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Geology program

Master's Thesis

Analysis of the subsidence trends in the central part of the Baltic basin (Lithuania)

Baltijos nuosėdinio baseino centrinės dalies (Lietuvos teritorijos) grimzdimo analizė

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TABLE OF CONTENTS

Introduction

Sedimentary basins are regions formed due to tectonically induced long-term subsidence of the Earth‘s surface in which sediments accumulate to considerable thickness and be preserved for relatively long geological time period (Allen and Allen, 2013).

Sediments and sedimentary rocks provide not only one of the critical interface of the geosphere with the biosphere and the anthroposphere but also provide large parts of major natural ressources such as groundwater and hydrocarbon (Eun Young Lee et la., 2018).

Subsidence histories are results of isostatic adjustment to lithospheric processes, including thermal events, thickness changes, and loading history, ending to provide insights into basin-forming mechanisms (Kusznir and Ziegler, 1992).

The previous studies on the Baltic basin especially the Paleozoic part, have proven basin’s subsidence history to be a long process throughout the whole Paleozoic, making it a unique geological feature (Poprawa et. al., 1999).

The tectonic setting and basin subsidence history driving forces of the Baltic basin has changed in time providing possibility to follow the evolution of the basin from the post-rifted passive margin and convergent continental margin to intracontinental basin showing unstable subsidence and changing geometry (Poprawa et al., 1999).

The Baltic basin during Ordovician period was considered superimposed by long – wave lithospheric folding (Poprawa et al., 1997). The late Ordovician – Silurian ended as an overfilling of the foreland basin during Early Devonian (Poprawa et al., 1997), with basin flexuring governed by dynamic and orogenic loadings. Uplift was observed during Carboniferous Early Permian due to thermal doming and dynamic response of the weak lithosphere to the compression, and Late Permian – Jurassic subsidence is related to the thermal sag, extension and loading (Poprawa et al., 1999). During Late Cretaceous, the tectonics were inversed related to the compressional regime (Šliaupa, 1997).

At the end of Cretaceous the orientation of the basin was westward. The sedimentation was confined mainly to the Mazury-Belarus anteclyse zone. Some fault reactivation was noted in south-western Lithuania between the Paleogene and Eocene with amplitude reaching 50 m of some west-east striking faults (Šliaupa, 1997).

Although the geodynamic stages of the Baltic basin evolution have been established decades ego, more detail studies were requested as the subsidence modelling and analysis has not been carried out in the Baltic basin for several years. The new data and hypothesis have been established that are valuable for interpretation of the input parameters for the subsidence modelling in order to test the importance for the input factors for the reconstruction of the basin subsidence in time.

The major aim of the thesis is to reconstruct the subsidence trends by adopting backstripping methodology and analyses of subsidence curves of the central part of the Baltic basin (Territory of Lithuania) to reveal the basin's geodynamic evolution.

The tasks of this master thesis are to:

1) To understand the overall backstripping modelling methodology;
   1D backstripping modelling procedures;
2) Collect and prepare the required well data for the backstripping and subsidence curves compilation, and to prepare the input files;
3) Create subsidence curves, to visualize and interpret obtained numerical backstripping results;
4) Analyze the obtained subsidence results while paying attention to the major subsidence trends both in selected wells and laterally;
5) Interpret the distinguished subsidence trends within the general context of the geodynamic evolution of the Baltic basin.

Relevance of the study. The carried out basin subsidence studies provided new numerical data that might help to better understand the relationship between the tectonic and sedimentation patterns, sediment provenance characterization through the Phanerozoic period in the basin evolution.

Research methods. This research was carried out on the basis of actual reference wells; and literature data by applying the backstripping modelling techniques and methodology.

The numerical 1D open source backstripping software Pybacktrack was selected to carry out the research of this master thesis with the help of the consultant assoc. prof. dr. Audrius Čečys. 2 wells have been selected for the test runs, input files have been prepared from the actual well data, the backstripping with Pybacktrack have been conducted and the subsidence curves compiled for the calculations‘ results.

The major input data for compilation of subsidence curves for 9 wells already calculated by BackPc software have been provided by the supervisor of the present scientific research work. Furtheremore, input files have been created based on actual geological and stratigraphycal data. The selected wells (with the help of the supervisor) cover the lateral extension of the basin from the deepest Baltic sea offshore part to the eastern part (territory of Lithuania), and located in different structural and lithofacial zones (figure 7).

The analysis of the backstripping results helped to reveal mechanisms of the basin subsidence and changes in sedimentation during different geological periods of basin evolution.

1. GEOLOGICAL SETTING

1.1 Geological and tectonic setting of the Baltic Basin

The plate tectonic model states that for the creation of ocean crust, hot asthenosphere material is emplaced at the spreading center and later accreted to the plates at either side of the ocean ridges in a process known as sea-floor spreading. As the plates move away from ocean ridges, thermal contraction of the newly formed oceanic plates increases its density and thickness to result in passive isostatic subsidence and formation of oceanic basins (Turcotte and Ahern, 1977). The tectonic evolution of the Baltic basin dated back in the Phanerozoic Eon and had gone a long time multi-stage basin geometrically characterized by NE-SW elongation of the main depocentre (Poprawa et al., 1999). The Baltic Depression is encountered between different distinctible zone known as Fennoscandian Shield in the north part and Mazury - Belarussian Anteclise (figure 1) in the South and South East. The basin fill is characterized by the Riphean-Vendian sediment, with thickness ranging from 200 m in the East to 3.5 km in the West. The lithological composition is dated from the Paleozoic Era and indicates the subsidence stage of the depression since Cambrian until Devonian time. The Carboniferous sediments represent much more less thickness, while no sediment was observed during the latest Paleozoic throughout Cenozoic Era interupted by shorter sedimentation events (Poprawa et al., 1999).

The subsidence history is affected by two main factors encountered in the Baltic basin:

the geographical location of the basin close to the craton margin and some specific mechanical properties of the lithosphere (Poprawa et al., 1999).

As the basin is in marginal emplacement, it was more intensely affected by processes originated in the adjacent active zones along the plate margins, essentially during the Paleozoic time. The mechanical structure of the lithosphere of the Baltic basin had been the second notable parameter. The shape of the basin in the Precambrian accretional belts shows the center of the basin overlying the weakest West Lithuanian Granulite (WGL) encountered by East Lithuanian Belts (ELB), Belarus-Baltic Granulite Belts (BBGB), etc (Poprawa et al., 1999).

Figure 1: The tectonic structure of the Baltic region and adjacent territories. TTZ – Teisseyre–Tornquist zone, KDF – Caledonian deformation front, dotted line – the boundary of the distribution of Silurian strata, bold dotted line – limits of distribution of Caledonian, Hercynian and Alpine complexes (after Poprawa et a., 1999).

1.1.1 Geological structure and stratigraphy of the study area

The Basin is comprised of Phanerozoic sedimentary rocks that cover the south-western part of the East European Craton.

Cambrian rocks occurred almost in the entire area of the East Baltic region, with exception given to some local positive structures (Paškevičius, 1997). Most complete beds (from a stratigraphic point of view) of Lower Cambrian occurred in the eastern Lithuania (Paškevičius, 1997).

Principles of zonation for the Ordovician are based on regularities in rock composition changes, composition of fossils, changes in deposit thickness, stratigraphical fullness of geological section, and stratigraphical gaps and breaks (Paškevičius, 1997). The Middle Ordovician started from the Upper Lianvirn subseries which is correlated to the Aseri Regional Stage (Paškevičius, 1997). The lithological composition of this stage is coloured organogenous limestone, and also red marl interlayers. In the Lithuanian-Latvian monocline, the formation thickness attains 1.5 – 3.7 m, increasing in the Livonian zone to 7.7 m. Grey limestones were found in the Lithuanian-Belarus monocline, where also it was demonstrated the presence of organisms such as cephalopods, ostracods and trilobites (Paškevičius, 1997).

The Lasnamagi Regional Stage coincides with the Vyžūnai Formation which is believed to contain variegated limestone. The lower part of the formation and boundary of the regional stage are marked by a sedimentary break surface, above which there are brachiopods, cephalopods, trilobites and graptolites found (Paškevičius, 1997).

In the Eastern part of the Baltic, the Llandeilo Series is composed of two regional stages: The Uhaku Regional Stage and the Kukruse Regional Stage (Paškevičius, 1997).

The Uhuku stage in the Lithuanian zone is composed of grey organogenous-detritic limestone with greenish grey detritic with marl interlayers, and dark grey organogenous detritus limestone with dark grey and greenish grey marl interlayers (Paškevičius, 1997).

The Kukruse Regional Stages is represented by Kriaunos Formation in the Lithuanian zone, and composed of grey organogenous detritus limestone with dark marl interlayer (Paškevičius, 1997).

During Tremadoc, the Baltic Sea had gone transgression spreading almost across the entire basin, and then ended up in marine regression. Consequently, the basin was filled with much sand and clayey facies occurred (Paškevičius, 1997).

The end of Tremadoc Epoch has seen a rising of the sea shore with aerobic condition occurring which led to the formation of red colour clay sediments (Paškevičius, 1997).

During Silurian period, the subsidence evolution is seen to be gradual which makes the appearance of subsidence a convex type of curve, confirming a foreland basin development.

The rate of Late Silurian tectonic subsidence increases towards the southwest margin of the Baltic basin and is seen to be adjacent to the present location of the North German-Polish Caledonides (Šliaupa et al., 2006. The Silurian period is also marked the development of Baltic Syneclise the majore tectonic element of the basin, with occurrence of clay facies, and also presence of carbonaceous facies.

The Baltic Syneclise development during Silurian started from the lower Llandovery limestone complex attaining 40 m in thickness with Llandovery, Wenlock and Ludlow black argillite and dark clay and marl deposits (Paškevičius, 1997).

The Baltic Syneclise contains the thickest Silurian beds and stratigraphically most complete geological section form beginning of Llandovery to the end of Pridoli (Paškevičius, 1997).

The lithological composition of Llandovery and Wenlock in the Belarus-Mazurian Anteclise (figure 1) seems similar and composed of limestone, marl, dolomitic limestone, marl and dolomite rocks with interlayers and nests of gypsum. As for Ludlow, it is composed of limestone and dolomite, whereas it is found dolomite, marl and clay rocks in Pridoli.

Stratigraphy and correlation of Devonian beds is based on the investigation of rather varying, from a facial point of view, lithological complexes, analysis of their logging curves, research of the fauna such as brachiopods, bivalves, etc). Continental lagoon Old-Red facies prevailed in the Lower Devonian in the Eastern Baltic Basin. Compared to the Lower Devonian, the Middle Devonian has seen much more bed rocks, while in the Upper Devonian some specific Old – Red facies with two vertebrate fauna zones were discovered called Asterolepis ornate in the lower Frasnian (Paškevičius, 1990). Rocks attributed to the Carboniferous are distributed at the western border between Lithuania and Latvia and make up a relictic sublatitudinal Baltic depression (Paškevičius, 1997).

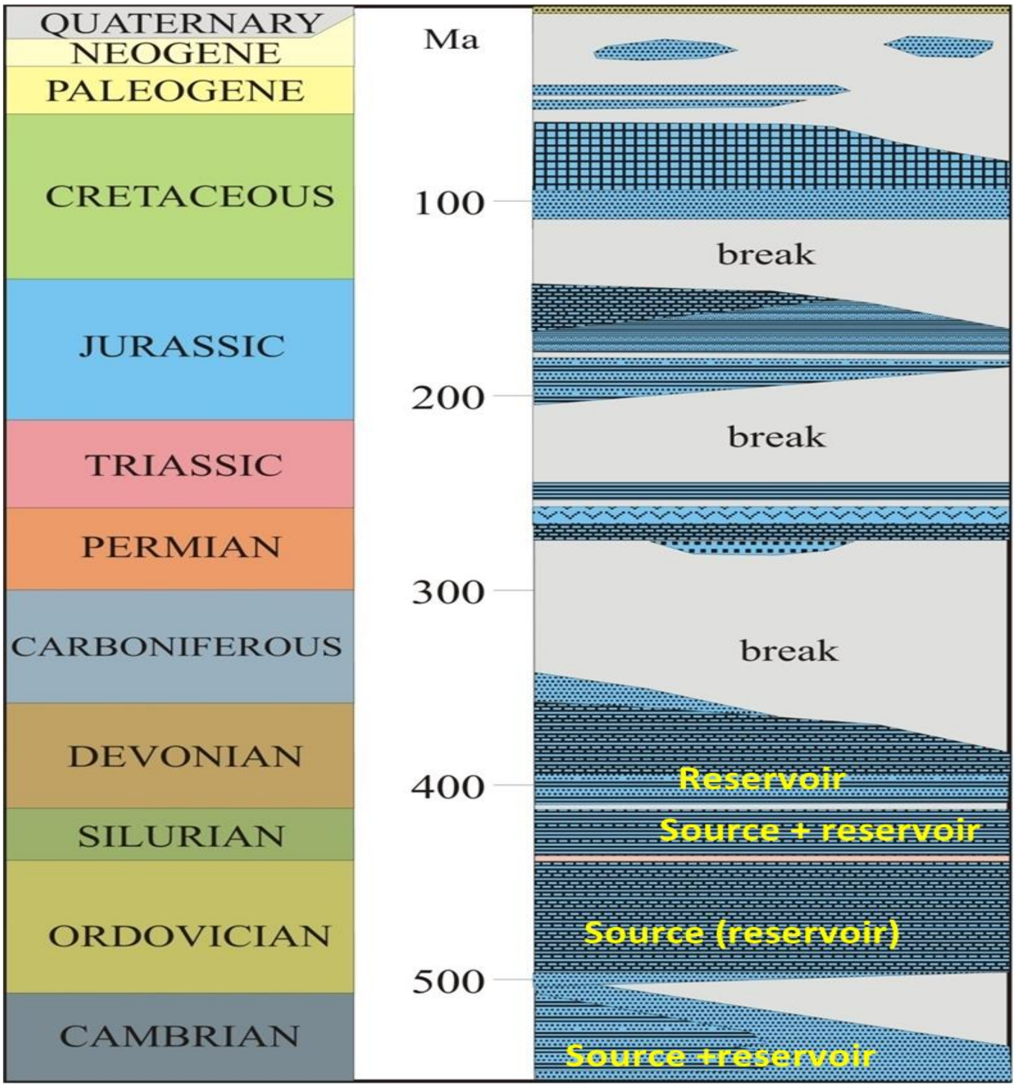

Fig.2: Stratigraphic chart of the Baltic region (after Paškevičius, 1997).

Upper Permian rocks are distributed in the Polish – Lithuania depression and on the slope of the Belarus – Mazurian Anteclise. The rocks were formed from terrigenous, Carbonaceous, sulphatic and halogenic sediments in the former marine – lagoon basin of west Europe and East Baltic area (Paškevičius, 1997).

The Triassic rocks are distributed in the Polish – Lithuanian Depression and Belarus – Mazurian Anteclise slope with structural tectonic plan resembling of that of the Permian period. Also, as for Jurassic sediments, they are mostly composed of sandy clayey continental and sub-continental (Paškevičius, 1997).

Cretaceous sediments were deposited in the southern part of the Polish-Lithuanian Depression or Lithuanian Belarussian Monoclise (Paškevičius, 1997).

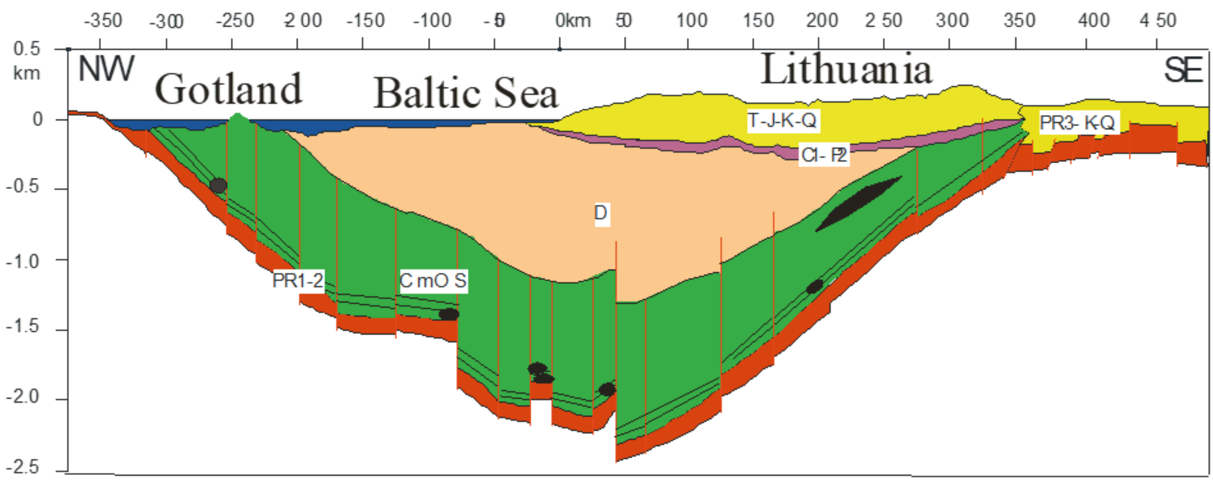

Figure 3: Geological cross-sections through the Baltic Basin (Stephenson, R., A., Šliaupa, S., Skridaite, G., Beekman, F., 1997. Lithosphere rheology along Eurobridge: what are the geoldynamic implications. EUROBRIDGE Meeting Book of Abstracts, Vilnius, P. 78-79).

1.1.2 Geodynamic evolution of the Baltic basin

The Baltic basin originated on the southwestern margin of the East European Craton as part of a marginal sedimentary basin system during the Early Palaeozoic (Poprawa et al., 1999). Initially it was established as a passive continental margin basin during latest Ediacaran-Early Cambrian times in response to the breaking apart of the Rodinia supercontinent (Šliaupa et al., 1997).

The subsidence history during Cambrian shows a basin in extensional regime with sedimentation taking place, and thermal loading. This time was associated with post-rifting stage which consequently explains the sedimentation processes. The extension of the basin created a considerable shift in the widening of the weak lithosphere which all together with the continuing subsidence resulted in the formation of the Baltic basin (Šliaupa et al., 1997).

The Cambrian-Middle Ordovician passive-margin setting changed to that of a convergent continental margin during the Late Ordovician-Silurian (Šliaupa et al., 1997; Poprawa et al. 1999). Both geodynamic constraints and lithofacies analysis suggest that there was a close relationship between the basin fill processes in the Silurian foreland basin and tectonic activity in the Caledonian orogenic belts (Poprawa et al., 1999).

It was observed that during Devonian period the sediments in the western Baltic basin are missing while the the Silurian deposits are increasingly eroded in the west too (Šliaupa et al., 1997). This was accounted to the isostatic rebound of the western margin of the plate after the orogenic processes as it was indicated by 2D modelling (Šliaupa et al., 1997).

During early Carboniferous – Permian period, a regression of the basin was noted in the latter parrt of Famennian time. The western and southern parts of the basin were high uplifted. The Lower Carboniferous sediments are only restricted to the south-western Latvia and north-western Lithuania (with some continuation offshore in the west). Their thickness did not exceed 100 m and are composed by triple alternation of sandy, clayey and carbonaceous layers. In general, the Carboniferous age of those sediments are still debatable (Šliaupa et al., 1997).

A comparison of the Upper Permian structures to that of the underlying Devonian indicates tectonic inversion. This led to sometimes confusing relationship of the Devonian and Upper Permian structures, the former showing less amplitudes compared to the overlying Permian sediments (Šliaupa et al., 1997).

During Triassic, some faults activity was recognized. The Vilkaviškis-Vilnius fault oriented from west to east is one of the most striking characteristic showing vertical offset of 60 – 80 m relating to different truncation of the Upper part of the Triassic succession suggesting the main tectonic activity took place after the Lower Triassic sedimentation (Šliaupa et al., 1997).

During Jurassic the subsidence rate decreased, while the basin was widening to the east. It showed transgression during the Callovian and Oxfordian (Šliaupa et al., 1997).

The non sediementation conditions were observed in the Baltic basin during Late Jurassic – Early Cretaceous that lasted for 50 Ma. The basin regression was of eustatic nature mainly , and the sedimentation was confined to the Polish and Danish troughs in the west (Šliaupa et al., 1997). The basin was in tilted stage during Quaternary with the shape similar to that of Upper – Permian Jurassic, showing distinct tilting to the south-west (Šliaupa et al., 1997).

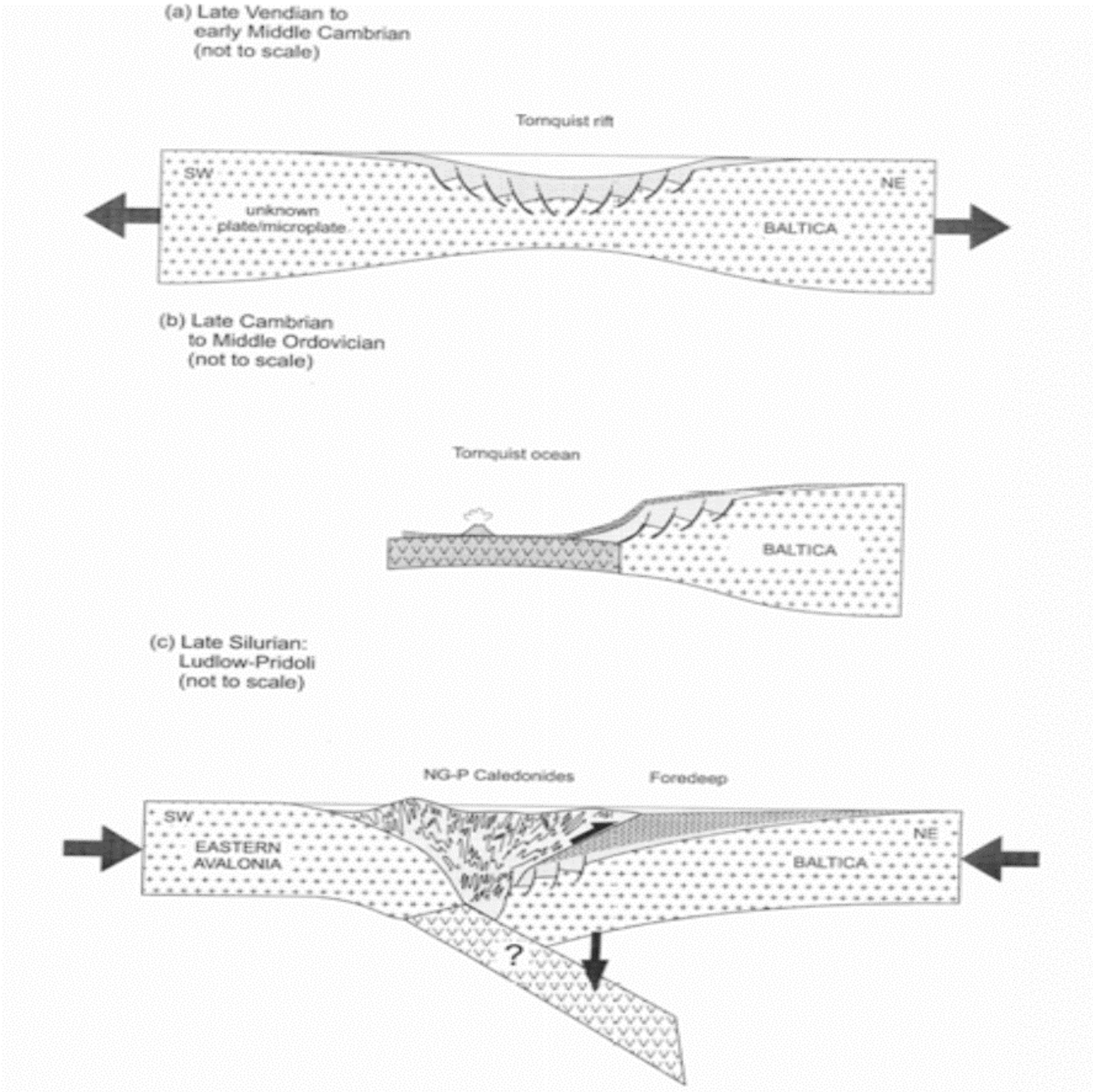

Figure 4: Cartoons showing the interpreted geotectonic evolution of the Baltic Basin in (a) Late Vendian to earliest Cambrian, active extension/rifting along the axis of the future Tornquist Sea; (b) Late Cambrian to Middle Ordovician passive margin setting evolution (Poprawa et al., 1999).

