The Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones of the East European Craton: geomorphology, architecture of the sedimentary cover and the crystalline basement

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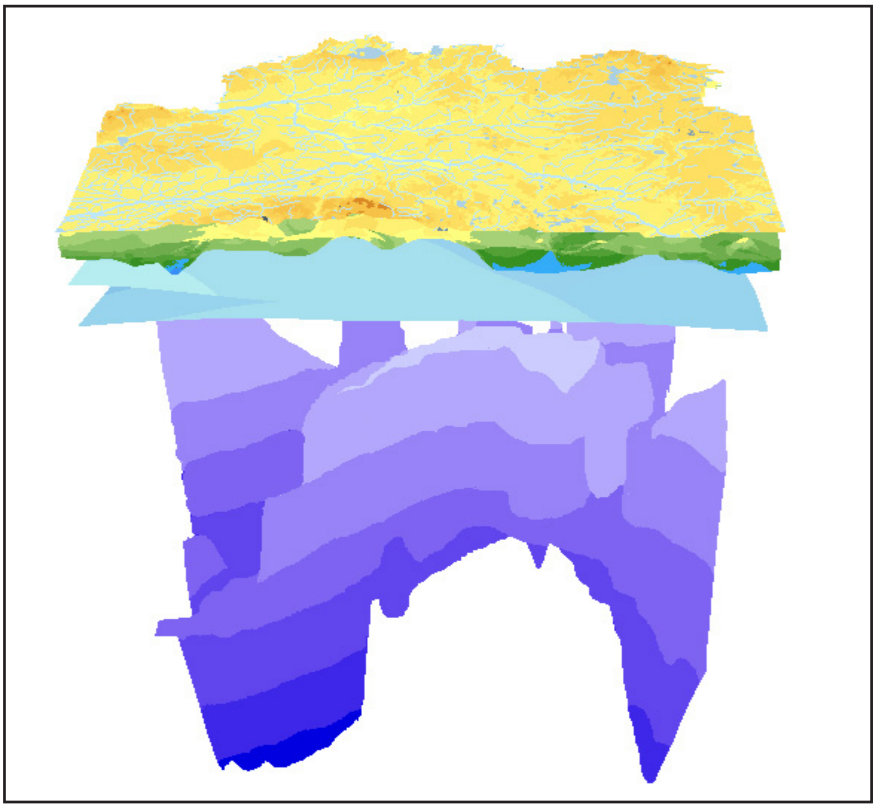

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Master Thesis
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Cover Picture: 3D models of the crystalline basement, layers of the sedimentary cover and the present topography in the Polotsk key area

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Abstract: This is a study of the influence of the crystalline basement faults of the Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones on the development of the sedimentary cover and the formation of the present topography. The purpose is to define the character and possible causes of this influence. The key target areas of this study are the Polotsk part of the Polotsk-Kurzeme Deformation Zone in northern Belarus and the eastern part of the Småland-Blekinge Deformation Zone in southeastern Sweden.

The influence of Mesoproterozoic faulting on the Paleozoic, Mesozoic, Cenozoic and recent evolutions of the Precambrian crust has been assessed using 3D reconstructions of paleosurfaces, GIS (=Geographical Information Systems) models of basement-cover correlation and topolineaments identification. The 3D upper paleosurfaces of the crystalline basement, the Ectasian-Stenian, Ediacaran, Ordovician, Devonian and Quaternary sedimentary deposits and the present landform surface for the Polotsk key area as well as the 3D upper paleosurfaces of the crystalline basement and the present landform surface for the eastern part of the SBDZ key area have been performed with ArcGis 9.1 software. A series of maps showing correlation coefficients between the upper paleosurface of the crystalline basement and all the various Phanerozoic deposits has been produced for the key target areas. We have also profiled the Quaternary deposits in the Polotsk area.

The results suggest that these deformation zones, after their first formation in the Mesoproterozoic in conjunction with orogenic processes at the southwestern margin of the East European Craton were still active during the Neoproterozoic-Phanerozoic. The tectonic activity of the Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones has had influence both on the formation of the sedimentary cover and the present topography.

Keywords: the Polotsk-Kurzeme Deformation Zone, the Småland-Blekinge Deformation Zone, GIS, fault, tectonic activity, geomorphology, sedimentary cover.

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Polotsk-Kurzeme och Småland-Blekinge deformationszonerna i den Östeuropeiska kratonen: geomorfologin samt arkitekturen av sedimenttäcket och det kristallina underlaget

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Sammanfattning: Denna undersökning rör frågan om vilket inflytande förkastningarna i de tektoniska Polotsk-Kurzeme och Småland-Blekingezonerna utövat på det överlagrande sedimenttäckets och den nutida topografins utbildning. Syftet var att bestämma karaktären av denna påverkan och dess tänkbara orsaker. De huvudsakliga undersökningsområdena utgjordes av Polotskdelen av Polotsk-Kurzeme deformationszonen i norra Vitryssland och östra delen av Småland-Blekingezonen i sydöstra Sverige.

Den mesoproterozoiska förkastningsaktivitetens inverkan på den paleozoiska, mesozoiska, kenozoiska samt recenta utvecklingen av den prekambriska jordskorpan fastställdes med hjälp av 3-D rekonstruktioner av paleoytornas lägen och GIS-modellering av topolineament och relationerna mellan underlag och sedimenttäcke. ArcGis 9.1 mjukvaran användes för att fastställa 3-D övre paleoytor for det kristallina underlaget, de ektasisk-steniska, ediakariska, ordoviciska, devonska och kvartära avlagringarna och den nutida jordytan i Polotskområdet samt den 3-D övre paleoytan för det kristallina underlaget och dagens landyta i östra delen av Småland-Blekingezonen. Dessutom sammanställdes en serie kartor som visar korrelationskoefficienterna mellan det kristallina underlagets paleoyta och alla de andra övre gränsytorna för de fanerozoiskasedimenten i de två huvudsakliga undersökningsområdena. Profilering av de kvartära avlagringarna utfördes i Polotskområdet.

Resultaten visar att deformationszonerna efter sin bildning i samband med mesoproterozoiska orogena processer vid den östeuropeiska kratonens sydvästkant fortsatte att vara aktiva även under neoproterozoikum och fanerozoikum. Den tektoniska verksamheten inom Polotsk-Kurzeme och Småland-Blekinge deformationszonerna påverkade såväl sedimenttäckets bildning som den nutida topografin.

Nyckelord: Polotsk-Kurzeme deformationszonen, Småland-Blekinge deformationszonen, GIS, förkastning, tektonisk verksamhet, geomorfologi, sedimenttäcket.

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1 Introduction

Continental topography is at the interface of processes taking place at depth in the Earth, at Earth's surface, and in the atmosphere above it. During the last 20 Ma plate-tectonic and other geodynamic processes in the Earth's interior have caused many changes in the Earth's surface topography. The impact of Solid-Earth processes on surface topography at plate boundaries has been known for several decades, but their influence in intraplate areas is only just being understood. The last studies of this problem (the EUROCORES Programme "TOPO-EUROPE" of the European Science Foundation) now recognize that there are critical feedback mechanisms between Solid-Earth processes and topography. The relationship between faults of the crystalline basement and topolineaments in the overlying cover is just one example of such feedback effects.

Combined information from topographical maps, air photographs and satellite images indicate a remarkable linear arrangement of landforms here called "lineaments". These lineaments can often be shown to be related to fault zones of the crystalline basement. A good example of this relationship is the Polotsk-Kurzeme Deformation Zone (PKDZ). The PKDZ extends from Moscow in Russia across the northern part of Belarus to Latvia and Lithuania, and its possible continuation across the Baltic Sea could be into the Småland-Blekinge Deformation Zone (SBDZ) in southern Sweden and the island of Bornholm (Denmark). This is one of the numerous fault zones in the Precambrian crust of the East European Craton, which was formed at ca. 1.5-1.4 Ga (Bogdanova et al. 2006). On the surface, the PKDZ and the SBDZ are reflected by linear landforms and by hydrography. The character of the Quaternary sediments (glaciodislocations, declining glacial and interglacial layers, changing thickness of sediments), seismic activity, emanations of radon and hydrogen, all indicate neotectonic and recent movements along these lineaments.

The PKDZ is an object of study of Belarusian, Lithuanian, Russian and Swedish geologists. However, the problems of its tectonic activity and its influence upon recent tectonics are still not solved. Thus, the main objectives of this study are: 1) to define the character and possible causes of tectonic activity of this zone during its late Precambrian and later geological history (with an emphasis to neotectonic and recent activity); 2) to reveal how the present landforms reflect this weakness zone; 3) to study Quaternary sediments in order to assess this relationship with the tectonic arrangement of this zone.

The key target areas of this study are the Polotsk part of the PKDZ in northern Belarus and the eastern part of the SBDZ in southeastern Sweden (Fig. 1). The crystalline basement in the Polotsk key area lies under a mostly thick sedimentary cover, while the present topography was formed by accumulation activity of the repeated Pleistocene glaciations over this area. The geological history of the eastern part of the SBDZ area is totally different. The thin Quaternary

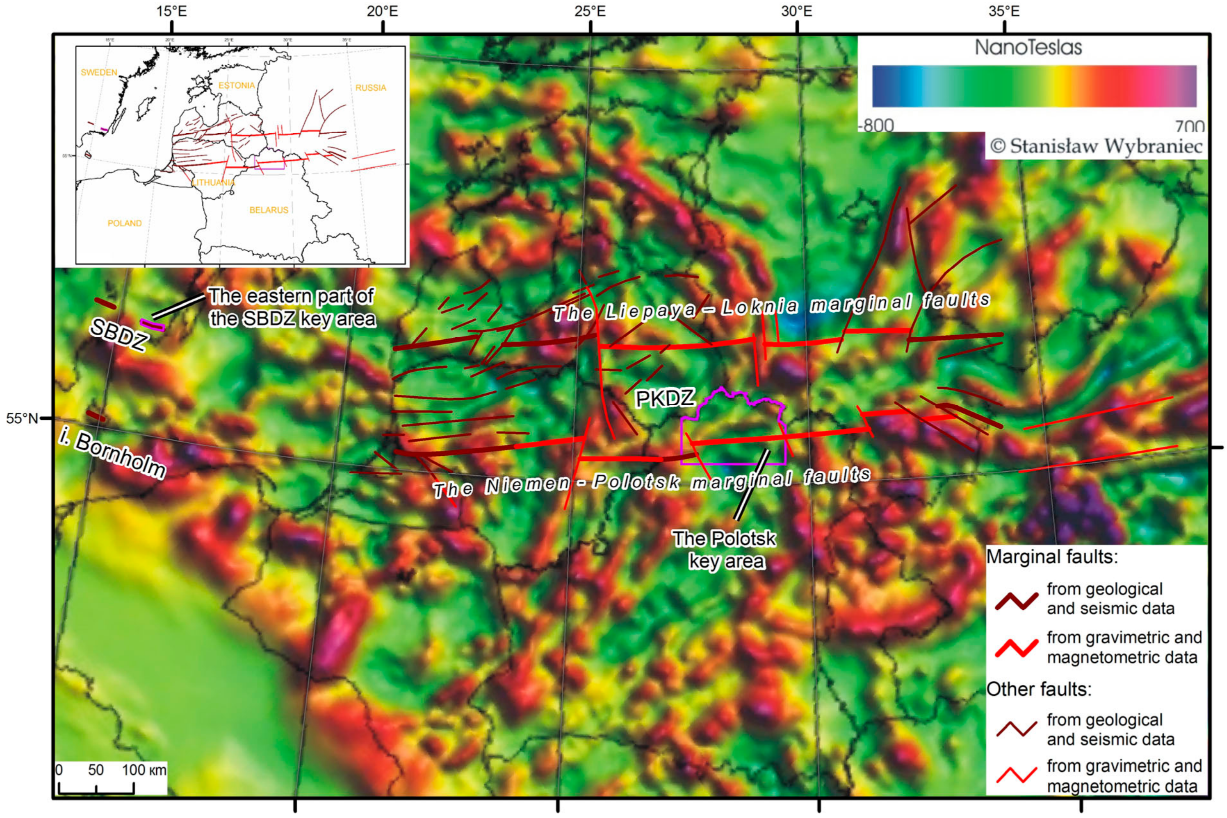


Fig. 1. Faults of the PKDZ and the SBDZ in the magnetic anomaly field. Faults of the PKDZ after Garetsky et al. (2006), faults of the SBDZ after Lindh et al. (2001), the magnetic anomaly field after Wybraniec (1999).

deposits hide the some parts of the crystalline basement, but there are also numerous bedrock outcrops. The present topography of the Quaternary deposits was primarily shaped by the melting dead ice of the last Scandinavian Ice Sheet (SIS), at least above the highest shoreline of the Baltic Ice Lake.

2 Materials and Methods

2.1 GIS modeling of the upper paleosurfaces of the crystalline basement and various layers of the sedimentary cover, and the digital terrain models

The main instrument of this study is Geographical Information Systems (GIS). GIS are getting a special significance in the current development of geology and geomorphology as GIS technologies allow landforms and geological data visualizing, as well as to carry out different kinds of geomorphological and geological analysis and modeling (three-dimensional models of landforms and geological paleosurfaces).

The influence of Mesoproterozoic faulting on the Paleozoic, Mesozoic, Cenozoic and recent evolutions of the Precambrian crust has been assessed using GIS models of paleosurfaces of the crystalline basement, various layers of the sedimentary cover and the digital terrain models. The 3D upper paleosurfaces of the crystalline basement, the Misoproterozoic Ectasian-Stenian, Neoproterozoic Ediacaran, Ordovician, Devonian and Quaternary sedimentary deposits and the present landform surface for the Polotsk key area, as well as the 3D upper paleosurfaces of the crystalline basement and the present landform surface for the eastern part of the SBDZ key area, have been performed with ArcGis 9.1 (ESRI, USA) software.

The already published maps of the upper paleosurfaces of the crystalline basement (Garetsky et al. 2004), and the Ectasian-Stenian, Ediacaran and Ordovician (Tectonics of the West of the Eastern European Platform 1990) sedimentary deposits in the Polotsk area have been transformed in digital form, using a special function of georeferencing. The 3D models of these paleosurfaces have been created with the interpolation function (the Inverse Distance Weighted (IDW) method, with option of faults as barrier polilines for the construction of the upper paleosurfaces of the crystalline basement and Ectasian-Stenian sedimentary deposits, and the Spline method with option of tension for the construction of the upper paleosurfaces of the Ediacaran and Ordovician sedimentary deposits) in Spatial Analyst of ArcGis 9.1.The results of interpretation of drillings in Quaternary deposits and description of natural outcrops (Levickaya 1990) have been used for reconstruction of the paleosurfaces of the Devonian and Quaternary sedimentary deposits. These geological materials include information about position (latitude/longitude) of drilling wells (or natural outcrops) and interpretation of drilling/outcrop logs (depth in m a.s.l. of the Quaternary layers). These data have been transformed in digital form according to coordinates. The upper paleosurfaces of pre-Quaternary (Devonian) sedimentary deposits and all glacial/interglacial complexes have been created with the interpolation function (Spline method with option of tension) in Spatial Analyst of ArcGis 9.1. The digital terrain model (DTM) of the Polotsk area has been constructed based on hypsometrical data (isolines and elevation numbers) of the topographical maps of the territory in the scale 1:100 000 (12 maps), using the Spline interpolation of Spatial Analyst.

The topographical maps of the eastern part of the SBDZ area (Karlskrona 3F NO, Kristianopel 3G NV) in scale of 1:50 000 have been used for analysing the present landform surfaces. The elevation isolines have been transformed into digital form, and then the DTM have been constructed with the interpolation function (the Spline method with option of tension) in Spatial Analyst of ArcGis 9.1. A model of the upper paleosurface of the crystalline basement in the area has been created based on information of sediment thickness, taken from the well archive of the Swedish Geological Survey (SGU) (http://www.sgu.se), combined with the constructed DTM within areas of exposed bedrock.

2.2 GIS models of correlation of the crystalline basement with sedimentary cover and present topography

The GIS analysis of the crystalline basement and the various layers of the sedimentary cover, and also the present topography in the key target areas, has been used for determination of the relationships between them, and to what degree they correlate. The GIS model of correlation of the crystalline basement with sedimentary cover and present topography has been made using Arc View 3.2 software ("Spatial.CalCorrCoefbyMovingWindow" script, http://arcscripts.esri.com). The correlation between the paleosurfaces has been obtained with the moving window. The steps of averaging of 5 (the Polotsk area) and 0.5 km (the eastern part of the SBDZ area) for each pair have been computerized (Kurlovich 2006). According to the methodology, the program divides territory into squares which size depends on step averaging (e.g., if the step is 5 km, the squares are 5×5 km). Then the script calculates values of the correlation coefficients of each pair of squares according to the Parson method of linear correlation. The correlation between two paleosurfaces is a measure of dependency between the layers. Correlation ranges from +1 to -1. A positive correlation indicates a direct relationship between two paleosurfaces, such as when the cell hypsometrical values of one paleosurface increase, the cell hypsometrical values of another paleosurface are also likely to increase (see Fig. 2). A negative correlation means that one variable changes inversely to the other. A correlation of 0 means that two paleosur-

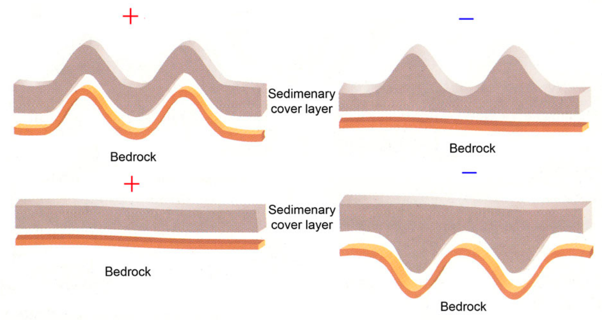


Fig. 2. A cartoon showing positive (+) and negative (-) basement-cover correlation (after Houmark-Nielsen et al. 2005 with some minor corrections).

faces are independent of one another. Finally, using the interpolation function (the Spline method with option of tension) of Spatial Analyst of ArcGis 9.0, the series of the maps of correlation coefficients between the crystalline basement and the various layers of the sedimentary cover, and also present topography in the key target areas, have been developed.

2.3 Topolineaments identification

The lineaments have been distinguished by visual identification using, the DTMs of the Polotsk and the eastern part of the SBDZ areas as well as positions of rivers and lakes. The rectified parts of the rivers, lakes and the linear landforms have been interpreted as topolineaments. Some topolineaments have been identified using a combined analysis of hillshaded reliefs, anaglyphs, steepness and aspect of slopes. Topolineaments, which are longer than 1500 m, have been interpreted as major lineaments, topolineaments with length of 1500–1000 m as local major lineaments, and topolineaments with a length shorter than 1000 m as local minor lineaments.

2.4 Profiling of the Quaternary deposits

The Catalogue of the interpreted drillings wells in Quaternary deposits (Levickaya 1990) has been used for construction of the two longitudinal profiles of Quaternary deposits in the Polotsk area.

2.5 Map of seismic activity

The map of seismic activity in the regions of the PKDZ and the SBDZ has been compiled from published data in the Seismic Bulletins (1375-2006 years) of the Institute of Seismology University of Helsinki (http://www.seismo.helsinki.fi/bul/) and from available data in the earthquake database (1600-2005 years) of the Center of Geophysical Monitoring (CGM) of the National Academy at Science of Belarus (Karabanov et al. 2005, Aronov et al. 2005).

2.6 Study of neotectonic pattern of northern Belarus

The V.P. Filosofov's morphometric method (Filosofov 1975) has been employed for the recognition of the neotectonic movement pattern of the Polotsk area (Kurlovich & Karabanov 2004, Kurlovich 2005). As a result of the morphometric analysis of the landforms, the regional, subregional and local neotectonic struc-

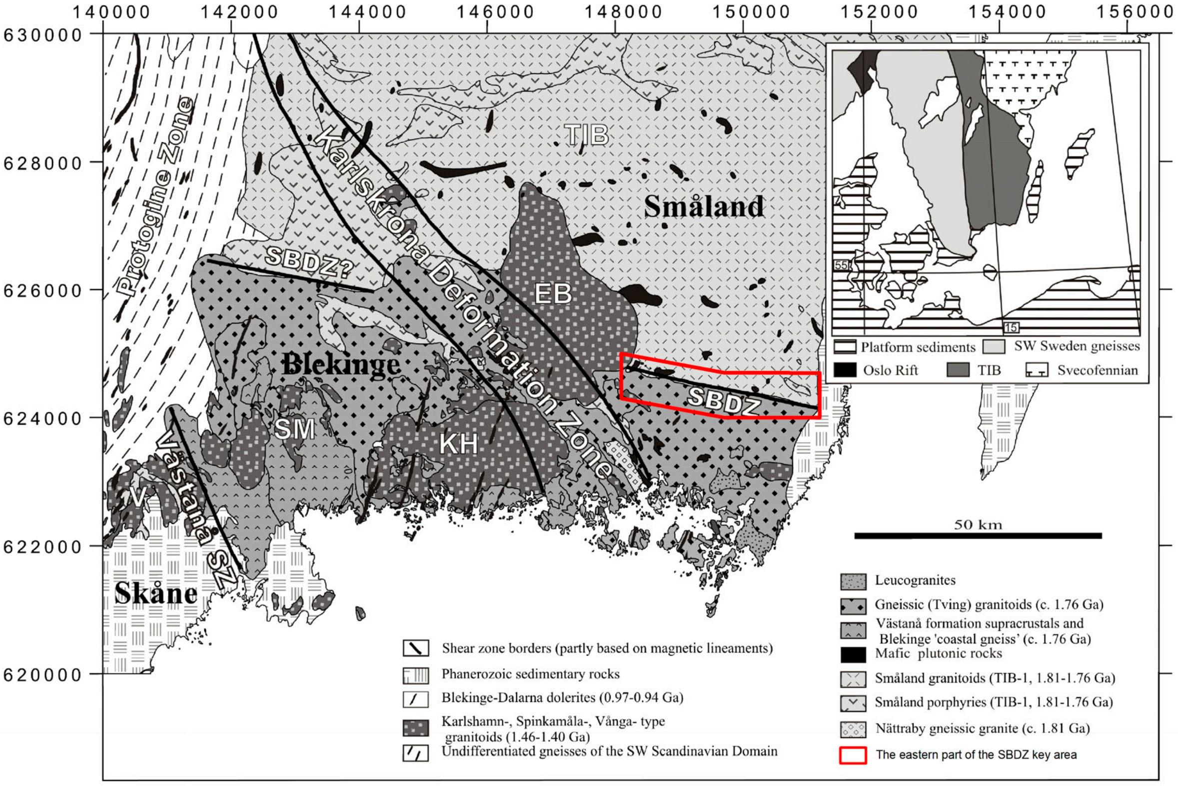


Fig. 3. Geological map of Blekinge and surrounding areas (after Johansson et al. 2006).

