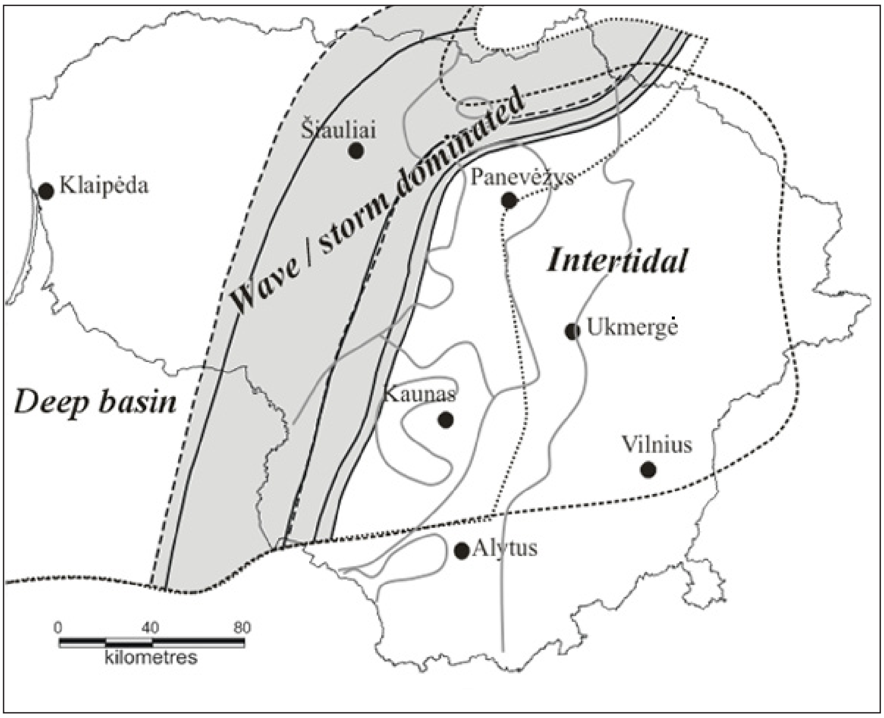

Fig. 16. Lithofacies distribution of the Dubysa RSt of Upper Silurian (Gorstian–Lower Ludfordian). Bold lines indicate boundaries of lithofacies zones of Lower Dubysa RSt, hatchet lines show boundaries of lithofacies zones of Middle Dubysa RSt (after Lapinskas, 2004). Dotted lines delimit the distribution of deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
16 pav. Viršutinio silūro Dubysos regioninio aukšto (gorstis–apatinis ludfordis) litofacijos. Storos linijos žymi litofacijų ribas (Lapinskas, 2004), taškinė linija – nuogulų paplitimo ribą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

Suture Zone. The marine basin expanded again in the latter part of the Dubysa time which, however, little affected the lithofacies boundaries.

The peculiar feature of the Silurian sedimentation of the Baltic basin is the establishment of the NNE–SSW and N–S tending belt of organogenic build-ups, mainly biostromes (Bičkauskas, Molenaar, 2010). It is often referred to as the reefogenic belt. The belt was initiated as early as upper Lower Silurian. It was gradually migrating following the basin regression / transgression trends (Stirpeika, 1999) (Fig. 17). The Gėluva and Dubysa belts are confined to the western periphery of the Mid-Lithuanian Suture Zone. The thickness distribution suggests some hinge zone in this zone that controlled the location of organogenic build-ups. The Pagėgiai and Minija belts are distributed further to the west. It was related to the basin regression.

Devonian

The sedimentation pattern changed dramatically during the Devonian time implying changes in the geodynamic regime. The thickness of the Devonian succession exceeds 1 km in the western part of Lithuania (Paškevičius, 1997). By contrast to the Lower Palaeozoic sedimentation showing deepening of the sedimentation pattern to the west, the Devonian basin can be classified as the centred basin. The lithological variations are rather drastic up the section. The sedimentation environment varied from alluvial / lacustrine to normal marine and lagoonal. The Devonian succession is composed accordingly by sandstones, siltstones, shales, limestones, dolomites, marlstones, gypsum.

