Explanation to the Map of Precambrian basement
of the Gulf of Finland and surrounding area 1 : 1 mill
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LATEST EVENTS AFFECTING THE PRECAMBRIAN BASEMENT, GULF OF FINLAND AND SURROUNDING AREAS

by

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Jotnian sedimentary rocks and Postjotnian mafic dykes and sills are regarded as the youngest basement rock types in the map area. Throughout the latest Mesoproterozoic and Neoproterozoic, erosion was the main geological process in the western part of the East European Craton, including the map area. A uniform peneplain surface was developed over all the basement units, with the formation of a kaolinitic regolith prior to the commencement of extensive Vendian and Phanerozoic sedimentation.

During Vendian and Cambrian through Silurian time, the lowest part of the sedimentary blanket was deposited; it is likely that these sediments also covered large parts of the present day shield area. After a break in sedimentation that coincided with the youngest phase of deformation in the Scandinavian Caledonian orogenic belt, Devonian sediments were deposited in the southern part of the map area.

Tectonic dislocations affecting both the basement and the lower part of the sedimentary cover sequence provide evidence for intracratonic compression during the Caledonian orogeny. Moreover, some Precambrian and Caledonian tectonic zones were again reactivated during and after the Devonian sedimentation. The late Paleozoic subsidence of the Bothnian Sea floor is interpreted as a distal consequence of the extensional processes that formed the early Permian Oslo rift.

Continued erosion during the late Phanerozoic produced the present topography, both in sediment-covered and shield areas. The gentle arching of the basement topography between the Gulf of Finland and the Bothnian Sea represents the exhumation of the Pre-Vendian peneplain surface from beneath the lower Paleozoic sedimentary cover as well as limited modification by both pre-Pleistocene continental erosion and Pleistocene glacial processes. The erosional escarpments occurring in the area covered by Vendian and Paleozoic platform sediments were formed by differential erosion due to the variable resistance of alternating soft and hard layers. The gentle dip of the basement surface and depositional layering in the overlying sediments was an important factor in escarpment creation. Pleistocene glacial erosion has generally removed from several meters to several tens of meters of material, although local gouging of overdeepened valleys and topographical depressions has also taken place.

The Quaternary glacial and postglacial deposits conceal most of both the basement and sedimentary bedrock.

Key words (GeoRef Thesaurus, AGI): areal geology, explanatory text, basement, sedimentary rocks, erosion, sedimentation, tectonics, Fennoscandian Shield, Phanerozoic, Precambrian, Finland, Estonia, Russian Federation, Gulf of Finland

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OVERVIEW

Following Jotnian sedimentation and Post-Jotnian intracratonic calc-alkaline magmatism, a long period of stable platform environments ensued, with no record of subsequent magmatic activity in the region. During this period, erosion and sedimentation alternated intermittently.

Two prolonged periods of continental erosion were responsible for producing the most important geomorphic features in the area under consideration: 1) Protracted late Proterozoic continental planation during which the topography of whole region, including the area containing the thickest crust in Europe, was gradually reduced to form the almost perfect Pre-Vendian peneplain surface. The generally level surface of the Precambrian in southern Finland, with a broad gentle NW-SE oriented arch between the Gulf of Bothnia and Gulf of Finland, represents an exhumed and probably recently slightly reworked Pre-Vendian peneplain. 2) A period of continental erosion during the late Phanerozoic that was responsible for the recent generally flat, but still slightly variable, topography (altitudes from -200 b.s.l. to +200 m a.s.l.) of both the Archean to Mesoproterozoic mainly crystalline bedrock and the Late Vendian to Phanerozoic sedimentary cover sequence.

During the latest Proterozoic (Vendian) and early to middle Paleozoic (Cambrian to Devonian), marine deposition prevailed in the downwarped northwestern part of the East European craton and the resulting sedimentary sequence temporarily covered Precambrian basement throughout the whole of the region. The second period of erosion referred to above subsequently exhumed the Precambrian basement again. Thus the present distribution of crystalline and sedimentary areas surrounding the Gulf of Finland is a relatively young, probably late Cenozoic feature.

The uppermost part of the planated basement was extensively weathered prior to the Late Vendian or, in the west, prior to Cambrian sedimentation. In the present shield area, late Cenozoic (preglacial) regoliths are widely preserved. To some extent these may represent the combined effect of late Cenozoic weathering superimposed on Pre-Vendian or even earlier Precambrian regoliths.