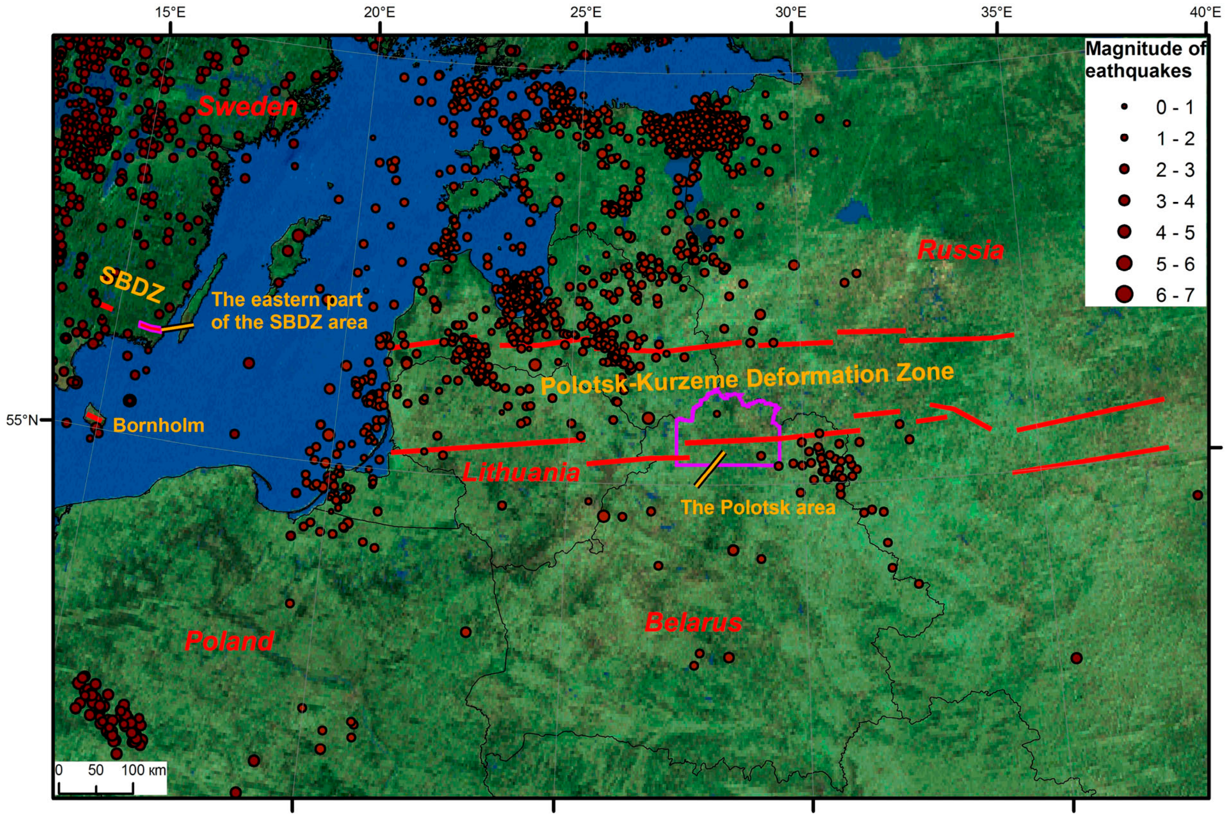


Fig. 4. The seismic activity in the region of the PKDZ and the SBDZ.

tures, as well as the neotectonic active linear zones of flexuring-faulting, have been distinguished. These were confirmed by geological data such as displacement, flexuring and fissuring in the Quaternary deposits.

3 Major features of the Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones

The PKDZ is a system of E-W trending faults of various orders (Fig. 1). The faults have been identified mainly from linear, intensive gravity and magnetic anomalies, high gradients of the potential fields, and from their truncations (Garetsky et al. 2002b, Garetsky et al. 2004, Garetsky et al. 2006). Potential fields adjacent to the belt in the north and south strike N-S and terminate abruptly at marginal faults. The PKDZ extends in an east-west direction for almost 800 km, and with a width of 120 to 160 km.

An E-W directed zone of the lithosphere, thickened up to 170 km, also coincides with the PKDZ and with an E-W depression on the geoid surface as well (Garetsky et al. 2002a). The thickness of the Earth's crust within the PKDZ averages ca 50 km (Garetsky et al. 2002a).

The PKDZ is bounded by the Niemen-Polotsk sub-latitudinal faults in the south, and the Liepaya–Loknia faults in the north (Fig. 1). The Niemen-Polotsk set of normal faults in the west cut the Early Paleozoic sedimentary cover and displace the basement surface up to 150 m. In the east, it coincides with a zone separating the crustal blocks of different deep structure with a 3 km offset at the Moho boundary (Garetsky et al. 2004). Eastwards the PKDZ accommodates several grabens (Garetsky et al. 2006).

The northern marginal fault system of the PKDZ meets in the west the western end of the Liepaya–Riga fault zone as was revealed by the Sovetsk–Kohtla–Järve deep seismic sounding profile (Ankundinov et al. 1991). The Moho boundary occurs at a depth of ca. 55 km north of, and at a depth of ca. 65 km south of this zone, i.e. a difference of ca. 10 km (Garetsky et al. 2006). The Liepaya–Riga fault zone is a pronounced feature of the platform cover. Extending for more than 300 km, it includes a set of echelon- and parallel normal faults and, sometimes, also reverse faults in its central part. Maximum displacements along the faults are as high as 600 to 650 m at the basement surface, but usually range from 100 to 150 m. The eastern continuation of the northern marginal faults, running nearby the town of Lokno, was identified from gravity and magnetic anomaly fields (Garetsky et al. 2004).

The PKDZ is one of the numerous east-west-trending zones of shearing in the western part of the East European Craton (EEC), which are associated c. 1.50-1.45 Ga AMCG and A-type granitoids intrusions (Bogdanova 2001, Skridlaite et al. 2003, Čečys 2004; Bogdanova et al. 2006, Motuza et al. 2006, Skridlaite et al. 2006). Those may have been a far-field effect of continuing or renewed orogeny in the westernmost

Baltic Shield but they may also have been related to collision with other plates, for example, the Amazonia (Bogdanova 2001).

The PKDZ possibly continues across the Baltic Sea into the SBDZ and the Danish island Bornholm. In the north, the SBDZ runs along the E-W boundary between the Tving granitoids of the eastern Blekinge and the Småland granitoids north thereof (Fig. 3) (Wiklander 1974, Krauss et al. 1996, Kornfält 1999a, b; Lindh et al. 2001, Kornfält & Braun 2002). According to Lindh et al. (2001) this narrow (up to 1.5 km wide) zone comprises a system of anastomosing shears. The rocks within the SBDZ contain high-grade gneisses and mylonites. Along this shear zone, pervasively deformed and metamorphosed Tving granitoids (Blekinge block) were uplifted relative to underformed and unmetamorphosed Småland rocks (Småland block) (Krauss et al. 1996, Kornfält 1999a, b; Lindh et al. 2001, Kornfält & Braun 2002). The deformation and uplift had occurred prior to or coevally with the intrusion of the Karlshamn-type granites at 1.45 Ga (Johansson et al. 2006). Going west, the SBDZ is intruded by the Eringsboda pluton. However, the magnetic anomaly map indicates that it is likely to continue west of the Eringsboda massif with some (about 4 km) offset along the Karlskrona Deformation Zone (Johansson et al. 2006).

All the marginal faults of the PKDZ as well as the SBDZ and Bornholm are seismically active (Fig. 4). Along the whole length of the northern Liepaya–Loknia marginal faults of the PKDZ the magnitudes of the earthquakes are about values of 2-3. The earthquakes hypocenters are related to the crystalline basement (3-15 km, the data from the earthquake database of the Center of Geophysical Monitoring (CGM) of the National Academy at Science of Belarus). The southern Niemen-Polotsk marginal faults of the PKDZ are less active. Here the earthquakes are rare and have magnitudes less than 3. In northeastern Belarus and in Lithuania they have been registered from the crystalline basement (9-15 km, CGM). Along the SBDZ and at Bornholm the earthquakes hypocenters also seem to originated from the crystalline basement (6-8 km, the Seismic Bulletins of the Institute of Seismology University of Helsinki (http://www.seismo.helsinki.fi/bul/).

4 The Polotsk (Belarus) area of the Polotsk-Kurzeme Deformation Zone

4.1 The crystalline basement

A model of the upper paleosurface of the crystalline basement in the Polotsk area (Fig. 6) made by Belarusian geologists (Garetsky et al. 2004) is based on detailed data and observations along gravity and magnetic profiles, calculations from deep drillings and magnetotelluric sounding, estimations of depths to the upper edges of magnetic bodies, and patterns of gravity and magnetic anomaly fields. The basement in the Polotsk area of the PKDZ in Belarus has a horst-and-graben structure. The depth to the basement is as great as 3.5 km in some areas. Two large depressions (Miori in the west and Dretun in the east) at 3-3.5 km depth are separated by a dome with an elevation of 1.8 km below sea lavel. The southern Niemen-Polotsk marginal faults, as well as the other PKDZ faults divide the crystalline basement into several blocks (Fig. 5). The Miori and Dretun grabens are characterized by positive anomaly of the magnetic field (100-200 nT) and negative gravity anomalies (up to -5 mgal). In contrast, the horsts (the Vetrino, Verchnedvinsk and Zaborie blocks of the crystalline basement) are recorded by negative magnetic anomaly (-100 – -300 nT) and positive gravity anomalies (up to +5 mgal) (Fig. 5a, b). All data are after Geology of Belarus (2001).

According to Bogdanova et al. (2006), the crust in the Polotsk key area consists of the following lithotectonic units: the Okolovo terrane, the Vitebsk Domain and the Lithuania-Belarus terrane (Fig. 7). The Okolovo terrane and the Vitebsk Domain are components of the Central Belarus Suture Zone between the Fennoscandian and Sarmatian crustal segments of the East European Craton (EEC), whereas the Lithuania-Belarus terrane is one of the Fennoscandian terranes of the Baltic-Belarus region. The Belarus-Podlasie Granulite Belt of the Lithuania-Belarus terrane within the Polotsk area is made up of several large lensoid bodies of granulites, separated from each other by faults (Aksamentova & Naydenkov 1990). The Belarus-Podlasie Granulite Belt rocks are mostly Palaeoproterozoic granulitic orthogneisses of mafic, enderbitic and charnockitic compositions (Bogdanova et al. 2006). The c. 2.0 Ga Okolovo terraine (Bibikova et al. 1995, Claesson et al. 2001) is built up of metamorphosed komatiitic and tholeiitic basalts, andesites, dacites and rhyolites of oceanic-arc affinities (Bogdanova et al. 2006). Along its border towards the overlying the Belarus-Podlasie Granulite Belt in the west, the rocks have been metamorphosed in the granulite facies. The Okolovo terrane is separated from the Vitebsk Domain by the NE-SW-trending Minsk fault. Juvenile metasediments and andesitic-dacitic metavolcanic rocks of the Vitebsk Domain were formed at c. 1.98 Ga (Bibikova et al. 1995).

4.2 The sedimentary cover and the present landforms

The Proterozoic crystalline basement in the Polotsk area is covered by Mesoproterozoic Ectasian-Stenian (Riphean, 1350-1000 Ma), Neoproterozoic Ediacaran (Vendian, 650-542 Ma), Cambrian (542-488 Ma), Ordovician (488-444 Ma), Devonian (416-359 Ma) and Quaternary sedimentary deposits.

Sedimentation in the Ectasian-Stenian relates to the infilling of the Volyn-Orsha Aulacogen. Sedimentary deposits of that period have been found only in the southeastern part of the key area (Fig. 9). They are oligomictic-quartzose sandstones of the Rudnia strata of the mid-Riphean Belarusian Formation (up to 300 m thick) and overlying fine- and medium-grained quartzose sandstones of the Orsha strata of the mid-Riphean Belarusian Formation, up to 620 m thick in the south-easternmost part of the area (Veretennikov et al. 2005). The upper paleosurface of the Ectasian-Stenian (Riphean) sedimentary deposits in the Polotsk area is completely similar to the upper paleosurface of the basement with the exception of the southeastern part (see Fig. 8). Here parts of the Dretun depression and a depression within the Obol block of the crystalline basement are filled with Ectasian-Stenian deposits up to -500 – -700 m above sea level (m a.s.l.). The faults of the PKDZ also are covered by these deposits.

The younger Ediacaran (Vendian) sedimentary complex (Makhnach et al. 2005a) in the Polotsk area consists of sandy tillites of the Vilcha strata (up to 730 m thick), tufagenes sandstones and siltstones of the Volyn strata (up to 130 m thick), as well as red sandstones and siltstones with clay streaks of the Valdai strata (up to 310 m thick) (Fig. 11). The upper paleosurface of the Ediacaran (Vendian) sedimentary deposits in the Polotsk area is a relatively flat plain with, striking E-W and tilting towards the north (Fig. 10). All the depressions of the crystalline basement as well as the faults of the PKDZ (compare with Fig. 6) are filled in by Ediacaran sediments.

The Cambrian and Ordovician deposits in the Polotsk area are related to the development of the Baltic marine basin. The Early and Middle Cambrian (up to 170 m thick) sandstones and siltstones with the clay streaks in the western part of the area are overlain by Ordovician limestones, marls and carbonate clay, up to 166 m thick (Makhnach et al. 2005b, Pushkin 2005, Fig. 13). However, the surface strikes in a more NW-SE direction and plunge toward the NE, starting in the south-west at ca. -70 m a.s.l. (Fig. 12).

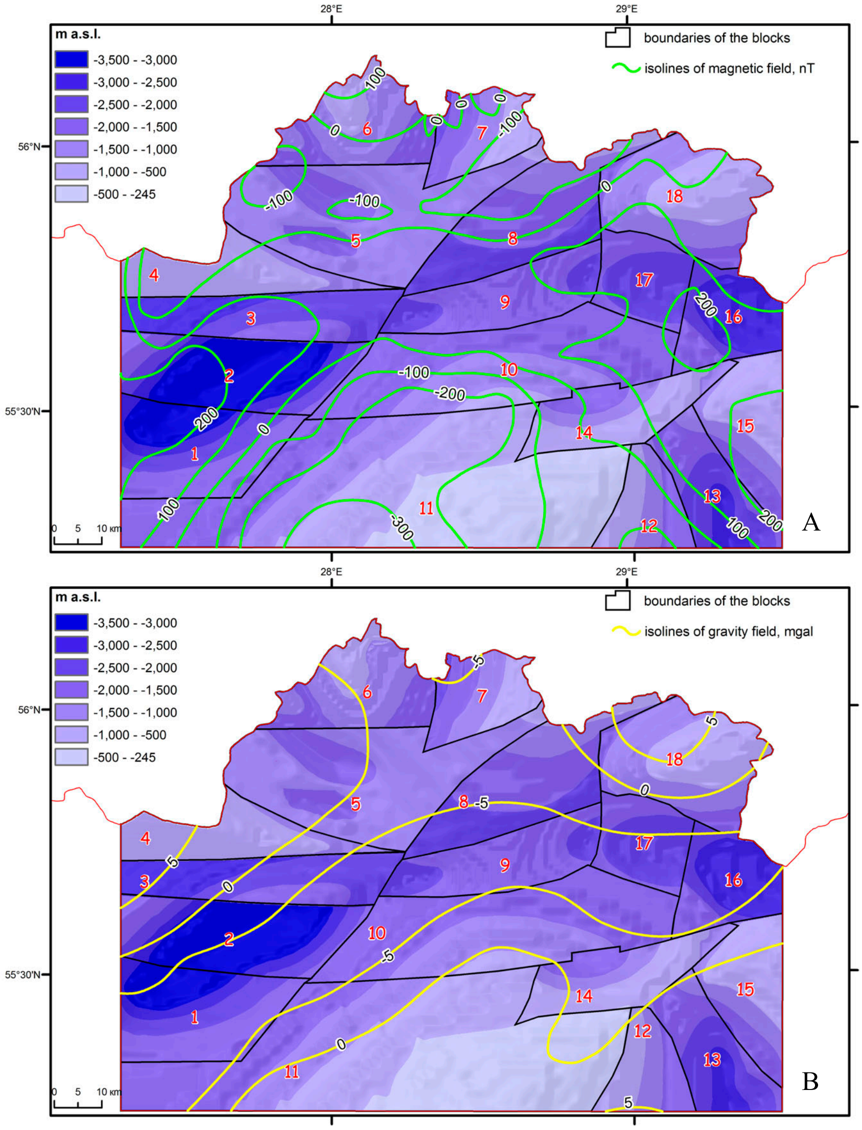


Fig. 5. The blocks of the crystalline basement in the Polotsk area in the magnetic (A) and gravity (B) anomaly field. The magnetic and gravity anomaly field after Geology of Belarus (2001). Numbers indicate the blocks of the crystalline basement: 1 – Sharkovschina, 2 – Miori, 3 – Povatie, 4 – Verchnedvinsk, 5 – Kochonovo, 6 – Osveya, 7 – Lisno, 8 – Rossony, 9 – Borkovichi, 10 – Novopolotsk, 11 – Vetrino, 12 – Goriany, 13 – Obol, 14 – Polotsk, 15 – Koziany, 16 – Dretun, 17 – Marinica, 18 – Zaborie.

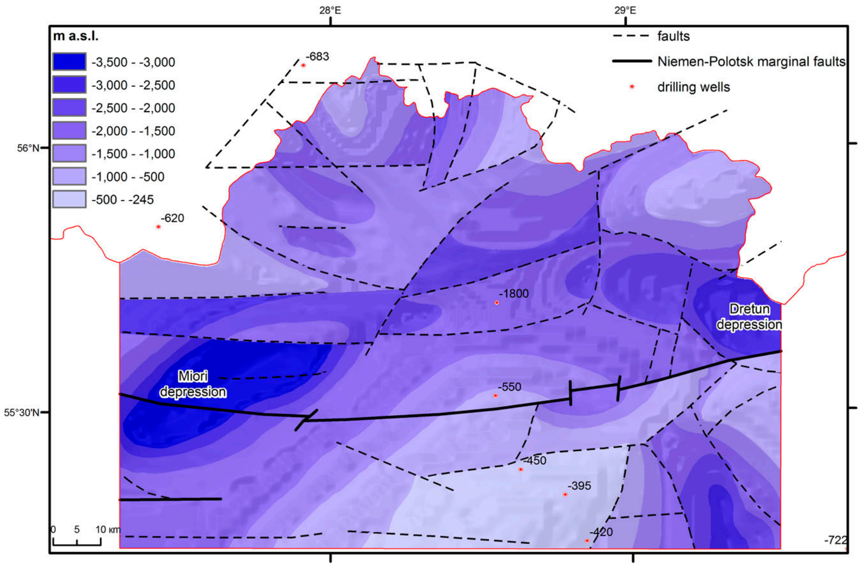


Fig. 6. Model of the crystalline basement upper paleosurface in the Polotsk area, modified after Garetsky et al. (2004).

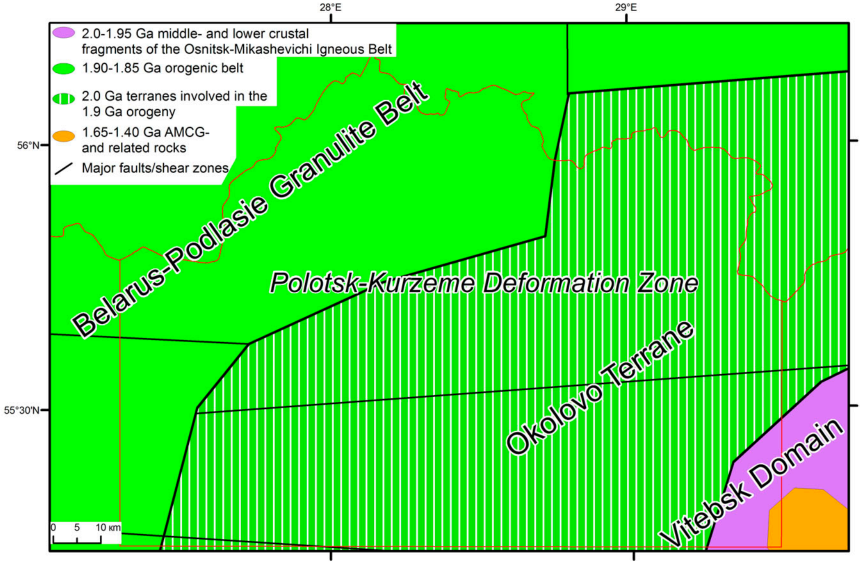


Fig. 7. Major lithotectonic units of the crust in the Polotsk area, modified after Bogdanova et al. (2006).

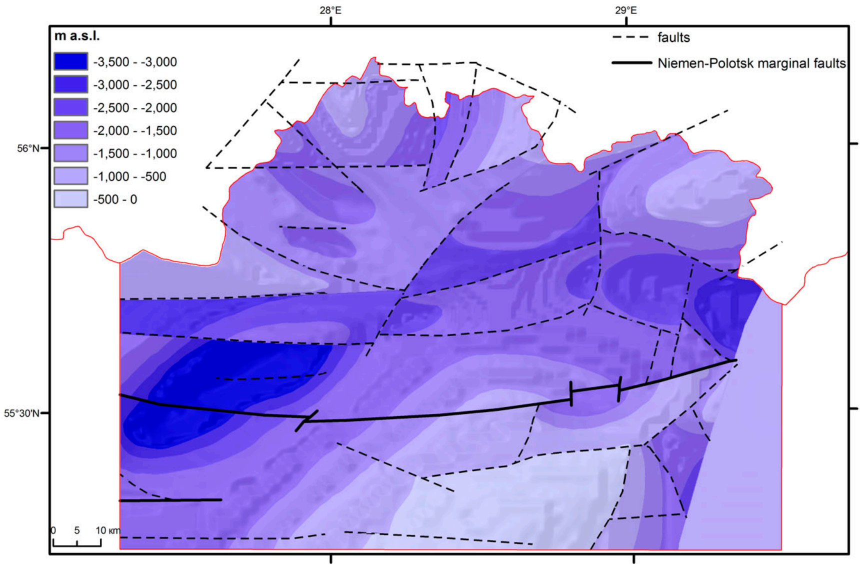


Fig. 8. Model of the upper paleosurface of the Ectasian-Stenian (Riphean) sedimentary deposits in the Polotsk area, modified after Tectonics of the West of the EEP (1990).

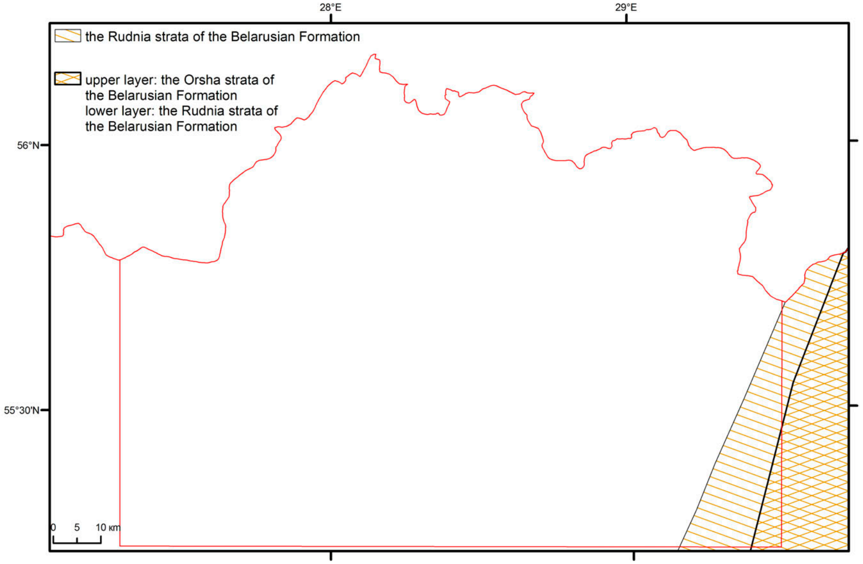


Fig. 9. The Ectasian-Stenian (Riphean) sedimentary deposits in the Polotsk area, modified after Geology of Belarus (2001).