The depths of the Devonian layers increase to the west that is, however, the result of mainly the

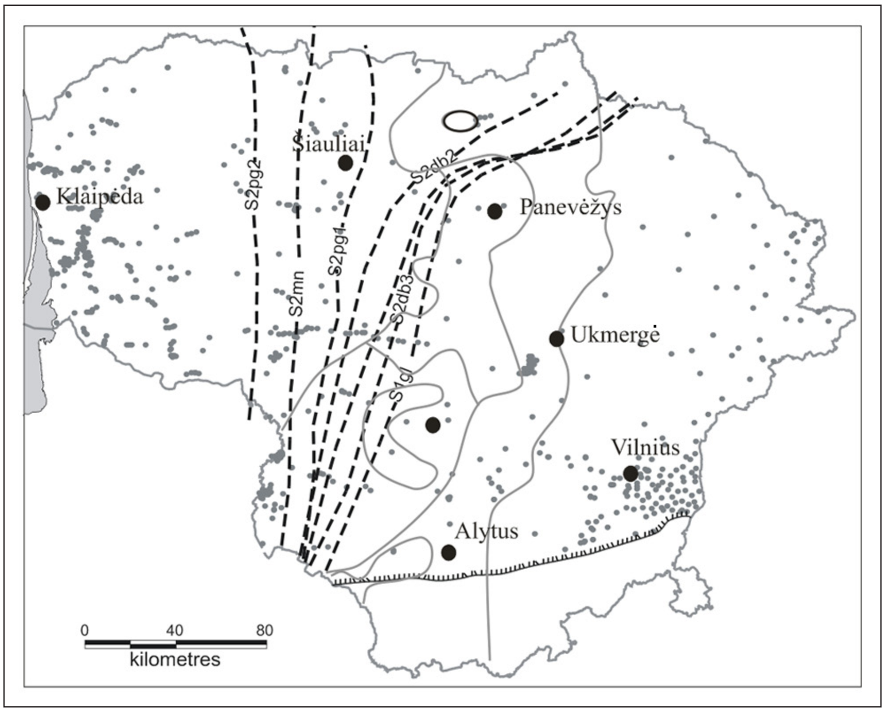

Fig. 17. Distribution of Silurian organic build-up belts (axes of belts are shown). S1g – Gėluva Formation, S2db – Dubysa Formation, S2pg – Pagėgiai Formation, S2mn – Minija Formation. Wells penetrating Silurian deposits are shown. Bergstrich line marks the southern limit of distribution of Silurian deposits. Contours of the Mid-Lithuanian Suture Zone are shown for comparison

17 pav. Silūro rifogeninių darinių paplitimas (parodytos rifogeninių juostų ašys). S1g – Gėluvos svita, S2db – Dubysos svita, S2pg – Pagėgių svita, S2mn – Minijos svita. Taškais pažymėti gręžiniai, įsigilinę į silūro storymę. Dantyta linija žymi silūro nuogulų paplitimą. Šviesiai pilkos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

post-Devonian tectonic processes. The age of the sub-cropping Devonian layers increases to the east due to increasing post-Devonian erosion.

The Narva RSt deposits of 70–140 m thick are the oldest Devonian sediments sub-cropping under the Quaternary cover of Lithuania. Consequently, it is the most widespread layer in the Lithuanian territory (Fig. 18). The succession is composed of the predominating dolomitic marlstones with subordinate dolomite and sandstone inerlayers. The depths of the base of the Narva RSt change from +60 in the east to −850 m in the west. The approach of the local residual anomalies was applied to unravel the local variations in the thickness (Fig. 19). A distinct uplift, clearly related to the Mid-Lithuanian Suture Zone, was identified. The amplitude attains 20–40 m that is close to that defined in the top of Silurian deposits.

Jurassic

The sedimentation pattern changed dramatically after Devonian. A long-termed non-sedimentation environment was established in the Baltic Region from the earliest Carboniferous to the late Early Permian times. The sedimentation conditions were re-established in late Early Permian and expanded in Late Permian. The sedimentation locus shifted to the west showing rearrangement in the basin subsidence pattern. The sedimentation area was distributed in west and south Lithuania and further southwest. Therefore there is a lack of geological evidences on the tectonic activity of the Mid-Lithuanian Suture Zone during the post-Devonian time.