Despite the probable existence of a sedimentary cover during part of the Phanerozoic, the present Fennoscandian Shield area has probably always acted as a broad anticlinal area, with minimal sedimentation compared to the main Vendian and Phanerozoic depocenters in the Baltic regional syncline to the south and Moscow syncline to the southeast. Between the central shield area and these surrounding synclines, homoclines with a very gently dipping Precambrian planation surface formed. In regional structural descriptions, these homoclines have usually been referred to as the sloping Fennoscandian shield surface (the southern slope in Estonia and southeastern in the NW Russia). The maximum thickness of the sedimentary cover overlying this sloping surface in the area covered by the map is about 2000 m, in SW Latvia, near the southwestern corner of the map area.

Differential tectonic movements took place during the Phanerozoic, mainly along discrete linear dislocations disrupting both cover sequences and basement. These movements can be recognized and dated in areas where the sedimentary cover has survived and have been found to transect both past and recent coastlines; they have therefore had little influence on the present position and configuration of the Gulf of Finland and the eastern coasts of the Baltic Sea and Gulf of Bothnia, nor even upon Lake Ladoga.

In Estonia, Latvia and NW Russia and on the adjoining seabed, a system of NE—SW, NW—SE and N—S-trending flexures and fracture zones (coupled with local upwarping) formed. Several episodes of movement have been identified, occurring near the Cambrian - Ordovician boundary, Silurian - Devonian boundary and in post-Devonian time, probably in either the late Carboniferous or early Permian. The first two faulting events occurred in compressional stress fields, probably in connection with thrusting along nearby plate boundaries (the TT-line in the SW and Caledonides in the NE), while the last event was probably connected with extension-related rifting in the Oslo area. The downfaulting and dislocation of the Paleozoic sedimentary cover in the Gulf of Bothnia depression (NE part of the map area) probably also coincided with the Permian tectonic and magmatic activity in the Oslo Rift area and coeval movements and magmatism in the lake Vänern area in central Sweden.

Successive crustal loading and unloading by Pleistocene continental ice sheets caused alternate subsidence and elastic rebound of the earth's surface in Fennoscandia and, to a lesser extent, in surrounding areas. Rebound from the last glacial retreat is still continuing at present. Intense erosional activity due to short term (in a geological sense) agents and processes in glaciers, seas, lakes and rivers occurred throughout the region, to varying degrees, depending on climate and sea-level changes. The flat topography of Fennoscandia and the cuesta-like landscape of its sedimentary surroundings became more intricately sculptured by both erosion and incision, including overdeepened valleys, and residual positive landforms, such as drumlins and roches moutinee, during both glacial and interglacial intervals.

Glacial and deglaciation processes resulting in ice-marginal formations that form a series of concentric arcuate ridges transecting Fennoscandia and the surrounding area, influencing drainage patterns, and locally modifying the pre-glacial topography.

The basin of the Gulf of Finland is a depression in the bedrock topography which was formed along the contact between the crystalline basement and the Vendian to Paleozoic cover sequence as a result of preferential erosion during both prolonged preglacial weathering and short-term, but intensive, glacial erosion. The northern slope of the seafloor is gentle, coinciding with the basement surface, while the southern slope is steeper and characterized by the submerged portion of the North Baltic Glint, which is a prominent preglacial cuesta that can be traced on land towards the Lake Ladoga region. The western part of Finland slopes gently towards the Gulf of Bothnia and the Precambrian peneplane surface, which can also be traced offshore, effectively coincides with the present land surface.

One of the authors of this chapter (A. Amantov) stresses the importance of Pleistocene glacial erosion in the formation of the Gulf of Finland and other bedrock depressions. Support for this argument is provided by significant overdeepening of the observable parts of Lake Ladoga and the Gulf of Bothnia Sea bottom bedrock topographies. The present shoreline of Lake Ladoga coincides closely with a Jotnian sediment-filled graben, thus displaying a structural inheritance. The basin of the Gulf of Bothnia also corresponds to a Jotnian sediment-filled graben-syncline that later experienced repeated subsidence during the Paleozoic.