1.2 The overview of the previous studies

The previous study of the Baltic basin evolution based on 1D subsidence modelling has revealed that the Baltic basin originated as a passive continental margin in the Late Ediacaran – Cambrian times owing to the breaking apart of Rodinia supercontinent (Šliaupa et al., 1997; Poprawa et al., 1999).

Details analysis of the changing geometry and variations in subsidence have been informative in reconstructing the process of the Baltic basin. Moreover, it was established that, the Cambrian subsidence of the Baltic basin list the extension, sedimentary and thermal loading. The changing geometry has impacted the Cambrian Baltic basin evolution making it unstable (Šliaupa et al., 1997). The tectonic subsidence rates were high in the Peri-Tronquist Zone, in the range 20-35 m MYr, and were maintained until the lower part of Middle Cambrian, and then decreased until the Middle Ordovician.

Based on backstripping modelling, it was identified the possibility of two separate basin – forming events:

The possible first event which started in Ediacaran until the Early Cambrian is characterized by a period of rapid subsidence followed by decreasing subsidence rates during the Late Early Cambrian, and was accompanied by the transgression of the basin throughout the area of the present Baltic Sea, encompassing the Baltic States, Northern Poland and SE Sweden (Poprawa et al., 1999).

The second event of the Ediacaran to Early Middle Cambrian subsidence phase began during the Early Middle Cambrian, along the Peri-Tronquist zone and the central part of Baltic Depression, with a high tectonic subsidence (Poprawa et al. 1999).

The 1 D subsidence modelling had revealed that Baltic basin originated initially as a passive continental margin in the late Ediacaran- Cambrian times owing to the breaking apart of Rodinia supercontinent (Šliaupa et al., 1997; Poprawa et al., 1999). Details analysis of the changing geometry and variations in subsidence have been informative in reconstructing the process of the Baltic basin. Moreover, it was established that, the Cambrian subsidence of the Baltic basin list the extension, sedimentary and thermal loading. The changing geodynamic regime has impacted the Cambrian Baltic basin evolution making it unstable (Poprawa et al., 1999).

During Ordovician, the subsidence slowed down typically by the later part of the passive continental margin stage. It was observed that the Ordovician Baltic basin was a system of long wavelengh sub-basins-oriented ENE – WSW, a possible explanation of such feature being lithospheric folding, the orientation of structures implying NW-SW tectonic compression that points to far-field stress (Poprawa et al., 1999).

The later part of Ordovician up to Llandovery was characterized by a gradual increase in subsidence driven by incipient flexuring of the plate margin in the west. Moreover, some inversions were observed during the early Silurian that suggest decrease in the tectonic stress. Late Llandovery was characterized by maximum transgression of the basin in the eastern part. The subsidence rate shows gradual increase from the Early Silurian times that climaxed during the Pridoli (Figure 5). Furthermore, in the Wenlock – Middle Ludlow, a gradual increase of subsidence was noted which was compensated by growing influx of terrigens to the basin from the western provenance (Poprawa et al., 1999). The basin regressed during the Early Devonian times, shown by considerable decrease of subsidence, given the basin the nature of an overfilled foreland basin stage during the Early Devonian. The sedimentation changed shaly-sandy during the times period (Šliaupa et al., 1997)).

During the Carboniferous, a new transgression took place in the east, from the progressing Moscow basin, while the western part of the basin was uplifted. The deposition pattern changed drastically, and most of the basin territory was uplifted above the sea level (Šliaupa et al., 1997).

The Permian period was characterized by regression of the Baltic basin especially during the Late Permian, with a wide spreading of Vera cycle deposits (Šliaupa et al., 1997).

The sedimentation renewed during the Early Triassic in the Baltic basin, given the basin a similar shape to that of Upper Permian time indicating the same geodynamic conditions (Poprawa, 1999).

In the Jurassic, significant changes were observed during the Bathonian time, with decreasing subsidence rate, whereas the basin started to widen in the east, showing transgression during the Callovian and Oxfordian.

The shape of the Cretaceous – Paleogene Baltic basin is presents similar trends (tilted to the South-west) of the Upper Permian – Jurassic times, with the main sedimentation shifting to the south (Grigelis, 1986). The tectonic regime changed from dominating extension to compression (Šliaupa et al., 1997).

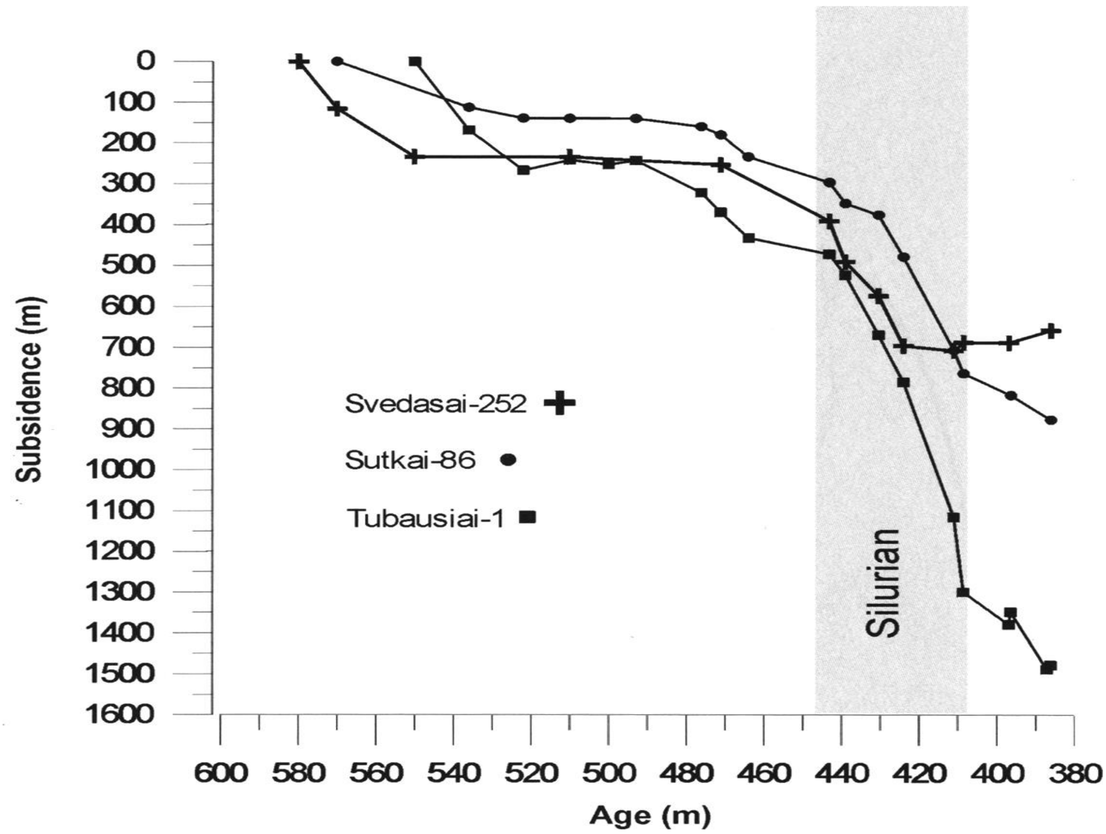

Figure 5: Tectonic subsidence curves modelled for the selected wells of central and eastern parts of the Baltic foreland basin (Lazauskiene et al. 2003).

2. DATA AND METHODS

2.1 1D backstripping methodology

The backstripping technique was first used by Watts and Ryan (1976) in a study of the subsidence of the Atlantic margins. Since then, it has become a widely practiced technique (Roberts et al., 1998; Fang et al., 2022).

Backstripping is a method used to analyze a sedimentary basin's subsidence history by simulating a gradual reversal of the depositional process (Roberts et al., 1998). To apply backstripping method, one needs to follow two main steps: the first is called decompaction, aiming to restore the original thickness of sediment layers in the stratigraphic column prior to compaction by loading of subsequent units. The recovered sediment thickness is then used to gradually unload basement lithological units while accounting for isostasy, along with a model of changes in water depth and long-term sea level (Ali and Awtts, 2013). Backstripping results in the division of the sediment build up into two components:

sediment contribution and water loading, and secondly, the unidentified tectonic subsidence and uplift (Steckler et al., 1999; Ali and Watts 2013; Allen and Allen, 2013).

2.1.1 1D backstripping modelling: the general procedure

Major input parameters: These parameters include layer thickness, absolute ages, lithological structure of the layer, eustatic sea level fluctuations (Allen and Allen, 2005).

The concave shape of subsidence curves demonstrates a passive continental margin stage of basin formation while the convex one refers to an active continental margin stage; the climax of active continental margin stage is of concve shape; the intracratonic stage is identified based considering the dynamic topography, while tilted extensional and compressional stage show extreme low amplitude (Allen and Allen, 2005).

The major general processes to consider in backstripping technique are presented below.

2.1.2 Decompaction

The sediments that deposited and eventually buried are compacted by the weight of the sediments above them (Holt, 2012). In order to backstrip multiple layers all the stratigraphic units in a sequence needs to be restored for each timestep by decompacting the younger units and compacting the older units (Figure 4). In the figure below, deepest layer 1 is decompacted in column 1 to give the second column at time 1. Subsequently, layers are added as time passes. In time 2, the deepest layer is compacted a little bit, but a new layer above remains uncompacted. As time passes, the layer even out to match the current thickness. This shows that, in order to backstrip multiple layers, all stratigraphic units need to be restored in a sequence for each time step, thus decompacting the younger units and compacting the older units (Allen and Allen, 2005).

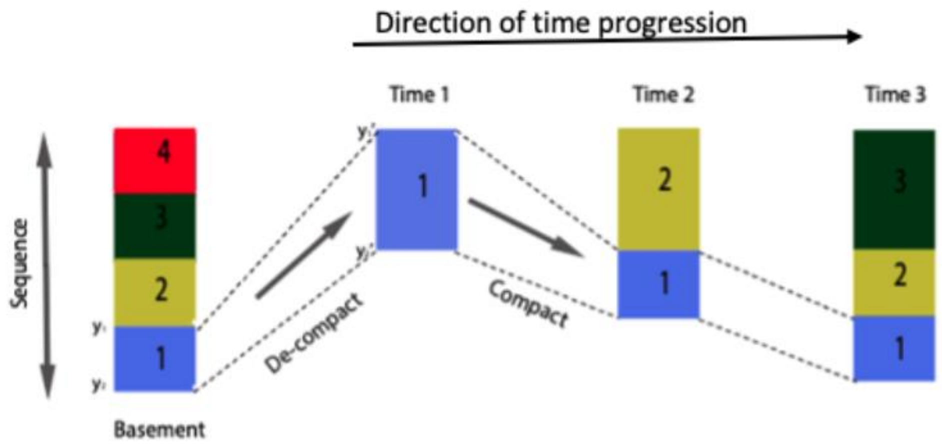

Figure 6: Timeline of the decompaction process. Where numbers 1,2,3 and 4 represent layers in a sedimentary column and 1 being the deepest (Allen and Allen, 2005).

2.2 Correcting for weight of sediments, changes in water depths and sea level

2.2.1 Correcting for weight of sediments

The second set of effects we need to correct for is sediment loading and sea level change. The weight of sediments can be corrected by calculating and correcting for the effect of subsidence (Allen and Allen, 2005).

The subsidence assuming a basin filled with water instead of sediments (Holt, 2012). Airy isostasy which assets that at compensation depth the weights of the two columns are balanced, is used to calculate tectonic subsidence (Holt, 2012). This technique was not used in this thesis as it wasn't necessary.

2.2.2 Correcting for changes in water depths and sea level

The next stage to take into consideration is weight effects of the water column once the sediments have been decompacted and the sedimentary load at each time interval has been corrected (Holt, 2012). At every step, the top of the sediment's column must be adjusted to the same datum (in this case sea level) in order to trace the subsidence through time (Holt, 2012). Since sea level is a datum from which subsidence is calculated, it is crucial to adjust sea level fluctuation as they may result in inaccuracies in the calculation of the basin's subsidence history. For example, the record will indicate increasing water depth if sea level increases. This can be used to mean that basin subsidence is increasing, and vice versa (Allen and Allen, 2005, Holt, 2012).

2.3 Description of the software

Pybacktrack is a python package that backtracks the paleo – water depth of ocean drill sites through time by combining a model of tectonic subsidence of the well site stratigraphic lithologies.

The Pybacktrack software provides a model of tectonic subsidence of oceanic and continental crust. Ocean crust subsidence is based on parameters such as litholospheric age, depth and the present day uploaded basement depth. At drill sites that did not penetrate to basement, the age coded stratigraphy is supplemented with a synthetic stratigraphic section that represents the undrilled section, whose thickness is estimated using a global sediment thickness map (Muller, R. D., Cannon, J., William, S. and Dutkiewicz, A. 2018). This is crucial, as it helps in estimating time, at drill sites on stretched continental crust where the paleo-water depth is known from benthic assemblage, tectonic subsidence can be computed via backstripping.

2.4 Input data for subsidence curves construction

2.4.1 Input data

The study was based on actual data of 11 wells located in different tectonic regions in the study territory of Lithuania and Latvian Baltic offshore territory. Wells E7-1 and E6-1 are located in the Latvian Baltic sea offshore area and the others Renava-1, Tūbausiai-1, Žūtautai-1, Šilute-1, in the Western Lithuanian Domain; Sutkai-86, Vilkaviškis-127, Stačiūnai-8 in the Mid-Lithuanian share Zone and Svėdasai-252 and Ukmergė-10 are onshore wells in the East Lithuanian Domain (HIKE, 2021).

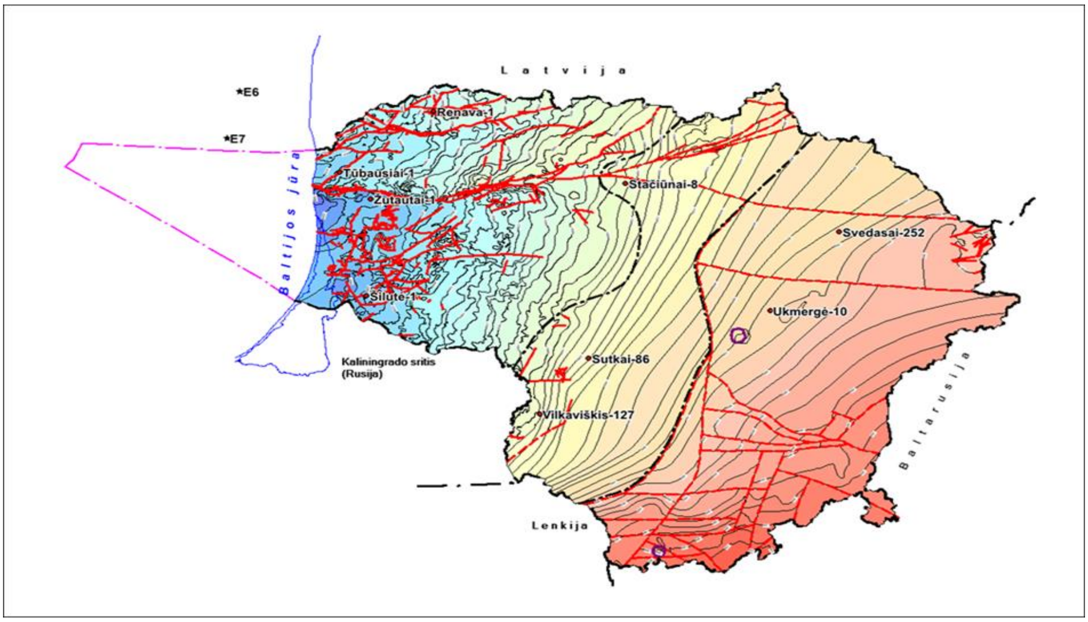

Figure 7: HORIZON2020 Geo-ERA project"Hazards & Impacts Knowledge for Europe" (HIKE). Final fault data collection report and database: Annex I. Lithuania. Lazauskienė et al. 2021. 220-234 p.

The stratigraphic table below is the input data from well Stačiūnai-8 represented as an example among all the 11 studied wells.

Well **Staciunai**
elevation: m

stratygraphic table

formation and events	**type [F, D, E, H]**	**beginning age [My]**	**thickness (or missing thicknes) [m]**	**lithology [%]**
Q	F	1.64	17.3	50-snd; 50-shl
hiatus	**H**	365.5	*0*	
D3-famenian	F	367	40.7	40-shl; 60-lms;
D3-upper frasnian	F	374	184.5	50-shl; 30-dol; 20-evp
D3-sventoji	F	377.4	103.5	40-snd; 30-slt; 20-shl
D2-upninkai	F	380.8	107	60-snd; 40-slt;
D2-nr-pr	F	386	133	15-snd;20-slt; 55-shl; 10-lms
D2-rz	**H**	386.5	*0*	
D1-km	F	396.3	95.5	60-snd; 20-slt; 20-shl
D1-km-gr	**H**	396.8	*0*	
D1gr	F	408.5	170.4	30-snd; 20-slt; 50-shl
S2 pr	F	410	37	70-shl; 30-lms
S2 ld	F	424	223.5	40-shl; 60-lms
S1w	F	430.4	114.5	95-shl; 05-lms
S1ln	F	439	64	50-shl; 50-lms
hiatus	**H**	439.5	*0*	
O3 as	F	443.1	56	40-shl; 60-lms
O2 kr	F	463.9	22.1	85-shl; 15-lms
O2 lnd	F	471.1	12.7	100-lms
O1 lnv	F	476.1	2.7	100-lms
O1 ar	F	493	13.8	20-snd; 30-slt; 50-shl
O1 tr	F	510	1	100-snd
Cm3-erosin hiatus	**E**	522	*-20*	
Cm2	D	527	20	
Cm 2	F	536	30.9	50-snd; 50-shl
Cm1	F	560	54.5	50-snd; 40-slt; 10-shl
		Age	**thick.**	**lithology**

Figure 8: Stratigraphic table of input data for the well Stačiūnai-8

2.4.2 The subsidence curves construction

11 different wells located in the western, central and Eastern Lithuania, which also cover the lateral extension of the Baltic basin and located in different structural and lithofacies zones were selected to conduct the research for this thesis.

Based on the major general parameters, I elaborated different input files that were necessary for this research. Some technical issues in intalling the programme have arised but, did not affect the overall methodological part of the research work carried out. The input wells data for the file elaboration were provided by the supervisor of the thesis.

The assistance of the consultant of this research assoc. Prof. Dr. Audrius Čečys has aided in getting output data for two wells, while the other output well data were provided by the supervisor due to the technical issues with the software.

The subsidence curves were compiled accordingly based on the output data. Moreover, the analyses, followed by interpretations and discussions were made appropriately.

The subsidence rates were calculated considering the first three stages (passive continental margin stage, active continental margin stage and climax of the active margin) of the Baltic basin evolution, and comparisons were made to get insights of the basin evolution and its sedimentation pattern during different stratigraphic time periods. Furthermore, maximum tectonic subsidence, minimum tectonic subsidence and maximum total subsidence, and difference between maximum total subsidence and maximum tectonic subsidence were calculated for clearance of the basin infilling process.

More than that, the subsidence depth from all wells were determined for Quaternary, and the values show increasing depth from the East to the West.

Maximum tectonic subsidence is the deepest vertical movement of a basin created by the tectonic forces including lithospheric stretching or faulting.

Maximum total subsidence is affected by not only the tectonic forces, but also implies other factors such as sediment loading and compaction effects.

3. COMPILATION, ANALYSES, DISCUSSIONS AND INTERPRETATION OF THE SUBSIDENCE RESULTS

3.1 Compilation of subsidence curves

The subsidence curves (figures 9 – 30) have been constructed from the input well data. The X axis values indicate geological ages in millions of years and the Y axis values represent subsidence depth in km.

In all the calculated curves the blue line represents minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence. The letters: A (passive continental margin stage); B (active continental margin stage); C (climax of active continental margin stage); D (intracratonic basin stage); E (uplift); F (tilted extensional stage); EL (tilted compressional stage) and EK (missing section or no strata).