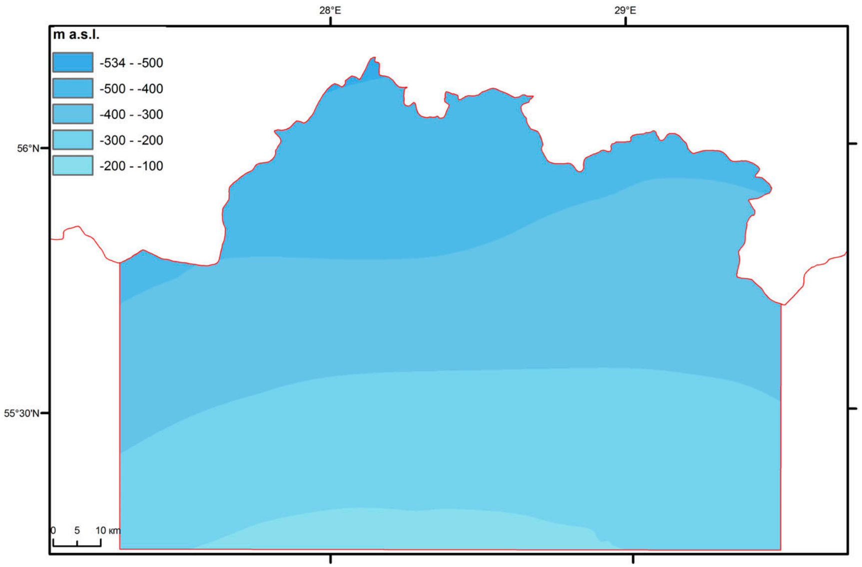


Fig. 10. Model of the upper paleosurface of the Ediacaran (Vendian) sedimentary deposits in the Polotsk area, modified after Tectonics of the West of the EEP (1990).

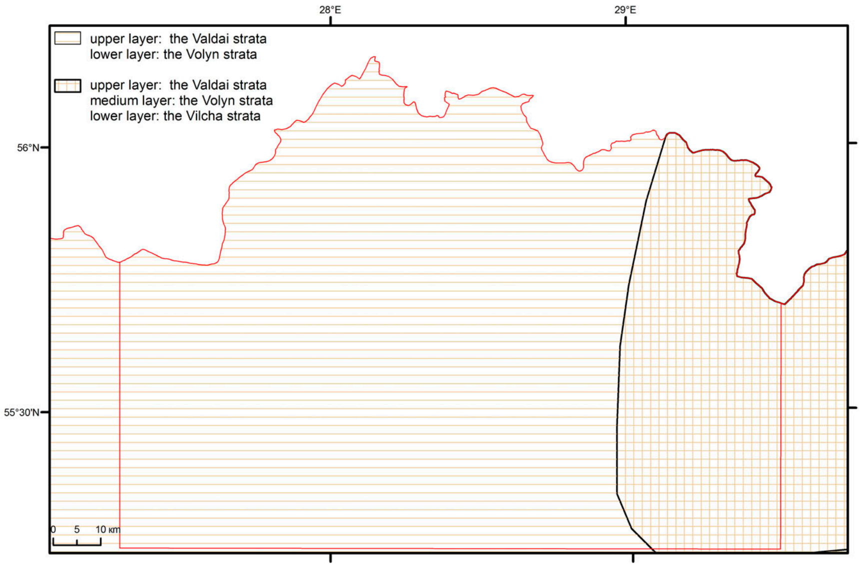


Fig. 11. The Ediacaran (Vendian) sedimentary deposits in the Polotsk area, modified after Geology of Belarus (2001).

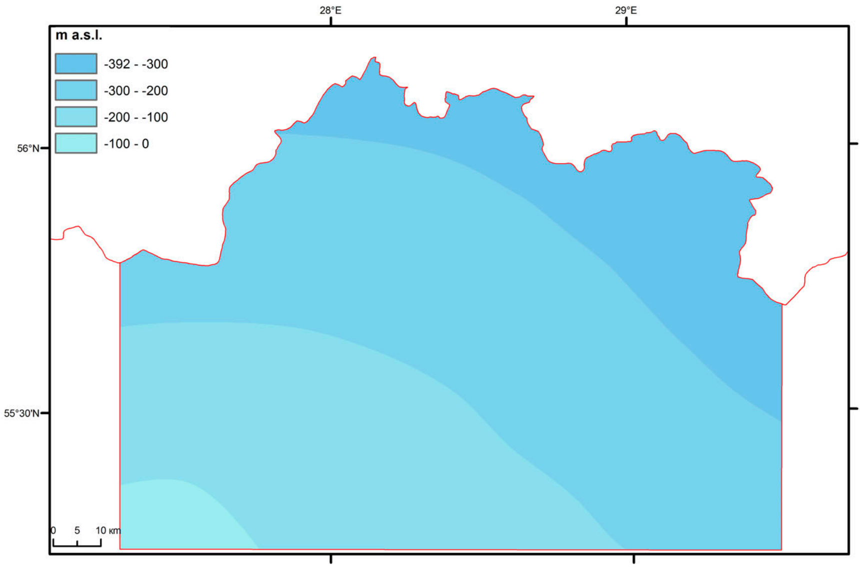


Fig. 12. Model of the upper paleosurface of the Ordovician sedimentary deposits in the Polotsk area, modified after Tectonics of the West of the EEP (1990).

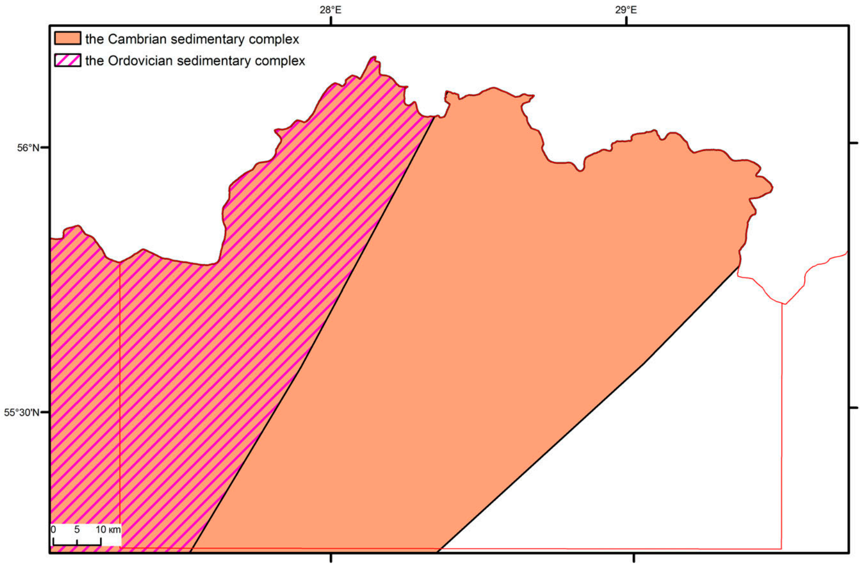


Fig. 13. The Cambrian and the Ordovician sedimentary deposits in the Polotsk area, modified after Geology of Belarus (2001).

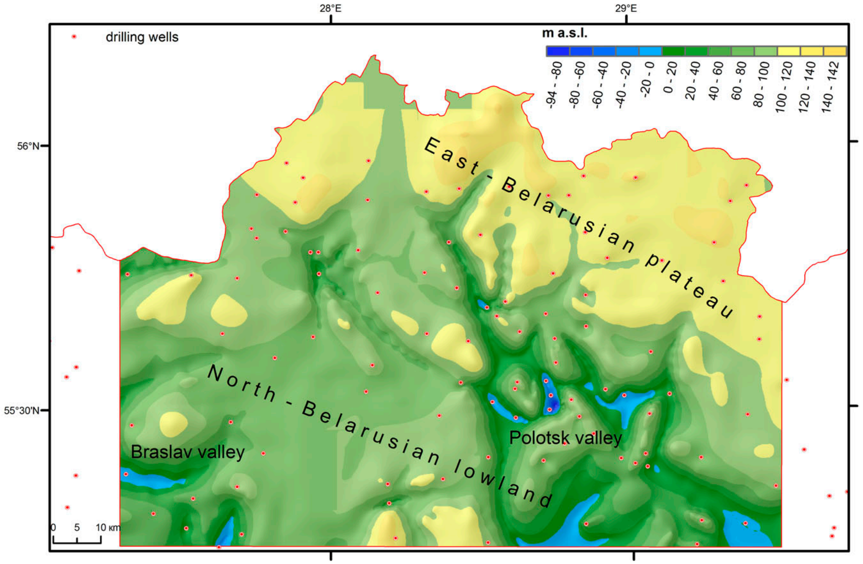


Fig. 14. Model of the pre-Quaternary upper paleosurface in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

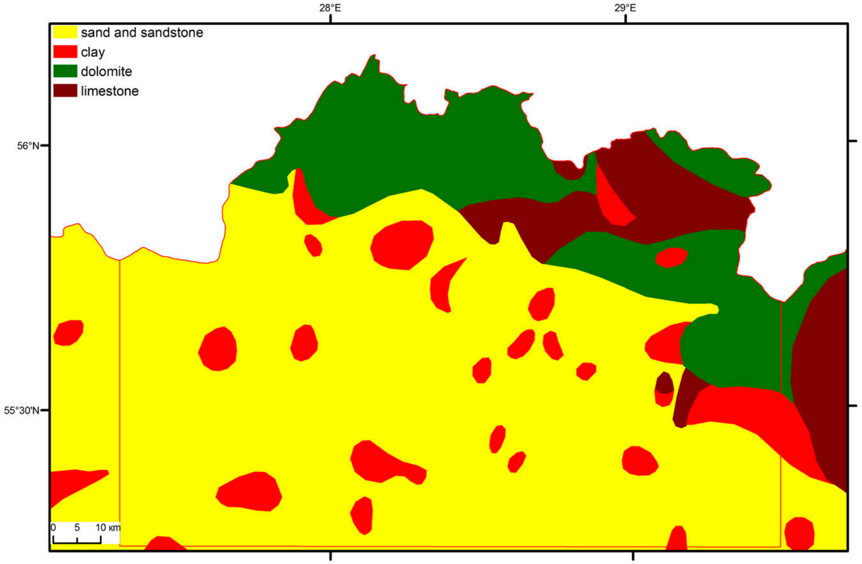


Fig. 15. Composition of the upper-Devonian sedimentary deposits in the Polotsk area, modified after Nechiporenko (1989).

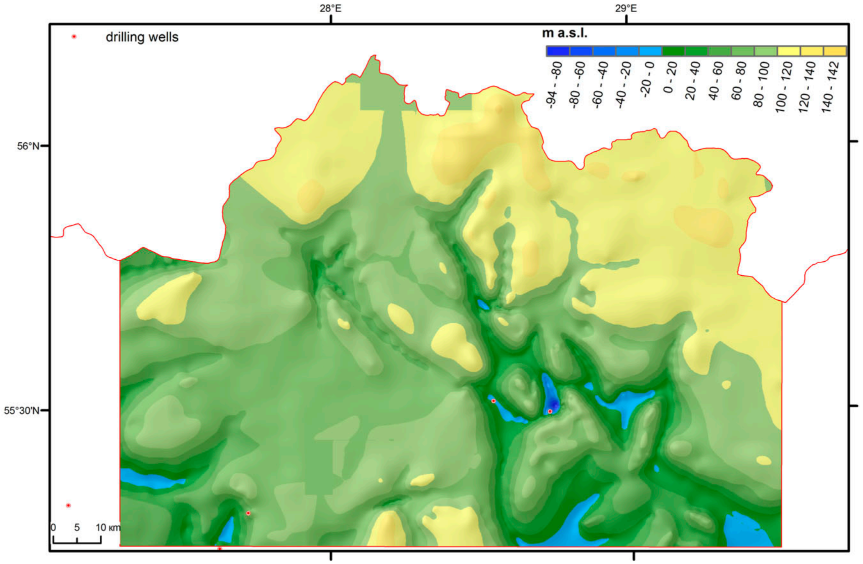


Fig. 16. Model of the upper paleosurface of the Narev glacial complex in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

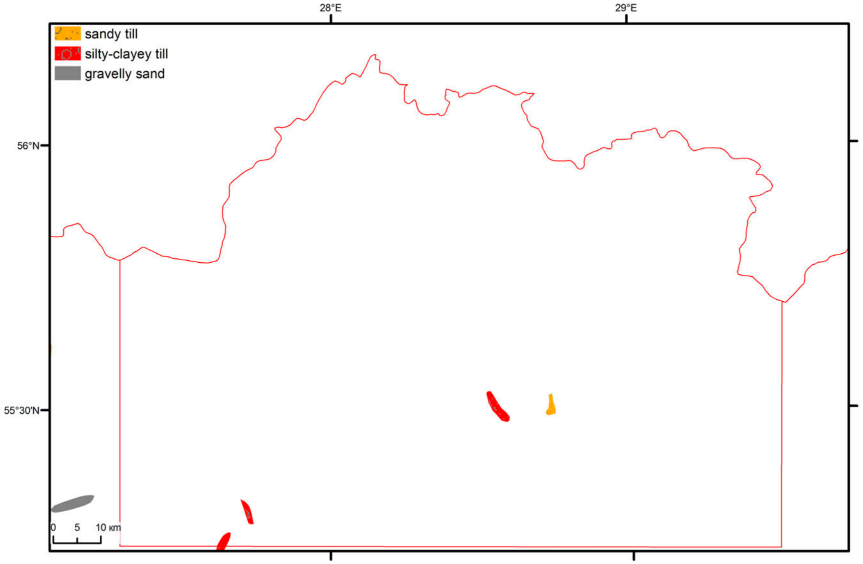


Fig. 17. Composition of deposits of the Narev glacial complex in the Polotsk area, modified after Levickaya (1990).

Table 1. Glaciations and interglacials in Belarus.

	Belarus	**Europe**
Late Pleistocene	Poozierie glaciation (Pz)	Weichselian glaciation
	Murava interglaciation (Mr)	Eemian interglaciation
Middle Pleistocene	Pripyat glaciation (Pt): *Sozh Stage(*Sz*)* *Dnieper Stage(*Dn*)*	Saalian glaciation
	Aleksandriya interglaciation(Alk)	Holsteinian interglaciation
	Berezina glaciation(Br)	Elsterian glaciation
	Beloviezha interglaciation(Bl)	
	Narev glaciation(Nr)	

The pre-Quaternary upper paleosurface (the Devonian sedimentary deposits), as indicated in Fig. 14, outline the pre-Quaternary topography of the East-Belarusian plateau and the North-Belarusian lowland (Nechiporenko 1989). The average altitude of this surface in the North-Belarusian lowland is 60-80 m a.s.l., rising to the northeast below the East-Belarusian plateau to 100-120 m a.s.l. There are several, both shallow and deep valleys in the pre-Quaternary paleosurface. The maximum depths of these valleys are ca. -90 m a.s.l. in the Polotsk valley and -40 m a.s.l. in the Braslav valley. These depressions are supposed to be due to exaration work of Middle Pleistocene ice sheets. The Devonian sediments beneath the Quaternary sediments in the most part of the Polotsk area consist of sandstone and unconsolidated sand, but also clay occurs (Fig. 15). The northernmost and the north-eastern parts of the area consist of dolomite and limestone.

The present-day landscape of the Polotsk area was shaped during repeated Pleistocene glaciations. Five major ice sheets affected the area during the Pleistocene: the Narev, Berezina, Dnieper, Sozh and Poozerian glaciations (see Table 1). The glacial/interglacial deposits reach a maximum thickness of 160 m, with an average thickness of 75-80 m (here and below: data on the thickness of glacial deposits cited after Matveyev (1995)).

The Narev glaciation is the oldest known in Belarus. The Narev ice sheet covered almost all of Belarus, except the southern part of the country (Karabanov et al. 2004). Deposits of this glaciation have been mostly eroded and disturbed during the subsequent ice advances. Today, the Narev glacial sediments have a limited distribution. Within the Polotsk area the Narev till was preserved in the Polotsk and the Braslav depressions (Fig. 17). The upper paleosurface of the Narev glacial complex in the Polotsk area is mostly the same one as the pre-Quaternary topography (Fig. 16).

During the Beloviezha interglacial the Narev ice sheet melted away from the territory of the Polotsk area. The Beloviezha interglacial sediments (mostly sands) have similar limited occurrences as the sediments of the Nerev glacial complex (Fig. 19). The paleotopography of the territory hasn't strongly changed from the previous Narev glaciaton (Fig. 18).

The Berezina ice sheet appears to have covered almost all of Belarus, except the southernmost part of the country. The Berezina glacial sediments (till and gravely sands) are up to 10 m thick in the Polotsk area (Fig. 21). The presence of an intricate network of glacial channels which are deeply-incised into the pre-Quaternary bedrock is a spectacular feature of the Berezina deposits (Fig. 20). After the Aleksandriya interglaciation, the landscape was relatively flat with very few highlands and with large morainic plateaux dissected by deep glacial valleys (Fig. 22). The Aleksandriya sediments (sands, silts, clays, silty clays and clayey sands) were deposited in the lowest topography (Fig. 23).

The main problem of the Quaternary stratigraphy in Belarus concerns the subdivision of the Middle Pleistocene. Different concepts are based mainly on paleobotanical evidence. There are two main points of view concerning the number of glaciations in the Late Middle Pleistocene. One group (Makhnach et al. 1970, Gursky et al. 1986, Matveyev 1990, 1995) proposes the existence of two separate glaciations, the Dnieper and Sozh glaciations. Another group of researches propose just one glaciation episode between the Alexandrian and the Muravian interglacials, e.g. Sanko et al. (2005). This view is mainly advocated by palaeobotanists and is based on isolated interglacial sections without a sufficient analysis of their relationships with glacial sediments. However, this stratigraphical concept is that which is officially accepted for mapping. According to the interpretation of drillings and description of natural outcrops (Levickaya 1990), the main Middle Pleistocene glaciation (the Pripyat glaciation) consists of the Dnieper and Sozh deposits, which belong to one glaciation cycle with two main stages – the Dnieper and Sozh ones (Sanko et al. 2005).

The Dnieper stage was the most extensive

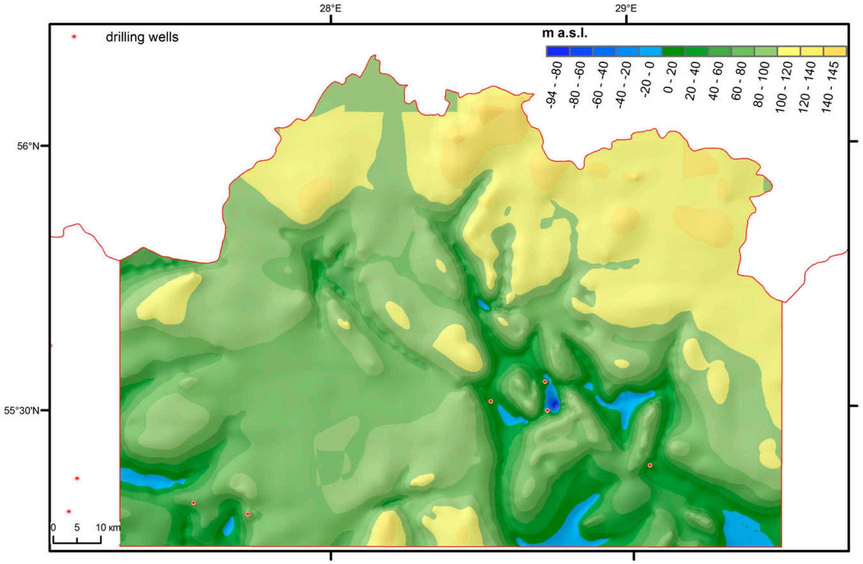


Fig. 18. Model of the upper paleosurface of the Beloviezha interglacial complex in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

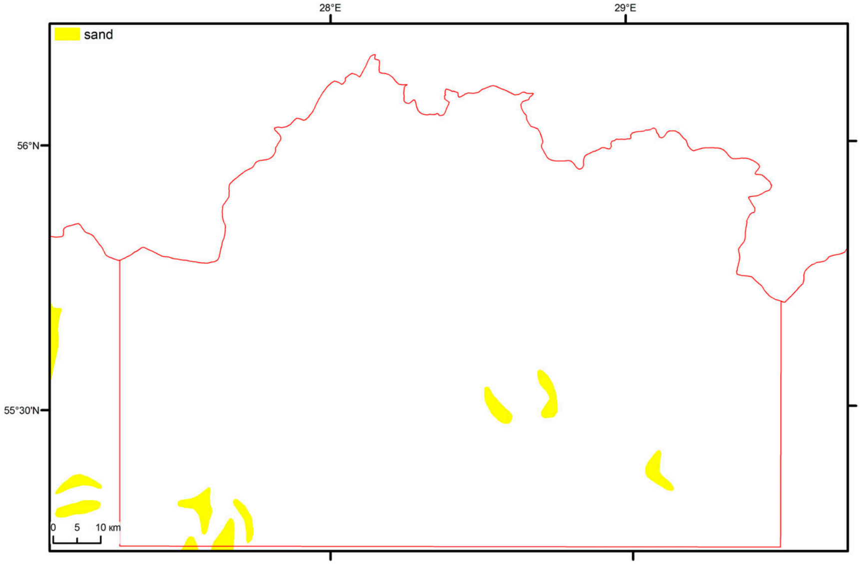


Fig. 19. Composition of deposits of the the Beloviezha interglacial complex in the Polotsk area, modified after Levickaya (1990).