PRE-VENDIAN PLANATION

During the Svecofennian orogeny, Subjotnian magmatism and even during Jotnian sedimentation and Postjotnian magmatism, differential tectonic movements and the uplift of fault-bounded upper crustal blocks resulted in variable erosion of the orogenic (Svecofennian) and early cratonic (Subjotnian - Jotnian - Postjotnian) structures. Only after Postjotnian magmatism, at about 1200–1000 Ma, was a really stable cratonic tectonic environment established and the gradual process peneplane formation initiated. The resulting Pre-Vendian peneplane surface was almost perfect, even though it developed on lithologies of widely differing resistance and character, such as crystalline basement and well stratified sedimentary (Jotnian sandstone) formations (see cross sections accompanying the map). The rare residual ***monadnock***-type landforms and ridges rising to heights of 100–300 m above the old peneplain surface consist almost invariably of exceptionally resistant rock types such as quartzite, as at Uljaste (Fig. 1) and Assamalla, where they are preserved beneath the sedimentary cover, or Subjotnian quartz porphyry, as on the island of Hogland (Puura 1974, Puura et al. 1983).

In order to estimate the rate of Neoproterozoic erosion, one has to consider that Jotnian sediments have been removed from the peripheral parts of the Jotnian sedimentary basins in Lake Ladoga and Gulf of Bothnia area, as well as in the surroundings of Åland and Gotska Sandön (just outside the SW border of the map area). The thickness of the missing sedimentary sequences and Postjotnian diabases probably reached some 500–2000 m in places. Obviously too, any regolith developed on the Svecofennian bedrock before or during Jotnian sedimentation was also eroded during the Neoproterozoic.

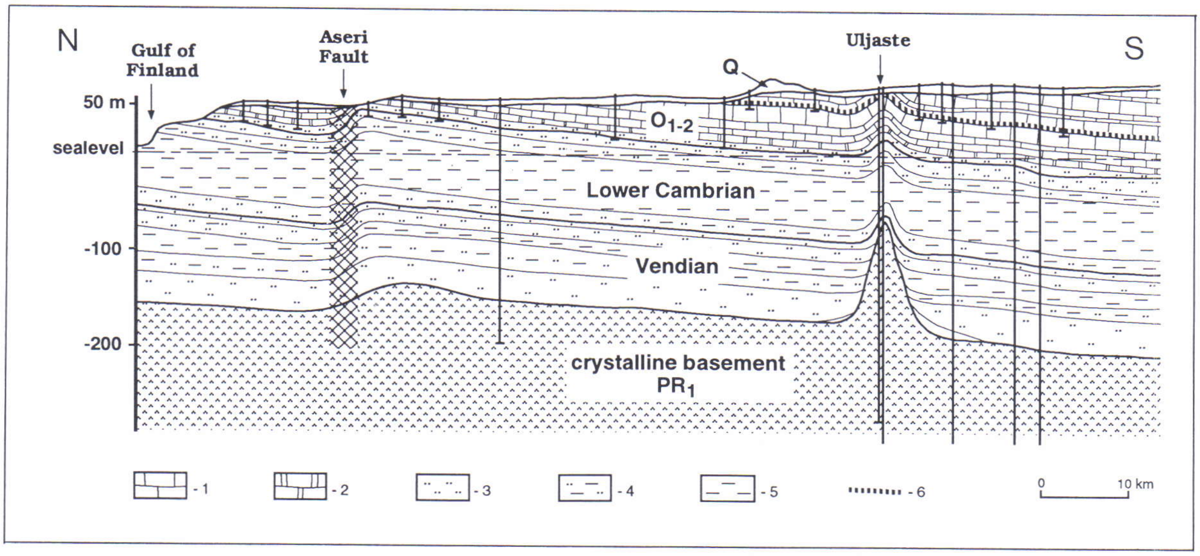

Fig. 1. Erosional paleotopography of the Precambrian basement (below sediments at Uljaste) and an example of a late fault-bounded basement topographical feature (at Aseri) for comparison.
1 — limestone, 2 — dolomite, 3 — sandstone, 4 — siltstone, 5 — claystone, 6 — oil shale unit;
O — Ordovician, Q — Quaternary.