3.1.1 Analyses of backstripping results with emphasis on subsidence trends

- **<u>Subsidence analysis based on well E6-1 data</u>**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

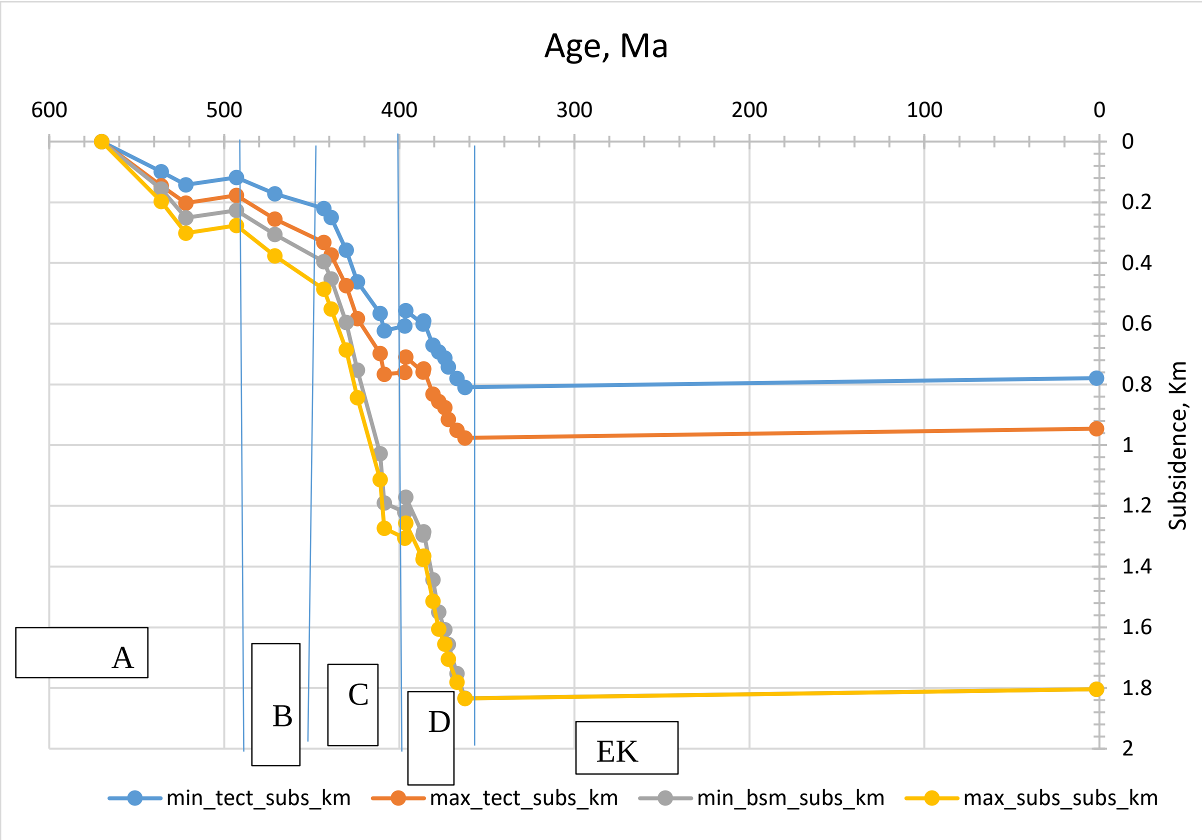

Fig 9: Subsidence curves from E6-1 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

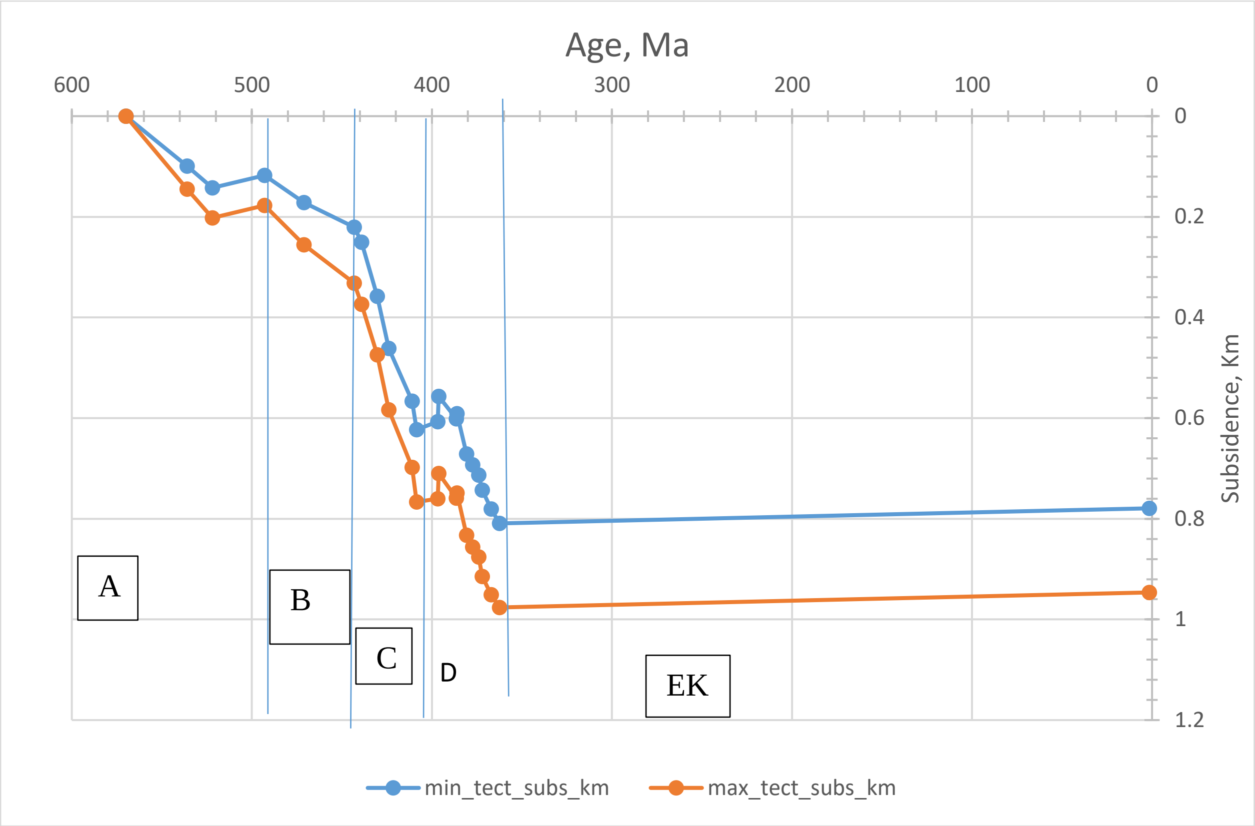

Fig 10: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line) of the well E6-1.

Well E6-1 is located in the most westward and deepest part of the studied territory of the Baltic Basin – Baltic Sea offshore (figure 7).

The backstripping results from the well E6-1 show four different stages (parts) of the subsidence history in that part of the Baltic basin (figure 9). Part (A) demonstrates that after the origin of the basin in the early Cambrian times, the subsidence was rather rapid with the maximum tectonic subsidence reaching 0.2 km (figure 10) while minimum tectonic subsidence reached 0.15 km (figure 10) by the year 520 Ma (Middle Cambrian) with subsidence rates 4 m/MY and a slow decrease of subsidence up to 490 Ma (lower Ordovician). The maximum and minimum total subsidence reached respectively 0.3 km and 0.25 km depth (figure 9).

The difference between maximum and minimum total subsidence 0.05 km (50 m); and between maximum tectonic and maximum total subsidence 0.1 km (100 m). The difference shows a small value which most probably indicates the modest initial infilling stage of the basin with sediments.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013) and, considering the history of the Baltic basin (Poprawa et al., 1999), most probably represents the passive continental margin stage.

The second stage (B) throughout the early Paleozoic time of 490 (Ma) - 443 Ma (From early to Middle Ordovician) with a slow increase of subsidence up to 440 Ma (Middle Ordovician) (fig.10).

The maximum and minimum tectonic subsidence here attain respectively 0.2 and 0.36 km (figure 10) while the maximum total subsidence reached about 0.48 km (figure 9). The difference between maximum total subsidence and maximum tectonic subsidence is 0.12 km (120 m). The general shape of subsidence curve at this stage is in overall compatible with tectonic setting of an active margin (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents the beginning of the active continental margin stage of the Baltic basin.

The following stage (part C) is represented throughout the time period 443 Ma - 410 Ma (Late Ordovician up to end Silurian). A rapid increase of subsidence is observed compared to that of Cambrian with the minimum tectonic subsidence attaining 0.6 km (figure 10) while maximum tectonic subsidence reached 0.8 km (figure 10) with subsidence rate 19.5 m/Ma; and maximum total subsidence 1.52 km (figure 9). The difference between maximum and minimum tectonic subsidence comprises 0.2 km (200 m); between maximum tectonic and maximum total subsidence is 0.5 km (500 m). The differential value between maximum tectonic subsidence and maximum total subsidence is high enough compared to the first part and, indicates high rate of basin infilling which started since the later part of Ordovician period (Poprawa et al., 1999). The general concave shape of the subsidence curve is in overall compatible with a tectonic setting of climax of an active margin (Allen and Allen, 2013) and, considering the history of the Baltic basin (Poprawa et al., 1999) most probably represents the climax of the active margin.

The following subsidence stage (part D) 443 Ma (Early Devonian) – 362 Ma (Carboniferous period) is represented by a stable increase of subsidence with maximum and minimum tectonic subsidence reaching respectively 1 km and 0.8 km (figure 10); and maximum total subsidence 1.8 km depth (figure 9). The difference between minimum and maximum tectonic subsidence is 0.2 km (200 m). This value is equal to that in the part C suggesting similar proportion in sedimentation in both stages in this particular part of the studied territory. The general convex shape of the subsidence curves in this stage is in overall compatible with a tectonic setting of an intracratonic centered sedimentary basin (Allen and Allen, 2013) and considering the history of the Baltic basin most probably represents an intracratonic centered stage of basin evolution.

The last subsidence stage, from Carboniferous throughout Quaternary (part EK), is represented by a constant subsidence trend. The subsidence curves demonstrate a lack of sedimentation. As in the Baltic Sea offshore geological section is strongly incomplete and, in the initial document of the well, the sediments from the age 360 Ma are missing (Paškevičius, 1997). There were insufficient information and data to reconstruct the missing geological strata for subsidence calculations. The subsidence curve in form of plateau represents this hiatus in geological section.

- **<u>Subsidence curves analysis based on well E7-1 data</u>**

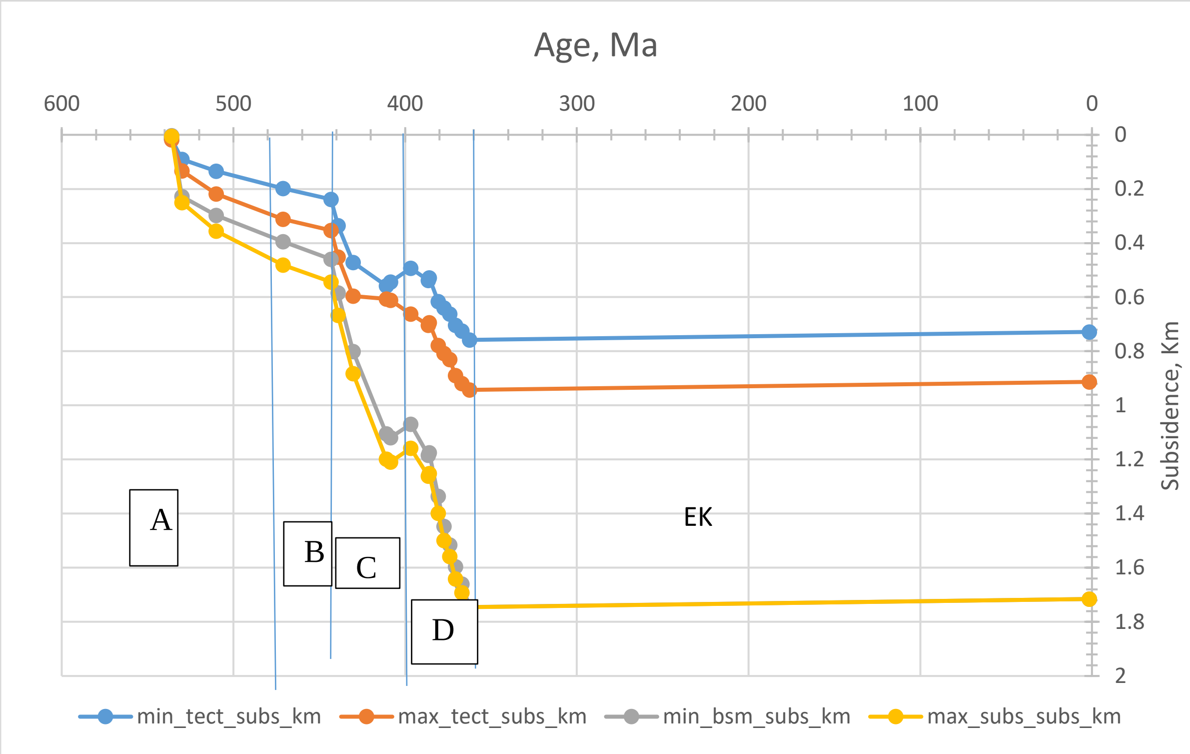

Fig 11: Subsidence curves from E7-1 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line – maximum total subsidence.

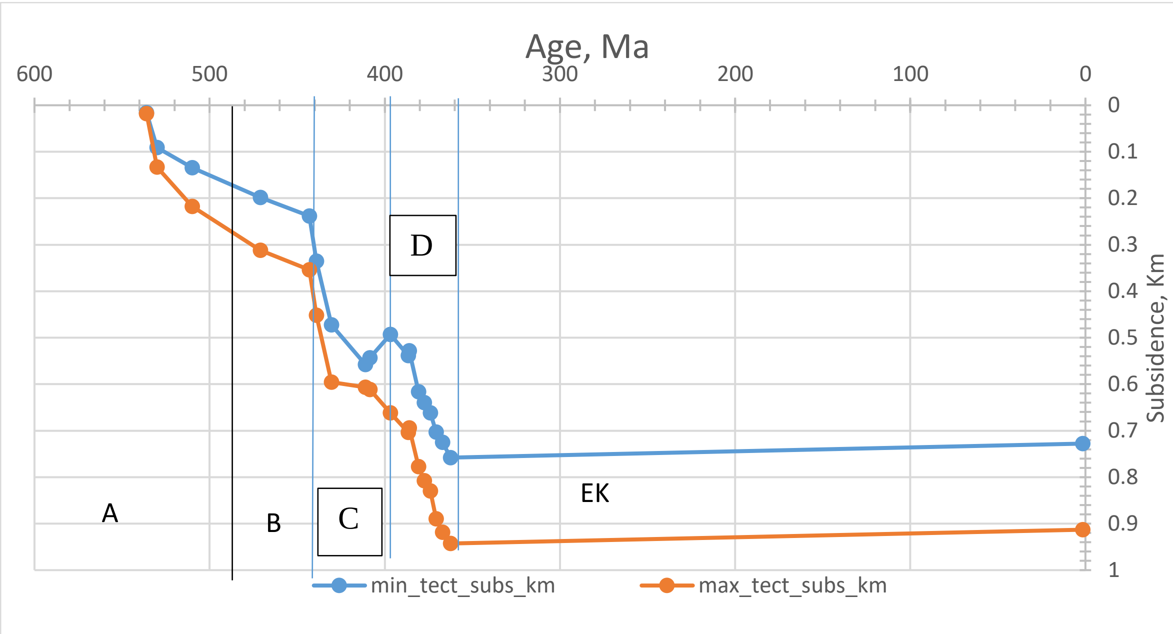

Fig 12: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from E7-1 well.

Well E7-1 is located in the westward and deepest part of the studied territory of Baltic basin – Baltic Sea offshore (Fig.7). The backstripping results from the well E7-1 show five different stages (parts) of subsidence history in that part of Baltic basin (Fig.11). The first part (A) demonstrates that after the origin of the basin in the Cambrian times, subsidence was rapid with minimum tectonic subsidence reaching 0.18 km while maximum tectonic subsidence is 0.28 km (figure 12) by the year 490 Ma (lower Ordovician), with subsidence 5.6 m/Ma; and maximum and minimum total subsidence respectively 0.4 km and 0.35 km km (Fig.11). The difference between minimum and maximum tectonic subsidence is 0.1 km (100 m). The differential value is low and most probably suggests the beginning of the infilling basin with sediments. The general concave shape of the subsidence curve is in overall compatible with a passive continental margin of a sedimentary basin (Allen and Allen, 2013).

The second subsidence stage (part B) throughout the time period 490 Ma (lower Ordovician) – 443 Ma (Upper Ordovician) is represented by a rapid subsidence with minimum and maximum tectonic subsidence reaching respectively approximate values of 0.23 km and 0.35 km with subsidence rate 9.5 m/Ma. The minimum and maximum total subsidence attain respectively 0.42 km and 0.5 km (Fig.11). The difference between minimum and maximum tectonic subsidence is 0.12 km (120) m, suggesting a higher rate of sedimentation compared to the first part (A). The general convex shape of the subsidence curve is in overall compatible to a tectonic setting of an active continental margin stage of a sedimentary basin (Allen and Allen, 2013) and, considering the history of the Baltic basin, most probably represents an initial stage of the active continental margin of the Baltic basin evolution (Poprawa et al., 1999).

The third subsidence stage (part C) throughout the time period 443 Ma (Upper Ordovician) – 400 Ma (lower Devonian) shows a rapid subsidence with minimum tectonic subsidence reaching 0.5 km (figure 15), while maximum tectonic subsidence reaches 0.65 km with subsidence rate 16. m/Ma. The general concave shape of the subsidence curve at this stage is in overall compatible with a tectonic setting of a climax of an active margin (Allen and Allen, 2013).

The following subsidence stage (part D) throughout time period 400 Ma (Early Devonian) – 362 Ma (Carboniferous) shows a rather stable increase of subsidence. Maximum and minimum tectonic subsidence reach respectively 0.95 km and 0.75 km with subsidence rate 23.8 m/Ma; and maximum tectonic subsidence 1.6 km. The overall shape of subsidence curves is compatible with a tectonic setting of an intracratonic centered basin (Allen and Allen, 2013) and, considering the history of Baltic basin (Poprawa et al., 1999) most probably represents an intracratonic centered basin evolution.

The last subsidence stage (part EK) from Carboniferous up to Quaternary shows a constant subsidence, demonstrating a lack of strata, as in the Baltic Sea offshore geological section is strongly incomplete and, in the initial document of the well, the sediments from the age 362 Ma are missing (Paškevičius, 1997). There was insufficient information to reconstruct the missing geological strata for subsidence calculations. The subsidence curve in form of plateau represents this hiatus in geological section.

- **<u>Subsidence curves analyses based on well Renava-1 data</u>**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

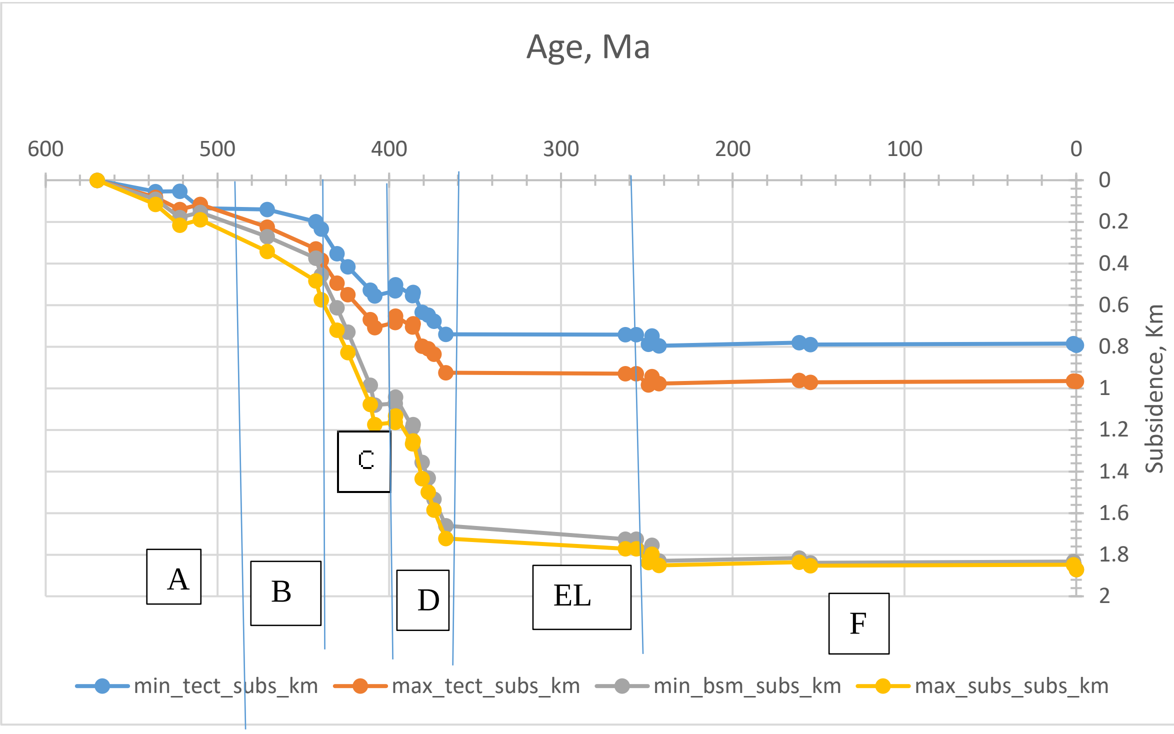

Fig 13: Subsidence curves from Renava-1 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

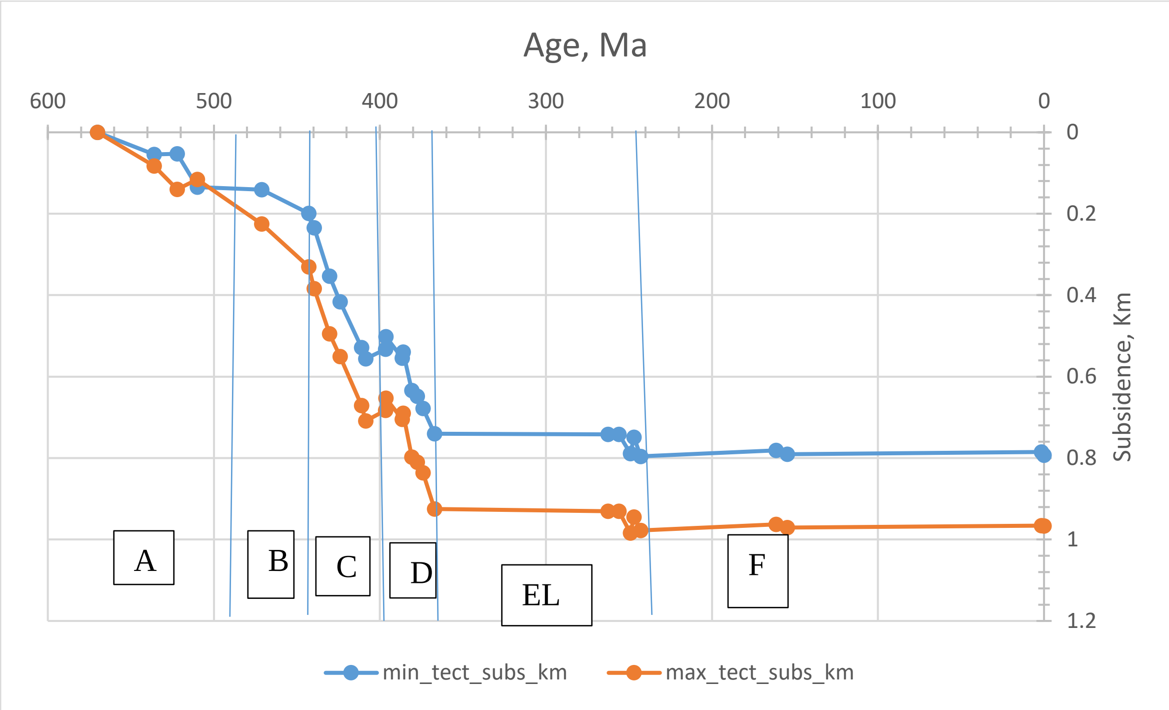

Fig 14: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line).