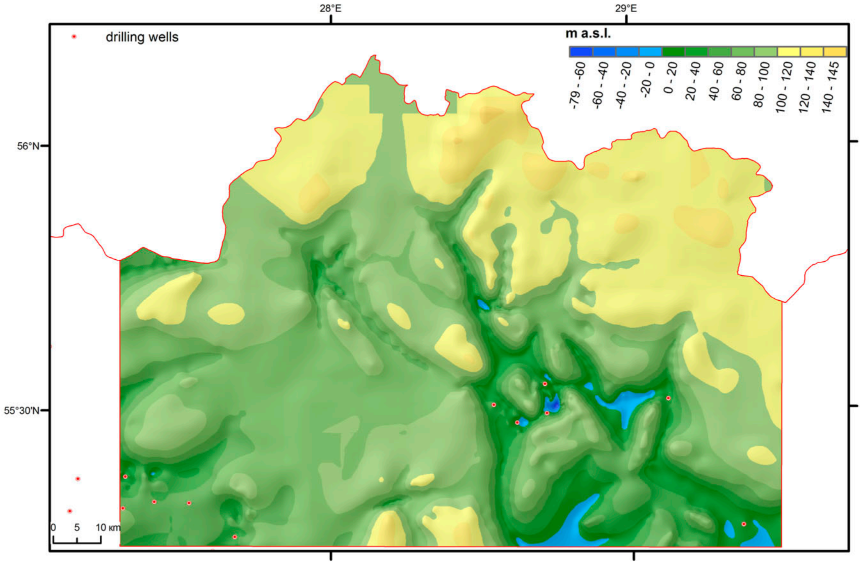


Fig. 20. Model of the upper paleosurface of the Berezina glacial complex in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

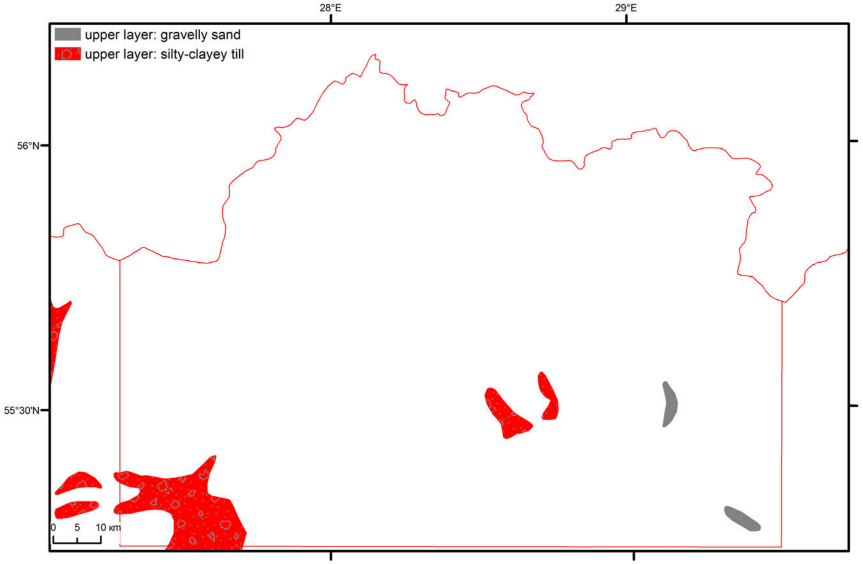


Fig. 21. Composition of deposits of the the Berezina glacial complex in the Polotsk area, modified after Levickaya (1990).

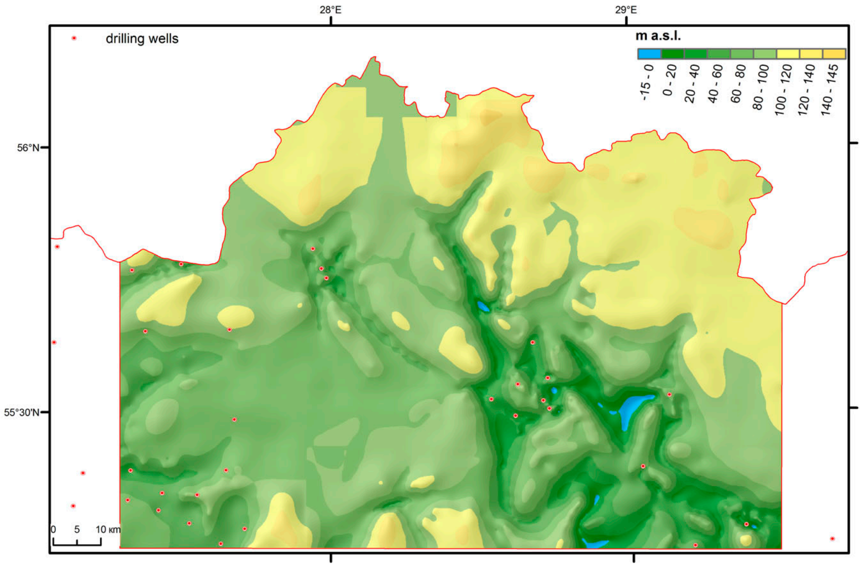


Fig. 22. Model of the upper paleosurface of the Aleksandriya interglacial complex in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

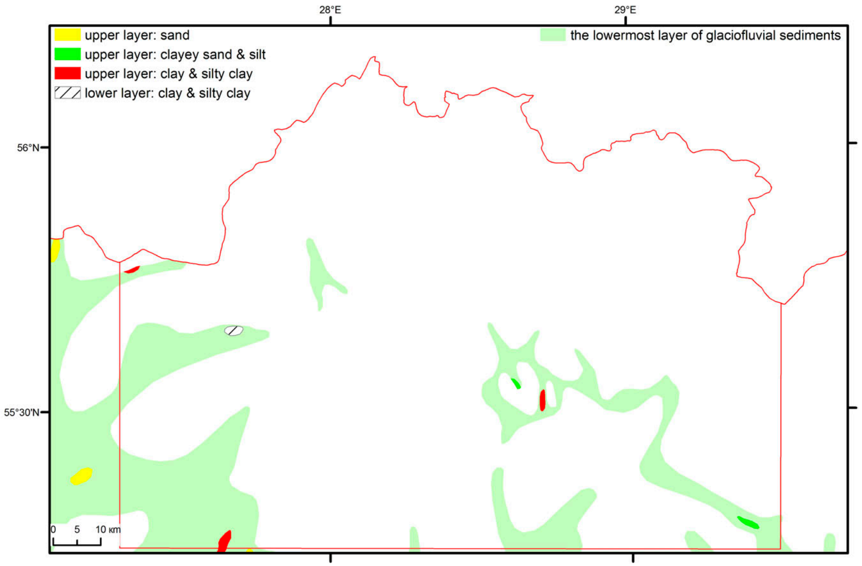


Fig. 23. Composition of deposits of the Aleksandriya interglacial complex in the Polotsk area, modified after Levickaya (1990).

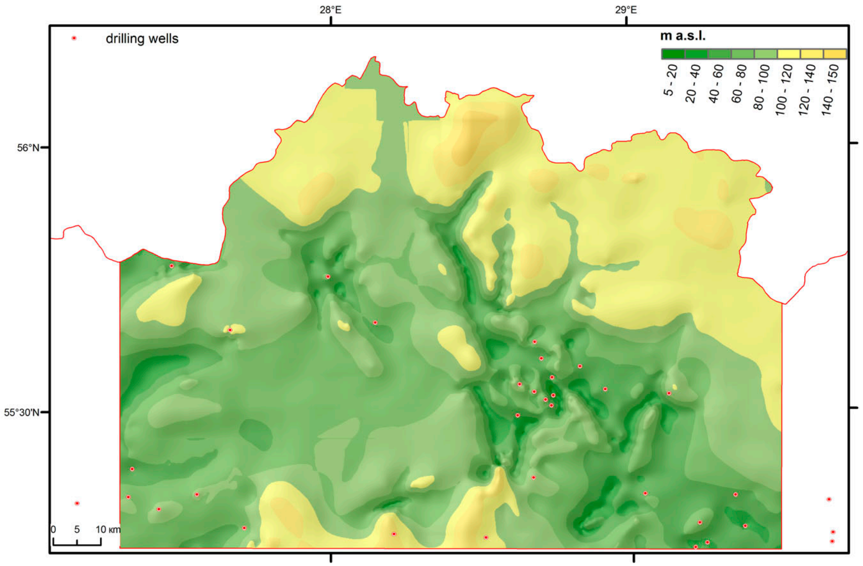


Fig. 24. Model of the upper paleosurface of the Dnieper stadial of the Pripyat glacial complex based on the Catalogue of drilling wells of Levickaya (1990).

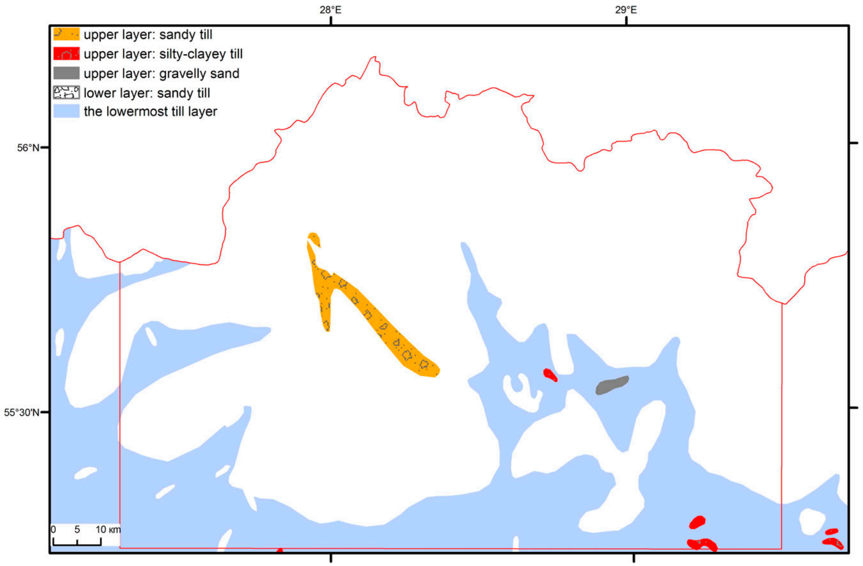


Fig. 25. Composition of deposits of the Dnieper stadial of the Pripyat glacial complex in the Polotsk area, modified after Levickaya (1990).

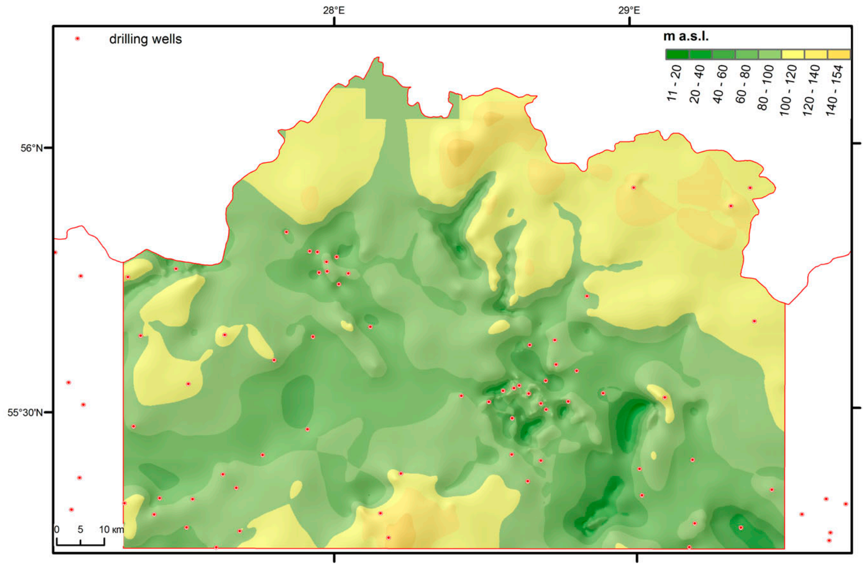


Fig. 26. Model of the upper paleosurface of the Dnieper-Sozh interstadial of the Pripyat glacial complex based on the Catalogue of drilling wells of Levickaya (1990).

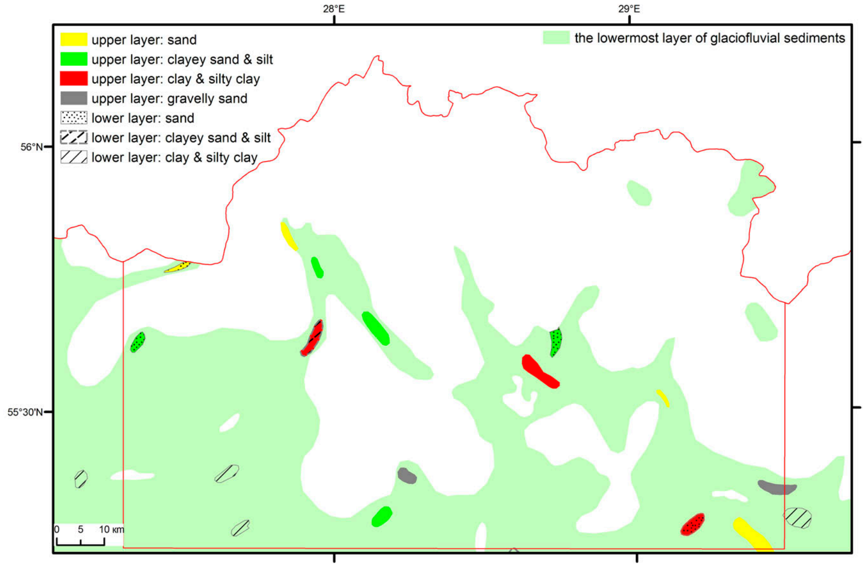


Fig. 27. Composition of deposits of the Dnieper-Sozh interstadial of the Pripyat complex in the Polotsk area, modified after Levickaya (1990).

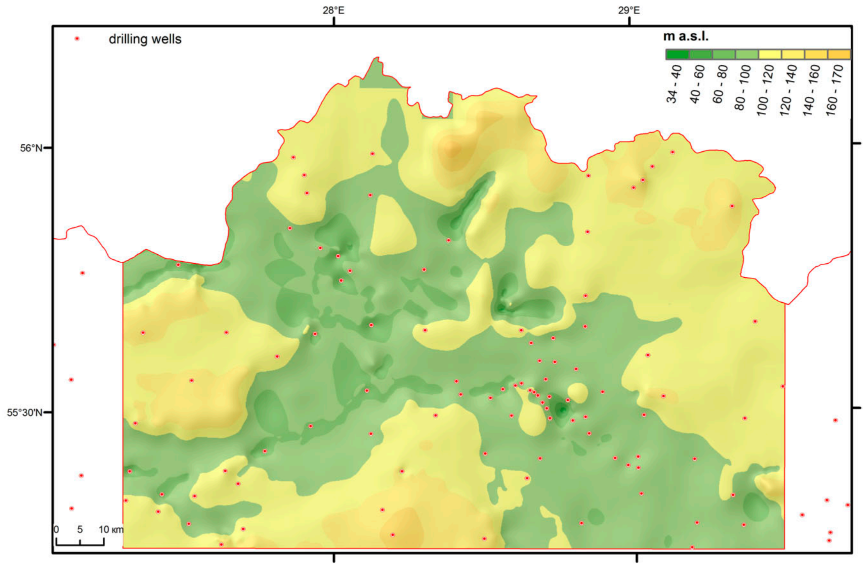


Fig. 28. Model of the upper paleosurface of the Sozh stadial of the Pripyat glacial complex based on the Catalogue of drilling wells of Levickaya (1990).

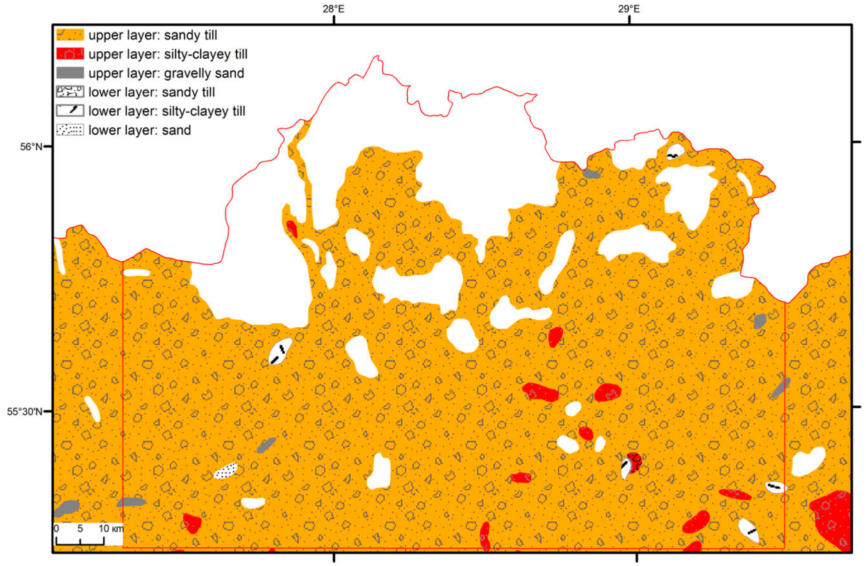


Fig. 29. Composition of deposits of the Sozh stadial of the Pripyat complex in the Polotsk area, modified after Levickaya (1990).

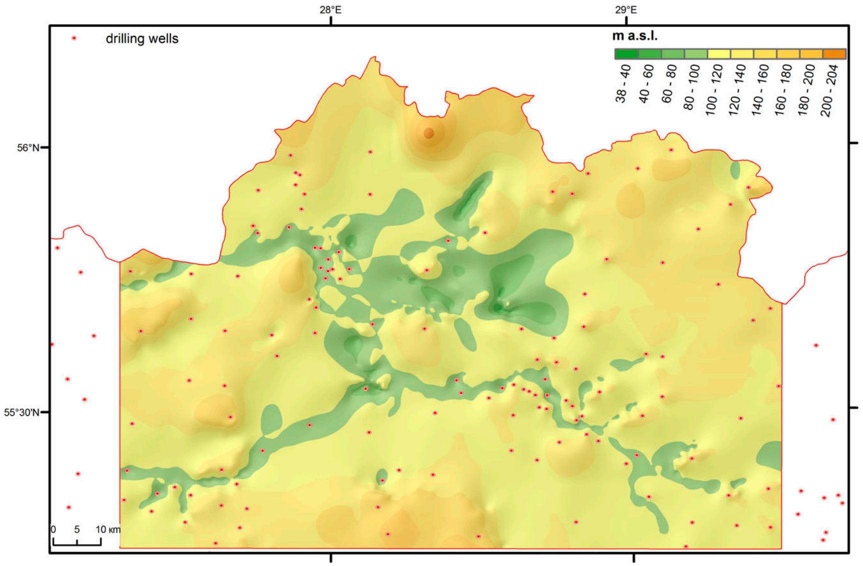


Fig. 30. Model of the upper paleosurface of the Murava interglacial complex in the Polotsk area based on the Catalogue of drilling wells of Levickaya (1990).

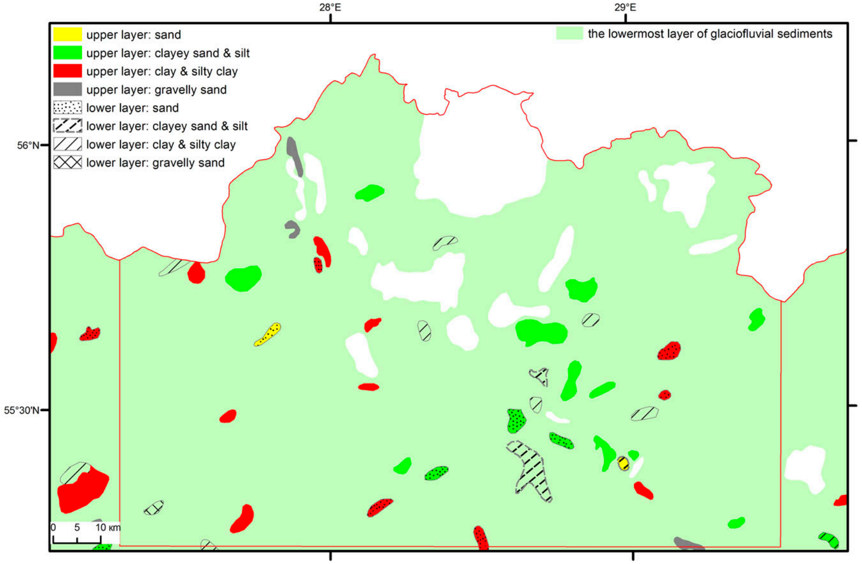


Fig. 31. Composition of deposits of the Murava interglacial complex in the Polotsk area, modified after Levickaya (1990).

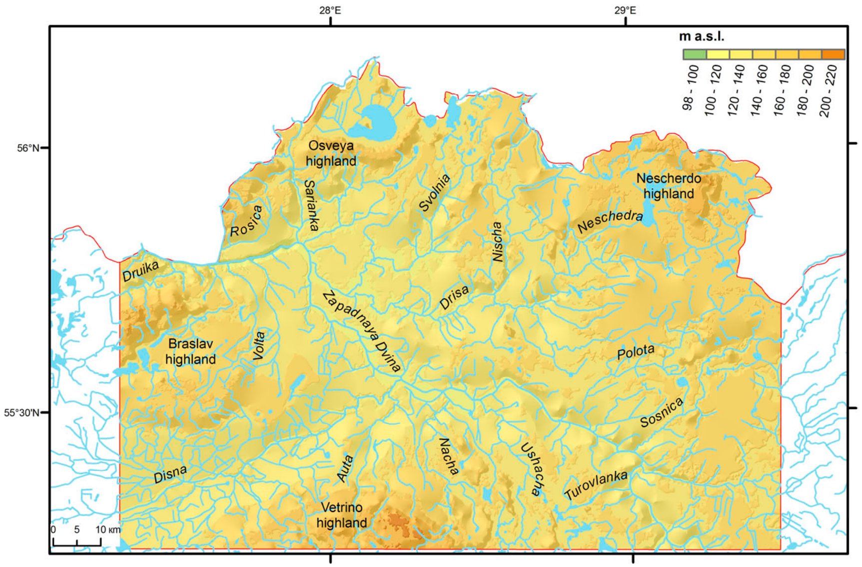


Fig. 32. The digital terrain model (the upper surface of the Poozerie glacial complex) in the Polotsk area based on topographical maps in scale of 1:100 000.

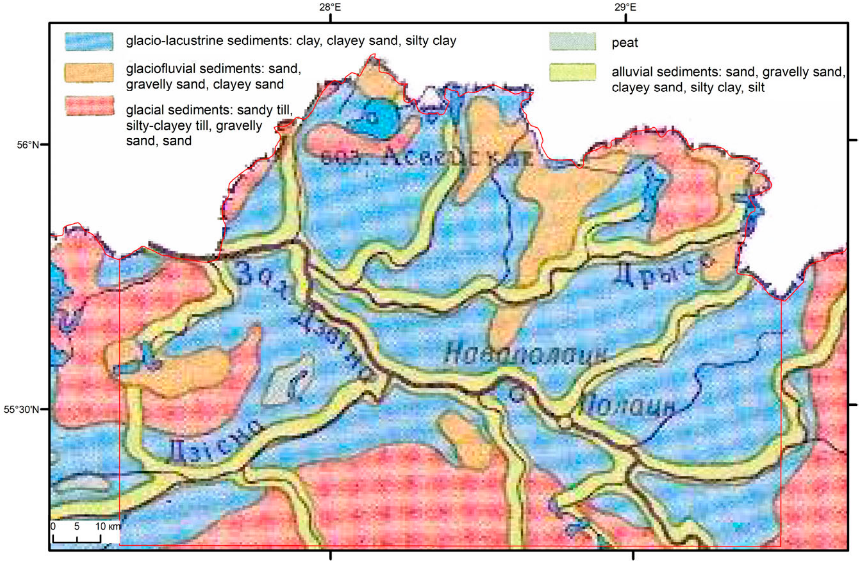


Fig. 33. Composition of deposits of the Poozerie glacial complex in the Polotsk area, modified after National atlas of Belarus (2002).