The uppermost part of the crystalline basement was affected by weathering processes before Late Vendian time or, in the west, before Cambrian sedimentation. More than a thousand bore-holes penetrated these regoliths before encountering fresh underlying basement rocks in the north Baltic and St. Petersburg areas. The thickness of the rocks weathered to some degree varies from 0.5–2 m up to 100–150 m, if alteration to clay minerals along fracture zones is also considered. A particularly thick regolith has developed on the migmatized peraluminous metasediments of NE Estonia. The most mature weathering profiles consists predominantly of kaolinite and other clay minerals, together with some resistant mineral grains including quartz and zircon. In less advanced stages of weathering, and depending on original bedrock compositions, other clay minerals, such as illite, chlorite and montmorillonite are characteristic. The intensely weathered rocks (saprolites) are generally soft or of variable hardness (Puura et al. 1983). In Finland, pseudostratification of weathered granites has been recognized and attributed to the development of subhorizontal fracture zones (Laitakari and Aro 1985), along which preferable chemical weathering has taken place. In some places beneath the sedimentary cover, fractured and weathered Pre-Vendian rocks may contain exceptionally mineral-rich ground waters.

Beneath the Baltic Sea, including its various bays and gulfs, as well as large lakes, the unconformity between the crystalline basement and the sedimentary cover sequence is evident as a strong reflector surface in seismic profiling. In comparison with onshore drilling data that indicate a smooth upper surface for the weathered basement rocks (Puura et al. 1983), offshore seismic data characterise the top of the Pre-Vendian surface as somewhat undulating, and only in the Lake Ladoga data is it nearly flat, due to the nearly parallel dips of both sub-Upper Vendian (Riphean) and Upper Vendian sedimentary strata. If a thick regolith is present below the basement contact, then the most prominent reflection may coincide with some lower level of within the regolith, or with the contact between saprolite and fresh rock, instead of the unconformity itself.

BURIAL BENEATH THE VENDIAN AND PHANEROZOIC SEDIMENTS

Three major lithological units within the Upper Vendian - Middle Paleozoic sedimentary sequence can be recognized in the area covered by the map:

- *Upper Vendian to Lower Ordovician* clays and other clastic deposits (from 100 m thickness in the SW up to 350 m to the east of Lake Ladoga, 100 m in the Bothnian Sea, 100–200 m beneath the Baltic countries);
- *Lower Ordovician to Upper Silurian* carbonate formation (up to 1000 m thick in SW Latvia, up to 100 m of Ordovician beneath the Bothnian Sea);
- *Devonian* clastic-dominated sediments (up to 800 m thick in SW Latvia and SE of St. Petersburg).

Deposition on the Svecofennian - Subjotnian - Jotnian basement peneplain surface commenced at least during the Neoproterozoic, as is indicated by the age of sediments within impact craters in Finland. However, the main stage of sedimentation in SE Fennoscandia and the Baltic area took place during the Late Vendian when central, northern and eastern parts of the East European Craton subsided below sea level and a large sedimentary basin formed. During the first half of the Late Vendian (Volhynian time), the transgression reached the eastern part of the region under consideration, including the area surrounding Lake Ladoga and east of St. Petersburg. It is quite probable that the area of early Late Vendian sedimentation reached as far west as Lauhanvuori in SW Finland, according to a preliminary interpretation based on the discovery of trace fossils and certain sedimentary features in the beds directly overlying the weathered basement by Pirrus in 1992 (E. A. Pirrus, pers. comm.). In Estonia the late Late Vendian sedimentation (Kotlin Stage) spread from NE to SW as far as the NW—SE trending line from Haapsalu to Valga. The present northern margin of the boundary of Vendian in the Gulf of Finland and North Baltic, as well as in the Lake Ladoga—St. Petersburg area, is erosional, and yet there is a trend of increasing thicknesses towards the north. It is therefore highly probable that the Late Vendian sediments once covered southern Finland. The lowermost Lower Cambrian deposits (e.g. "blue clay" of the Lontova stage) in the Lake Ladoga and St. Petersburg areas, as well as Estonia, show the same broad pattern of distribution.

Commencing in the late early Cambrian, a marine basin also formed in the W and SW of the Gulf of Finland. In connection with the latter late Early Cambrian, Middle and Late Cambrian sediments were deposited in the N Baltic, Bothnian Sea and probably also in southern Finland. It has been suggested (Puura et al. 1987), that at the end of the Cambrian the whole region under consideration was covered by a thin blanket (100–350 m) of fine clastic sediments (sands, silts) and clays deposited in shallow-water basins.

During the Ordovician and Silurian a pericontinental marine basin existed that was open either at the NW and SW margins (in the Ordovician) or only in the SW of the craton (in the Silurian). Peripheral, mostly shallow-water and transitional facies associations are present in Estonia, and the St. Petersburg and Bothnian Sea areas, and were probably also present in southern Finland (Männil, 1966). During the late Silurian, within the broad paleo-Baltic shallow continental shelf, a deep synecline-type sedimentary basin developed as a pericratonic depression within the SW Baltic area, covering the Riga rapakivi pluton and the area to the S. It was at this time that the gentle southerly dip of the peneplane surface developed.