Well Renava-1 is located in the northward part of the studied area (Fig.7).

The first part (A) demonstrates that after the origin of the basin in the Cambrian times, subsidence was rapid until 510 Ma (lower Ordovician time) (Fig.14). Then, a subsidence decrease is observed up to 470 Ma (Middle Ordovician). The minimum and maximum tectonic subsidence reach respectively 0.15 and 0.22 km; maximum total subsidence 0.28 km.

The general shape of subsidence curves at this stage is in overall compatible to a passive continental margin stage of a sedimentary basin (Allen and Allen, 2013) and, considering the history of the Baltic basin (Poprawa et al., 1999), most probably represents the passive continental margin stage.

The second subsidence stage (part B) is represented by a relatively slow increase of subsidence throughout the time period 470 Ma (lower Ordovician) - 440 Ma (upper Ordovician), with subsidence rate 13.3 m/Ma. Minimum tectonic subsidence attains 0.2 km (figure 14) while maximum tectonic subsidence reaches 0.4 km (figure 13). The difference between minimum and maximum tectonic subsidence is 0.2 km (200 m). This value is relatively high compared to the first part indicating a high rate of sedimentation (Fig.14). The general convex shape of the subsidence curve at this stage is in overall compatible with tectonic settings of an active continental margin stage of a sedimentary basin (Allen and Allen, 2013).

The following subsidence stage (C) is represented by a high increase of subsidence throughout 440 Ma (upper Ordovician) – 400 Ma (lower Devonian). Minimum and maximum subsidence reached respectively 0.59 km and 0.7 km with subsidence rate 17.5 m/Ma.

The general shape of the subsidence curves in this stage is in overall compatible with tectonic settings of a climax of an active continental margin stage of a sedimentary basin (Allen and Allen, 2005).

The fourth subsidence stage (part D) is represented throughout the time period 400 Ma (lower Devonian) - 360 Ma (Carboniferous). The maximum tectonic subsidence reaching 0.95 km while the minimum tectonic subsidence is 0.75 km, with subsidence rate 20.2 m/Ma. The difference between both subsidence is 0.2 km (200 m). The differential value is the same to that in the part B, suggesting a similar proportion of infilling sediments in both parts of stages of basin evolution. The general convex shape of subsidence presents a similar subsidence trend of an intracratonic centered basin (Šliaupa et al., 1997).

The following subsidence stage (part EL) is represented throughout the period 360 Ma (Carboniferous) – 242 Ma (Triassic – Jurassic boundary), with hiatus at the boundary. The subsidence curve shows a relatively constant evolutionary trends suggesting a tilted compressional regime of Baltic basin evolution (Šliaupa et al., 1997).

The last stage of subsidence (part F) from early Jurassic throughout Quaternary is represented by more or less sedimentation. The subsidence trend shows a constant evolution. The general shape of the subsidence curves at this stage is in overall compatible with a tilted extensional evolution of a sedimentary basin (Šliaupa et al. 1997).

- **Subsidence analysis based on well Tūbausiai-1 data**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570- 521	521- 443.1	443.1- 410	410- 362.5-	362- 356.1	356.1- 249	249- 243	243- 154.7	105- 74

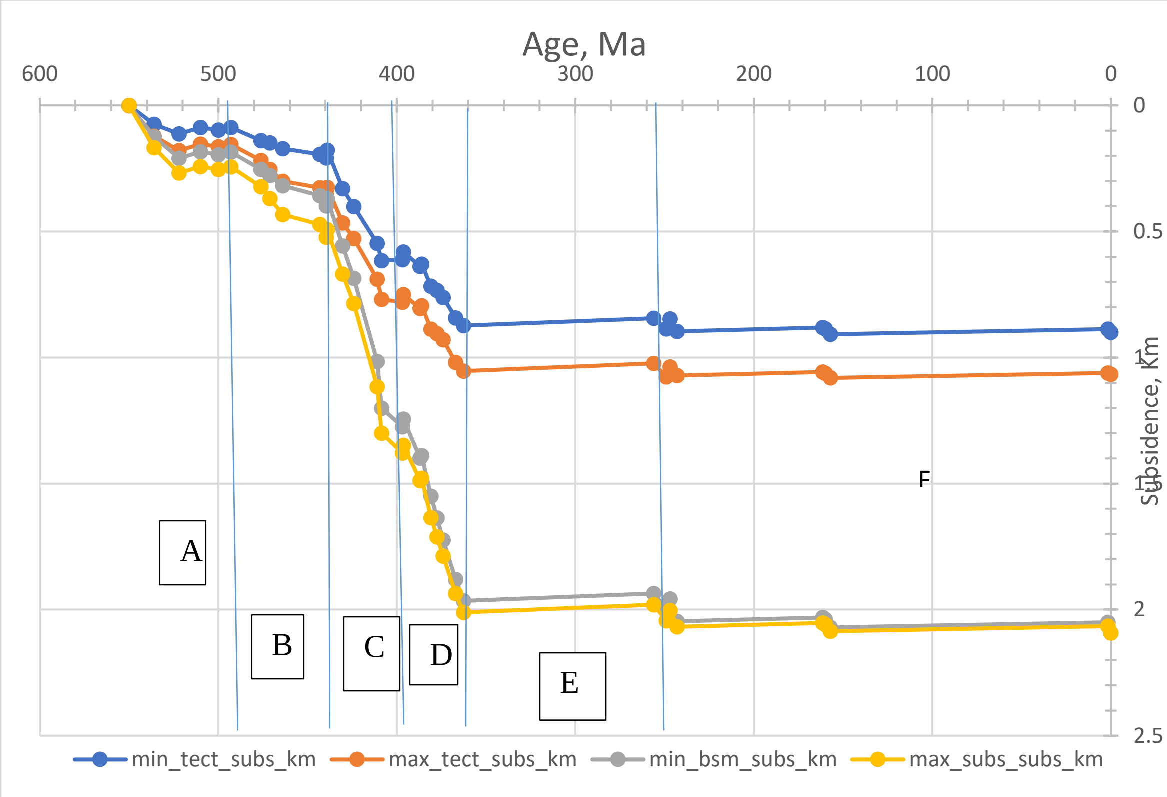

Fig 15: Subsidence curves from Tūbausiai-1 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

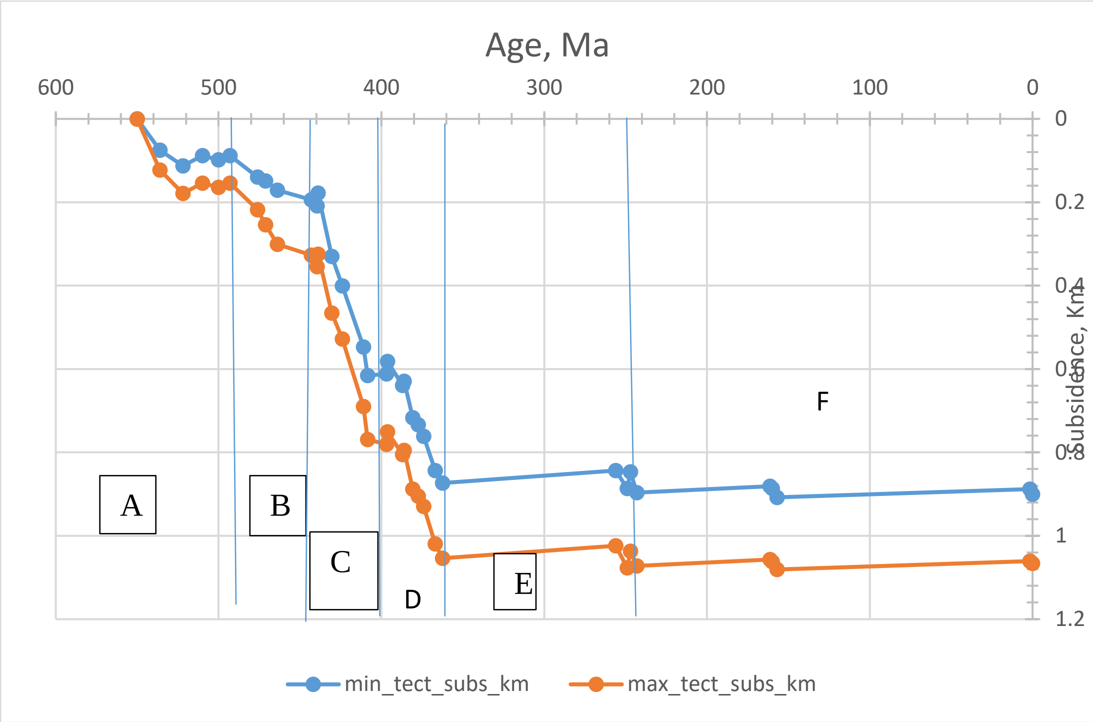

Fig 16: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from Tūbausiai-1 well.

The backstripping results from well Tūbausiai-1 located in the western part of Lithuania - onshore (figure 7) shows different subsidence stages reflected in the subsidence curves.

The backstripping results from the well Tūbausiai-1 also demonstrates that the subsidence at the beginning (part A) was rather rapid with minimum tectonic subsidence 0.1 km while the maximum tectonic subsidence is 0.2 km (figure 16) by 520 Ma (Middle Cambrian) with subsidence rate 6.7 m/Ma. Then, a slow decrease of subsidence is observed up to 490 Ma (Early Ordovician period).

The difference between minimum and maximum tectonic subsidence comprises 0.1 (100 m); between maximum and minimum total subsidence 0.1 km (100 m); These slightly low values suggest the beginning of the sedimentation taking place in the basin by the time.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin (Alen and Allen, 2013).

The second subsidence stage (B) throughout the time period 490 Ma (lower Ordovician) until 443 Ma (Upper Ordovician) is represented by rather stable increase of subsidence. Minimum and maximum tectonic subsidence attain respectively 0.9 and 1.1 km (figure 15) with subsidence rate of 18.6 m/Ma. Minimum total subsidence is 1.2 km (figure 15) while maximum total subsidence is 1.3 km.

The difference between maximum tectonic subsidence and minimum tectonic subsidence is 0.2 km (200 m), which suggest slightly higher rate of sedimentation compared to that of the passive margin setting.

The general convex shape of subsidence curves presents similar trends of an active continental margin setting (Allen and Allen, 2013).

The third subsidence stage (C) started from the year 443 Ma (Upper Ordovician ended at 400 Ma Lower Devonian) demonstrates a rapid increase of subsidence, with minimum and maximum tectonic subsidence reaching respectively 0.8 and 1.1 km with subsidence rate 20 m/Ma (figure 16) while total maximum subsidence is 2 km (figure 15). The difference between maximum and minimum tectonic subsidence is 0.3 km (300 m). The general concave shape of the subsidence curve in this stage is in overall compatible with a tectonic setting of climax of an active continental margin stage of a sedimentary basin (Allen and Allen, 2013).

The fourth subsidence stage (D) throughout the period 400 Ma (lower Devonian – 362 Ma (Carboniferous), shows a rather stable increase of subsidence compared to the previous stage (C). Maximum tectonic subsidence reaching 1.04 km while the minimum tectonic subsidence is 0.9 km, with subsidence rate 25.4 m/Ma. The general shape of subsidence presents a similar trend of an intracratonic centered basin (Šliaupa et al., 1997).

The following subsidence stage (part E) from the year 362 Ma (Carboniferous) until 243 Ma (Triassic). An overall a slight uplift is observed with minimum and maximum tectonic subsidence reaching respectively 0.8 and 1.1 km (figure 16) respectively while the total maximum subsidence reached 2.1 km (figure 15). This slight uplift is most probably the Carboniferous uplift of the Baltic basin. Moreover, a hiatus is observed by the end of Triassic.

The remaining stage (F) starting from 243 Ma (end of Middle Triassic) shows an overall a plateau suggesting a lack of sufficient strata thereby low sedimentation and, the basin is tilted extensional stage.

- **Subsidence curves analysis based on well Žūtautai-1 data**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

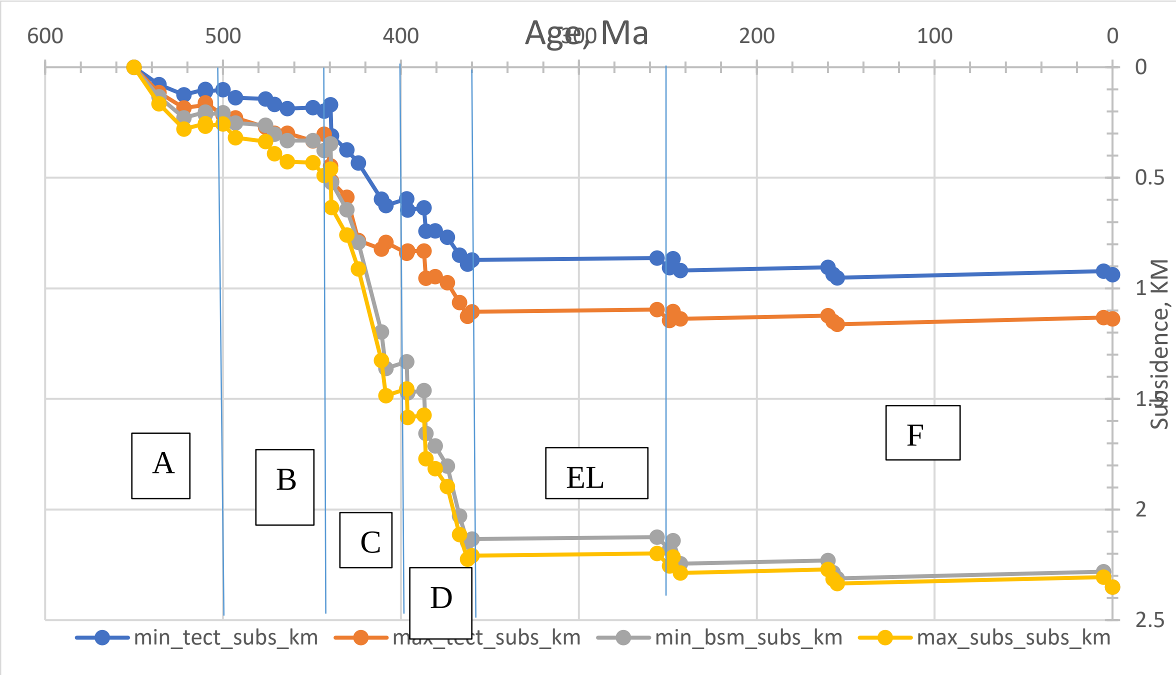

Fig 17: Subsidence curves from Žūtautai-1 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

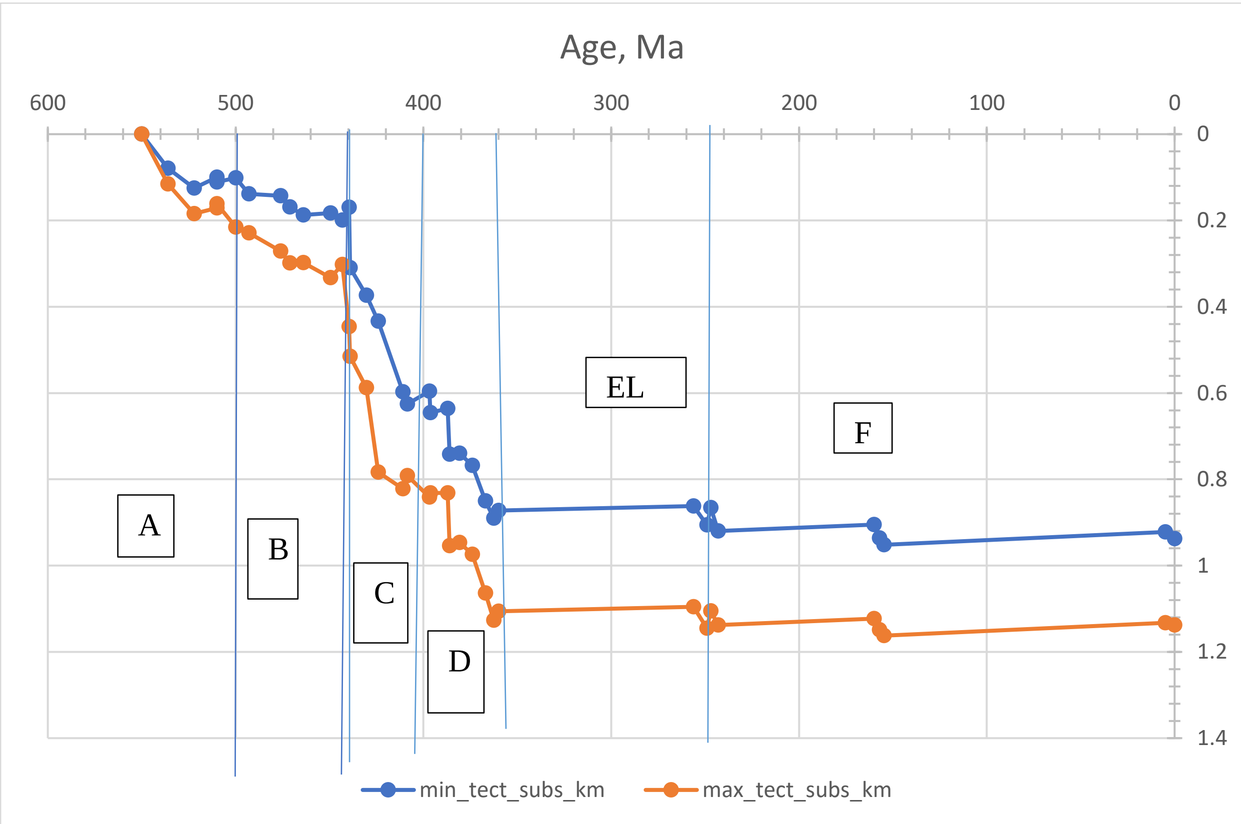

Fig 18: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from Žūtautai-1 well.

The Well Žūtautai-1 is located in the western part of the studied territory of the Baltic Basin (figure 7).

The backstripping results from the well Žūtautai-1 show four different stages (parts) of the subsidence history in that part of the Baltic basin (figure 17). The first part (A) demonstrates that after the origin of the basin in Cambrian times the subsidence was rapid increase with the maximum tectonic subsidence reaching 0.2 km while minimum tectonic subsidence reached 0.18 km by the year 520 Ma (late Cambrian) with subsidence rates 6.6 m/Ma and a slow decrease of subsidence up to 500 Ma (lower Ordovician). The maximum total subsidence (figure 17) reached 0.25 km depth.

The difference between maximum tectonic and maximum total subsidence 0.05 km (50 m); and between maximum tectonic and minimum tectonic subsidence is 0.02 km (20 m). The difference shows a small value which most probably indicates the very moderate infilling stage of the basin with sediments.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013).

The second stage (B) throughout the time period 500 Ma (lower Ordovician) - 440 Ma (upper Ordovician), shows a slow increasing subsidence with a subsidence rate 5.3 m/Ma. The maximum and minimum tectonic subsidence (figure 18) attain respectively 0.4 and 0.2 km while the maximum total subsidence (figure 17) reached about 1.5 km. The general shape of subsidence curve at this stage is in overall compatible with tectonic setting of an active margin (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents an initial stage of the active continental margin stage of the Baltic basin evolution (Poprawa et al, 1999).

The following subsidence stage (part C) is represented throughout the time period 440 Ma (upper Ordovician)-400 Ma (lower Devonian (Aeronian)). Subsidence curves show a rapid increase of subsidence with the minimum tectonic subsidence attaining 0.6 km while maximum tectonic subsidence (figure 18) reached 0.8 km with subsidence rate 20 m/Ma; and maximum total subsidence (figure 17) 1.5 km relatively equal to minimum total subsidence. The difference between maximum and minimum tectonic subsidence comprises 0.2 km (200 m); between maximum tectonic and maximum total subsidence is 0.7 km (700 m). The differential value between maximum tectonic subsidence and maximum total subsidence is high enough compared to the first part and, indicates higher rate of sediments infilling basin. The general convex shape of the subsidence curves at this stage is in overall compatible with climax of an active continental margin (Allen and Allen, 2013)

The fourth subsidence stage (part D) is represented throughout lower Devonian period (400 Ma) up to Carboniferous (360 Ma). The minimum and maximum tectonic subsidence reach respectively 0.9 and 1.15 km with subsidence rate 28.8 m/Ma; Maximum total subsidence (figure 17) equals 2.2 km, with subsidence rate of 27, 5 m/Ma. The general shape of subsidence curves at this stage is in overall indicative of an intracratonic centred basin (Allen and Allen, 2013) and, considering the history of the Baltic basin, most probably represents an intracratonic centered basin stage (Poprawa et al., 1999).

The following subsidence stage (part EL) from Carboniferous 361 Ma up to Boundary Triassic - Jurassic (243 Ma) shows a relatively constant trends of subsidence curves and can be considered as a lower rate of basin infilling stage during this tilted compressional stage.

The last subsidence stage (part F) shows a constant subsidence trend, with a general subsidence shape suggesting the tectonic setting of a tilted extensional stage of the basin (Poprawa, 1999).