Pleistocene glaciation which advanced well beyond the limits of the Belarus. The Dnieper deposits (Fig. 25) are generally up to 30 m thick. The most remarkable result of this glaciation was the formation of the first cores of the Braslav, Nescherdo and Vetrino morainic highlands (Fig. 24). In many respects these uplands controlled the dynamics of the later Sozh stage of the Pripyat glaciation, as well as the last (Poozerian) glaciation.

The sediments of the Dneiper-Sozh interstadial are wedged in between the sediments of the Dnieper and the Sozh stadial (Figs. 26, 27). This means that after the Dnieper stadial, the ice sheet completely retreated from the Polotsk area.

The Sozh ice sheet covered almost all of Belarus except the southern part. The Sozh glacial complex (Fig. 29) is up to 10 m thick. As a result of this glaciation the pre-Quaternary and pre-Quaternary-like topography of the Narev, Beloviezha, Berezina, Aleksandriya and Dnieper glaciations/interglacials was completely changed (Fig. 28). The cores of the Braslav, Nescherdo and Vetrino highland as well as the first elements of the Zapadnaya Dvina River, Disna River and Drisa River were formed after the retreat of the Sozh ice sheet. Very interesting is that the most parts of these rivers paleonetwork occupy the weakness zones of the sedimentary cover on top of the faults of the PKDZ.

The Muravian relief within the Polotsk area is more flat, compared with the present one (Fig. 30). The larger part of the territory formed a morainic plain with glaciofluvial and glaciolacustrine landforms. The thickest Muravian sediments were deposited in vast lakes that existed in the Polotsk lowlands (Fig. 31).

Deposits of the subsequent Poozerian Glaciation cover the northern and north-western part of Belarus. The thickness of deposited glacialsediments is up to 15 m. During the Poozerian Glaciation the Braslav, Vetrino, Osveya and Nescherdo glacial highlands were completely developed (Figs. 32, 33). The large Polotsk and Disna glacial lakes came into existence as a result of blocked meltwater drainage (Pavlovskaya 1994). The maximum extent of the last ice-sheet was controlled by the pre-existing topography and depended on the distribution of the morainic highlands and lowlands formed during the Dnieper and Sozh stages of the Pripyat glaciation.

The present topography of the Polotsk area has a basin-like form (Fig. 32). The Polotsk glaciolacustrine lowland (average altitudes 100-140 m a.s.l.) occupies the central part of the study area. The lowland was formed as a result of draining of the Polotsk and Disna glacial lakes (Pavlovskaya 1994, Geology of Belarus 2001). The present river network was formed after this drainage. The Zapadnaya Dvina River and its main tributaries the Disna, Ushacha, Drisa, Obol and Polota are the major rivers of the area. The Polotsk glacio-lacustrine lowland is composed of clay, silty clay and clayey sand (Fig. 33).

The lowland is surrounded by the Vetrino, Braslav, Nescherdo and Osveya highlands. The Vetrino highland was formed during the Orsha and Lepel phases of the degradation of the Poozerian Ice Sheet (PIS), during which the ice margin split up in the Disna and the Polotsk ice lobes (National atlas of Belarus 2002). These highland areas consist of end-morine ridges, hummocky moraine and kames, separated from each other by lake depressions and river valleys (Matveyev et. al. 1988). The Braslav highland (maximum altitude at 210 m a.s.l.) has a complicated configuration and comprises end-morine ridges, kames, eskers, lake depressions, sandur plains and river valleys. It was shaped during the Braslav phase of the degradation of the PIS. The Osveya and the Nescherdo end-morine ridges of the pressure-accumulation type were also formed during the Braslav phase of degradation (National atlas of Belarus 2002).

4.3 Discussion

In the present study, the influence of the Mesoproterozoic PKDZ-faulting on the Phanerozoic and recent evolutions of the Precambrian crust in the Polotsk key area has been assessed using 3D reconstructions of paleosurfaces of the crystalline basement, sedimentary cover and present topography, their GIS correlation modeling and the topolineaments identification.

In the Mesoproterozoic, the Paleoproterozoic crystalline basement in the Polotsk key area was divided into several horst and graben elements along the major EW- and linked NS-trending fault system of the PKDZ. The faulting was developed in conjunction with orogenic processes at the southwestern margin of the East European Craton (Bogdanova et al. 2006). The horst-and-graben structure of the basement and the geographical position of the PKDZ faults, as shown on Fig. 6, have been determined by detailed geophysical investigation (Garetsky et al. 2004, Garetsky et al. 2006). By using the magnetic anomaly field and rare drilling data (Figs. 5a and 6) we suggest that the majority of the basement horsts (the Kochonovo, Lisno, Novopolotsk, Vetrino, Goriany and Polotsk, Fig. 5) consists of low-density rocks with low magnetization like granites, gneisses and migmatites, while all grabens (the Sharkovschina, Miori, Povatie, Borkovichi, Rossony, Marinica, Dretun and Obol blocks) and some of the horsts (Verchnedvinsk, Osveya and Koziany) appear to be made up of more mafic rocks of higher density and magnetization.

The horst-and-graben structure of the basement and the rock composition can have influenced the development of the sedimentary cover. In order to determine this influence we have analysed an array of parameters, such as hypsometry of the basement, composition of the basement rocks, hypsometry of the paleosurfaces of the sedimentary cover, lithology of the cover deposits and the correlation between the upper paleosurfaces of the crystalline basement and of the cover layers (see Table 2). We suggest that the low-density basement rocks with low magnetization, like

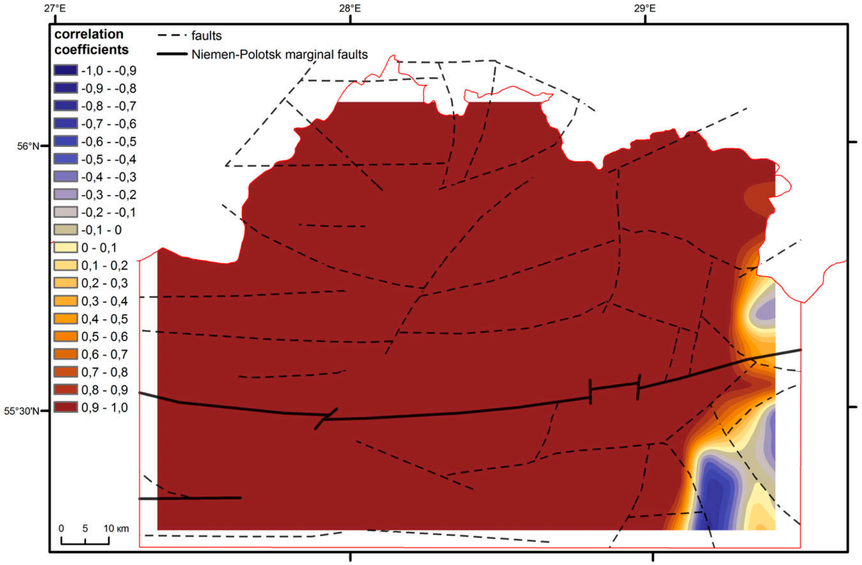


Fig. 34. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Ectasian-Stenian (Ripheian) deposits.

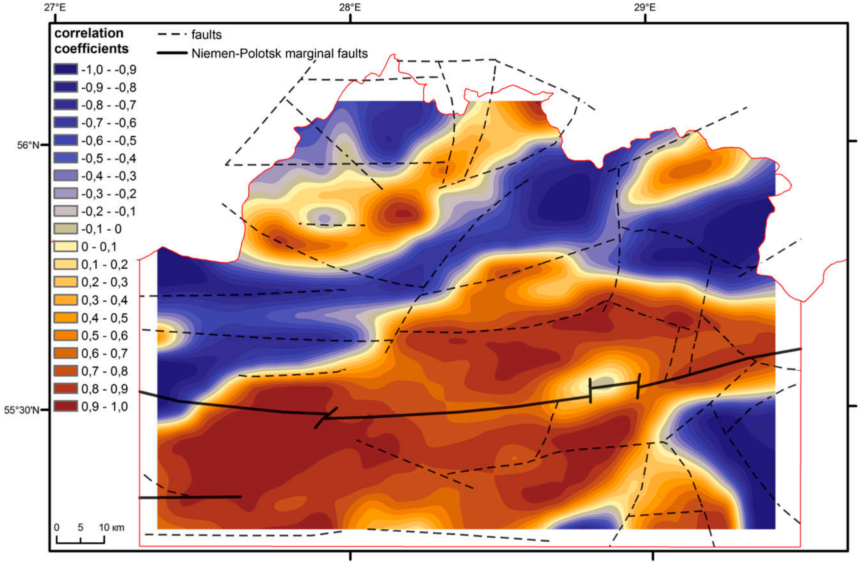


Fig. 35. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Ediacarian (Vendian) deposits.

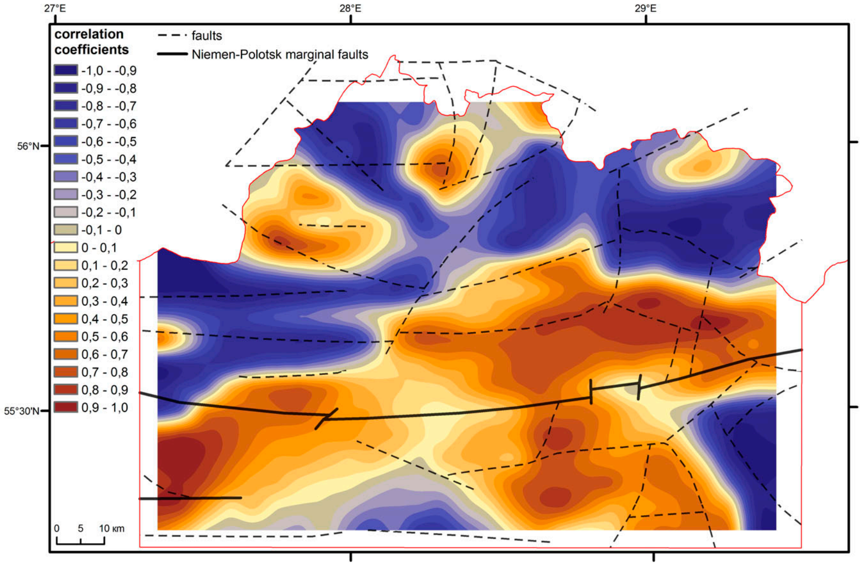


Fig. 36. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Ordovician deposits.

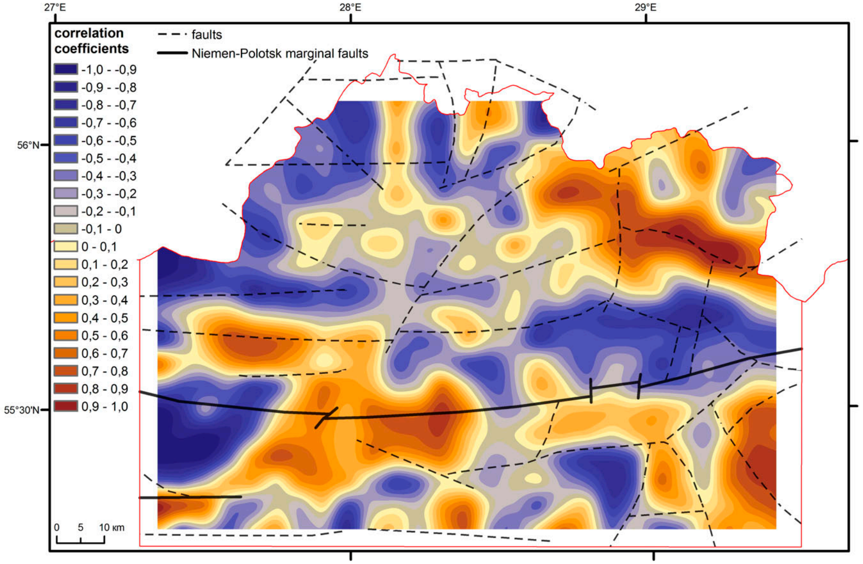


Fig. 37. Map of correlation coefficients between the crystalline basement upper paleosurface and the pre-Quaternary upper paleosurface.

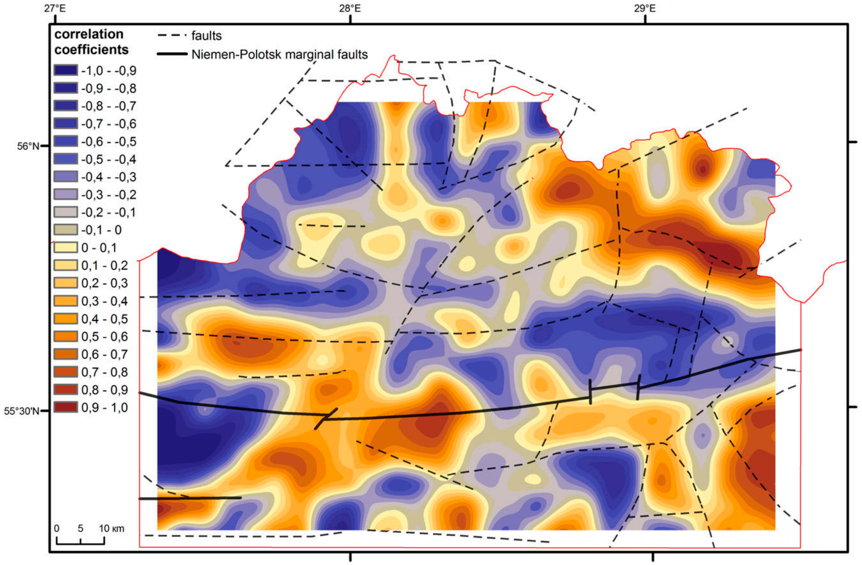


Fig. 38. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Narev glacial complex.

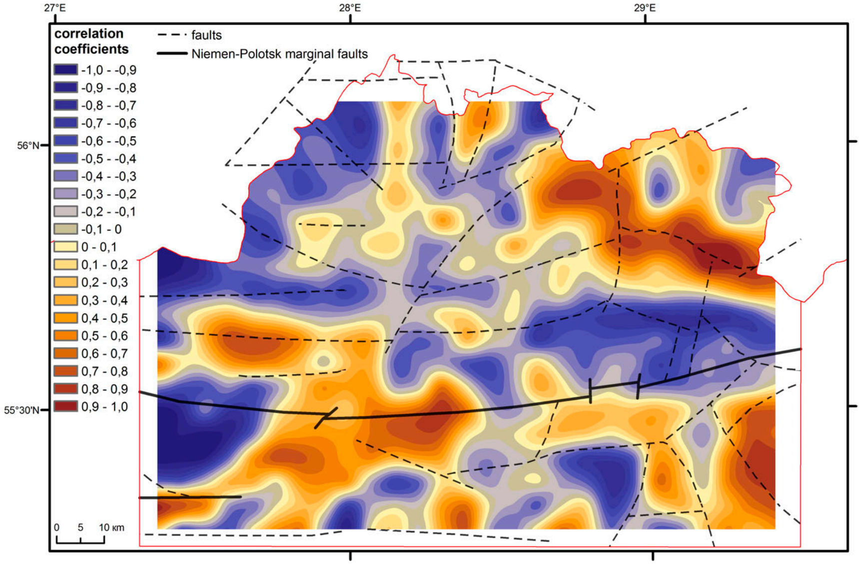


Fig. 39. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Beloviezha interglacial complex.

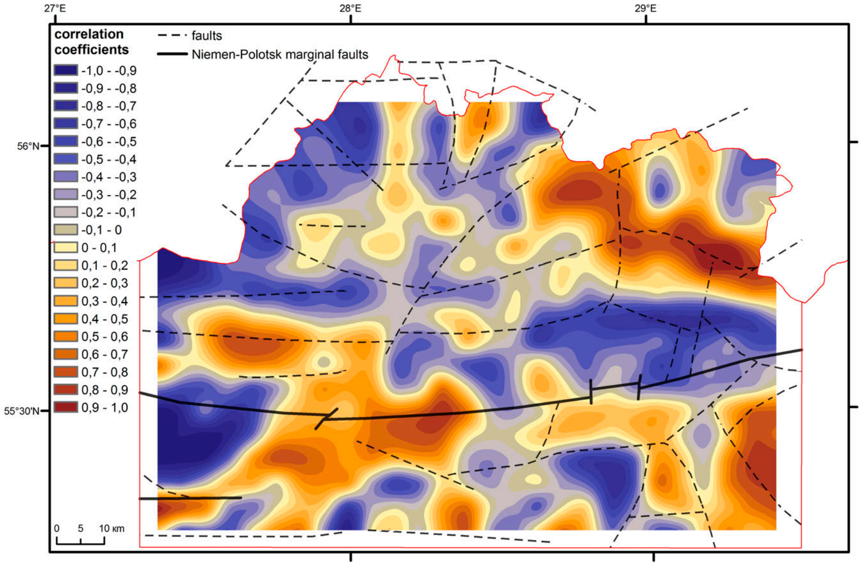


Fig. 40. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Berezina glacial complex.

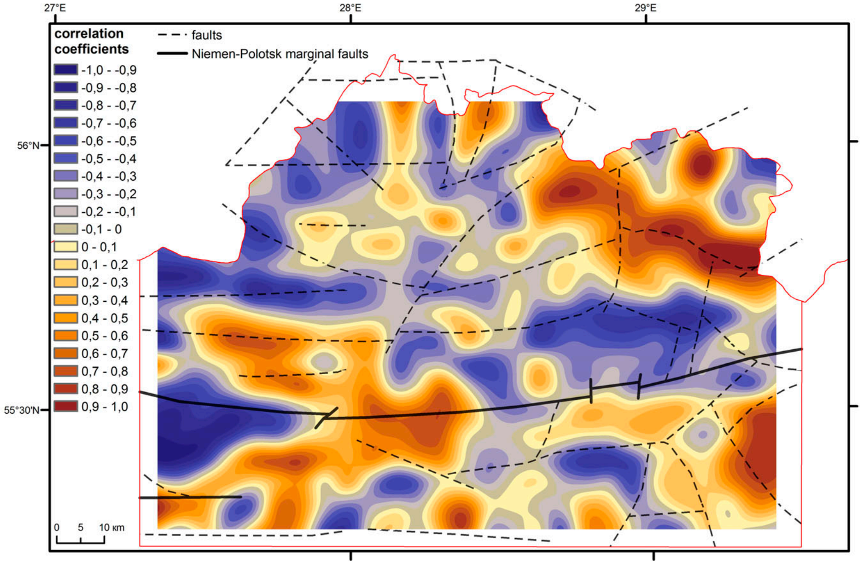


Fig. 41. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Aleksandriya interglacial complex.

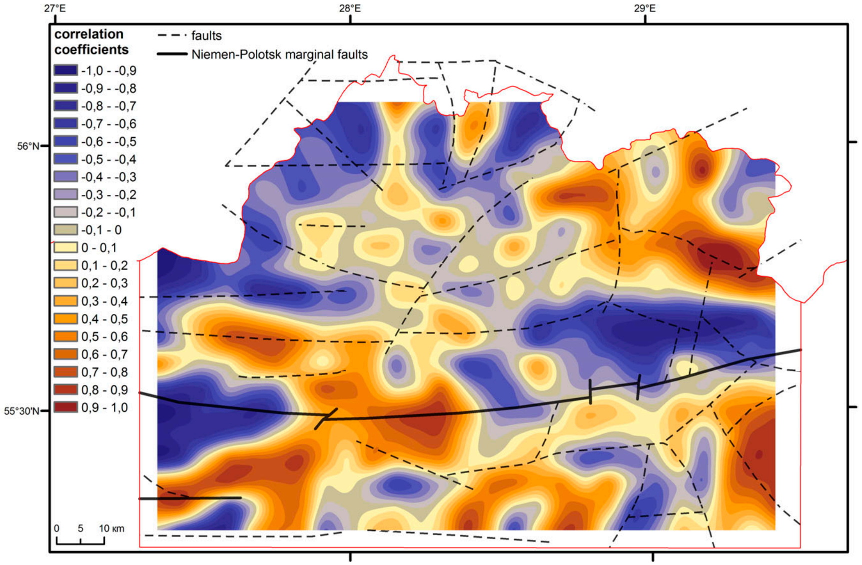


Fig. 42. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Dnieper stadial of the Pripyat glaciation.

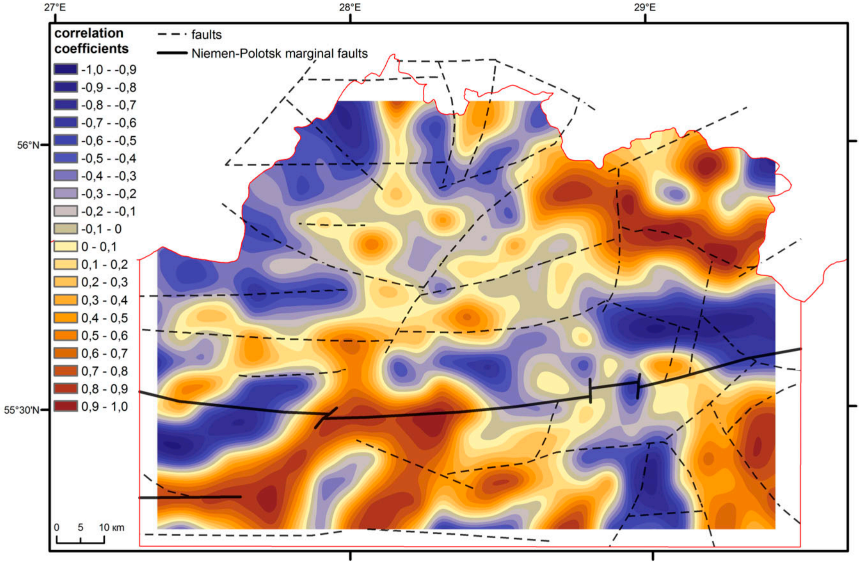


Fig. 43. Map of correlation coefficients between the crystalline basement paleosurface and the upper paleosurface of the Dnieper-Sozh interstadial of the Pripyat glaciation.

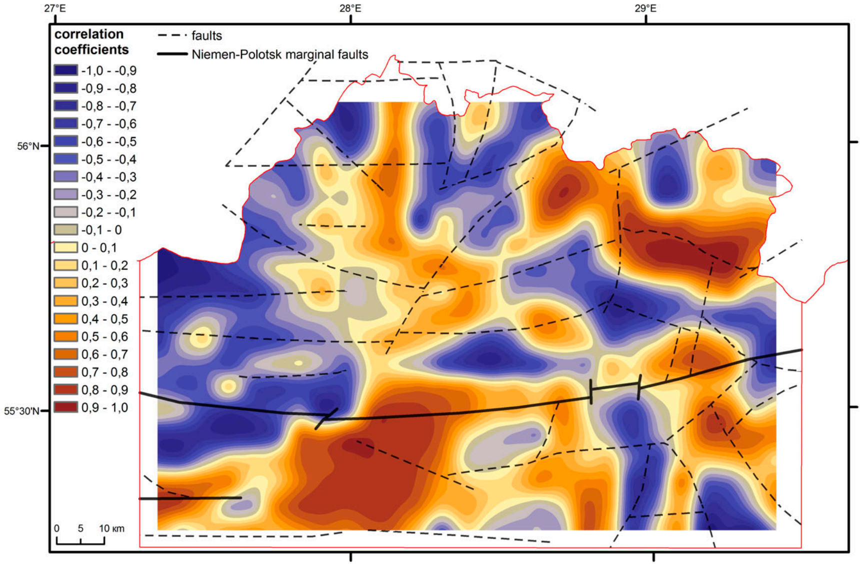


Fig. 44. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Sozh stadial of the Pripyat glaciation.