Following the depositional hiatus at the Silurian - Devonian boundary and restricted sedimentation during the Early Devonian, an E—W oriented depression formed with a maximum sediment thickness of 800 m in the axial zone in Latvia. Middle Devonian "Old Red" sandstones were deposited in Estonia and south of St. Petersburg and represent near-shore marine sedimentation of sandy and silty clastic material transported from the NW — probably reflecting erosion of the Caledonian Mountain chains and transport across the central Fennoscandian continental plain. The subsidence of this Devonian basin was the second important phase in development of the south and southeastward slope of the Fennoscandian peneplain surface.

The upper surface of the Devonian sequence is erosional throughout the whole of the region under consideration, and largely buried beneath Quaternary deposits.

TECTONIC DEFORMATION OF BASEMENT AND OVERLYING VENDIAN AND PHANEROZOIC DEPOSITS

After Subjotnian (rapakivi) magmatism and Postjotnian (diabase) magmatism, the NW East European Craton has remained a very stable domain throughout the Neoproterozoic and Phanerozoic. Intracratonic tectonic activity has nevertheless episodically taken place, including rifting with formation of "aulacogens" in the Russian Platform during Proterozoic and Phanerozoic, and the Oslo Rift in SW Fennoscandia during the Late Paleozoic and also pericratonic compression related to Caledonian collision and thrusting during the Early Paleozoic.

Basin subsidence was more pronounced east of the region during the Vendian and Early Cambrian, to the south, southwest and west during Cambrian, Ordovician and Silurian time, and to the south and southeast in the Devonian, eventually resulted in a very gentle southwards dip (less than ½ degree) of the Pre-Vendian peneplain in the Baltic - Lake Ladoga region of the Fennoscandian Shield. No significant fault zones controlling these features, or regional subsidence processes have been found.

The main system of faults and fracture lineaments in the S and SE sedimentary area of the map, which has been documented during detailed geological and geophysical mapping, obviously formed under the influence of compressional stress regimes of various different ages and orientations that involved both the crystalline basement and sedimentary cover. The results of geophysical studies and drilling facilitate the interpretation of these structures and indicate that they relate to a combination of broad flexures and anticlinal folding, with local reverse movements as well. Near the crystalline shield, predominantly NE—ENE-trending fault zones disrupt both basement and cover with a vertical component of displacement between 20–50 m over a strike of tens of km. Some of these features have also been recognized offshore in the Gulf of Finland, as a result of seismic profiling in several areas, including Narva Bay (Amantov et al. 1988). To the SE and S of St. Petersburg, local domes of Vendian and Lower Cambrian clays have been studied in detail (refer to map). Further S, where the basement surface is buried to depths of 500 m to 2 km, hundreds of faults have been mapped that can be traced for a km or so, and which displace the basement-cover contact by up to 600 m in a vertical sense (Suveizdis 1979). In the uplifted parts of these zones, as in western Latvia and southeastern Estonia, anticlines reach amplitudes of 50–500 m. Anticlinal features of this kind can be used for storage of gas and liquid fuels (SE and S of St. Petersburg, E of Riga). The origin of these complicated linear fault systems and associated broad anticline in the Baltic sedimentary basin (syneclise) may be explained as a distal expression of late Caledonian compressional movements in Scandinavia and along Tornquist line. On the whole, at least three Paleozoic tectonic events can be recognized and dated:

1) at the Cambrian-Ordovician transition (for example, the NNW-striking Vihterpalu zone in western Estonia (Puura and Suuroja 1984),

2) at the transition of Silurian - Devonian boundary (late Caledonian), which includes the majority of the linear features in Estonia, Latvia and the St. Petersburg district (Puura 1979),
3) post-Devonian, mainly as rejuvenation of different pre-Devonian faults (Puura and Sudov 1976).

Prolonged and multiple episodes of alteration are also evident in deformed rocks within the fault zones, with evidence for fluid migration in the upper crust, including epizonal hydrothermal metasomatic dolomitisation of limestones, lead and zinc sulfide mineralisation, and karst formation. The regional dolomitisation and ore mineralisation occurrences could be connected with the Late Paleozoic event that produced the Oslo rift system.