- **<u>Subsidence curves analysis based on well Šilute-1 data</u>**

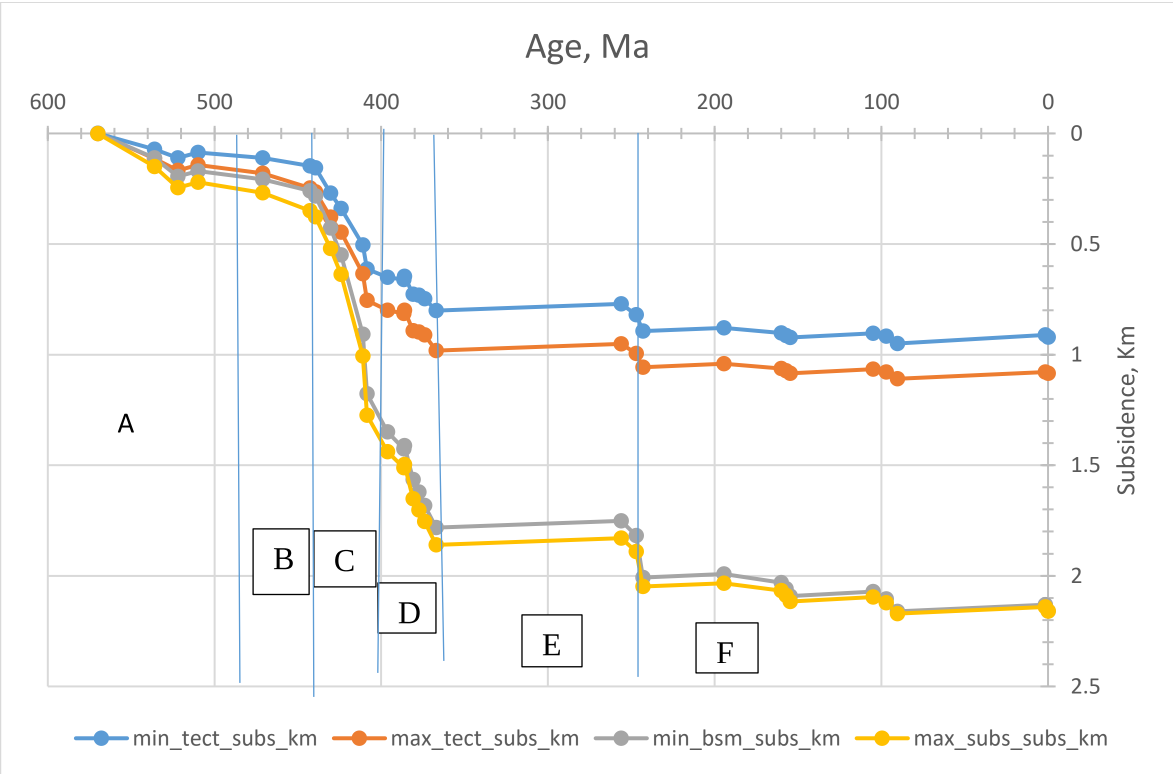

Fig 19: Subsidence curves from Šilute- well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line maximum total subsidence.

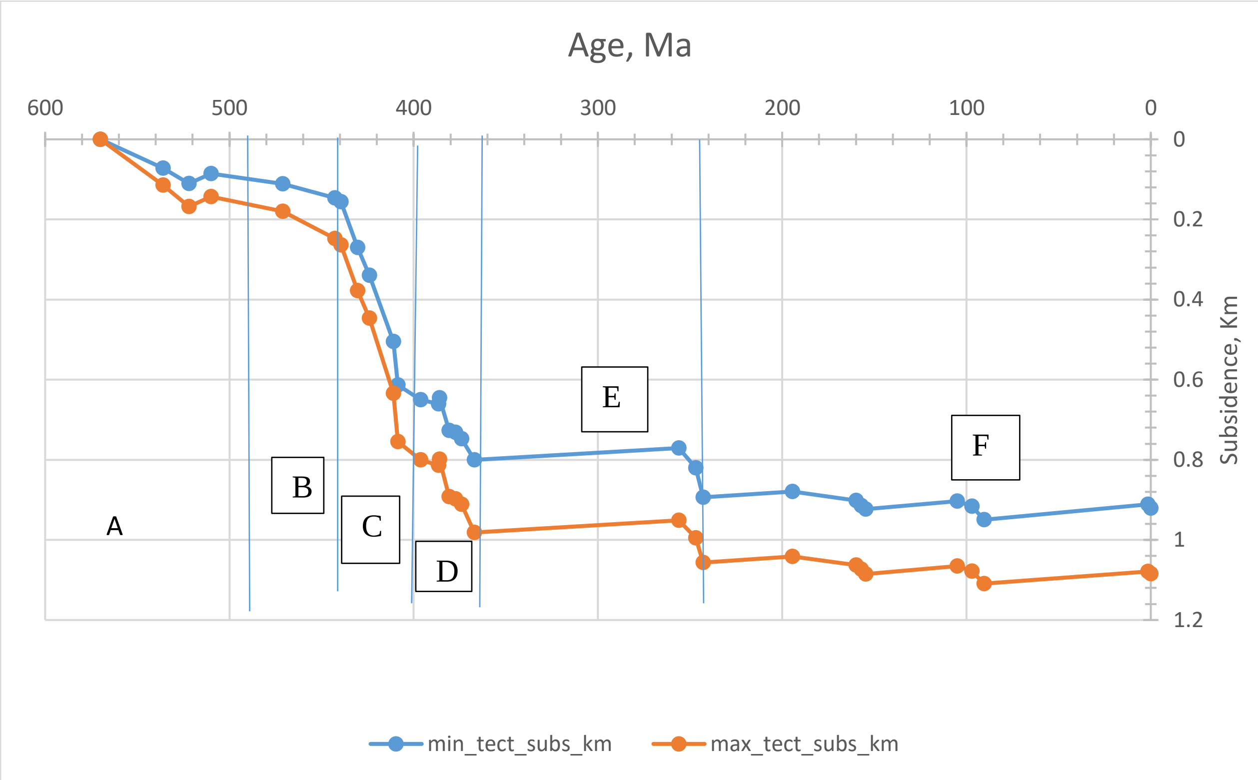

Fig 20: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from Šilute-1 well.

The well Šilute-1 is located in the most western part of the studied territory of the Baltic Basin (figure 7).

The backstripping results from the well Šilute-1 show five different stages (parts) of the subsidence history in that part of the Baltic basin (figure 19). The first part (A) demonstrates that after the origin of the basin in the early Cambrian times, the subsidence was rather rapid with the maximum tectonic subsidence reaching 0.19 km while minimum tectonic subsidence reached 0.12 km by the year 520 Ma (later part of Cambrian) with subsidence rates 3.8 m/Ma and a slow decrease of subsidence up to 490 Ma (lower Ordovician). The maximum and minimum total subsidence (figure 19) reached respectively 0.3 and 0.25 km depth.

The difference between maximum and minimum total subsidence 0.05 km (50 m); and between maximum tectonic and maximum total subsidence 0.11 km (110 m). The difference shows a small value which most probably indicates the beginning of sedimentation stage of the basin.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013).

The second stage (B) throughout the time period 490 Ma (lower Ordovician) - 443 Ma (Upper Ordovician) shows a relative increase of subsidence up to upper Ordovician with a subsidence rate 6.5 m/Ma. The maximum and minimum tectonic subsidence (figure 20) attain respectively 0.8 and 0.65 km while the maximum total subsidence (figure 19) reached about 1.5 km. The general convex shape of subsidence curves at this stage is in overall compatible with tectonic setting of an active margin (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents an active continental margin stage of the Baltic basin.

The following subsidence stage (part C) is represented starting from upper Ordovician (443 Ma) up to lower Devonian (400 Ma) shows a rapid increase of subsidence with the minimum tectonic subsidence attaining 0.65 km while maximum tectonic subsidence (figure 20) reached 0.8 km with subsidence rate 20 m/Ma; and maximum total subsidence (figure 19) 1.5 km. The difference between maximum and minimum tectonic subsidence comprises 0.15 km (150 m); between maximum tectonic and maximum total subsidence is 0.7 km (700 m). The differential value between maximum tectonic subsidence and maximum total subsidence is high enough compared to the first part and, indicates high rate of basin infilling. The general concave shape of subsidence curve at this stage is in overall compatible with tectonic setting of climax of an active margin (Allen and Allen, 2013).

The following subsidence stage (part D) is represented throughout the time period 400 Ma (lower Devonian) – 362 Ma (Carboniferous). The subsidence curves show slight increasing of subsidence. The maximum and minimum tectonic subsidence reach respectively 1 km and 0.8 km with subsidence rate 25 m/Ma. The general shape of subsidence curve is in overall compatible with tectonic setting of an intracratonic centred evolution of a sedimentary basin (Allen and Allen, 2013).

The fifth subsidence stage (E) throughout Carboniferous up to the boundary Triassic – Jurassic, shows a relatively constant trends of subsidence curves suggesting a lower rate of basin infilling. A slight uplift is observed, and also a break of that uplift at the boundary of Triassic – Jurassic.

The last subsidence stage (part F) is represented throughout Jurassic up to Quaternary. The subsidence curves show a relatively constant trend suggesting e very low infilling stage of the basin. The general shape of the subsidence curves at this stage is in overall compatible with a tilted extensional evolution of a sedimentary basin (Šliaupa et al. 1997).

- **<u>Subsidence curves analysis based on well Stačiūnai-8 data</u>**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570- 521	521- 443.1	443.1- 410	410- 362.5-	362- 356.1	356.1- 249	249- 243	243- 154.7	105- 74

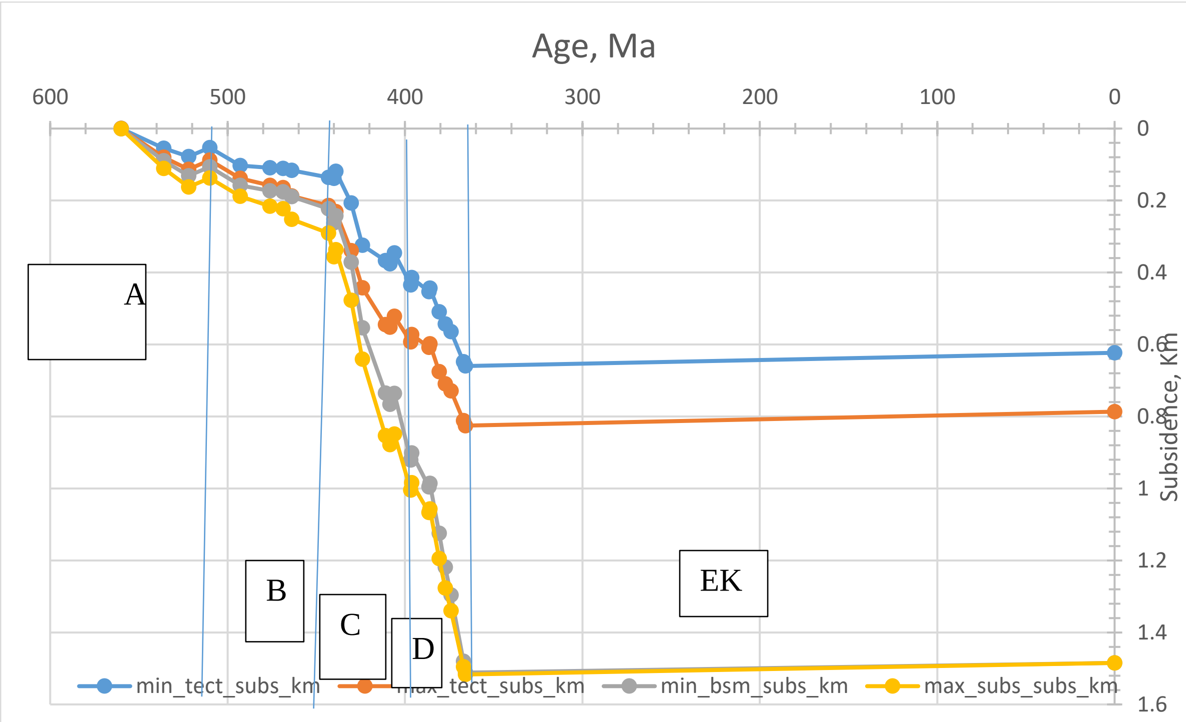

Fig 21: Subsidence curves from Stačiūnai-8 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

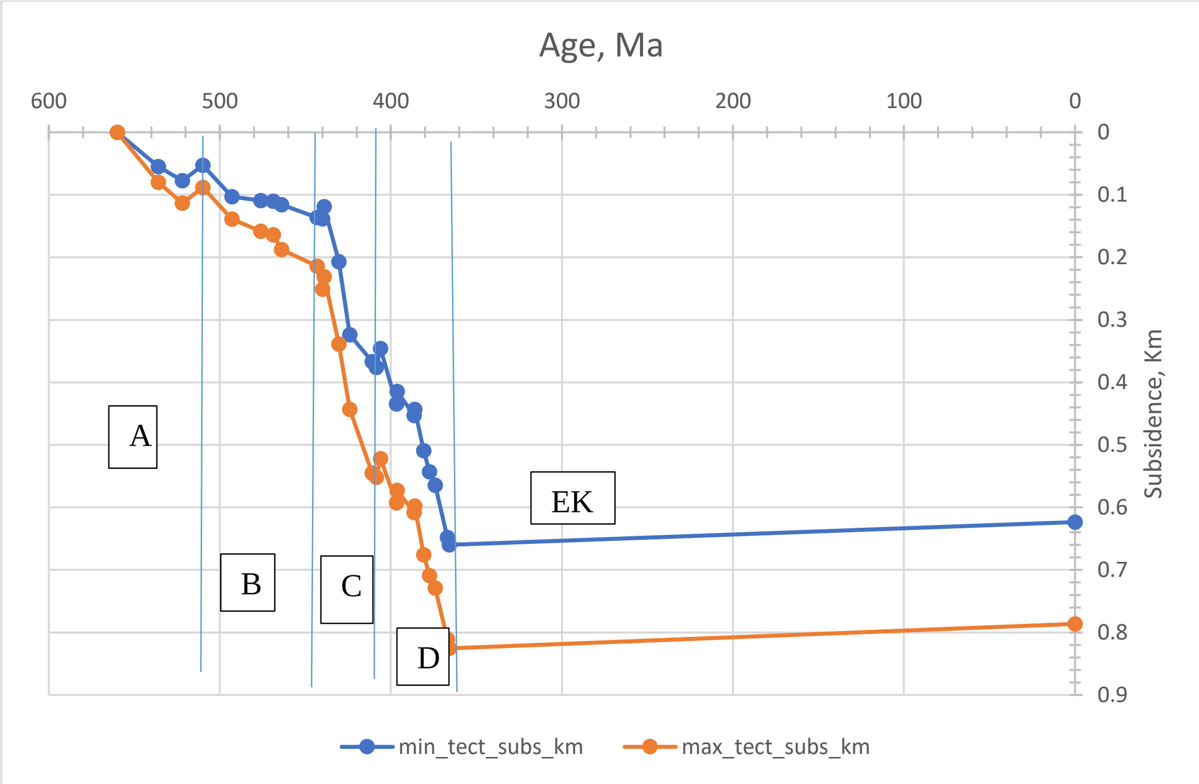

Fig 22: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line).

The Well Stačiūnai-8 is located in the most northward part of the studied territory of the Baltic Basin (figure 7).

The backstripping results from the well Stačiūnai-8 show five different stages (parts) of the subsidence history in that part of the Baltic basin (figure 21). The first part (A) demonstrates that after the origin of the basin in the Cambrian times, the subsidence was rather rapid with the maximum tectonic subsidence reaching 0.1 km (figure 22) while minimum tectonic subsidence reached 0.09 km by the year 520 Ma (Middle Cambrian period) with subsidence rates 2.5 m/Ma and a slow decrease of subsidence up to 510 Ma (Early Ordovician). The maximum and minimum total subsidence reached respectively 0.19 and 0.18 km (figure 21).

The difference between maximum and minimum total subsidence 0.01 km (10 m); and between maximum tectonic and maximum total subsidence 0.09 km (90 m). The difference shows a small value which most probably indicates the infilling stage of the basin with sediments.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013) and, considering the history of Baltic basin, most probably represents the passive continental margin stage.

The second stage (B) throughout the time period 510 Ma (lower Ordovician) - 443 Ma (Upper Ordovician) with rather a slightly increasing, with maximum and minimum tectonic subsidence (figure 22) attaining respectively 0.2 and 0.12 km while the maximum total subsidence reached about

0.3 km, with subsidence rate 3.5 m/Ma. The general convex shape of subsidence curve at this stage is in overall compatible with tectonic setting of an active margin (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents an active continental margin stage of the Baltic basin (Poprawa et al., 1999).

The following stage (part C) is represented throughout the time period 443 Ma (Upper Ordovician) - 400 Ma (lower Devonian period) with minimum tectonic subsidence (figure 22) attaining 0.4 km while maximum tectonic subsidence reached 0.6 km, and maximum total subsidence (figure 21) 1 km, with subsidence rate 14 m/Ma. The difference between maximum and minimum tectonic subsidence comprises 0.2 km (200 m); between maximum tectonic and maximum total subsidence is 0.4 km (400 m). The differential value between maximum tectonic subsidence and maximum total subsidence is high enough compared to the first part and, indicates high rate of basin infilling since Upper Ordovician throughout Silurian period. The general shape of subsidence curve at this stage is in overall compatible with tectonic setting of a climax of an active margin (Allen and Allen, 2013).

The following subsidence stage (part D) throughout the time period 400 Ma (lower Devonian period) – 362 Ma (Carboniferous) is represented by rather slightly increase of subsidence with maximum and minimum tectonic subsidence reaching respectively 0.82 and 0.68 km (figure 19), with subsidence rate 20.5 m/Ma; while maximum total subsidence (figure 21) equals approximately 1.5 km. The difference between minimum and maximum tectonic subsidence is 0.14 km (140 m); difference between maximum total and maximum tectonic subsidence is 0.68 km (680 m). The difference value between maximum tectonic and minimum tectonic subsidence is moderately high suggesting a more or less high rate of sedimentation taking place in that part of the studied territory. The general convex shape of subsidence curve at this stage is in overall compatible with tectonic setting of an intracratonic centered basin development (Šliaupa et al. 1997).

The last subsidence stage (part EK) throughout Carboniferous until Quaternary displays a constant evolutionary trend of subsidence curves, which most probably demonstrate no infilling sediments at this stage, in that part of the studied Area.

- **<u>Subsidence curves analysis based on well Vilkaviškis-127 data</u>**

Period	Cm	O	S	D	C	P	T	J	K
Age(Ma)	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

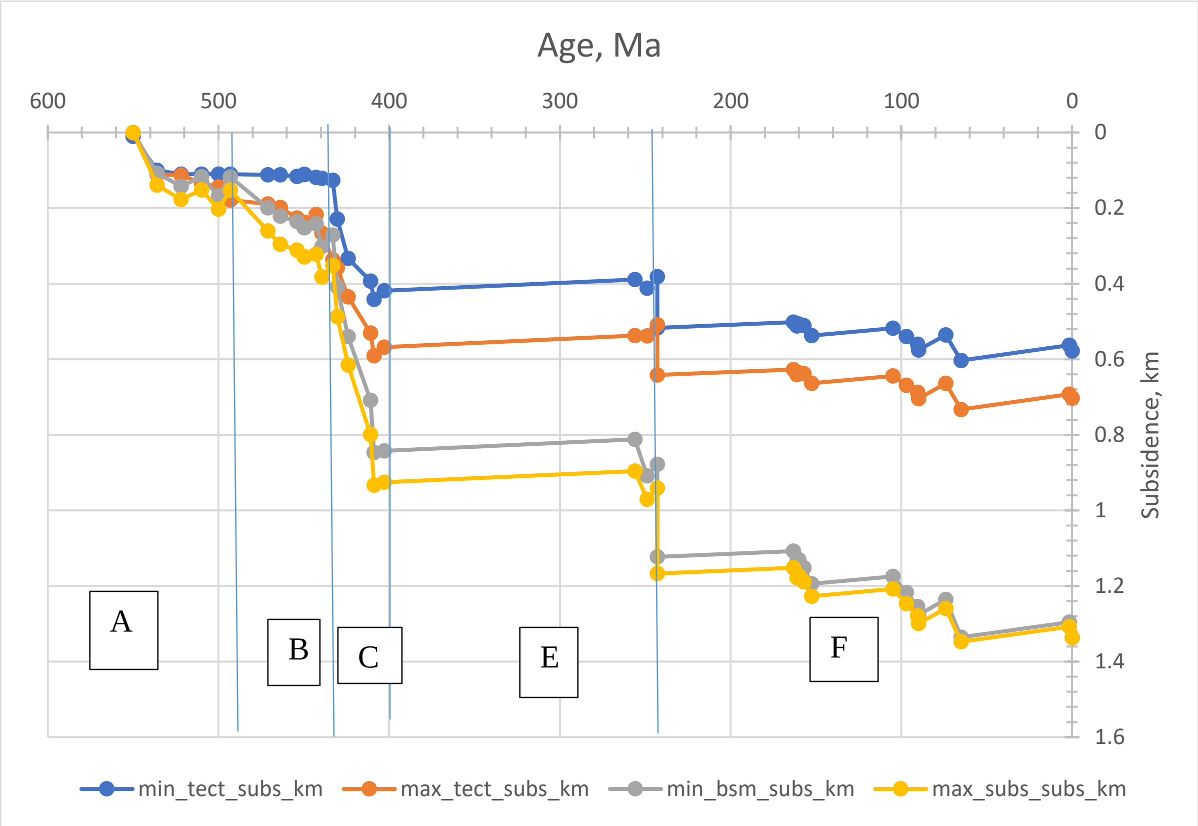

Fig 23: Subsidence curves from the well Vilkaviškis-127: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

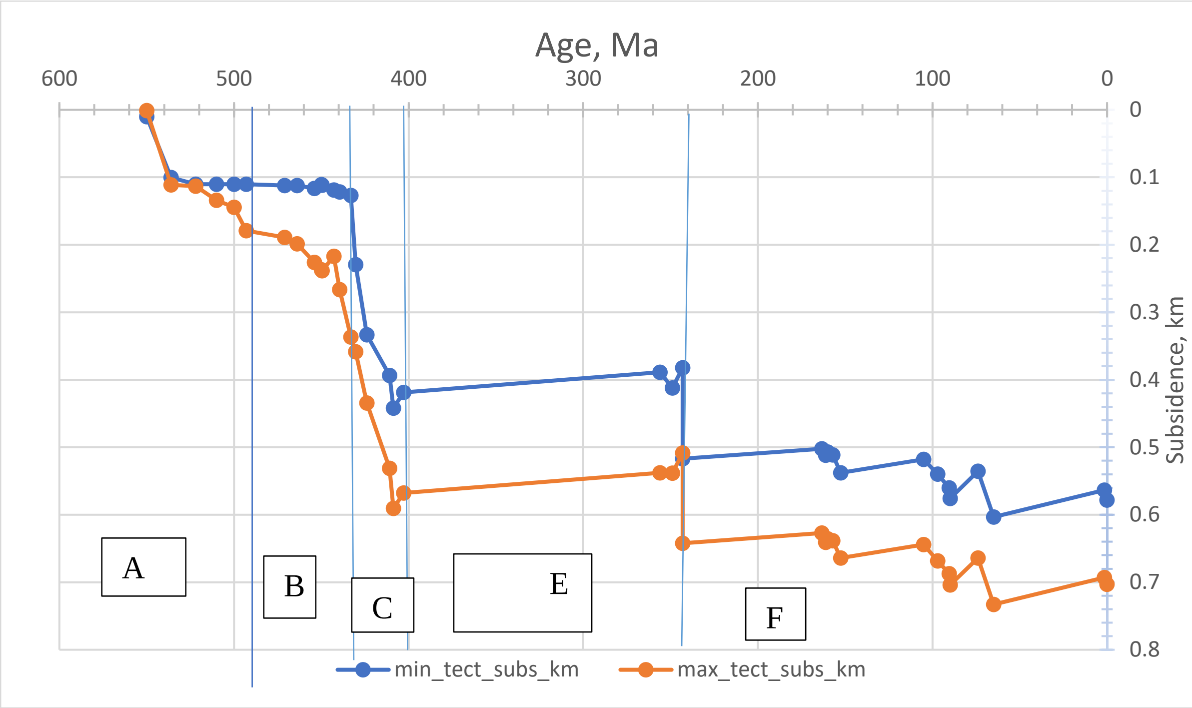

Fig 24: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from well Vilkaviškis-127.