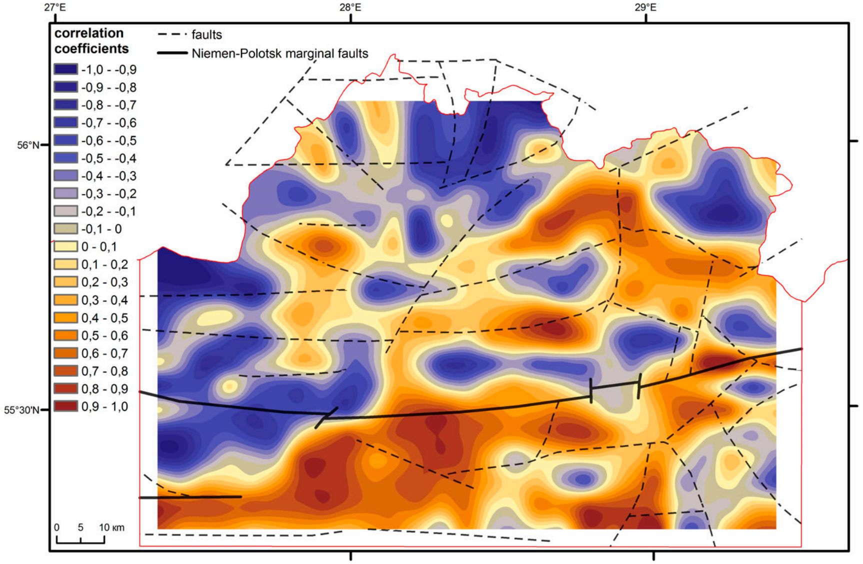


Fig. 45. Map of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurface of the Murava interglacial complex.

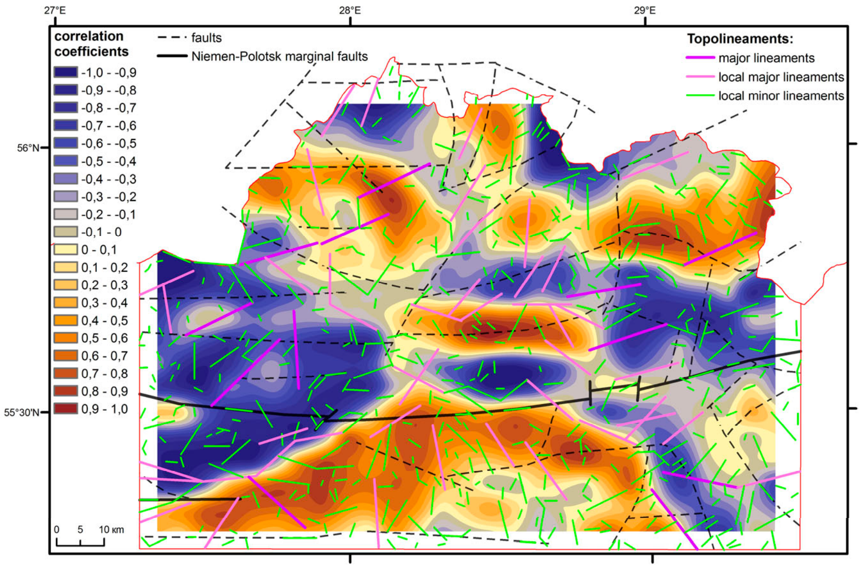


Fig. 46. Map of correlation coefficients between the crystalline basement upper paleo-surface and the present topography (the upper surface of the Poozerie glacial complex).

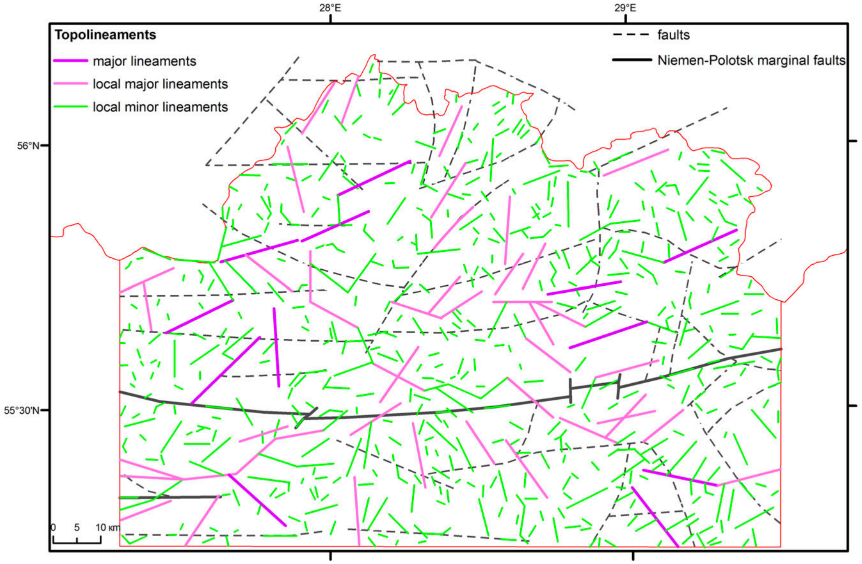


Fig. 47. Faults of the PKDZ and topolineaments in the Polotsk area.

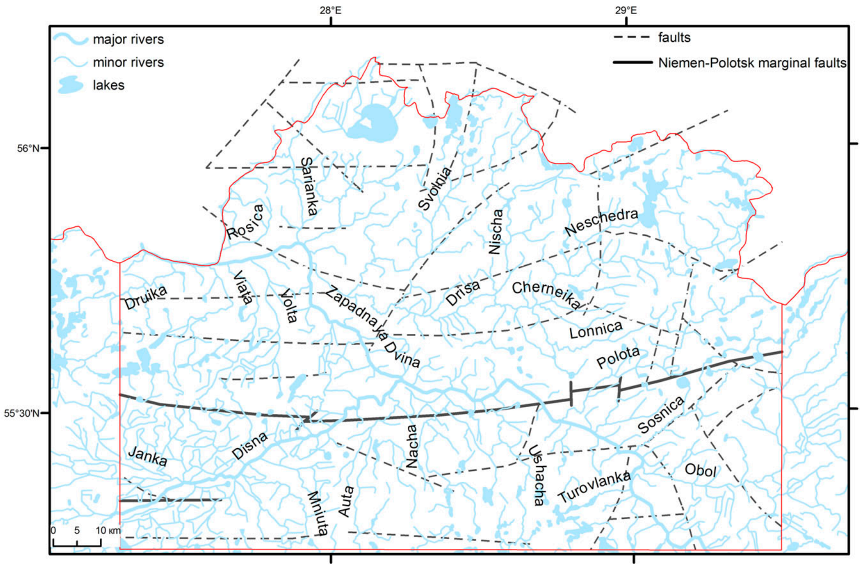


Fig. 48. Faults of the PKDZ and hydrological network in the Polotsk area.

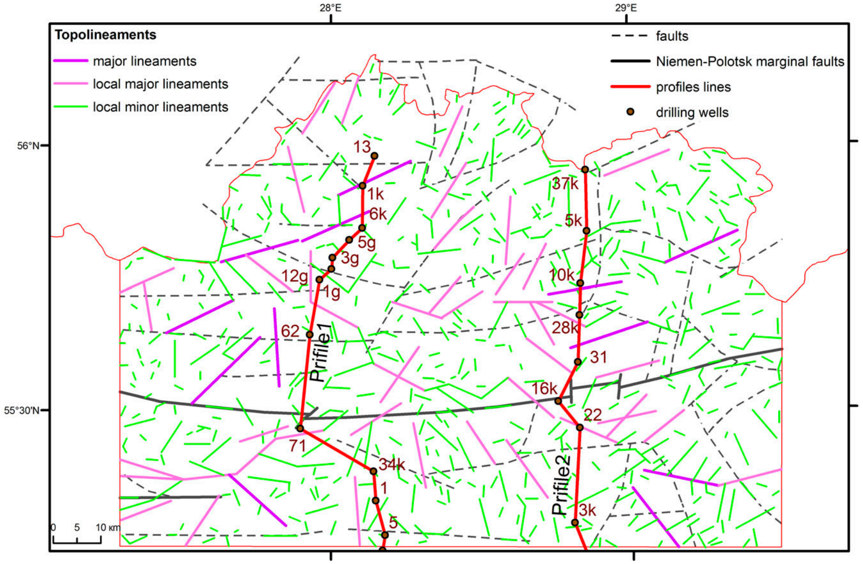


Fig. 49. Location of the geological profiles of the Quaternary deposits.

Table 2. Major characteristics of the crystalline basement and sedimentary cover in the Polotsk area and their correlation.

No.	Names of the basement blocks	Hypsometry of the basement	Magnetic anomaly field, nT	Ectasian-Stenian	Ediacaran	Cambrian, Ordovician	pre-Q	Pleistocene								
								Nr	Bl	Br	Alk	Pt (Dn)	Pt (Dn-Sz)	Pt (Sz)	Mr	Pz
1	Sharkovschina	-3200 – -1800	up to +250		+ S, Si	+ S, Si, L	– S		–	–	–	–	–	–	–	–
2	Miori	-3500 – - 1800	up to +250		+ S, Si	– S, Si, L	+ S				+	+	+	–	–	–
3	Povatie	-2700 – -1900	up to +120		– S, Si	– S, Si, L	– S				–	–	–	–	–	–
4	Verchnedvinsk	-1200 – -600	up to +100		– S, Si	– S, Si, L	– S				–	–	–	–	–	–
5	Kochonovo	-1700 – -1000	up to -110		+ S, Si	– S, Si, L	– S, D				–	–	–	+	+	+
6	Osveya	-1500 – -600	up to +110		– S, Si	– S, Si, L	– D							–	–	–
7	Lisno	-2000 – -650	up to -110		+ S, Si	+ S, Si, L	+ D									+
8	Rossony	-2000 – -1000	up to +100		– S, Si	– S, Si	+ D, L, S					+	+	+	+	+
9	Borkovichi	-2200 – -1800	up to +125		+ S, Si	+ S, Si	+ S					+	+	+	+	+
10	Novopolotsk	-1800 – -950	up to -210		+ T, S, Si	+ S, Si	– S	–	–	–	–	–	–	+	+	–
11	Vetrino	-1500 – -245	up to -300		+ S, Si	+ S, Si	+ S	+	+	+	+	+	+	+	+	+
12	Goriany	-1500 – -500	up to -110		+ T, S, Si		+ S		+		–	–	–	–	+	+
13	Obol	-2800 – -1300	up to +200	+ S	– T, S, Si		+ S		+	+	+	+	+	–	–	–
14	Polotsk	-1500 – -500	up to -120		+ T, S, Si		+ S	+	+	+	+	+	+	+	+	+
15	Koziany	-1500 – -900	up to +225	+ S	– T, S, Si		+ S, C,D					+	+	+	+	+
16	Dretun	-2700 – -1800	up to +210	+ S	+ T, S, Si		– D						–	–	–	–
17	Marinica	-2300 – -1800	up to +200		– T, S, Si		+ D, S							+	+	–
18	Zaborie	-1500 – -700	up to +110		– T, S, Si		+ L, D						+	+	+	+

Notes. Colors indicate: yellow – horsts, violet – grabens, red – basement blocks of mostly granitoid composition, blue – basement blocks containing mafic rocks.
Lithology of the sedimentary cover: S – sandstones, Si – siltstones, T – tillites, L – limestones, D – dolostones.
Coefficients of correlation between upper paleosurfaces of the crystalline basement and the certain layers of the sedimentary cover: + - mostly positive, – - mostly negative.

granites, gneisses and migmatites, can have contributed to uplifting, whereas the mafic rocks of the basement with higher density and magnetization can be a cause for subsidence.

The lithology of the cover deposits allows us to reconstruct the paleogeographical environments and paleogeomorphology when the sedimentary cover was developing during various periods. Thus, terrigenous deposits (sandstones and siltstones) point to a relatively shallow water sedimentation, while dolostones and limestones suggest a deeper water deposition.

The correlation between the upper paleosurfaces of the crystalline basement and various layers of the sedimentary cover indicates periods of similar hypsometric characteristics of the basement and sedimentary strata (positive correlation coefficients) or the hypsometric inverse situation when, for example, a depression in the basement corresponds to an uplifted cover (negative correlation coefficients).

The analysis of such the indicators allows us to group the basement blocks in the Polotsk area as follows.

- ***Group 1*** includes the basement blocks (4, 6, 11 and 14 in Fig. 5), which have had a strong tendency of either uplift or subsidence during the whole history of the sedimentary cover development. This tendency is related to the composition of the basement (the low-density, “granitoids” blocks have experienced tectonic uplifting, whereas the “mafic” blocks have been subsiding). This is also confirmed by the mostly terrigeneous lithology of the cover sediments above the “granitoids” blocks and more carbonatic, covering “mafic” ones.
- ***Group 2*** comprises blocks of the basement, which were the most tectonically active during the last (neotectonic) period. In some of these blocks (7, 8 and 9 in Fig. 5), the composition of the basement has determined the character of the neotectonic activity, so that low-density “granitoids” blocks (7) maintained uplifting, whereas ”mafic” blocks (8 and 9) participated in subsidence. In the other blocks (1, 15, 16 and 18) the composition of the basement rocks has played a dependent role because of those grabens was filled in by the thick sedimentary deposits and “mafic” horsts have high content of less magnetized rocks (Fig 5a).
- ***Group 3*** represents basement blocks (2, 3, 5, 10, 12, 13 and 17 in Fig. 5), which have had periods of both uplift and subsidence during the development of the sedimentary cover. In such cases, different tectonic behavior can partly have been related to the basement composition, but might also be caused by far-field effects of orogenic processes outside the East European Craton (Caledonian, Variscan, Alpine), glaciations, etc.

The grouping of the basement blocks, as well as the analysis of the major characteristics of the crystalline basement, sedimentary cover and their correlation, all allow us to better understand of the evolution of the sedimentary cover in the Polotsk area and the basement-cover relationships within the Polotsk-Kurzeme Deformation Zone.

All the time during the Neoproterozoic and Early Paleozoic the first group of the Polotsk (number 14 as indicate in Fig. 5) and Vetrino (11) “granitoids” blocks were uplifted and the Verhnedvinsk (4) and Osveya (6) ”mafic” blocks subsided. The Obol (13) and Dretun (16) grabens started to subside during the Ectasian-Stenian extension of the crust and the development of the Volyn-Orsha Aulacogen (Tectonics of the western part of the East European Craton 1990). As a result of this subsidence, these blocks were covered by an intracontinental marine basin. Activation of the PKDZ faults occurred also in the Cryogenian-Ediacaran (ca. 850-540 Ma). In that period the study area was affected by glaciations, which reinforced the tectonic subsidence (Geology of Belarus 2001). Changing of the tectonic regimes from subsidence during the glaciations to uplift during the interglaciations/deglaciation activated the faults system. The Sharkovschina (1), Miori (2), Povatie (3), Verchnedvinsk (4) and Osveya (6) ”mafic” blocks, as well as Kochonovo (5) and Lisno (7) “granitoids” blocks of the basement subsided during the Ordovician, which was caused by far-field effects of the Caledonian orogeny (Tectonics of the West of the Eastern European platform 1990). Those blocks were covered by the thick layer of the mostly carbonatic Cambrian and Ordovician sediments.

According to the obtained models of the development of the sedimentary cover during the Ectasian-Stenian, Ediacaran, Cambrian and Ordovician periods (Figs. 8, 10 and 12), most of the PKDZ faults caused flexuring in the Ectasian-Stenian, Ediacaran, Cambrian and Ordovician deposits, particularly on top of the Niemen-Polotsk marginal faults. This is confirmed by maps of correlation coefficients between the upper paleosurfaces of the crystalline basement and of the Ectasian-Stenian, Ediacaran and Ordovician sedimentary deposits, respectively (Figs. 34-36). A wide belt of positive correlation coefficients (from +0.10 to +0.95) above the Niemen-Polotsk marginal faults is recorded by these maps, which means that the flexures in the Ectasian-Stenian, Ediacaran and Ordovician sedimentary deposits are in direct relationship with the Niemen-Polotsk faults. The flexuring character of those sediments can be interpreted as a result of tectonic movements of the basement blocks in relation to each other, or as the influence of the Caledonian reactivation of these faults.

In the Devonian, a new sedimentational cycle occurred in the study area. The Polotsk area was covered by a marine basin. The uplift of the “granitoid” blocks and subsidence of the ”mafic” blocks of the first group was continued. The Kohonovo (15) and Novopolotsk (10) “granitoid” blocks, the Miori (2) and Marinica (17) ”mafic” blocks of the third group ex-

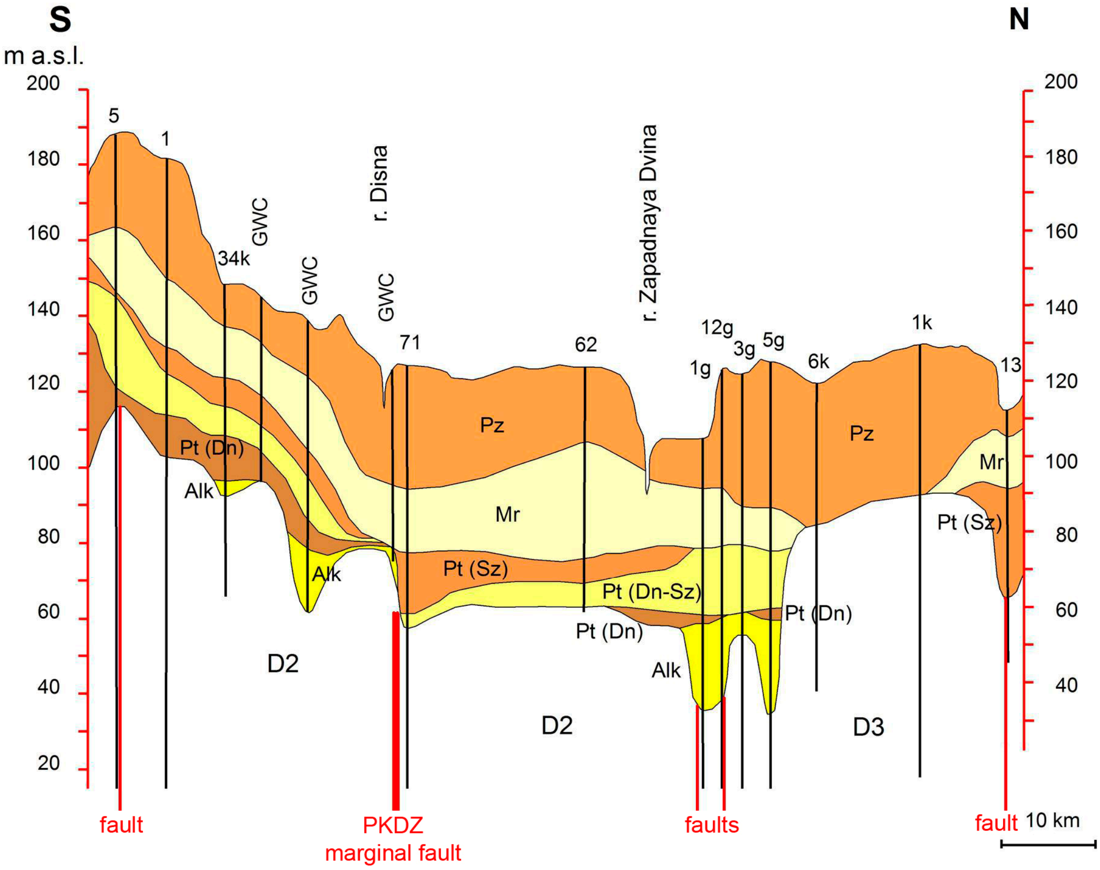


Fig. 50. Profile 1.

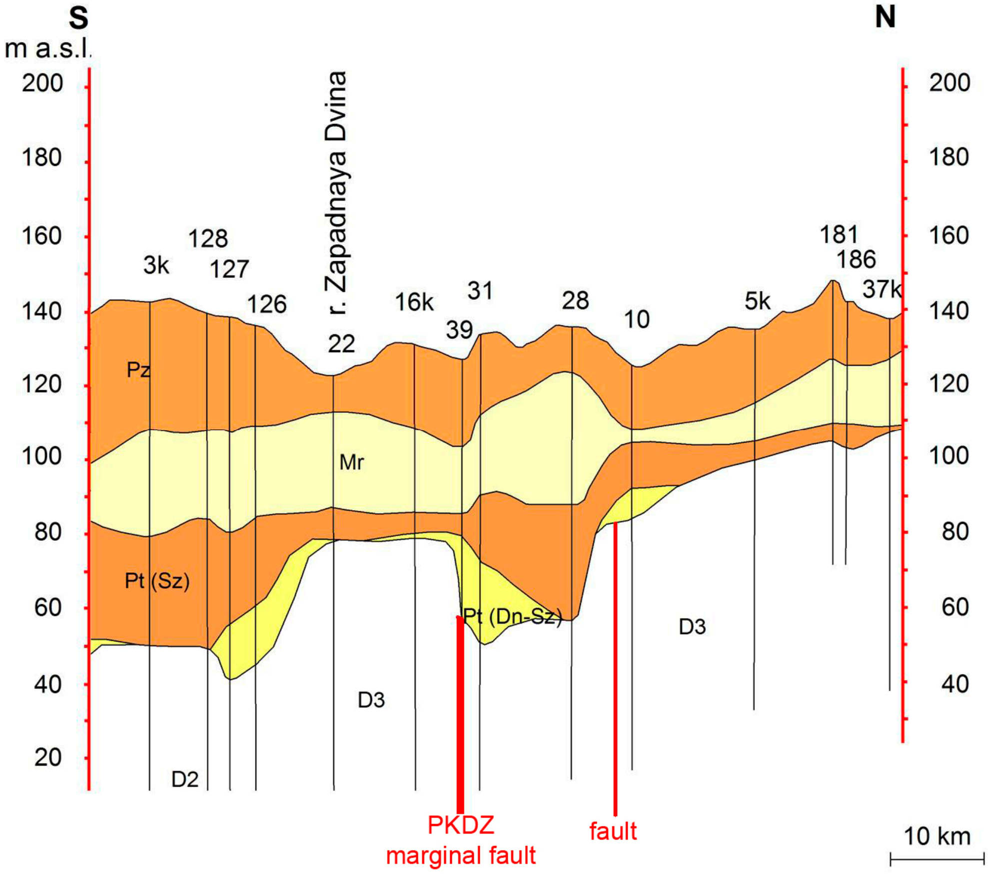


Fig. 51. Profile 2.