In addition to anticlines associated with linear tectonic zones, a number of local isolated anticlines (Assamalla, Hogland, Tüters) or groups of anticlines (Sonda—Uljaste) have been mapped. These are usually expressed as erosional remnants, that may have originated by differential block movement caused by alternating tensional and compressional far-field stresses. In addition to structural features caused by compaction of surrounding sediments, specific features related to episodic block uplift and fluid flow throughout the Phanerozoic have been recognized (Vaher et al. 1962, Mens et al. 1981).

A number of Paleozoic faults and other dislocations within the sedimentary cover represent reactivation of inherited Svecofennian orogenic, Subjotnian anorogenic and Postjotnian structures. For example the late Paleozoic Gulf of Bothnia graben-syncline corresponds closely to the earlier Postjotnian graben-syncline. The late Svecofennian Tapa—Paide and Subjotnian Saaremaa—Peipsijärv shear zones also coincide with flexure zones in the sedimentary cover. The western part of a major complex fault and upthrust zone in Latvia, known as the Liepaja—Riga—Lokno dislocation zone, coincides with the tectonized southern boundary zone of the Riga rapakivi-anorthosite pluton, although its eastern part cuts across Svecofennian orogenic trends. However, there are some basement dislocations that have no effect on the overlying cover sequences, such as the Svecofennian (Åland—)Paldiski—Pskov shear zone (cf. Fig. 1, Koistinen et al. this volume). Conversely, numerous examples exist where Phanerozoic faults cutting the basement-cover interface bear no relation to structures in the basement, including the Vihterpalu, Aseri, and Ahtme zones in Estonia.

A special explanation is required for the formation of the Bothnian Sea graben-syncline basin. It probably formed in an extensional deformation field coeval with the Oslo rift, as was also proposed and demonstrated for the lake Vänern and Vättern areas in Sweden, which are characterized by the same type of disruption of the Paleozoic and sub-Cambrian peneplain (Vikström and Karis 1991). A network of faults was created in the Paleozoic strata and basement beneath the Bothnian Sea (Winterhalter 1972).

LATE PHANEROZOIC PLANATION AND PRESENT-DAY TOPOGRAPHY

If the Cambrian and Ordovician sedimentary basins were the last to cover all of present SE Fennoscandia and the N Baltic, then it follows that erosion and planation has continued uninterrupted for more than 400 Million years. The final regression of the Late Devonian basin from Latvia took place some 350 million years ago. Erosion rates since the late Paleozoic have evidently been rather low since the sedimentary cover has only been partially removed from the southern part of the map area. Consideration of data relating to detrital influx into sedimentary basins south of Fennoscandia (in Poland, Denmark, Germany and North Sea), the bulk of the erosion of Scandinavia and the North Baltic region took place during the Cenozoic, commencing in the Eocene, in connexion with the regional uplift of Fennoscandia, and especially during the late Neogene, as a result of eustatic lowering of sealevel, and the Pleistocene, due to glacial erosion.

One further exhumed ancient surface can be distinguished in the sedimentary area. Local depressions and positive features in the sub-Devonian planation surface (developed on the Ordovician and Silurian deposits) are currently exhumed in the uplands of Pandivere (N Estonia), Ahtme (NE

Estonia) and Isuri (Russian Ingria), together with southerly sloping surfaces and a depression to both the W and E of the Narva River (Tuuling 1988).

Successive crustal loading and unloading due to the advance and retreat of the Pleistocene ice sheets have led to subsidence and uplift throughout Fennoscandia and, to a lesser extent, in the surrounding region. Uplift from the most recent deglaciation is still in progress. Intense erosional prosesses caused by short-term (in a geological sense) glaciers, seas, lakes and rivers occurred all over the area depending on climatic and realtive sealevel changes. The low topographical relief of Fennoscandia and cuesta-like landscape of its sedimentary surroundings became more intricately sculptured with both incision of negative features, including overdeepened valleys and enhancement of residual positive forms, such as roches moutinée and drumlins during glacial and interglacial times. A concentric series of prominent arcuate ice-marginal formations developed during retreat of the last ice sheet, and have substantially modifed drainage pattern in the shield area and surrounding platform.