The well Vilkaviškis-127 is located in the Southwestern part of the studied territory of the Baltic Basin (figure 7).

The backstripping results from the well Vilkaviškis-127 show five different stages (parts) of the subsidence history in studied part of the Baltic basin (territory of Lithuania) (figure 24). The first part (A) demonstrates that after the origin of the basin in Cambrian times the subsidence increased rapidly with the maximum tectonic subsidence reaching 0.11 km while minimum tectonic subsidence reached 0.1 km by the year 520 Ma (late Cambrian) with subsidence rates 3.2 m/Ma and a slow decrease of subsidence up to 510 Ma (lower Ordovician). The maximum total subsidence (figure 23) reached 0.2 km depth.

The difference between maximum tectonic and maximum total subsidence 0.09 km (90 m); and between maximum tectonic and minimum tectonic subsidence is 0.01 km (10 m). The difference shows a small value which most probably indicates the beginning of sedimentation in that part of studied territory.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013).

The second stage (B) throughout the time period 490 Ma (lower Ordovician) - 430 Ma (Llandovery), shows a slow increasing subsidence up to Llandovery with a subsidence rate 5.5 m/Ma. The maximum and minimum tectonic subsidence (figure 24) attain respectively 0.25 and 0.2 km while the maximum total subsidence (figure 23) reached about 0.4 km. The general convex shape of subsidence curve at this stage is in overall compatible with tectonic setting of an active margin (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents an intial stage of the active continental margin of the Baltic basin evolution (Poprawa et al., 1999).

The following subsidence stage (part C) is represented throughout the time period 430 Ma Early Silurian) – 400 Ma (lower Devonian). Subsidence curves show a rapid increase with the minimum tectonic subsidence attaining 0.4 km while maximum tectonic subsidence (figure 24) reached 0.6 km with subsidence rate 20 m/Ma; and maximum total subsidence (figure 23) 0.9 km. The difference between maximum and minimum tectonic subsidence comprises 0.2 km (200 m); between maximum tectonic and maximum total subsidence is 0.3 km (300 m). The differential value between maximum tectonic subsidence and maximum total subsidence is slightly high compared to the first part and, indicates higher rate of infilling basin with sediments. The general concave shape of the subsidence curves at this stage is in overall compatible with climax of an active continental margin (Allen and Allen, 2013)

The fourth subsidence stage (part E) from the lower Devonian (400 Ma) up to Triassic – Jurassic boundary (240 Ma), shows an uplift during Carboniferous (360 Ma). The minimum and maximum tectonic subsidence reach respectively 0.4 and 0.65 km; Maximum total subsidence (figure 23) equals 1.2 km. The difference between minimum and maximum tectonic subsidence is 0.25 (250 m). The differential value is medium high suggesting more or less high rate of infilling basin with sediments in that part of the studied area.

The remaining subsidence stage (part F), throughout Jurassic up to Quaternary, the subsidence curves show a relatively constant trend of subsidence suggesting an extreme lower rate of infilling basin with sediments, with a general subsidence shape indicating a tectonic setting of a tilted extensional stage of the Baltic basin (Šliaupa et al. 1997).

- **<u>Subsidence analyses based on well Sutkai-86 data</u>**

Period	Cm	O	S	D	C	P	T	J	K
Age (Ma)	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

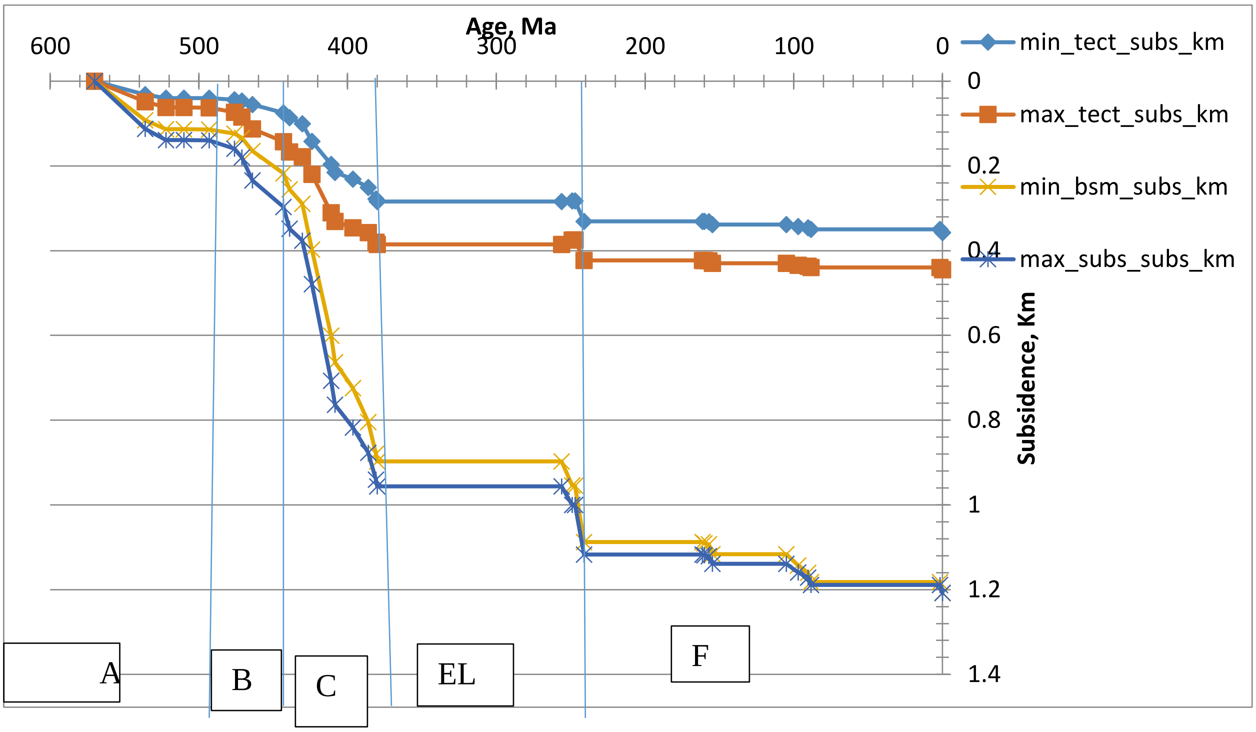

Fig 25: Subsidence curves from Sutkai - 86 well: pink line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; yellow line - minimum total subsidence and blue line - maximum total subsidence.

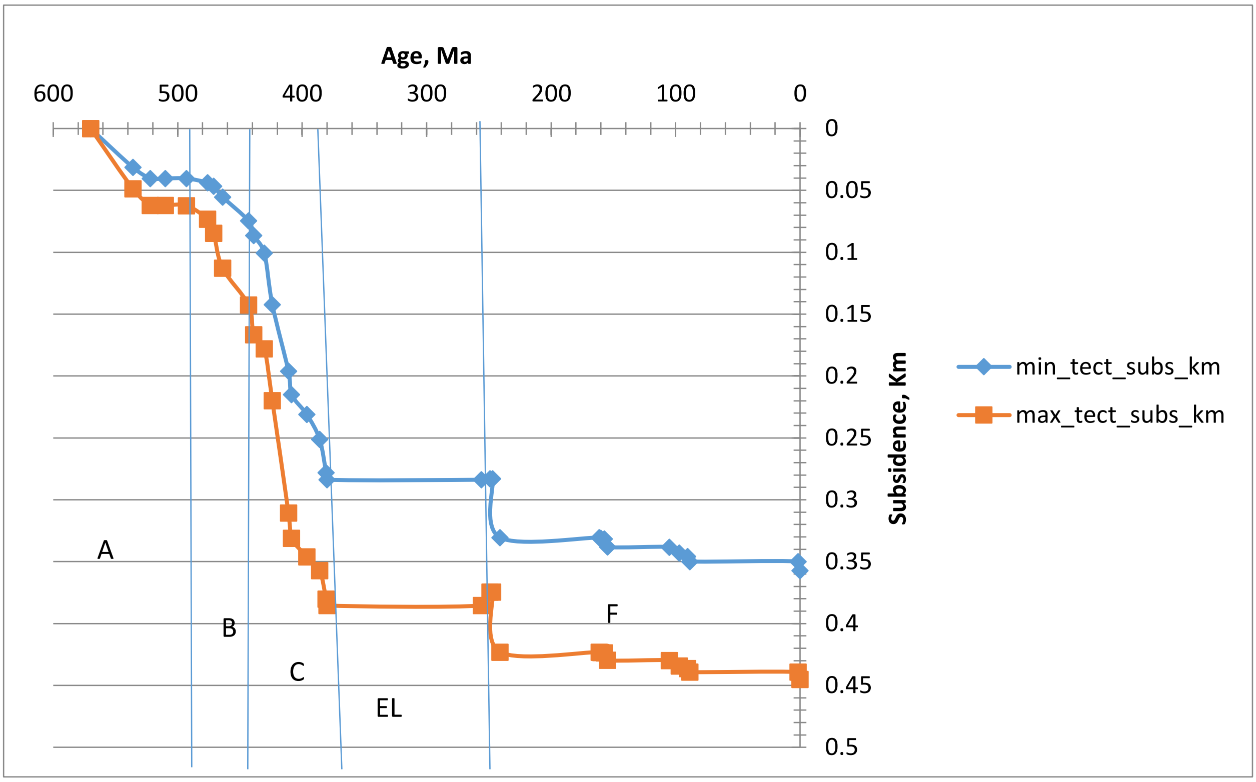

Figure 26: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line)

Well Sutkai-86 is located in the West-Central part of the studied territory of the Baltic Basin (Figure 7). Backstripping results from the Sutkai-86 well show different stages of the subsidence history in that part of the Baltic basin. The first part (A) demonstrates that after the origin of basin the Cambrian times, subsidence was rapid until 540 Ma corresponding to Middle Cambrian period with subsidence rate 1.6 m/Ma followed by a decrease up to 490 (lower Ordovician) (figure 25); maximum tectonic and minimum tectonic subsidence attain respectively 0.07 km and 0.05 km (figure 26) by 490 Ma; and maximum total subsidence reaches 0.18 km (figure 25). The difference between maximum tectonic and minimum tectonic subsidence is 0.02 km (20 m), and the difference between maximum total and maximum tectonic subsidence is 0.11 km (110 m). The low differential value between maximum and minimum tectonic subsidence suggests the beginning stage of infilling basin with sediments. The general concave shape of the subsidence at this stage is in overall compatible with the tectonic setting of a passive continental margin of a sedimentary basin (Allen and Allen, 2013).

The second subsidence stage (part B) is represented throughout the time period 490 Ma lower Ordovician) – 443 Ma (Upper Ordovician). An increasing subsidence is observed, with minimum and maximum tectonic subsidence reaching respectively 0.1 km and 0.18 km (figure 26) while maximum total subsidence (figure 25) equals an approximate value of 0.4 km with subsidence rate 4.9 m/Ma. The difference between minimum and maximum tectonic subsidence is 0.08 km (80 m), and the difference between maximum total subsidence and maximum tectonic subsidence is 0.22 km (220 m). The difference between maximum and minimum tectonic subsidence shows a higher value compared to that in the passive continental margin stage suggesting high rate of sedimentation which, moreover, is confirmed from the value of sedimentation rate. The general convex shape of subsidence curves at this stage is in overall compatible with tectonic setting of an active continental margin (Allen and Allen, 2005).

The following subsidence stage (part C) throughout the period 443 Ma (Upper Ordovician) – 360 Ma (Early Carboniferous) shows a rapid increase of subsidence with maximum and minimum tectonic subsidence reaching respectively 0.28 and 0.38 km (figure 26), and subsidence rate 6.3 m/Ma, while maximum total subsidence (figure 25) is 1.15 km. The difference between maximum and minimum tectonic subsidence is 0.1 (100 m) and the difference between maximum total subsidence and maximum tectonic subsidence is 0.77 (770 m). These high subsidence difference values suggest a higher rate of infilling sediments, and also the deepening of the basin. The general concave shape of the subsidence curves is in overall compatible with tectonic setting of climax of an active continental margin (Allen and Allen, 2013).

The next subsidence stage (part EL) is represented throughout the year 380 Ma (Middle Devonian) – 243 Ma (late Triassic), shows a constant subsidence trend (tilted compressional) and hiatus represented at the Triassic – Jurassic boundary.

The last subsidence stage (part F) starting from Jurassic up to Carboniferous shows a slightly constant subsidence trends suggesting an extreme low infilling sediments in this part of studied territory. The general shape of the subsidence curves at this stage is in overall compatible with a tilted extensional evolution of a sedimentary basin (Šliaupa et al. 1997).

Subsidence curves analysis based on well Svėdasai – 252 data

Period	Ediacaran	Cm	O	S	D	C	P	T	J	K
Age(Ma)	635-580	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

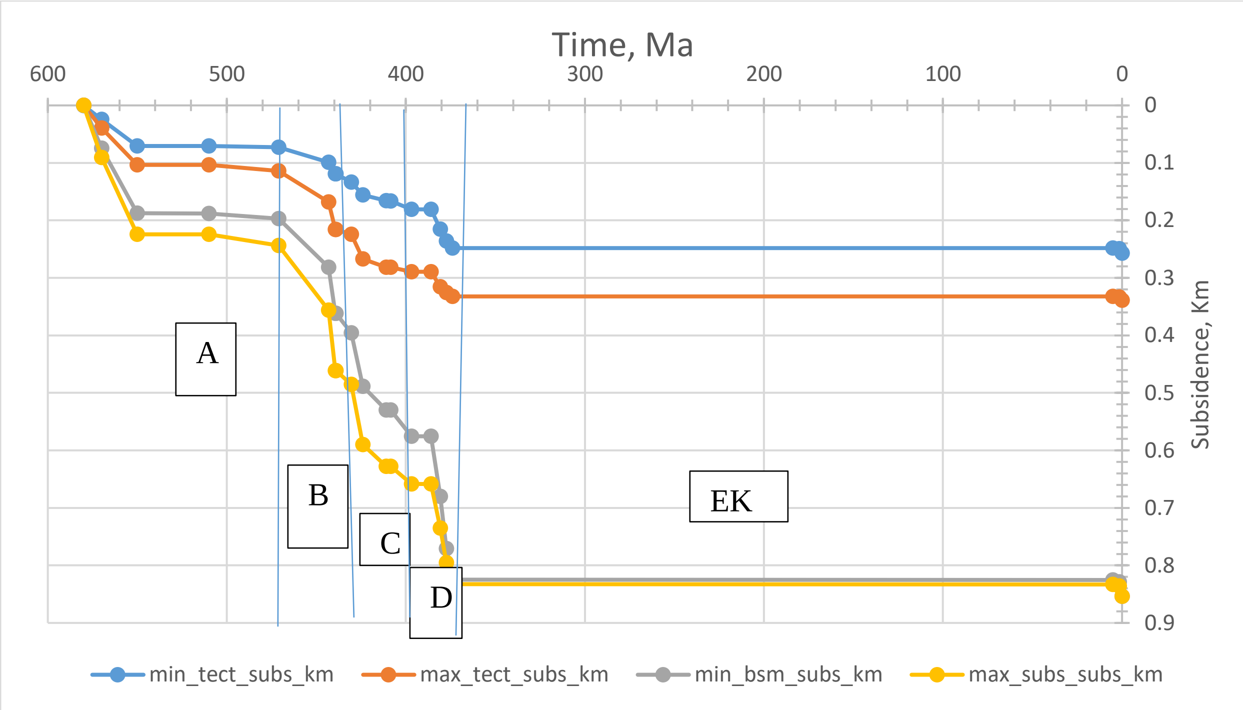

Fig 27: Subsidence curves from Svėdasai-252 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

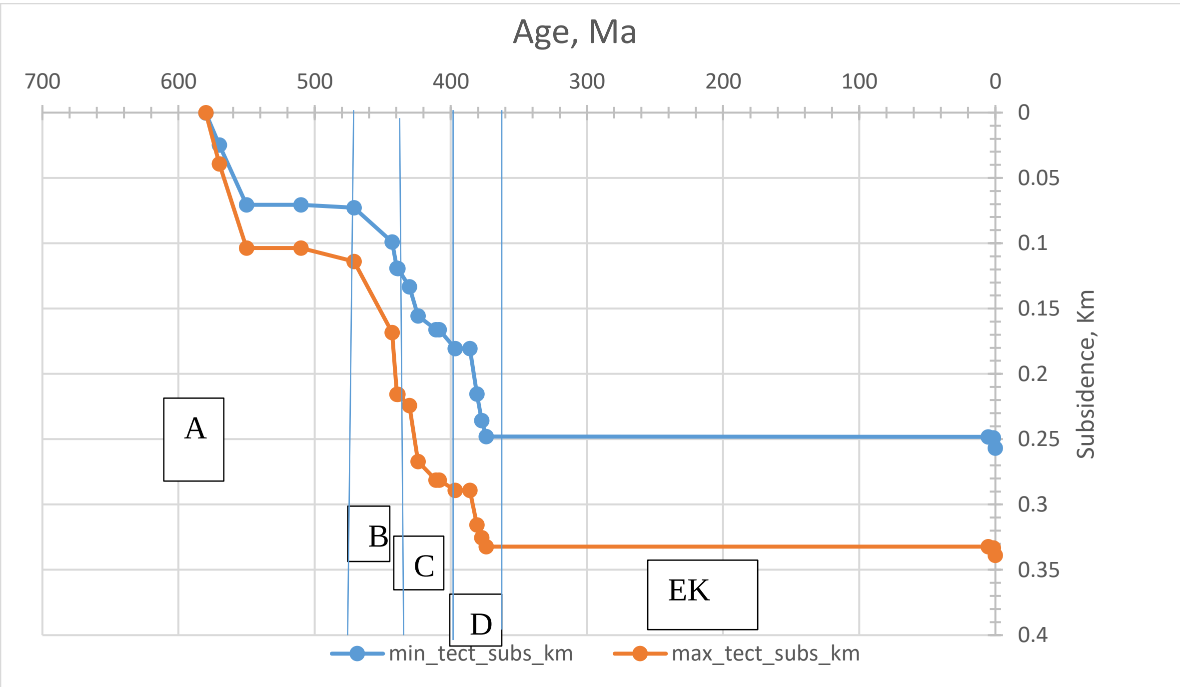

Fig 28: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from Svėdasai-252 well

Well Svėdasai-252 is located in the most Eastern part of the studied territory of the Baltic Basin (figure 7).

The backstripping results from the well Svėdasai-252 show four different stages (parts) of the subsidence history in that part of the Baltic basin (figure 27). The first part (A) demonstrates that the subsidence at the post-rift during the late Ediacaran times was rapid with the maximum tectonic subsidence reaching 0.1 km while minimum tectonic subsidence reached 0.07 km by the year 540 Ma (Middle Cambrian) with subsidence rates 1.4 m/Ma and a slow decrease of subsidence up to 510 Ma (Early Ordovician). The maximum and minimum total subsidence (figure 27) reached respectively 0.25 and 0.2 km depth by 510 Ma.

The difference between maximum and minimum total subsidence 0.05 km (50 m); and between maximum tectonic and maximum total subsidence 0.15 km (150 m). The difference shows a small value which most probably indicates the infilling stage of the basin with sediments.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin stage of sedimentary basin (Alen and Allen, 2013) and, considering the history of the Baltic basin, most probably represents a passive margin.

The second subsidence stage (B) throughout the time period 470 Ma (Middle Ordovician) - 440 Ma (Early Silurian), shows rapid increase of subsidence up to Llandovery with a subsidence rate 3.1 m/Ma. The maximum and minimum tectonic subsidence (figure 28) attain respectively 0.22 and 0.13 km while the maximum total subsidence (figure 27) reached about 0.48 km. The difference between maximum and minimum tectonic subsidence is 0.9 (900 m). The general convex shape of subsidence curves at this stage is in overall compatible with tectonic setting of an active continental margin stage (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents the initial stage of active continental margin of the Baltic basin evolution.

The following subsidence stage (part C) is represented throughout the time period 440 Ma (Llandovery) - 400 Ma (Early Devonian). Subsidence curves show a stable increase with the minimum tectonic subsidence attaining 0.18 km while maximum tectonic subsidence (figure 28) reached 0.29 km with subsidence rate 7.3 m/Ma; and maximum total subsidence (figure 27) 0.62 km. The difference between maximum and minimum tectonic subsidence comprises 0.11 km (110 m); between maximum tectonic and maximum total subsidence is 0.33 km (330 m). The differential value between maximum tectonic subsidence and maximum total subsidence is lower compared to that of part B and, most probably indicates less basin infilling compared to part B. The general convex shape of subsidence curves is in overall compatible with tectonic setting of climax of an active margin (Allen and Allen, 2013).

The following subsidence stage (part D) throughout 400 Ma (Early Devonian) – 362 Ma (Middle Carboniferous) shows more or less rapid increase of subsidence, with a general convex shape characteristic of an intracratonic centered basin (Allen, 2013). The maximum and minimum tectonic subsidence attain respectively 0.33 km and 0.25 km depth (Figure 28), with subsidence rate 8.3 m/Ma.

The last subsidence stage (part EK) shows the subsidence in form of plateau, thereby a lack of strata, visibly strong lack of sedimentation since the late Carboniferous up to Quaternary in that part of Baltic basin.