However, some influence of the zone can be suggested from the pattern of the Jurassic sediments (Fig. 20). The western boundary of the Jurassic

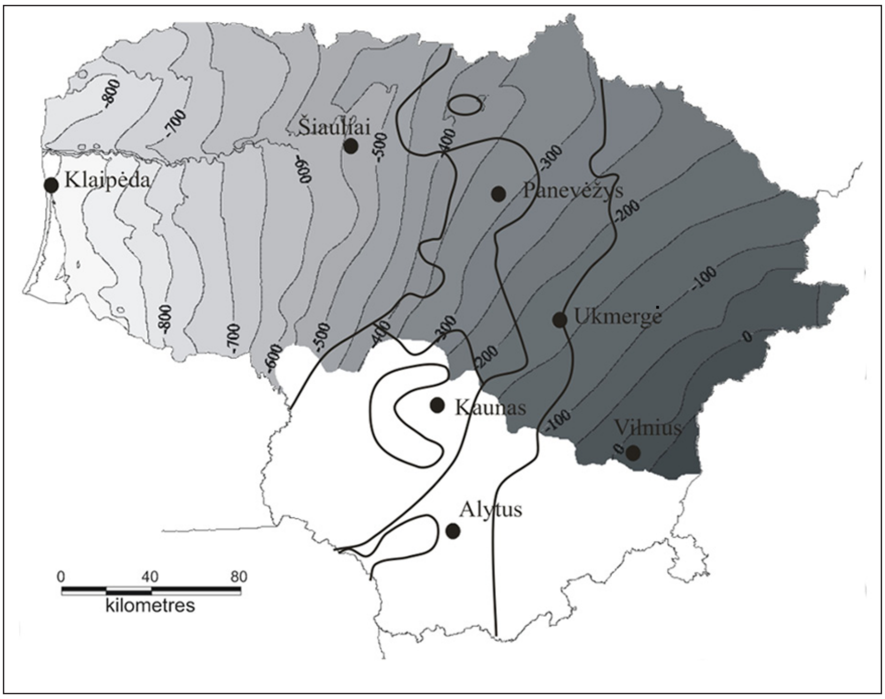

Fig. 18. Base depths of Narva Regional Stage of Middle Devonian. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
18 pav. Narvos regioninio aukšto pado gyliai. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

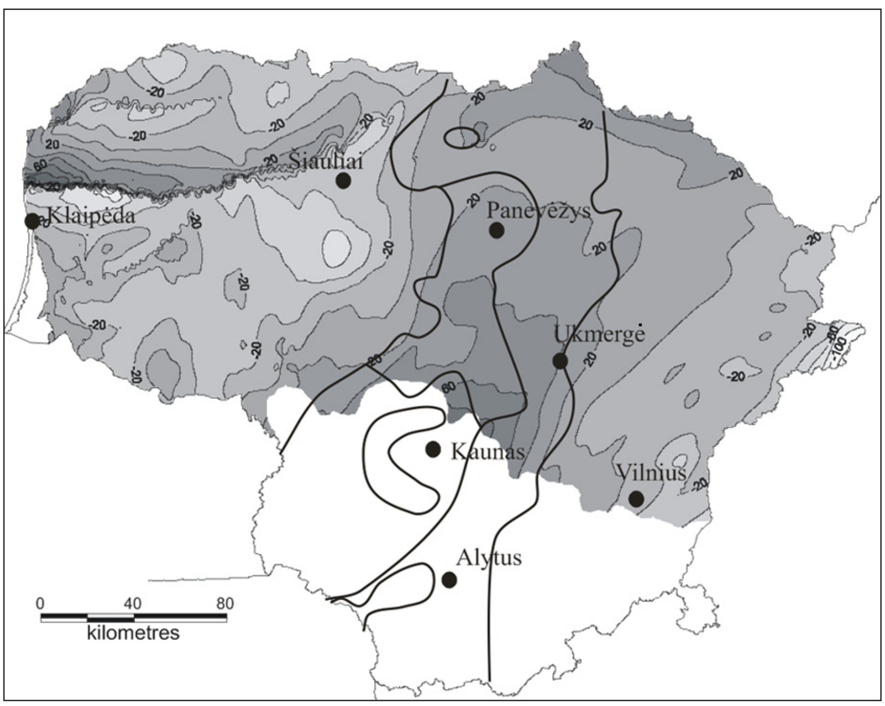

Fig. 19. Map of the second-order residuals for base depths of Narva Regional Stage of Middle Devonian. Contours of the Mid-Lithuanian Suture Zone are shown for comparison
19 pav. Narvos regioninio aukšto pado gylių 2-os eilės liekaninės anomalijos. Storos linijos žymi Vidurio Lietuvos sandūros zonos geologines ribas