The basin of the Gulf of Finland is a depression in the bedrock topography that formed along the contact between the basement and sedimentary cover, which represented the most important lithologic contrast in the region during the prolonged preglacial weathering phase. The northern slope of the seafloor is gentle, conforming to the general southwards dip of the basement planation surface, while the south slope is steep and represents the submarine continuation of the North Estonian Glint, which is a prominent preglacial cuesta. One of the authors of this chapter (Amantov; cf. Amantov 1992) stresses the importance of glacial erosion in formation of the Gulf of Finland depression.

Linear tectonic dislocations affecting both the basement and sedimentary cover in Latvia, Estonia and Russia appear to cross previous and present and consequently they have had little control on the present position of the Gulf of Finland, nor upon the northern Baltic Sea in general. There is no data available concerning the coast-parallel or Glint-parallel fracture zones that have sometimes been reported in papers concerning the geology of the Gulf of Finland. In contrast however, the basins of the Gulf of Bothnia and Lake Ladoga coincide with Jotnian sediment-filled graben-synclines and have thus, at least, structurally inherited earlier tectonic features.

DISCUSSION

Following intrusion of Postjotnian dykes at about 1200 Ma, the region under discussion formed an extraordinarily stable craton, even when compared with the rest of the East European Craton. No major deformation has taken place since that time. The present deep crustal structure recorded by DSP probably still corresponds to the structures formed during the Svecofennian orogeny and, presumably, with some influence of rapakivi magmatism. However, as a result of distant or local structural events and reactivation, gentle flexuring and warping of the ancient earth surface took place, as evident from the depressions beneath the Jotnian sedimentary basins (Lake Ladoga and Gulf of Bothnia) and the Silurian Baltic Syneclise, or the very gentle slope of the Fennoscandian Shield developed progressively during Vendian, Cambrian, Ordovician and Devonian time.

Horizontal far-field stresses were typically transmitted with low intensity in the region under consideration and resulted in the development of flexures and faults of varying ages. A contractional deformation phase occurred at the Silurian - Devonian boundary in connexion with the closure of Iapetus and formation of the Caledonian Orogenic Belt in Scandinavia. The Late Paleozoic extensional event responsible for the Oslo Rift System, probably also caused regional subsidence in the Gulf of Bothnia graben-syncline and the opening of fractures over the whole region.

The formation and permeability of fractures and fracture zones during such extensional events (and also the presence of laterally permeable sedimentary strata and vertically permeable impact crater destruction zones) permitted the migration of both superficial and deeply sourced fluids and gases within the basement and sedimentary cover. Dolomitisation and sulfide mineralization were associated with hydrothermal activity during the late Precambrian and, presumably also during the late Paleozoic. Clastic dykes in the basement and sedimentary cover as well as karst and weathering features were formed at various times by a variety of superficial processes. Both ancient and recent zones of permeability are of great importance to the study of ground water migration.

An oblique dome-like uplift of Fennoscandia and the surrounding Baltic and Russian area took place during the Cenozoic in connexion with rifting and opening of the North Atlantic. Because of the land uplift in Eocene and a fall in sea level during the Miocene and Pliocene, erosional processes removed much of the sedimentary cover and regolith overlying the crystalline basement in large areas of the present Fennoscandian Shield. Repeated Pleistocene glaciations caused isostatic uplift and subsidence cycles and further erosion. Due to subsidence during the last glaciation, the land surface in the northwestern half of the region is still beneath its preglacial position and thus continuing uplift is still in progress.

The interaction between tectonically induced uplift in the early Cenozoic and successive uplift and subsidence due to Pleistocene glaciation is still shaping the present-day topography of the sub-Quaternary bedrock and the present-day earth surface. As shown on the geological profiles to the map, flat-lying topography is characteristic over both the crystalline area in the north and sedimentary area in the south. The two areas are however separated by a depression in the bedrock topography that currently coincides with the basins of the Gulf of Finland and Lake Ladoga. The position of the depression under the northwestern Baltic Sea basin between the crystalline area of southern Sweden and the Baltic sedimentary area is actually analogous to the Gulf of Finland, since in both cases the crystalline basement dips gently outwards away from the shield. Unlike the above sea and lake basins, the Gulf of Bothnia basin is located in a local tectonic depression.

The basins of the Gulf of Finland, Lake Ladoga and the northwestern Baltic Sea have structurally and lithologically predetermined positions between the sedimentary and crystalline area, due to preferential erosion of the soft sandy and clayey Vendian and Cambrian deposits lying between the crystalline basement and more resistant Ordovician limestones.

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