- **<u>subsidence curves analysis based on well Ukmergė-10 data</u>**

Period	Ediacaran	Cm	O	S	D	C	P	T	J	K
Age(Ma)	635-580	570-521	521-443.1	443.1-410	410-362.5-	362-356.1	356.1-249	249-243	243-154.7	105-74

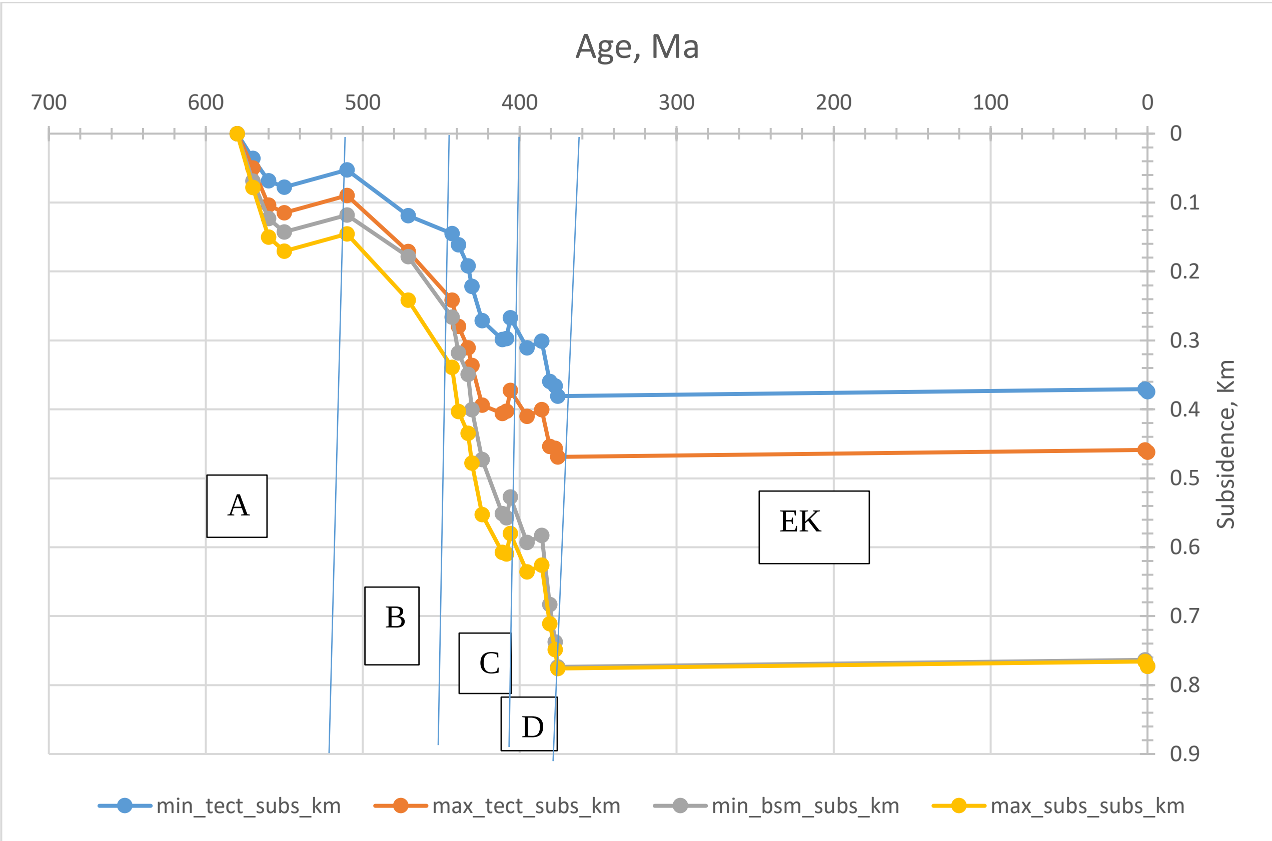

Fig 29: Subsidence curves from Ukmergė-10 well: blue line - minimum tectonic subsidence; orange line - maximum tectonic subsidence; grey line - minimum total subsidence and yellow line - maximum total subsidence.

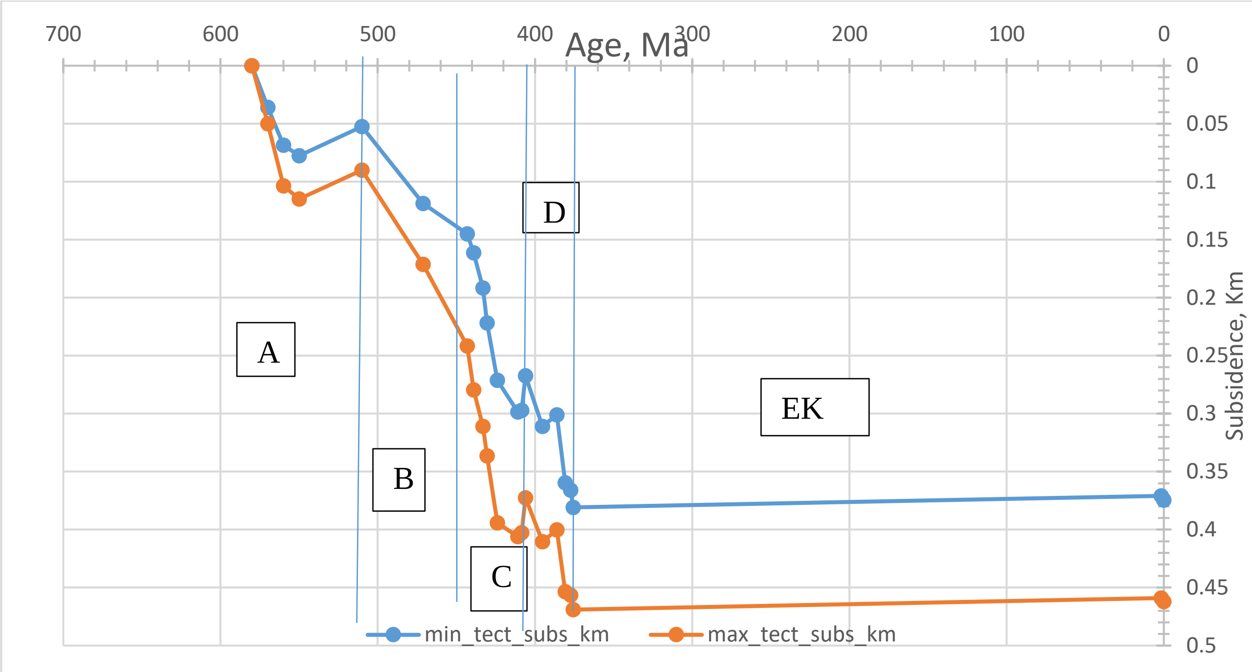

Fig 30: Maximum tectonic subsidence (orange line); and minimum tectonic subsidence (blue line). Results from Ukmergė-10 well.

Well Ukmergė-10 is located in the central part of the studied territory of the Baltic basin (eastern Lithuania) (figure 7).

The backstripping results from well Ukmergė-10 show five different stages (parts) of the subsidence history in that part of the Baltic basin (figure 30). The first part (A) demonstrates that the subsidece at the post-rift late Ediacaran times was rapid with the maximum tectonic subsidence reaching 0.12 km while minimum tectonic subsidence reached 0.08 km by the year 550 Ma (Ediacaran period) with subsidence rates 1.4 m/Ma and a slow decrease of subsidence up to 510 Ma (early Ordovician). The maximum total subsidence (figure 29) reached 0.19 km depth.

The difference between maximum tectonic and maximum total subsidence 0.07 km (70 m); and between maximum tectonic and minimum tectonic subsidence is 0.04 km (40 m). The difference shows a small value which most probably indicates a rather moderate infilling stage of the basin with sediments.

The general concave shape of the subsidence curves at this stage is in overall compatible with tectonic settings of a passive continental margin sedimentary basin (Alen and Allen, 2013).

The second stage (B) throughout the time period 510-440 Ma (early Ordovician up to Llandovery), shows an increasing subsidence up to Llandovery with a subsidence rate 3.6 m/Ma. The maximum and minimum tectonic subsidence (figure 30) attain respectively 0.25 and 0.15 km while the maximum total subsidence (figure 29) reached about 0.34 km. The general shape of subsidence curve at this stage is in overall compatible with tectonic setting of an active continental margin stage (Allen and Allen, 2013) and, considering the history of Baltic basin, most probably represents an active continental margin stage of the Baltic basin.

The following subsidence stage (part C) is represented throughout the time period 440 Ma – 400 Ma (Llandovery – Lower Devonian). Subsidence curves show a rapid increase with the minimum tectonic subsidence attaining 0.3 km while maximum tectonic subsidence (figure 30) reached 0.4 km with subsidence rate 10 m/Ma m/Ma; and maximum total subsidence (figure 29) 1.5 km. The difference between maximum and minimum tectonic subsidence comprises 0.1 km (100 m); between maximum tectonic and maximum total subsidence is 1.1 km (1100 m). The differential value between maximum tectonic subsidence and maximum total subsidence is high enough compared to the first part and, indicates high rate of infilling basin. The general shape of the subsidence curves at this stage is in overall compatible with Climax of an active continental margin stage (Allen and Allen, 2013)

The fourth subsidence stage (part D) is represented throughout the time period 400 Ma – 362 Ma corresponding to Devonian period. The minimum and maximum tectonic subsidence reach respectively 0.38 and 0.47 km with subsidence rate 11.8 m/Ma; Maximum total subsidence (figure 29) equals 0.78 km. The difference between minimum and maximum tectonic subsidence is 0.09 (90 m); between maximum total subsidence and maximum tectonic subsidence 0.31 km (310 m). This slightly high differential value suggests a high rate of ongoing sedimentation in this part of the studied area. The general shape of subsidence curves at this stage is in overall indicative of an intracratonic centered basin (Allen and Allen, 2013) and, considering the history of the Baltic basin, most probably represents an intracratonic centered basin Poprawa et al., 1999).

The remaining subsidence stage (part EK), throughout Carboniferous up to Quaternary, the subsidence curves show a constant evolutionary trend, demonstrating a lack of strata.

Summary of the results

The subsidence curves reconstructed in this study, and characteristics of the Baltic basin evolution have demonstrated instability in terms of the subsidence trends and sedimentation rates since the Ediacaran – Cambrian times throughout the Quaternary period. The table 1 shows the summary of these subsidence rates during the Paleozoic in the westernmost situated wells, the table table 2 presents subsidence rates of central part representing wells, the table 3 shows subsidence rates of the eastern wells, while the table 4 shows the different subsidence depths recorded from all the wells by the Quaternary period. Table 5 is a summary of difference between maximum total subsidence and maximum tectonic subsidence calculated for three wells located in western, central and eastern parts during first tree stages of the Baltic basin evolution. In the table 6, difference values between maximum total subsidence and maximum tectonic subsidence of all the wells recorded from the Quaternary period are summarized.

Statistically, the wells located in the western part of the studied territory Baltic basin show highest minimum and maximum tectonic subsidence depths, and maximum total subsidence depths values (table 4). The subsidence rates in the western part of the study area, compared to those in the central and eastern demonstrate highest subsidence rates during the most of the basin evolutionary stages.

Table 1: Summary of subsidence rates recorded from western wells during different stages of the Baltic basin development

Western Wells	**E6-1**	**E7-1**	**Tūbausiai-1**	**Žūtautai-1**	**Renava-1**	**Šilute-1**	**Stages**
Subs rate (m/Ma)	4	5.6	6.7	6.6	5.7	3.8	Passive Margin
Subs rate (m/Ma)	6.4	9.5	18.8	5.3	13.3	6.5	Active margin
Subs rate (m/Ma)	19.5	16.3	20	20	17.5	20	Climax

Furthermore, the difference between maximum tectonic subsidence and maximum total subsidence for three selected wells from the western, central and eastern part of the basin shows highest differential values in the west during the passive continental margin stage, active continental margin stages and the climax of active continental margin stage (table 5). Most evidently, the widening of the Baltic basin has created much more accommodation space for infilling sediments with west – east orientation.

Table 2: Subsidence rates recorded from the central wells during different stages of the Baltic basin development.

Central wells	**Sutkai-86**	**Vilkaviškis-127**	**Stačiūnai-8**	**Stages**
Subs rate (m/Ma)	1.6	2.5	3.2	Passive margin
Subs rate (m/Ma)	4.9	5.5	3.5	Active margin
Subs rate (m/Ma)	6.3	20	20.5	Climax

Table 3: Subsidence rates recorded from the eastern wells during different stages of the Baltic basin development.

Eastern wells	**Ukmergė-10**	**Svėdasai-252**	**stages**
Subs rate (m/Ma)	1.4	1.4	Passive c. margin
Subs rate (m/Ma)	4	3.1	Active c. margin
Subs rate (m/Ma)	10	7.3	Climax of active c. Margin

Table 4: Minimum tectonic, maximum tectonic, and maximum total subsidence recorded by Quaternary from selected represented wells.

Wells	**Minimum tectonic subsidence (m)**	**Max tectonic Subsidence (m)**	**Maximum total subsidence (m)**
E6-1	800	1000	1800
E7-1	720	920	1720
Žūtautai-1	860	1120	2300
Tūbausiai-1	900	1100	2000
Renava-1	800	960	1840
Šilute-1	860	1080	2100
Sutkai-86	*350*	*440*	*1200*
Vilkaviškis-127	*560*	*680*	*1320*
Stačiūnai-8	*640*	*800*	*1480*
Ukmergė-10	370	460	760
Svėdasai-252	250	330	840

Table 5: Differential values between maximum total subsidence and maximum tectonic subsidence of three different wells from the three parts of the studied territory (Western, Central and Eastern).

Wells	**E6-1**	**Stačiūnai-8**	**Ukmergė-10**	**Stages**
Difference between maximum total subsidence and maximum tectonic subsidence (m)	100	90	80	Passive c. Margin stage
Difference between maximum total subsidence and maximum tectonic subsidence (m)	120	100	100	Active c. Margin stage
Difference between maximum total subsidence and maximum tectonic subsidence (m)	720	400	200	Climax of active c. Margin stage

Table 6: summary of all calculated difference values during all the basin stages by Quaternary period

Wells	**Difference between maximum total subsidence and maximum tectonic subsidence (m)**
E6-1	800
E7-1	800
Žūtautai-1	1180
Tūbausiai-1	900
Renava-1	880
Šilute-1	1020
Sutkai-86	760
Vilkaviškis-127	640
Stačiūnai-8	680
Ukmergė-10	300
Svėdasai-252	510

4. Discussions

The analysis of the subsidence curves constructed from the actual reference wells data has aided to reveal different stages of the Baltic basin evolution, comprising passive continental margin stage, active continental margin stage, climax of active continental margin stage, intracratonic centred basin stage and tilted extensional and compressional stage corresponding to the previously defined geodynamic stages (Šliaupa et al., 1997). These stages of the Baltic basin were driven by different geodynamic factors (Poprawa et al., 1997, 1999).

<u>Passive continental margin stage (Ediacaran – Early Ordovician)</u>

The establishment of the Baltic basin followed the cessation of intense igneous activity coupled with lithospheric extension leading to rift – related basin and inversion of basin to adjacent platform areas involving the eastern part of Baltic basin areas (Šliaupa et al., 1997). The sedimentation trespassed the limits of rift depression and started to gradually widen related to the steffening of the lithosphere of the rifted basins that caused involvement of the adjacent platform areas to the subsidence due to continuing extension, sedimentary and thermal loading (Šliaupa et al., 1997). Furthermore, analysis from Late Ediacaran and lowermost Cambrian deposits of the southeast Lithuania had revealed a weak tectonic activity of the north-south and west-east orientation (Poprawa et al., 1999).

The major driving mechanisms of the subsidence of the Baltic basin during Paleozoic include extension, sedimentary and thermal loading (Poprawa et al., 1999). The changing geodynamic evolution of the Baltic basin seen from the subsidence results can be explained as related to the changing geodynamic factors. For instance, in the earliest evolution of the Baltic basin, which was a post - rift related, the basin was driven by thermal sag, lithosphere extension followed by deceleration of subsidence with changes in sedimentation pattern (Poprawa et al., 1999).

In all studied cases (studied wells), it can be seen that, throughout the Ediacaran – Middle Cambrian period, the backstripping results show an initial rapid subsidence with subsidence rate 4 m/Ma followed by a relative decrease of subsidence rate. The possible explanation of that is not only due to the post – rift expansion coupled with breakup of the Rodinia supercontinent, but also, the stage marked the beginning of sedimentation. Moreover, earlier investigations of the Baltic basin had proven a limited sedimentation during the Cambrian related to the rifting of the Tornquist sea to the west part from the Baltic basin (Šliaupa et al., 1997).

This relative change of subsidence trend (initial rather rapid followed by decreasing subsidence) in this passive continental margin stage could also be related to the decrease of the lithosphere extension contributing to the complete establishment of the Baltic basin by Early - Middle Cambrian. Indeed, one of the examples is seen from the backstripping results of well Stačiūnai-8 with maximum tectonic subsidence reaching 0.12 km (120 m) with subsidence rate 2.5 m/Ma after the rapid stage followed by decreased with the same tectonic subsidence 0.1 km (100 m) and subsidence rate 2 m/Ma.

Ordovician – Silurian period

The backstripping results show high subsidence rate during the Late Ordovician period compared to the late Cambrian development of the basin suggesting an activation of a new geodynamic situation in the Baltic basin. The time period marked an increased influence of orogenic formation on sedimentary-lithological structural processes at the platform margin (Poprawa et al., 1999). Therefore, orogenic systems advancement had affected the Baltic basin formation during Ordovician times identified as initial part of the active continental margin stage, causing the deepening of the basin from the west (Poprawa et al. 1999, Lazauskiene et al., 2002).

Orogenic effects were some of the predominent factors that contributed in changing geodynamic setting of the basin during the Ordovician time to an active continental margin. This change has been recorded in all the studied wells (represented in this study by letter B in the subsidence curves). Furthermore, previous studies had revealed that an event of lithosphere faulting occurred during Ordovician, which contributed in shaping Baltic Ordovician basin formation and subsidence trends (Poprawa et al., 1999).

The early Silurian period marked the most rapid and deep evolution of the Baltic basin development driven by the lithosphere flexuring (Šliaupa et al., 1997). Consequently, the rate of the tectonic subsidence was higher than that of the above-mentioned stages. For instance, in the Eastern well Svėdasai – 252, the tectonic subsidence rate values are respectively in the stages A, B, and C, 1.4 m/Ma, 3.1 m/Ma and 7.3 m/Ma; whilst for the westernmost well E7-1 representing the western part of the central part of the Baltic basin the subsidence rates are respectively for the stages A, B and C equal 5.6 m/Ma, 9.5 m/Ma and 16.3 m/Ma and, for the central well Sutkai-86 the subsidence rate for the stages A, B and C are respectively 1.6 m/Ma, 4.9 m/Ma, and 6.3 m/Ma.

The profoundly increased subsidence since the Late Ordovician which characterizes climax of an active continental margin stage (part C in subsidence curves) development was associated with the increasing influence of converging orogenic systems (Šliaupa et al., 1997, Poprawa et al., 1999; Lazauskiene et al., 2002). The subsidence rate at this stage is high and comprises 20.5 m/Ma in the well Stačiūnai-8.

Devonian – Carboniferous period

The subsidence pattern which was highest in Silurian decelerated during Devonian in the Baltic basin just as it can be seen from the backstripping results. In all studied wells, Devonian evolution of the Baltic basin is represented by the letter D in the subsidence curves (400 Ma up to 360 Ma), which has been interpreted as the intracratonic centred basin stage with still increasing subsidence according to the previous interpretations on the evolution of the Baltic basin (Poprawa et al., 1999), and also based on the dynamic topography of the subsidence. The subsidence of such type of basin evolution is in most cases a result of thermal cooling due to the thermal perturbation of the thick lithosphere (Haxby et al. 1976) and subsidence due to the ceasing of negative ‘dynamic topography’ (Lazauskiene et al., 2002). Negative topography is the topography resulting from the transmission to the earth’s surface of stresses caused by large – scale mantle flow (Liu et al., 1979, Middleton, 1989).

The intracratonic period marked a new phase of subsidence which started in the Pragian time with a low (in this case low dynamic topography) subsidence trend (Poprawa et al., 1999). Tectonic subsidence trends changed during Givetian and Early Frasnian which were associated with changes in sedimentation. The late Famennian decrease of subsidence might have been driven by regression of sea level and shallowing of the Baltic basin development transiting to the Carboniferous period (Poprawa et al., 1999).

Previous studies have shown that, in some areas of the Baltic basin, geological section is strongly incomplete (Paškevičius, 1997), and this hiatus is well recorded in the initial documentation of wells‘ sections where the sediments from the age Carbniferous are missing.

Starting from Carboniferous throughout Quaternary, the Carboniferous as well as the overlying of the Mesozoic sediemnts in offshore wells E6-1 and E7-1, and the eastern wells Ukmergė-10, and Svėdasai-252, Stačiūnai-8 are missing. This might suggests that from the Carboniferous period, the sedimentation rate in the Baltic basin was extremely low in some areas in the central part of the Baltic basin or simply there was no sediment deposition. Previous studies have shown that, in some areas of the Baltic basin, geological section is strongly incomplete and, in the initial document of the well, the sediments from the age Carboniferous are missing (Paškevičius, 1997).

Subsidence trend in well Vilkaviškis-127 best representing the southwestern part of the studied part of the basin shows a slight uplift event during Carboniferous suggesting probably the starting point of the Carboniferous uplift (figure 23) in the central part of the studied area.

Late Carboniferous – Quaternary period

Starting from the end of Carboniferous up to the late Triassic, the subsidence curves of wells Sutkai-86, Žūtautai-1, Renava-1 show an extensional characteristic (Šliaupa, 1997) (F in the subsidence curves), a trend of tectonic subsidence particuar for a tilted extensional basins stage. Therefore, the tilted extensional development of the Baltic basin was mostly affecting the western and central region of the studied territory, and suggesting most intense thermal sag in the area by the Late Carboniferous (in general, thermal sag is one of the most known driven factors of a tilted basin development).

The Early Jurassic period marked a different basin evolution stage (represented by letter EL in the subsidence curves of wells Vilkaviškis-127, Sutkai -86, Renava-1, Žūtautai-1, Šilute-1 and Tūbausiai-1, all of them located in the western and central parts of the studied territory (figure 7). This period has been identified as tilted compressional stage resulted from oscillating tectonic regime (Poprawa, 1999).

CONCLUSIONS

1. Different subsidence trends of the central part of the Baltic basin have been revealed based on subsidence analysis of 11 reference wells indicating the changing dynamics in subsidence and sedimentation rates throughout the time period from the Late Ediacaran to Quaternary, with the particular focus to Paleozoic period Era. Moreover, the subsidence trends have given insights on the influence of tectonic mechanisms and factors of sedimentary load on the total subsidence through the Baltic basin‘s evolution.