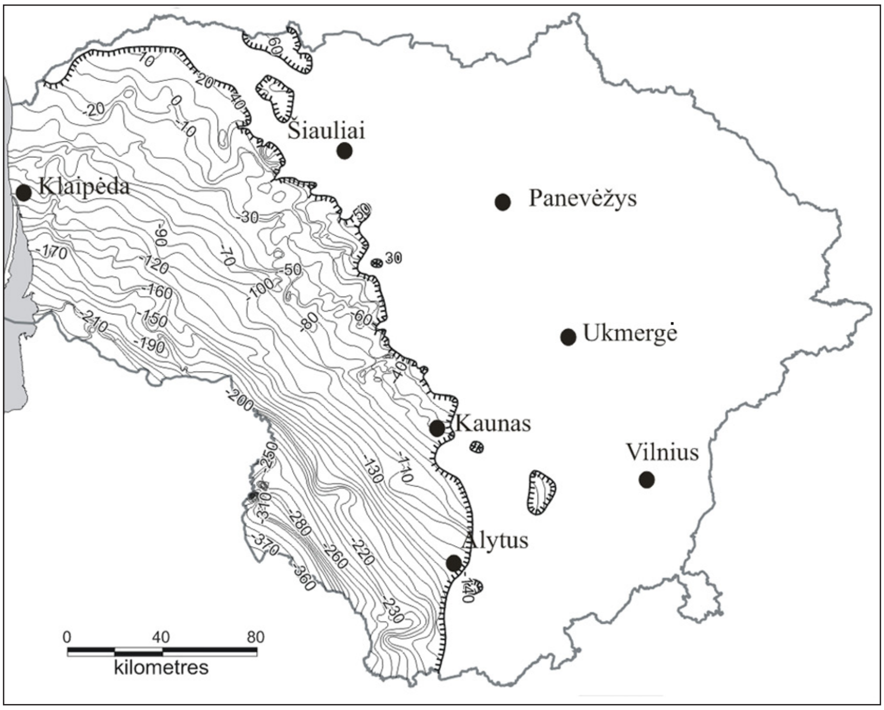

Fig. 20. Depths of the bottom of Jurassic deposits. Bergstrich line marks the limit of distribution of Jurassic deposits
20 pav. Juros nuogulų pado gyliai. Dantyta linija žymi nuogulų paplitimą

deposits is confined to the Mid-Lithuanian Suture Zone. Only local remnants of Jurassic deposits were identified east of the zone. It suggests the relative uplift of the region east of the Mid-Lithuanian Suture Zone.

DISCUSSIONS AND CONCLUSIONS

The Mid-Lithuanian Suture Zone represents the first-order tectonic structure defined in the crystalline basement of Lithuania. It crosses the whole territory of Lithuania from SSW to NNE. The zone is as old as the Palaeoproterozoic.

The vast basin sedimentation was established after more than 1 Ga years break and persisted from Late Vendian to Quaternary. The geodynamic conditions were rather different during different geological periods. Accordingly, the structural pattern of the basin varied significantly.

Despite of the varying tectonic situation, the ancient Mid-Lithuanian Suture Zone shows a persistent impact on the sedimentation pattern and structuring of the overlying sedimentary cover. This influence is well traced in the distribution of the Upper Vendian deposits, the western boundary of which is confined to the Mid-Lithuanian Suture Zone implying the subsidence trend east of the zone and erosion of the crystalline basement lithologies exposed on the surface in the west. This trend persisted until the earliest Early Cambrian, the zone limiting extension of the Moscow marine basin transgressing from the east.

The sedimentation pattern dramatically changed in the middle Early Cambrian time showing the transgression of the newly established marine basin from the west which implies dramatic rearrangement of the geodynamic situation. Analysis of the thickness distribution of the trilobitic Cambrian deposits indicates, however, the preservation of the controlling role of the Mid-Lithuanian Suture Zone on the local sedimentation variations. The zone is marked by the distinct depression characterised by increased thicknesses. Furthermore, it controlled the distribution of the lithofacies distribution, also the extent of the marine sedimentation during the Middle Cambrian.

Some changes are recognised in the structural pattern during the Ordovician that reflect the changed tectonic situation (lithosphere buckling?). The southern part of the Mid-Lithuanian Suture Zone preserved the subsidence trend inherited since the Cambrian, while the northern part is not discernible in the thickness variations. It can be related to different orientation of the southern and northern parts of the Mid-Lithuanian Suture Zone with respect to the affecting tectonic forces.