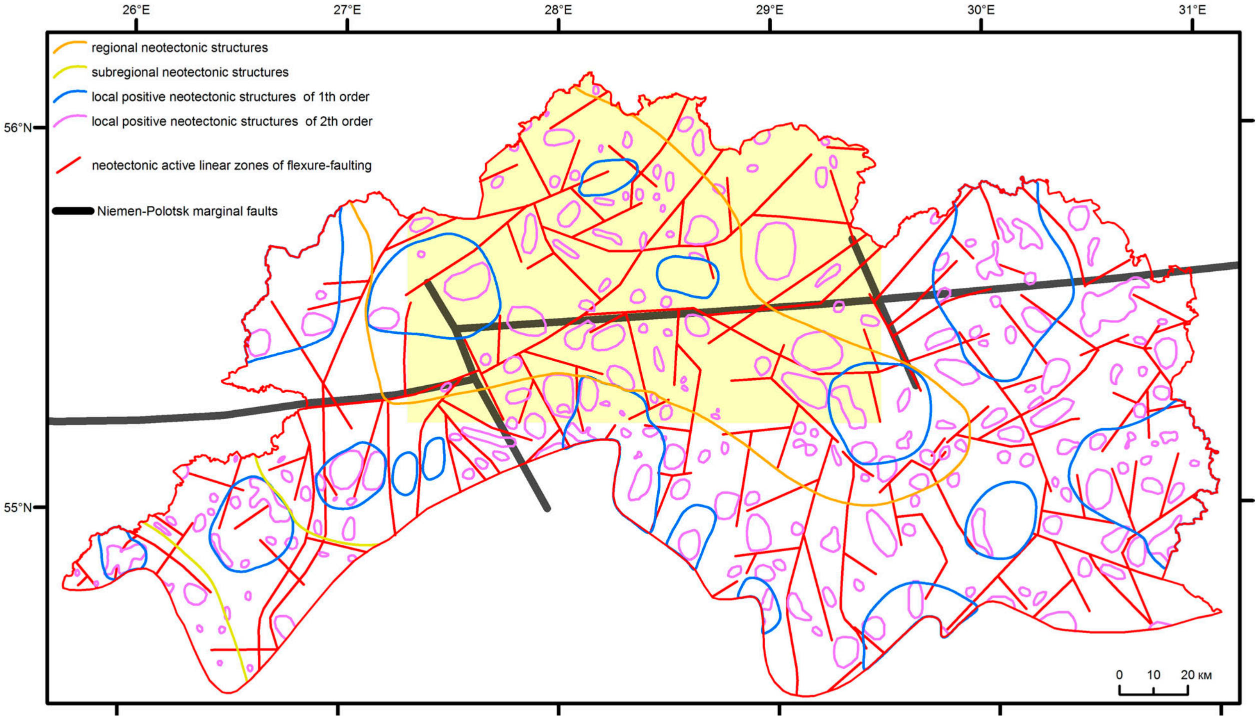


Fig. 52. Neotectonic pattern of northern Belarus.

perienced subsidence, while the Povatie (3), Obol (13), Goriany blocks of this group were uplifted during this period. Different tectonic behavior can partly have been related to the basement composition, but might also have been caused by far-field effects of Variscan orogeny. The pre-Quaternary upper paleosurface, as well as in the Middle Pleistocene glacial/interglacial upper paleosurfaces (Figs. 14, 16, 18, 20, 22, 24 and 26), indicate the Polotsk and the Braslav valleys, situated mostly on top the PKDZ faults. We suggest that these places were some kind of weakness zones in the sedimentary cover, which was affected by the exaration work of the Middle Pleistocene ice sheets. The maps of correlation coefficients between the crystalline basement upper paleosurface and the upper paleosurfaces of the pre-Quaternary sedimentary deposits, the Narev, Beloviezha, Berezina, Aleksandriya, Dnieper and Dnieper-Sozh glacial/interglacial complexes, show mostly the same correlation pattern because of limited distribution of those sediments (Figs. 37-43). The positive correlation coefficients (up to +0.85) on top the Niemen-Polotsk marginal faults in the central part of the study area indicate a flexuring character of the Devonian and the Middle Pleistocene deposition. The flexuring of the Devonian and the Middle Pleistocene sediments above the PKDZ marginal faults is confirmed by geological profiling (Figs. 49-51).

The rapid changes of neotectonic regimes within the Pleistocene, such as far-field effect of the Alpine orogeny, neotectonic subsidence during the glacial advances and neotectonic uplift during the glacial retreats caused by the thickness of the ice sheets during the glaciations (during the Last Glacial Maximum estimated to 100 m (the 'maximum' model reconstruction after Siegert et al. (2001)), have affected the sedimentary cover and most part of the faults of the PKDZ (Kurlovich et al. 2007). The second group of the basement blocks was activated during this period. The uplifted position of the Vetrino (11), Zaborie (18), Koziany (15) "granitoid" blocks of the basement caused the formation of the Nescherdo, Vetrino and other glacial highland. This is indicated by areas of positive correlation coefficients (up to +0.90) in the map of correlation coefficients between the upper paleosurfaces of the basement and the of the Sozh, Murava and Poozerie glaciations/interglacial complexes (Figs. 44-46). The glacial highland has been formed on top the Miori and Dretun depression (Fig. 6) of the crystalline basement. This is confirmed by the wide area of negative correlation coefficients (from -0.10 to -0.85).

The Pleistocene complexes respond to the PKDZ faults as changing of the thickness and structures (declining glacial and interglacial layers) of the Quaternary sediments across the fault zone (Figs. 49-51). The neotectonic active linear zones of flexure-faulting is situated on top the Mesoproterozoic faults (Fig. 52). These were distinguished by morphometric methods and confirmed by geological data such as displacement, flexuring and fissuring in the Quaternary deposits. The present topography also reacts to the faults of the PKDZ. A number of topolineaments is situated on top the PKDZ faults (Fig. 47). The majority of the recognized topolineaments are rectified parts of rivers. Thus, as examples,

- Parts of the Nacha River and several tributaries of the Ushacha and Disna rivers run along the Niemen-Polotsk marginal faults;

- The left tributary of the Svolna River and the right tributary of the Drisa River flow along a fault bounded in the west by the Rossony (8) block of the basement;
- The right tributary of the Svolna river run along a fault, bounded in the south by the Lisno (7) block of the basement;
- Parts of the Polota River react to a fault, bounded in the west the Dretun (16) block;
- The Sosnica River flows along a fault, bounded in the west the Obol (13) and Koziany (15) blocks;
- The tributaries of the Sarianka River run along a fault, bounded in the south the Osveya (6) block (Figs. 47 and 48).

A lot of small lake depressions are situated above the Niemen-Polotsk marginal faults. The PKDZ faults are also suggested to have controlled the formation the morainic highlands within the study area. Thus, the Niemen-Polotsk marginal faults confine the position of the Braslav highland and the faults bounding the Osveya (6) block in the south seem to control the position of Osveya highland. Further faults bounding the Zaborie (18) in the south seem to control the position of the Nescherdo end-morine riges.

4.3 Summary

As a result of the study of the Polotsk key area of the PKDZ we conclude that the structure and the composition of the basement rocks have influenced the development of the sedimentary cover. The activity of the PKDZ was caused by far-field effects of orogenic processes outside the East European Craton (Caledonian, Variscan, Alpine), as well as by glaciations. In the Cenozoic, the faults of the PKDZ were affected by both neotectonics and varying pressures of ice sheets on the sedimentary cover in the Polotsk area. We reached these conclusions related to the Cenozoic on the basis of the following indicators:

- Positive correlation of the upper paleosurface of the crystalline basement with the Quaternary glacial/interglacial paleosurfaces and present landforms;
- Changes of sediment thickness and structures (e.g. glacio-dislocations and declining glacial and interglacial layers) of the Quaternary sediments across the Polotsk-Kurzeme Deformation Zone;
- The presence of neotectonic active linear zones with flexure-faulting above the Mesoproterozoic faults;
- The faults of the Polotsk-Kurzeme Deformation Zone substantially influenced the formation and development of the present landforms;
- The present seismic activity.

5 The eastern part of the Småland-Blekinge Deformation Zone (Sweden) area

5.1 The crystalline basement

The crystalline basement in the eastern part of the SBDZ area is situated very close to the present ground surface. According to the well archive of the Swedish Geological Survey (SGU), the maximum depths of the crystalline basement surface are ca. 10 m in the area of the Silletorpsån River and the Kulerydsgölen and Knallagölen lakes, ca. 9 m in the area of the left tributaries to the Lillån River, ca. 8 m in the area of the tributary to the Brömsebäck River in the north-easternmost region of the key area and the area of the tributary of the Lower Landabäcken River in the south-easternmost region of the key area. The depths average from 2 to 4 m. The crystalline basement outcrops at numerous places more or less uniformly distributed within the area.

The paleosurface of the crystalline basement has a block structure (Figs. 53 and 54), blocks that were separated by faults of the SBDZ during the uplift of the Blekinge Province relative to the Småland Province at approximately 1.45 Ga (Johansson et al. 2006). The available structural data (Lindh et al. 2001, Rimša 2002) suggest that the Blekinge Province was uplifted along planes striking approximately 110° and dipping steeply towards the south. There is also a small horizontal component of movement along the SBDZ. The crystalline basement upper paleosurface in the eastern part of the SBDZ area is more elevated in the west and in the north.

The eastern part of the SBDZ is markedly offset by a number of later NE-SW-trending faults (Fig. 53). It abuts on, but does not perceptibly affect the approximately 1.45 Ga old Eringsboda granite in the west (Johansson et al. 2006). To the south of the SBDZ, the gneissic granitoid of the Tving group (ca. 1.77-1.75 Ga, Johansson et al. 2006) dominates. North of the SBDZ, granites belonging to the Småland-type (ca. 1.8-1.75 Ga, Johansson et al. 2006) prevail. Within both areas mafic rocks also occur.

5.2 The sedimentary cover and the present landforms

The sedimentary cover of the eastern part of the SBDZ area is poorly mapped, the northeastern part has not been mapped at all. Thus, we have used the only available source, i.e. a SGU specialmap (Gammal jordartskarta 3F 4e - 4G 3d in scale 1:100 000).

The sedimentary cover in the area consists of quite thin Quaternary deposits, preliminary of a last glacial (Weichselian) and postglacial (Holocene) age. We suggest that previous sedimentary deposits, as well as the part of the bedrock, have been eroded during previous Pleistocene ice advances. The sequence of glacial/postglacial deposits reaches a maximum thick-

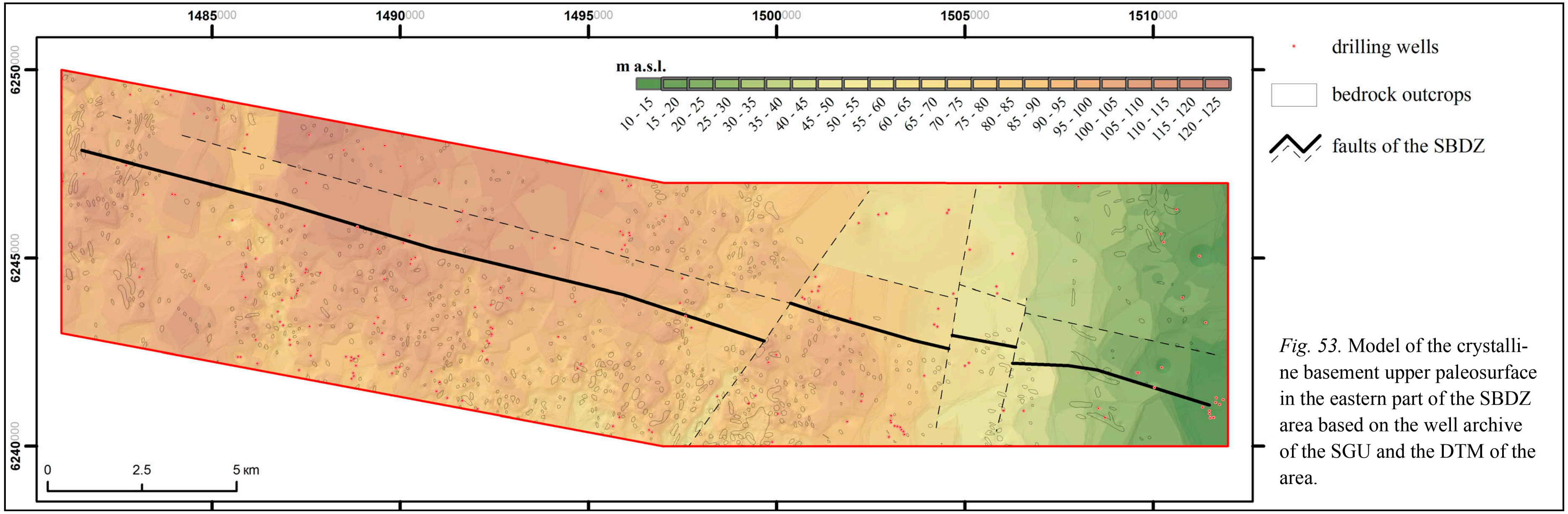


Fig. 53. Model of the crystalline basement upper paleosurface in the eastern part of the SBDZ area based on the well archive of the SGU and the DTM of the area.

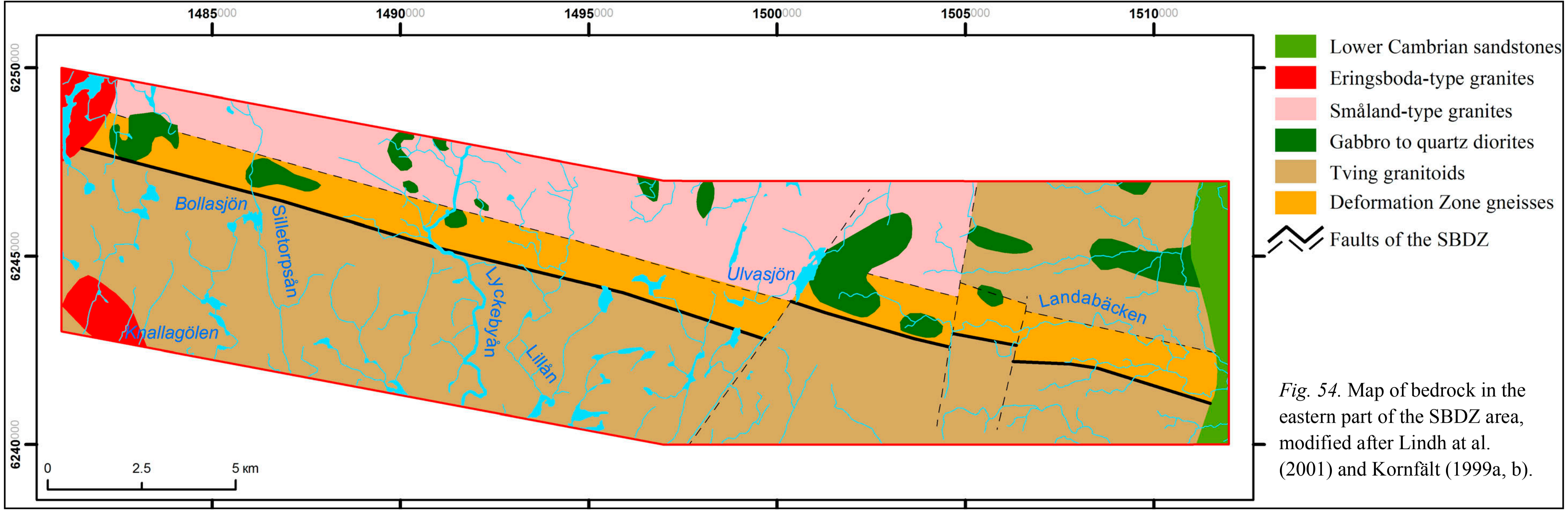


Fig. 54. Map of bedrock in the eastern part of the SBDZ area, modified after Lindh at al. (2001) and Kornfält (1999a, b).

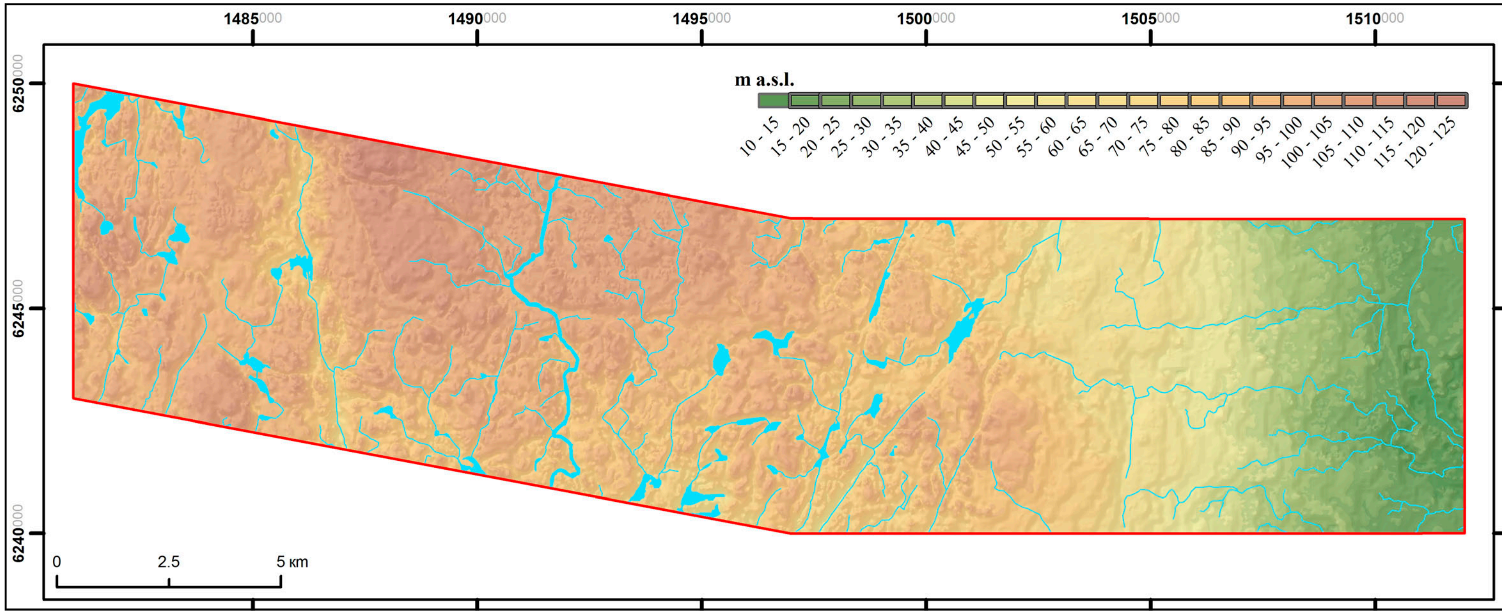
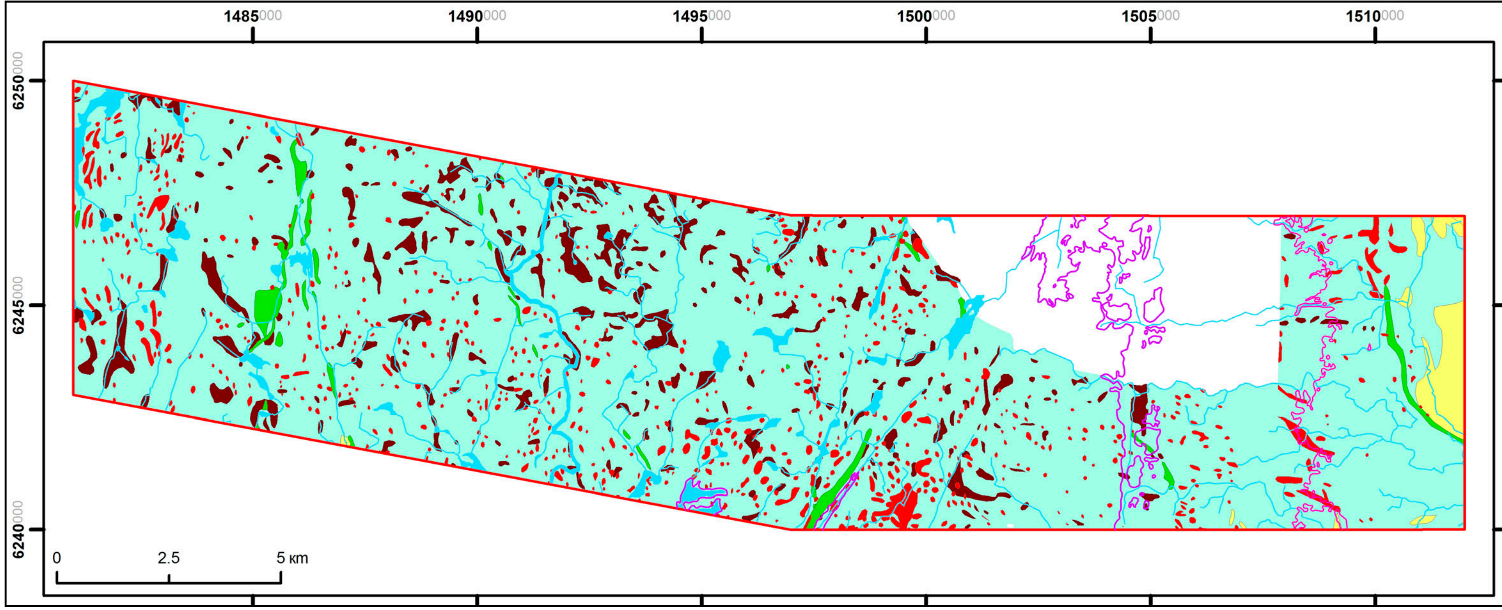


Fig. 55. The digital terrain model of the eastern part of the SBDZ area based on topographical maps: Karlskrona 3F NO, Kristianopel 3G NV, scale 1:50 000.



🟥	peat
🟨	postglacial sand
🟩	fluvioglacial deposits
🟦	till
🟥	bedrock
☐	not explored area
∼	65 m a.s.l. (the highest coastline)
∼	30 m a.s.l.

Fig. 56. Map of Quaternary deposits in the eastern part of the SBDZ area, modified after Gammal jordartskarta 3F 4e - 4G 3d in scale 1:100 000 (2007).