2. The interpretation of subsidence trends allowed to distinguish passive continental margin stage, active continental margin stage and climax of active continental margin stage of the basin evolution in all studied wells. The other stages such as intracratonic, tilted extensional and compressional basin stages are not observable in all the studied wells. Possibly, this could be due to the fact that some sections are not full, and thus, there were no actual well data to reconstruct with confidence the tectonic evolution of the basin in the area of interest. The different geodynamic stages identified are interpreted as related to different tectonic setting evolving in the Baltic basin formation.

3. The Late Ediacaran – Early Cambrian period was described with rapid initial subsidence on an average of 0.2 km (200 m) followed by a subsidence deceleration 0.16 km (160 m) leading to the establishment of the passive continental margin stage by the Early Ordovician period. However, in some northwestern wells such as Šilute-1 and Renava-1, the initial subsidence was not so dicernably rapid (average maximum tectonic subsidence 0.16 km) indicating on the difference of the tectonic mechanisms.

4. The comparisons made from the subsidence rates of the passive continental margin stage, active continental margin stage and the climax of active continental margin stage have shown decreasing subsidence rates from the West to the East. Possibly, this suggests that the central Baltic basin evolved from the west to the east .

5. The calculated difference between maximum tectonic subsidence and maximum total subsidence of all the basin stages has given insights on the influence of sedimentary load in the total basin‘s subsidence, changing in a range of 800 m – 1020 m in the western part; to 640 m – 760 m in the central part of the study area, and in a range of 300 m - 510 m in the eastern part. This suggests higher sedimentation occurence in the western part of the studied territory, consequently implying the widening of the basin West – East orientation, as more accomodation space was created in the west. The subsidence curves show the deepest subsidence during Silurian time pointing with a particular accent on that period characterized by a high tectonic activity due to the flexuring of lithosphere, creating high accomodation space.

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SUMMARY

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Analysis of the subsidence trends in the central part of the Baltic basin (Lithuania).

The masters thesis research is aimed to reconstruct subsidence trends of the central part of the Baltic basin, with focuse mainly on the Lithuanian territory, by adopting backstripping methodology to construct and analyze subsidence curves to get insights of basin‘s geodynamic evolution.

In total, the work consisted in 4 differnt chapters:

The work overviewed the geological and tectonic setting, and the previous investigations in the Baltic basin. A description of the geological structure and the geodynamic evolution of the area of interest were performed to situate the general view of the study domain.

The second chapter focused on the methodological part, including general procedure of backstripping methods, and, more importantly, the procedure applied in this thesis, such as input files preparation from the actual well data and subsidence curves construction from the backstripped results.

A thorough analysis and interpretation of the subsidence curves were performed considering the different trends distinguishable from the curves, and all the findings were summarized in 6 different tables.

The summarizing chapter was dedicated to the discussions part which consisted in structuration of the Baltic basin evolution throughout different stratigraphic period of times.

In clear, the masters thesis research provided insights on the Baltic basin subsidence evolution going from the passive continental margin stage, active continental margin stage, climax of the active continental margin stage, intracratonic centred basin stage, tilted extensional and compressional basin stages. The Carboniferous uplift wasn‘t observed in all the studied wells. During early Carboniferous – Permian period, a regression of the basin was noted in the latter part of Famennian time. The western and southern parts of the basin were high uplifted.

Moreover, the sedimentation rates calculated had shown highest values from the westernmost wells including the Latvian offshore wells, and the lowest sedimentation rates were found in the eastern part of the area of consideration.

The calculated difference values between maximum total subsidence and maximum tectonic subsidence have shown higher values from wells located in the western part of the studied area,

leading to conclude that the widening of the basin was predominantly west – East orientatation, with higher accommodation space created in the west compared to the central and eastern parts.

Baltijos nuosėdinio baseino centrinės dalies (Lietuvos teritorijos) grimzdimo analizė.

Magistro baigiamojo darbo tikslas – rekonstruoti centrinės Baltijos baseino dalies, daugiausia dėmesio skiriant Lietuvos teritorijai, grimzdimo tendencijas, taikant ‘‘backstripping“ metodiką grimzdimo duomenims gauti ir grimzdimo kreivėms sudaryti bei analizuoti, siekiant gauti įžvalgų apie baseino geodinaminę evoliuciją.

Iš viso darbas susidėjo iš 4 skirtingų skyrių:

Darbe apžvelgta geologinė ir tektoninė tiriamosios Baltijos baseino dalies sandara bei ankstesni tyrimai Baltijos baseine: buvo aprašyta tiriamos teritorijos geologinė struktūra ir geodinaminė evoliucija.

Antrajame skyriuje daugiausia dėmesio skirta tyrimų metodikai, įskaitant bendrą grįžtamojo’’backstripping“ metodų procedūrą ir, svarbiausiai, šiame darbe taikytus metodus ir procedūras, t.y., įvesties failų parengimą pagal faktinius gręžinių duomenis ir grimzdimo kreivių sudarymą iš suskaičiuotų ’’backstripping“ duomenų.

Darbe buvo atlikta išsami grimzdimo kreivių analizė ir interpretacija, išskiriant į skirtingas grimzdimo tendencijas, kurias galima buvi išskirti grimzdimo kreivėse, interpretacijos rezultatai buvo apibendrinti 6 skirtingose lentelėse.

Apibendrinamasis skyrius buvo skirtas platesnėms diskusijoms, kuriose buvo nagrinėjama Baltijos baseino grimzdimo ir geodinaminė evoliucija skirtingais geologiniais laikotarpiais.

Magistro darbas leido suformuoti įžvalgas apie tirtos centrinės Baltijos baseino dalies grimzdimo evoliuciją, pradedant nuo pasyvaus kontinentinio pakraščio etapo, toliau išskiriant aktyviaus kontinentiniopakraščio etapą, aktyvaus kontinentinio pakraščio kulminacinio etapą, intrakratoninio centrinio baseino etapą, tempimo ir suspaudimo baseinų etapus. Karbono laikotarpio kilimas nebuvo identifikuotas visuose tirtuose gręžiniuose. Ankstyvojo karbono – permo laikotarpio baseino regresija buvo vėlyvojoje fameno laikotarpiu, o vakarinė ir pietinė Baltijos baseino dalys buvo liškilusios.

Apskaičiuoti sedimentacijos greičiai parodė didžiausias vertes vakarinėje dalyje išsidėsčiusiuose gręžiniuose, įskaitant Baltijos jūros Latvijos akvatorijoje esančius gręžinius, o mažiausi sedimentacijos greičiai buvo nustatyti rytinėje nagrinėjamos teritorijos dalyje. Apskaičiuotos skirtumo tarp maksimalaus bendro grimzdimo ir maksimalaus tektoninio grimzdimo duomenys parodė didesnes vertes gręžiniuose, esančiuose vakarinėje tiriamos teritorijos dalyje, o tai leidžia daryti išvadą, kad Baltijos baseino plėtimasis vyko vakarų-rytų kryptimi, o vakaruose dėl

aktyvesnio grimzdimo susidarė daugiau erdvės nuosėdų akumuliacijai, palyginus su centrine ir rytine tirtos Baltijos baseino centrinės teritorijos dalimis.

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APPENDICES

Appendix 1. Backstripping data for the compilation of subsidence curves.

1. Well E6-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.7796	0.9463	1.80509	1.80507
1.6	0.77922	0.94616	1.80405	1.80447
362.5	0.80921	0.97616	1.83398	1.83443
367	0.78044	0.9511	1.75243	1.78068
372	0.74274	0.91475	1.65683	1.70512
374	0.71298	0.87602	1.60834	1.65522
377.4	0.69298	0.85603	1.55029	1.60584
380.8	0.67104	0.83232	1.44369	1.51414
386	0.59096	0.74898	1.28571	1.36549
386.5	0.60095	0.75897	1.29564	1.37543
396.3	0.55698	0.70986	1.17092	1.25683
396.8	0.60697	0.75986	1.22085	1.30678
408.5	0.62291	0.76655	1.19047	1.27391
411	0.56604	0.698	1.02784	1.11311
424	0.46155	0.58349	0.75284	0.84381
430.4	0.35763	0.47435	0.59537	0.68597
439	0.25014	0.37345	0.45219	0.55126
443.1	0.22035	0.3316	0.39503	0.48609
471.1	0.17173	0.2555	0.306	0.37595
493	0.11762	0.17735	0.22641	0.27641
522	0.14259	0.20231	0.25131	0.30131
536	0.09897	0.14499	0.15586	0.19707
570	0.00005	0.00008	0.00011	0.00013

2. Well E7-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
1.6	0.72798	0.91271	1.71536	1.71567
362.5	0.75796	0.94271	1.74529	1.74563
367	0.72527	0.91875	1.65951	1.69221

370.7	0.70338	0.8894	1.59654	1.64082
374	0.66165	0.82991	1.51551	1.55842
377.4	0.63948	0.80746	1.44658	1.49935
380.8	0.616	0.77773	1.33564	1.39862
386	0.52837	0.69405	1.17456	1.25165
386.5	0.53837	0.70404	1.18448	1.26159
396.8	0.49334	0.66191	1.06908	1.15849
408.5	0.54332	0.61119	1.119	1.20843
411	0.55793	0.60662	1.10518	1.19854
430.4	0.47215	0.59545	0.80016	0.88205
439	0.33547	0.45187	0.58415	0.66737
443.1	0.23861	0.35368	0.45947	0.54436
471.1	0.19846	0.31198	0.39525	0.48076
510	0.13414	0.21778	0.29736	0.35567
530	0.09097	0.13292	0.2279	0.2503
536	0.01589	0.01769	0.00275	0.00501

3. Well Tūbausiai-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.89994	1.06595	2.09208	2.09207
1.6	0.8878	1.0608	2.05022	2.06542
157	0.90777	1.08078	2.07015	2.08537
160	0.88645	1.062	2.03843	2.0594
161.3	0.8812	1.05697	2.03152	2.0532
243	0.89617	1.07195	2.04645	2.06815
247	0.84625	1.03669	1.95741	2.00371
249	0.88621	1.07667	1.99733	2.04366
256.1	0.84369	1.02349	1.93536	1.98091
362.5	0.87368	1.05349	1.96529	2.01087
367	0.84343	1.01901	1.88009	1.93623
374	0.76117	0.92974	1.72389	1.78712
377.4	0.73387	0.90487	1.63626	1.71133
380.8	0.71701	0.88767	1.55006	1.63478
386	0.62909	0.79526	1.38845	1.47831

387	0.63907	0.80525	1.39837	1.48825
396.3	0.582	0.75055	1.24469	1.34872
396.8	0.61199	0.78055	1.27462	1.37866
408.5	0.61522	0.76894	1.20054	1.29986
411	0.54748	0.68982	1.016	1.11592
424	0.40055	0.52802	0.68574	0.78549
430.4	0.32978	0.46587	0.55789	0.66931
439	0.17829	0.32457	0.3693	0.49318
439.5	0.20825	0.35457	0.3992	0.52312
443.1	0.19438	0.32654	0.35786	0.47193
463.9	0.17114	0.30036	0.31919	0.43225
471.1	0.14903	0.25371	0.27806	0.36999
476.1	0.13947	0.21799	0.25352	0.32208
493	0.08818	0.15437	0.18551	0.24342
500	0.09814	0.16432	0.1954	0.25331
510	0.08773	0.15387	0.18442	0.24236
522	0.11269	0.17881	0.20931	0.26725
536	0.07471	0.12241	0.1246	0.16815
550	0.00005	0.0008	0.00012	0.00014

4. Well Renava-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.79303	0.96647	1.87109	1.87108
1.6	0.78517	0.9659	1.83358	1.84805
154.7	0.79015	0.9709	1.83851	1.85301
161.3	0.7807	0.96251	1.81538	1.83647
243	0.79568	0.97752	1.83031	1.85143
247	0.74913	0.94433	1.75457	1.79707
249	0.78911	0.98434	1.7945	1.83703
256.1	0.74212	0.93051	1.72573	1.77187
262.5	0.7421	0.93051	1.72566	1.77182
367	0.74022	0.92485	1.66028	1.72163
374	0.67774	0.83596	1.53235	1.58567
377.4	0.64851	0.80986	1.4309	1.49973

380.8	0.63435	0.7978	1.35581	1.43504
386	0.53926	0.68972	1.1741	1.25242
386.5	0.55424	0.70471	1.18902	1.26736
396.3	0.50217	0.65311	1.04258	1.13338
396.5	0.53216	0.68311	1.07251	1.16333
408.5	0.55591	0.7085	1.0799	1.17375
411	0.52825	0.67066	0.98517	1.07761
424	0.41647	0.55063	0.73022	0.8276
430.4	0.35319	0.49442	0.61226	0.72065
439.5	0.23469	0.3836	0.45561	0.57468
442.8	0.19927	0.33037	0.37476	0.48327
471.1	0.14093	0.22479	0.27177	0.34165
510	0.13445	0.1154	0.15422	0.19052
522	0.0525	0.14033	0.17911	0.2154
536	0.05472	0.08298	0.09147	0.1167
570	0.00005	0.00008	0.00004	0.00013

5. Well Šilute-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.92061	1.08462	2.16009	2.16007
1.6	0.91098	1.07914	2.13078	2.14082
90.4	0.9497	1.10914	2.16071	2.17078
97	0.91598	1.07808	2.10392	2.12256
105	0.90295	1.06505	2.07148	2.09597
154.7	0.92294	1.08505	2.09142	2.11593
157.1	0.91407	1.07316	2.05874	2.08885
160	0.90162	1.06283	2.03104	2.06691
194.5	0.87901	1.04133	1.99234	2.03305
243	0.894	1.05633	2.00728	2.04801
247	0.82047	0.99512	1.81808	1.8911
256.1	0.77056	0.95116	1.75139	1.82999
367	0.80052	0.98111	1.7813	1.8599
374	0.74781	0.91152	1.6824	1.75448
377.4	0.73176	0.89781	1.62183	1.70301

380.8	0.72701	0.8919	1.56503	1.65198
386	0.64553	0.79898	1.41164	1.49681
386.5	0.66051	0.81397	1.42657	1.51175
396.3	0.65036	0.80019	1.34915	1.43882
408.5	0.61313	0.75508	1.17698	1.2736
411	0.50499	0.63432	0.90867	1.00613
424	0.33935	0.44671	0.5485	0.63811
430.4	0.27036	0.37804	0.42825	0.52084
439.5	0.15625	0.26368	0.28323	0.37756
442.8	0.14659	0.24741	0.26033	0.34969
471.1	0.11126	0.18003	0.20808	0.26859
510	0.08551	0.1429	0.16982	0.22019
522	0.11047	0.16785	0.19471	0.24509
536	0.07196	0.11412	0.11063	0.14938
570	0.00005	0.00008	0.00012	0.00014

6. Well Žūtautai-1

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.93772	1.13752	2.35109	2.35108
5	0.9219	1.13247	2.28088	2.30493
154.7	0.95188	1.16247	2.31081	2.33489
157.1	0.93653	1.14928	2.28496	2.31439
160	0.90471	1.12271	2.22979	2.27111
243	0.9197	1.13771	2.24472	2.28607
247	0.86553	1.10508	2.14024	2.21442
249	0.90551	1.14509	2.18017	2.25439
256.1	0.86219	1.09595	2.12396	2.19826
360	0.87218	1.10596	2.13389	2.20822
362.5	0.8905	1.12661	2.14664	2.22442
367	0.8502	1.06339	2.02949	2.11273
374	0.76807	0.97385	1.80373	1.89634
380.8	0.73949	0.94693	1.7117	1.81495
386	0.74185	0.95402	1.65524	1.77034
387	0.6357	0.83145	1.46191	1.57405

396.3	0.64568	0.83145	1.47183	1.58398
396.8	0.59554	0.84144	1.33213	1.45511
408.5	0.62552	0.79193	1.36205	1.48505
411	0.59717	0.82192	1.19728	1.32625
424	0.43364	0.78365	0.7925	0.91159
430.4	0.37339	0.5875	0.64449	0.75849
439	0.31005	0.5149	0.52141	0.63447
439.5	0.16921	0.44587	0.34676	0.46011
443.1	0.19911	0.30254	0.37661	0.48997
449.5	0.18286	0.33246	0.33218	0.43129
463.9	0.18767	0.29804	0.33156	0.4272
471.1	0.16845	0.29858	0.30284	0.39162
476.1	0.1429	0.2711	0.26164	0.33653
493	0.13839	0.2292	0.25161	0.31856
500	0.10098	0.21573	0.20522	0.25673
510	0.11094	0.1611	0.21512	0.26657
510	0.09997	0.171	0.20359	0.25465
522	0.12486	0.18443	0.22842	0.27944
536	0.07882	0.11511	0.13302	0.16511
550	0.00005	0.00008	0.00012	0.00014

7. Well Stačiūnai-8

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.62343	0.78651	1.48489	1.48485
365.9	0.65983	0.82543	1.51171	1.51681
367	0.64821	0.81112	1.48046	1.49533
374	0.56429	0.72922	1.29617	1.34016
377.4	0.5432	0.70909	1.21867	1.2763
380.8	0.50918	0.67576	1.12425	1.19446
386	0.44315	0.59784	0.9854	1.05677
386.5	0.45313	0.60783	0.99531	1.0667
396.3	0.41431	0.5725	0.90127	0.98417
396.8	0.43429	0.59249	0.92119	1.00411
406	0.34591	0.52201	0.73584	0.84845

408.5	0.37587	0.55199	0.76574	0.87838
411	0.36703	0.54496	0.73535	0.85332
424	0.32401	0.44293	0.55362	0.64085
430.4	0.20693	0.3389	0.37119	0.47731
439	0.11864	0.23108	0.24223	0.33636
440	0.1386	0.25106	0.26213	0.35629
443.1	0.13607	0.21432	0.22317	0.29072
463.9	0.11585	0.18756	0.18945	0.25247
468.8	0.11042	0.16381	0.17565	0.22261
476.1	0.10926	0.15824	0.17272	0.21577
493	0.1031	0.13869	0.15781	0.18834
510	0.05265	0.08811	0.10674	0.13722
522	0.07761	0.11303	0.13163	0.16211
536	0.05483	0.07993	0.08911	0.11094
560	0.00005	0.00008	0.00011	0.00013

8. Well Vilkaviškis-127

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.57805	0.70302	1.33638	1.33636
1.6	0.56333	0.69287	1.29559	1.30744
65	0.60332	0.73287	1.33552	1.34739
74	0.53558	0.66407	1.23607	1.25912
89.9	0.57556	0.70405	1.27599	1.29906
90.4	0.55999	0.68745	1.2543	1.27852
97	0.53965	0.66844	1.21737	1.24675
105	0.51772	0.64389	1.1744	1.20744
152.5	0.53771	0.66388	1.19433	1.22739
157.1	0.51105	0.63822	1.15207	1.18926
160	0.50688	0.63561	1.13056	1.17295
161.1	0.51187	0.6406	1.13549	1.1779
163.3	0.50211	0.62705	1.10811	1.15179
243	0.5171	0.64204	1.12304	1.16674
247	0.38196	0.5083	0.87838	0.94047
249	0.41193	0.53828	0.9083	0.97041

256.1	0.38886	0.53781	0.81241	0.89597
496.8	0.41885	0.56781	0.84233	0.92592
408.8	0.44175	0.59065	0.84701	0.93282
411	0.3934	0.53108	0.70881	0.79942
424	0.3332	0.43456	0.54032	0.61508
430.4	0.25934	0.35844	0.40889	0.48762
433	0.13682	0.2365	0.27173	0.35234
439.5	0.16679	0.26648	0.30163	0.38227
442.8	0.11903	0.21703	0.24161	0.32202
449.5	0.146	0.23816	0.2517	0.32871
450	0.14596	0.23813	0.25159	0.32863
454	0.13657	0.22617	0.23559	0.31103
463.9	0.12836	0.12836	0.22173	0.2957
471.1	0.11797	0.18923	0.19972	0.26027
493	0.05238	0.18923	0.1179	0.15273
500	0.10234	0.14425	0.16779	0.20262
510	0.0522	0.09407	0.11747	0.15227
522	0.07715	0.11901	0.14236	0.17716
536	0.06215	0.0982	0.1077	0.13915
550	0.00005	0.00007	0.00011	0.00013

9. Well Ukmergė-10

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.37453	0.46203	0.77279	0.77278
1.6	0.37084	0.459	0.76372	0.76603
375.7	0.38082	0.46899	0.77365	0.77597
377.4	0.36584	0.45651	0.73763	0.74853
380.8	0.3597	0.45361	0.68333	0.71089
386	0.30094	0.40031	0.58308	0.62584
369.3	0.31092	0.4103	0.59301	0.63579
406	0.26722	0.37255	0.52726	0.58002
408.5	0.29719	0.40255	0.55718	0.60997
411	0.29867	0.4059	0.55148	0.6075
424	0.27132	0.39402	0.47282	0.55278

430.4	0.22164	0.33631	0.40034	0.47806
433	0.19172	0.31093	0.34945	0.43493
439	0.16125	0.2796	0.31812	0.40301
443.1	0.14487	0.24163	0.26632	0.33906
471.1	0.9189	0.17118	0.17837	0.24148
510	0.05255	0.08993	0.11801	0.14559
550	0.0775	0.11487	0.1429	0.17049
560	0.0686	0.10345	0.12318	0.14989
570	0.0358	0.04991	0.06902	0.07821
580	0.00005	0.00007	0.00011	0.00012

10. Well Svėdasai-252

age_my	min_tect_subs_km	max_tect_subs_km	min_bsm_subs_km	max_subs_subs_km
0	0.37453	0.46203	0.77279	0.77278
1.6	0.37084	0.459	0.76372	0.76603
375.7	0.38082	0.46899	0.77365	0.77597
377.4	0.36584	0.45651	0.73763	0.74853
380.8	0.3597	0.45361	0.68333	0.71089
386	0.30094	0.40031	0.58308	0.62584
369.3	0.31092	0.4103	0.59301	0.63579
406	0.26722	0.37255	0.52726	0.58002
408.5	0.29719	0.40255	0.55718	0.60997
411	0.29867	0.4059	0.55148	0.6075
424	0.27132	0.39402	0.47282	0.55278
430.4	0.22164	0.33631	0.40034	0.47806
433	0.19172	0.31093	0.34945	0.43493
439	0.16125	0.2796	0.31812	0.40301
443.1	0.14487	0.24163	0.26632	0.33906
471.1	0.9189	0.17118	0.17837	0.24148
510	0.05255	0.08993	0.11801	0.14559
550	0.0775	0.11487	0.1429	0.17049
560	0.0686	0.10345	0.12318	0.14989
570	0.0358	0.04991	0.06902	0.07821
580	0.00005	0.00007	0.00011	0.00012