The dramatically increased subsidence and associated sedimentation rates mark the flexuring stage of the Baltic Basin evolution, different from the passive margin setting during the Cambrian–Ordovician. The Mid-Lithuanian Suture Zone is, however, well defined in the lithofacies and thickness distribution. It is marked by the transition zone from deep basin facies in the west to inner shelf shallow sedimentation in the east.

The Mid-Lithuanian Suture Zone is not identified as the controlling feature in the Devonian sediments, i.e. neither thickness nor lithofacies variations unravel this zone. However, the Mid-Lithuanian Suture Zone is very well defined in the map of local structures. Application of the method of local residuals unravelled the local uplift confined to the zone. It likely suggests the post-Devonian formation of the Middle Lithuanian uplift. Furthermore, this uplift is very well traced in the Cambrian and Silurian layers. The amplitudes of the uplift are compatible for Cambrian, Silurian, and Devonian successions that point to the post-Devonian age of this structural feature.

The later history of the Middle Lithuanian uplift cannot be restored due to absence of younger sediments straggling along the Mid-Lithuanian Suture Zone. The distribution of the Jurassic sediments makes a hint to persisting activity of the zone.

Based on the evidences provided above, it is implied that the Mid-Lithuanian Suture Zone represents the important feature of the Earth's crust with specific mechanical properties that resulted in persistent activity under changing tectonic forces.

ACKNOWLEDGMENTS

The study was supported by the Lithuanian Science Board (Project No. MIP 11319).

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PALEOPROTEROZOJAUS VIDURIO LIETUVOS SANDŪROS ZONOS ATSPINDYS NUOSĖDINĖJE STORYMĖJE

Santrauka

Vidurio Lietuvos sandūros zona yra stambiausia tektoninė struktūra Lietuvos kristalinio pamato sandaroje. Ši zona, susiformavusi paleoproterozojaus metu, kerta visą Lietuvos teritoriją ŠŠR–PPV kryptimi.

Platforminė sedimentacija Baltijos regione prasidėjo vendo metu ir tęsėsi iki kvartero. Per ilgą laikotarpį ne kartą keitėsi Baltijos sedimentacinio baseino geodinaminė padėtis, taigi kito ir regiono tektoninis-struktūrinis planas.

Nors tektoninė aplinka buvo kaiti, Vidurio Lietuvos sandūros zona pasižymėjo gana pastoviu aktyvumu – darė įtaką nuosėdinės dangos formavimuisi Lietuvoje. Tą rodo vendo ir ankstyviausio kambro nuogulų paplitimas – sedimentacijos arealą vakaruose apribojo Vidurio Lietuvos sandūros zonos. Vakariau vyko kristalinio pamato denudacija, terigeninė medžiaga buvo pernešama į ryčiau esančią Maskvos jūrą.

Struktūrinis planas labai pasikeitė ankstyvojo kambro viduryje. Naujai besiformuojanti Baltijos jūra transgresavo iš vakarų, kur jungėsi su besiplečiančiu Tornkvisto vandenynu. Vidurio Lietuvos sandūros zona kontroliavo tektoninį įlinkį, ji yra ryški žvelgiant į litofacijų pasiskirstymą. Sandūros zonos poveikis nustatytas ir ordoviko bei silūro sedimentacijos procesams.

Struktūrinė analizė rodo, kad po devono periodo Vidurio Lietuvos sandūros zona patyrė santykinį pakilimą, kuris gerai matyti apatinio paleozojaus sluoksniuose.

Zonos raidos istorija po devono nėra aiški, kadangi jaunesnės uolienos daugiausia paplitusios vakariau Vidurio Lietuvos sandūros zonos, išskyrus Pietų Lietuvos teritoriją. Juros nuogulų paplitimas leidžia spėti besitęsiantį zonos tektoninį aktyvumą ir mezozojaus metu.

Atlikta analizė leidžia daryti išvadą, kad Vidurio Lietuvos sandūros zona pasireiškė kaip svarbi kontroliuojanti struktūra nuosėdinės storymės vystymosi metu. Tai gali būti siejama su jos specifinėmis mechaninėmis savybėmis, lėmusiomis didesnį jos aktyvumą veikiant tektoninėms jėgoms.

Raktažodžiai: sandūros zona, tektoninė struktūra, Baltijos regionas, paleozojus, paleoproterozojus, sedimentacinis baseinas