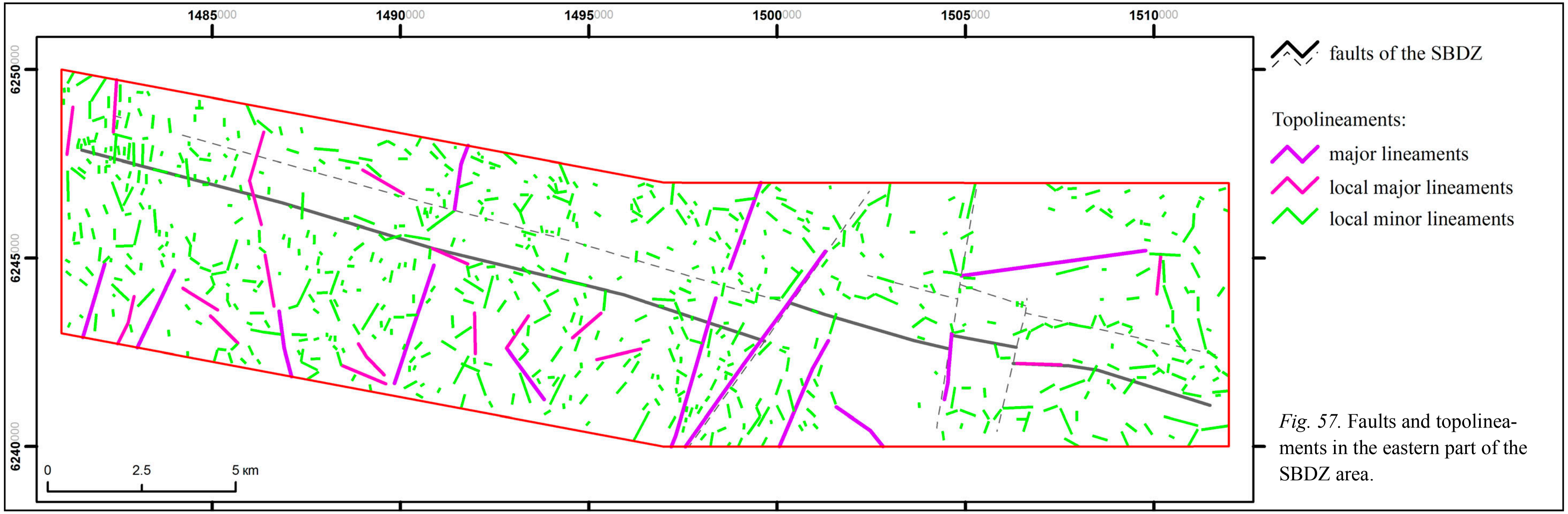


Fig. 57. Faults and topolineaments in the eastern part of the SBDZ area.

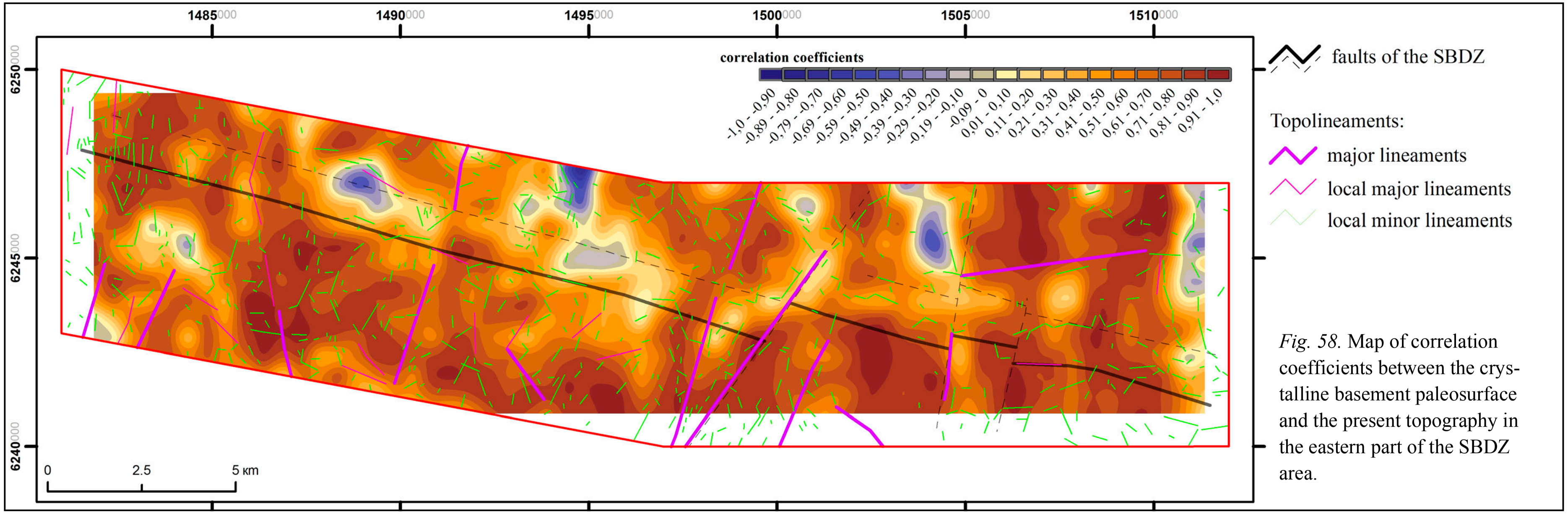


Fig. 58. Map of correlation coefficients between the crystalline basement paleosurface and the present topography in the eastern part of the SBDZ area.

ness of 8-10 m, mostly in the depressions of the basement upper paleosurface, with an average thickness of 2-4 m. According to Ringberg (1971) and Björck (1979), the highest shoreline is situated an altitude of 63-67 m (average 65 m), formed by the Baltic Ice Lake at the time when the retreating ice margin changed from a subaquatic to a terrestrial position. Sediments and landforms were formed both below and above the highest shoreline, depending on altitudinal relations (see Figs. 55, 56). The highest shoreline divides the area into specific landscape types (Björck & Möller 1987). Within the key area a few territories in the south and the whole eastern part below the highest shoreline are characterized by relatively flat valleys or low-lying areas filled with glacio-lacustrine deposits. These areas also have bedrock uplands, characterized by wave-washed thin till covers. The territory above the highest shoreline is characterized by vast areas of hummocky moraine.

According to the classification of Lagerlund & Björck (1979) the glacial and late-glacial sediments in the easternmost part of the area of flat valleys (below 30 m) belong to the Listerby Formation. Its lower part was formed in a glacial-proglacial environment, while and the upper part in nonglacial subaqueous and littoral environment (Björck & Möller 1987). Within the area (see Fig. 56) the glacial part consists of till and glaciofluvial sediments of wide wave-washed eskers. The nonglacial sandy part was formed during the regression of the Baltic Ice Lake. The area above ca. 30 m is occupied by the Svängsta Formation, which is composed of till and glaciofluvial deposits. In the SBDZ key area this is exemplified by the eskers near the Lillån River and Landabäcken River. The hummocky moraine above 65 m a.s.l. also belongs to the Svängsta Formation (Lagerlund & Björck 1979) and can be correlated to the Hälsegylet member of the Ryd Formation (Möller 1987). The hummocky moraine covers high grounds as well as depressions. The hummocks are made up of flowtill complex resting on melt-out till or of melt-out till entirely (Möller 1987). The glaciofluvial sediments above the highest shoreline also belong to the Svängsta Formation or the Ryd formation (Lagerlund & Björck 1979, Möller 1987, respectively).

The presence of the two groups of landforms within the eastern part of the SBDZ area is explained by Möller (1987) and Björck & Möller (1987) as differences in basal thermal regimes and flow characteristics of ice during the final retreat of the Scandinavian Ice Sheet (SIS) in the Late Weichselian. At the first stage the ice sheet was at Blekinge's present coastline. The ice was at the pressure melting point at the base and sliding over its bed. The flat valley fills below the highest shoreline in the eastern and southern parts of the key area were formed during the recession of ice toward the north as the Baltic Ice Lake following the receding ice margin. During the second stage the basal thermal regime of the ice changed. Deceleration towards the glacier margin decreased frictional heat at the bed. Together with other parameters influencing basal temperatures in the ablation area, such as ice thickness, surface temperature, upward-directed velocity and ablation rate, transformed a melting bed to a freezing bed and finally into a totally frozen bed. The basal freezing and subsequent stagnation of basal debris-rich ice is suggested to be the main reasons for the formation of the hummocky moraine landscape (Möller 1987).

5.3 Discussion

The degree of inheritance of the present topography from past geological events in the eastern part of the SBDZ area has been assessed by GIS modeling of the crystalline basement upper paleosurface, the present topography surface and basement-present topography correlation, as well as topolineaments identification.

A comparison of the model of the crystalline basement upper paleosurface (Fig. 53) with the DTM (Fig. 55) suggests that the formation of the present topography depended on the crystalline basement topography, as well as on glacial and postglacial depositional processes. Rivers and likes are the most respondent elements of the present landscapes, reflecting the faults of the SBDZ. The majority of the recognized topolineaments (Fig. 57) atop the faults are the rectified parts of rivers and lakes. Thus, as a few examples the valley of the left tributary to the Lillån River, the depression of Ulvasjön Lake and the right tributary of the Landabäcken River, all inherit the younger NE-SW-trending faults. The Lyckebyån River abruptly changes its flow when crossing the older WNW-ESE-trending fault system. Some rectified parts of the tributaries of the Landabäcken River and the Lillån River flow along the WNW-ESE directed faults. The map of correlation coefficients between the crystalline basement upper paleosurface and the present topography (Fig. 58) suggest that the present surface is mostly inherited form the crystalline basement. The correlation coefficients field is mostly positive in the eastern part of the SBDZ area. Within the areas of the thinnest sedimentary cover the correlation coefficients reach +8.5-9.0 (within the area where the Lyckebyån River is crossing the older WNW-ESE-trending fault system and in areas of the Lillån River and its tributaries).

Those relations allow us to suggest that the SBDZ was still active after its formation in the Mesoproterozoic. The displacement of the major WNW-ESE-trending fault system has occurred later along the linked NE-SW faults. Possible accumulation of sedimentary deposit, laid down before the Pleistocene glaciations within the area, must have been eroded away during the Pleistocene ice advances. The stress in the basement, caused by the thickness of the inland ice during full glaciations (during the Last Glacial Maximum (LGM) estimated from 1750 m, as the 'maximum' model reconstruction after Siegert et al. (2001), to 750 m, as the 'minimum' model reconstruction after Siegert et al. (2001)) would cause a neotectonic subsidence of the territory during the glacial advances, changing to neotectonic uplift during the glacial retreats within the Pleistocene. Such rapid changes of neotectonic regimes must have affected the faults of the SBDZ. We suggest that there were seismic activity and neotectonic deformations along the Zone during this time. After the last retreat of the SIS, one part of the area (below the highest shoreline) was hidden by water of the Baltic Ice Lake, and the second part (above the highest shoreline) was covered by stagnant debris-rich ice. As a result of following uplift and melting of dead ice, two types of landscapes were formed within the key area. The formation of the present landforms and the river networks in the study area depended on the topography of the crystalline basement, as well as on the glacial/postglacial environment.

5.4 Summary

As a result of the study of the eastern part of the SBDZ key area the Mesoproterozoic-Phanerozoic activity of the SBDZ has been identified. We reached this conclusion on the basis of the following indicators:

- Positive correlation of the upper paleosurface of the crystalline basement with present topography;
- The faults of the Mesoproterozoic SBDZ substantially influenced the formation and development of the most part of the present hydrological network and a part of the present landforms.
- The present seismic activity.

6 Conclusions

1. After the formation in the Mesoproterozoic in conjunction with orogenic processes at the southwestern margin of the East European Craton, the Polotsk-Kurzeme Deformation Zone and its possible continuation into the Småland-Blekinge Deformation Zone was still active during the Neoproterozoic– to Phanerozoic.
2. Phases of activity within the deformation zones was caused by internal (structure and composition of rocks of the crystalline basement) and external (far-field effects of orogenic processes outside the East European Craton (Caledonian, Variscan, Alpine), glaciations) processes. The Cenozoic activity of the Zones was caused by both neotectonics and varying pressures of ice sheets on the sedimentary cover.
3. The tectonic activity of the Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones has influenced the formation of the sedimentary cover and parts of the present rivers network and large-scale landforms.

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7 References

Aksamentova, N.V. and Naydenkov, I.V., 1990: *Geological map of the crystalline basement of Belorussia and adjoining areas in the scale 1:1000000.* Institute of Geochemistry and Geophysics of the Academy of Sciences of the Belorussian SSR, Minsk.

Ankundinov, S.A., Brio, H.S. and Sadov A.S., 1991: Deep structure of the Earth crust in the territories of the Peribaltic Republics according to the exploration seismology data of the deep seismic sounding. *Belarusian Seismological Bulletin* 1, 162-171 [in Russian].

Aronov, A.G., Seroglazov, R.R., Aronova, T.I. and Kurlovich, D.M., 2005: Application of GIS-Technologies in Estimation of Seismic Environment of Western Part of Eastern-European Platform. *Modern Progress of Geodesy, Geoinformatics and Organization of the Use of Land:*

Materials of International Scientific Conference. Chernigov, Ukraine, 179-182 [in Russian].

Bibikova, E. V., Bogdanova, S. V., Claesson, S., Gorbatschev, R. and Kirnozova, T. I., 1995: Age, nature and structure of the Precambrian crust in Belarus. *Stratigraphy and Geological Correlation* 6, 591–601.

Björck, S., 1979: Late Weichselian stratigraphy of Blekinge, SE Sweden, and water level changes in the Baltic Ice Lake. *Universiy of Lund, Department of Quaternary Geology, Thesis 7*, 1-248.

Björck, S. and Möller, P., 1987: Late Weichselian environmental history in southeastern Sweden during the deglaciation of the Scandinavian ice sheet. *Quaternary Research* 28, 1‑37.

Bogdanova, S. V., 2001: Tectonic settings of 1.65–1.4 Ga AMCG magmatism in the western East European Craton (western Baltica). *Journal of Conference Abstracts* 6, 769.

Bogdanova, S., Gorbatschev, R., Grad, M., Janik, T., Guterch, A., Kozlovskaya, E., Motuza, G., Skridlaite, G., Starostenko, V., Taran, L. and EUROBRIDGE and POLONAISE working groups, 2006: EUROBRIDGE: new insight into the geodynamic evolution of the East European Craton. In: *European Lithosphere Dynamics* (Eds: Gee, D. G. and Stephenson, R. A., 2006), Geological Society, London, Memoirs, 32, 599–625.

Čečys, A., 2004: Tectonic implications of the ca. 1.45 Ga granitoid magmatism at the southwestern margin of the East European Craton. *Doctoral thesis, Lund University, Sweden.*

Claesson, S., Bogdanova, S. V., Bibikova, E. V. and Gorbatschev, R., 2001: Isotopic evidence of Palaeoproterozoic accretion in the basement of the East European Craton. *Tectonophysics* 339, 1–18.

Filosofov, V.P., 1975. *Fundamentals of the morphometric method of tectonic features recognition.*, Saratov, 232 pp. [in Russian].

Gammal jordartskarta 3F 4e - 4G 3d in scale 1:100 000, 2007: *Sveriges Geologiska Undersökning.*

Garetsky, R.G., Karatayev, G.I., Astapenko, V.N. and Dankevich, I.V., 2006: The Polotsk-Kurzeme fault belt in the East European Platform. *Geophysical journal* 6 (28), 131-134.

Garetsky, R.G., Karatayev, G.I., Astapenko, V.N. and Dankevich, I.V., 2004: Geological and geophysical characteristics of the Polotsk-Kurzem fault belt. *Lithosphere* 2 (21), 10-27 [in Russian].

Garetsky, R.G., Karatayev, G.I., Astapenko, V.N. and Dankevich, I.V., 2002a: *The geophysical fields and the dynamics of the tectonosphere of Belarus*, Minsk [in Russian].

Garetsky, R.G., Karatayev, G.I., Astapenko, V.N. and Dankevich, I.V., 2002b: The Polotsk-Kurzeme fault belt. *Reports of the National Academy of Sciences of Belarus* 6 (46), 85-89 [in Russian].

Geology of Belarus, 2001: 815 pp, Institute of geological sciences of NAS of Belarus, Minsk [in Russian].

Gursky, B.N., Makhnach, N.A., Levkov, E.A. and Ilkevich, G.I., 1986: Stratigraphic scheme of the Quaternary deposits of Belarus. In: *Problems of study of the Earth crust of Belorussa and adjoining areas*, 30-37. Nauka i tekhnika, Minsk [in Russian].

Houmark-Nielsen, K., Krüger, J., Kjær, K.H., 2005: De seneste 150.000 År i Denmark. *Geoviden. Geology og geografi* 2, 2-19.

Johansson, Å, Bogdanova, S and Čečys, A., 2006: A revised geochronology for the Blekinge Province, southern Sweden. *GFF* 128 (2006), 287-302.

Karabanov, A, Garetsky, R, Aizberg, R, Aronova, T and Kurlovich, D., 2005: Neogeodynamics Phenomena Investigation and Computerized Mapping in Belarus. In: *The Current Role of Geological Mapping in Geosciences. NATO Science Series. Series IV: Earth and Environmental Sciences* 56, 157-168.

Karabanov, A.K., Matveyev, A.V. and Pavlovskaya, I.E., 2004: The main glacial limits in Belarus. In Ehlers, J., and Gibbard, P. (eds.): *Quaternary Glaciations - Extent and Chronology*, 15-18. Elsevier B.V., Amsterdam.

Kornfält, K.-A. and Bruun, Å., 2002: Beskrivning till berggrundskartan 3G Kristianopel NV. *Sveriges Geologiska Undersökning Af 211,* 1–52.

Kornfält, K.-A., 1999a: Beskrivning till berggrundskartan 3F Karlskrona NO. *Sveriges Geologiska Undersökning Af 199,* 1–73.

Kornfält, K.-A., 1999b: Beskrivning till berggrundskartan 3F Karlskrona SO. *Sveriges Geologiska Undersökning Af 205,* 1–59.

Krauss, M., Franz, K.-M., Hammer, J. and Lindh, A., 1996: Zur Geologie der Småland-Blekinge-Störungszone (SE-Schweden). *Zeitschrift für geologische Wissenschaften 24*, 273–282.

Kurlovich, D.M. and Karabanov, A.K., 2004: Application of Modern GIS-Technologies in Structural-Geomorphological Reconstruction. *Proceedings of the Belarusian Engineering Academy* 1(17)/4, 31-34 [in Russian].

Kurlovich, D., 2005: GIS-technologies in Sructural-Geomorphological Analysis of the Belarusian Poozerye. *Quaternary Geology and Landforming Processes: International Field Symposium, Kola Peninsula, NW Russia, September 4-9, 2005*, 32-34 [in Russian].

Kurlovich, D.M., 2006: A GIS-model of the basement-cover correlation in the Poozerye area of the Polotsk-Kurzeme fault belt in Belarus. *Geophysical journal* 6 (28), 137-138.

Kurlovich, D.M., Bogdanova, S.V. and Karabanov, A.K., 2007: The Cenozoic activity of the Polotsk-Kurzeme fault belt in the East European

Craton and its influence on the topography. *Geophysical research abstracts of European Geosciences Union General Assembly 2007,* 9, 04994.

Lagerlund, E., and Bjorck, S., 1979: Lithostratigraphy of the Quaternary Deposits in Blekinge, Sweden. *University of Lund, Department of Quaternary Geology, Report 17,* 1-65.

Levickaya, R.I., 1990: *Collection and summarizing of materials of Quaternary sediments of the northern part of Belarusian SSR for the composition of maps of Quaternary layers in the scale of 1:500000.* Institute of Geochemistry and Geophysics of the Academy of Sciences of the Belorussian SSR, Minsk.

Lindh, A., Krauss, M. and Franz, K.-M., 2001: Interpreting the Småland-Blekinge Deformation Zone from chemical and structural data. *GFF* 123 (2001), 181-191.

Makhnach, A.S., Veretennikov, N.V., Shkuratov, V.I., Laptsevich, A.G. and Piskun, L.V., 2005a: Stratigraphic chart of Vendian deposits of Belarus. *Lithosphere* 1 (22), 36-43.

Makhnach, A.S., Zinovenko, G.V., Abramenko, V.I. and Piskun, L.V., 2005b: Stratigraphic chart of Cambrian deposits of Belarus. *Lithosphere* 1 (22), 44-52 [in Russian].

Makhnach, N.A., Levkov, E.A. and Gurski, B.N., 1970: Stratigraphic subdivision of the Quaternary in Belorussia. *Reports of the Academy of Sciences of Belorussia*, 14 (1), 45-47 [in Russian].

Matveyev, A.V., 1990: *History of the landform development in Belarus.* Nauka i tekhnika, Minsk [in Russian].

Matveyev, A.V., 1995: Glacial history of Belarus. In: *Glacial deposits in north-eastern Europe* (Eds: Ehlers, J., Kozarski, S., Gibbard, Ph., 1995), 267-276. Brookfield, Rotterdam.

Matveyev, A.V., Gursky, B.N. and Levitskaya, R.I., 1988: *Relief of Belarus*, 320 pp. Universitetskoye, Minsk [in Russian].

Möller, P., 1987: Moraine Morphology, Till Genesis and Deglaciation Pattern in the Åsnen Area, Southcentral Småland, Sweden. *LUNDQUA thesis 20.*

Motuza, G., Čečys, A., Kotov, A.B. and Salnikova, E.B., 2006: The Žemaičių Naumiestis granitoids: new evidences for Mesoproterozoic magmatism in western Lithuania. *GFF* 128 (2006), 243-254.

National atlas of Belarus, 2002, Minsk [in Russian].

Nechiporenko, L.A. 1989: *Deposition conditions and tectonically predetermination of the Anthropogenic cover of Belorussia.* 114 pp . Nauka i tekhnika, Minsk [in Russian].

Pavlovskaya, I., 1994: *The Polotsk glaciolacustrine basin: structure, relief and history.* 128 pp. Nauka i tekhnika, Minsk [in Russian].

Pushkin, V.I., 2005: Stratigraphic chart of Ordovician deposits of Belarus. *Lithosphere* 1 (22), 53-61 [in Russian].

Rimša, A., 2002: Petrological study of the metamafic rocks across the Småland-Blrkinge Deformation Zone. *Masters thesis, Lund University, Sweden.*

Ringberg, B., 1971: Glacialgeologi och isavsmlltning i Gstra Blekinge. *Sveriges Geologiska Undersiikning c 661*, 1-174.

Sanko, A.F., Velichkevich, F.Yu., Rylova, T.B.,. Khursevich, G.K, Matveyev, A.V., Karabanov, A.K., Motuzko, A.N. and Ilkevich, G.I., 2005: Stratigraphic chart of Quaternary deposits of Belarus. *Lithosphere* 1 (22), 146-156 [in Russian].

Siegert, M.J., Dowdeswell, J.A., Hald, M. and Svendsen, J.I., 2001: Modelling the Eurasian Ice Sheet through a full (Weichselian) glacial cycle. *Global and Planetary Change* 31, 367–385.

Skridlaite, G., Bogdanova, S., and Page, L., 2006: Mesoproterozoic events in eastern and central Lithuania as recorded by 40Ar/39Ar ages. *Baltica* 19(2), 91-98.

Skridlaite, G., Wiszniewska, J. and Duchesne, J.-C., 2003: Ferropotassic A-type granites and related rocks in NE Poland and S Lithuania: west of the East European Craton. *Precambrian Research* 124, 305–326.

Tectonics of the West of the Eastern European platform, 1990: Ed: Garetsky, R.G. 1990. 168 pp. Nauka i tekhnika, Minsk [in Russian].

Veretennikov, N.V., Makhnach, A.S., Laptsevich, A.G. and Shkuratov, V.I., 2005: Stratigraphic chart of Riphean deposits of Belarus. *Lithosphere* 1 (22), 27-35 [in Russian].

Wiklander, U., 1974: Precambrian geology, geochemistry and age relations of northeastern Blekinge, southern Sweden. *Sveriges Geologiska Undersökning C 704*, 3–142.

Wybraniec, S., 1999: Transformations and visualization of potential field data. *Special Papers of Polish Geological Institute.* Paper 1.

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214. Kurlovich, Dzmitry, 2007: The Polotsk-Kurzeme and the Småland-Blekinge Deformation Zones of the East European Craton: geomorphology, architecture of the sedimentary cover and the crystalline basement.

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