
GEORIFT
Svalbard
Barents Sea
Atlantic
Ocean
Caledonides
Pechora
Basin
Timanides
East-European Craton
Variscides
Alps
Carpathians
GEORIFT
Pericaspian
Basin
Black Sea
Caspian Sea
Mediterranean

# GEORIFT

## Geodynamics of Intracratonic Rifting

*by Randell Stephenson (Amsterdam) and GEORIFT colleagues*

Precambrian cratons form the oldest and most stable parts of the Earth's lithosphere. Their sedimentary cover preserves a long and detailed record of intraplate deformations, ranging from rifting, hot-spot magmatism and the uplift of broad arches, to thermal subsidence of intracratonic basins, compressional reactivation with basin inversion, and crustal and lithospheric buckling. These deformations reflect changes in the intraplate stress regime and must be related to plate boundary and mantle processes. The East-European Craton (EEC), largely covered by Phanerozoic sedimentary successions, forms the core of Europe and consists of a collage of continental and arc-related terranes that were welded together during Proterozoic times. The overlying East-European Platform (EEP) sedimentary succession represents one of the globe's best natural laboratories for studying the response of craton lithosphere to changing tectonic stress regimes. In particular, Devonian and Early Carboniferous rifting of EEC lithosphere reflects a fundamentally different tectonic setting to that of the North American part of what was then one contiguous continental plate; this has important implications for understanding the driving mechanisms of intracratonic rifting.

GEORIFT addresses the mechanisms of rifting by means of regional studies of the Late Proterozoic-Palaeozoic sedimentary basins of the EEP as well as by detailed analysis of the exceptionally well documented Pripyat-Dniepr-Donets (PDD) Basin, the largest and deepest Late Palaeozoic rift in Europe. Highlights of GEORIFT include:

1) Availability of a vast geological and geophysical data base, permitting development and quantitative testing of tectonic and tectono-sedimentary models and their comparison with neotectonic analogues.
2) Analysis of the entire geodynamic record of the EEC from the Riphean to the Present concentrating on the Late Palaeozoic, a period of exceptionally intense rifting, causing the development of major sedimentary basins, some of which host important hydrocarbon provinces.
3) Integrated geological-geophysical study of the PDD basin with its exceptionally well documented structural and stratigraphic record, to better understand the interplay of tectonic, magmatic, climatic, eustatic, and other processes during the evolution of rifted intracratonic sedimentary basins.
4) Potential to resolve fundamental questions about the dynamics of rifting and basin inversion and tectonic controls on post-rift subsidence and sedimentation.
5) Comparison of the evolution of the EEC, in a plate tectonic framework, with that of the North American and other cratons in order to distinguish relative sea-level changes induced by intraplate deformations from those related to eustatic fluctuations.
6) Development of proposals for acquisition of new deep seismic near-vertical and wide-angle reflection surveys across the PDD basin and other sedimentary basins of the EEC.

### Introduction

The East-European Craton (EEC) has been considered as one of the most stable blocks of the Earth's crust. However, the sedimentary record of the overlying East-European Platform (EEP) shows that, after Palaeoproterozoic consolidation, the EEC was repeatedly affected by rifting cycles, separated by periods of tectonic quiescence and phases of intraplate compression. As such, the EEP is an excellent natural laboratory for investigating the response of an ancient craton to changing stress regimes and for studying the relationships between tectonic processes affecting its margins and interior.

Since the publication of the landmark Palaeogeographical Atlas of the USSR by Vinogradov (1969) and Milanovsky's Geology of the USSR (1987), a vast amount of new geological and geophysical data has been acquired by geological organisations of the Baltic States, Belarus, Russia and the Ukraine. Moreover, development of modern concepts on the evolution of the lithosphere, and particularly on processes governing the development and destruction of sedimentary basins, provide the tools for a reassessment of the evolution of the EEC. In view of its sedimentary record, spanning Riphean to Recent times, and the huge data sets available, an integrated study of the EEP allows an unparalleled opportunity for evaluat-

ing the dynamic processes governing intraplate deformations and their effects on the habitat of natural resources as well as the contribution of tectonic and eustatic effects to relative sea level changes.
GEORIFT integrates the geological and geophysical data available for the EEP and the Baltic and Ukrainian Shields in an effort to model the dynamic processes controlling the evolution of rifted sedimentary basins within and along the margins of the EEC. This requires a multidisciplinary approach and a close cooperation between researchers from eastern and western Europe including teams from Belarus, France, Germany, Netherlands, Poland, Russia, Sweden, Switzerland, the Ukraine and United Kingdom. Close links have also been established with the IGCP Projects 343, 369 (Peri-Tethyan Rift Basins) and 371 (COPENA) and the Peri-Tethys Project.

## Development of the Research Plan

The science plan of the GEORIFT project was initially developed at a small workshop in Kiev in February 1992, an outgrowth of the first EUROPROBE Workshop at Jabłonna, Poland, several months earlier. The plan was refined at the EUROPROBE Intraplate Tectonics and Basin Dynamics (ITBD) Workshop in Amsterdam in November 1992, after which a number of collaborative activities were initiated. During the first workshop devoted exclusively to the GEORIFT project (held near Kiev in October 1994), on-going research and new proposals were discussed further and redefined. At that time it was decided to summarise the results of the ongoing collaborative scientific studies in a Special Volume of Tectonophysics. Some 25 papers submitted to this volume were reviewed by participants of an ITBD-GEORIFT workshop held in Leeds in July 1995. The Special Volume will be published in December 1996.
Protocols establishing the relationships and rights of the scientific partners of GEORIFT and for making datasets from the Ukraine and Russia available for collaborative research were agreed with the State Geological Committee of Ukraine and the National Academy of Sciences of Ukraine in 1992 and with the Russian State Committee for Geology (RosKomNedra) and Russian Academy of Sciences in 1993.

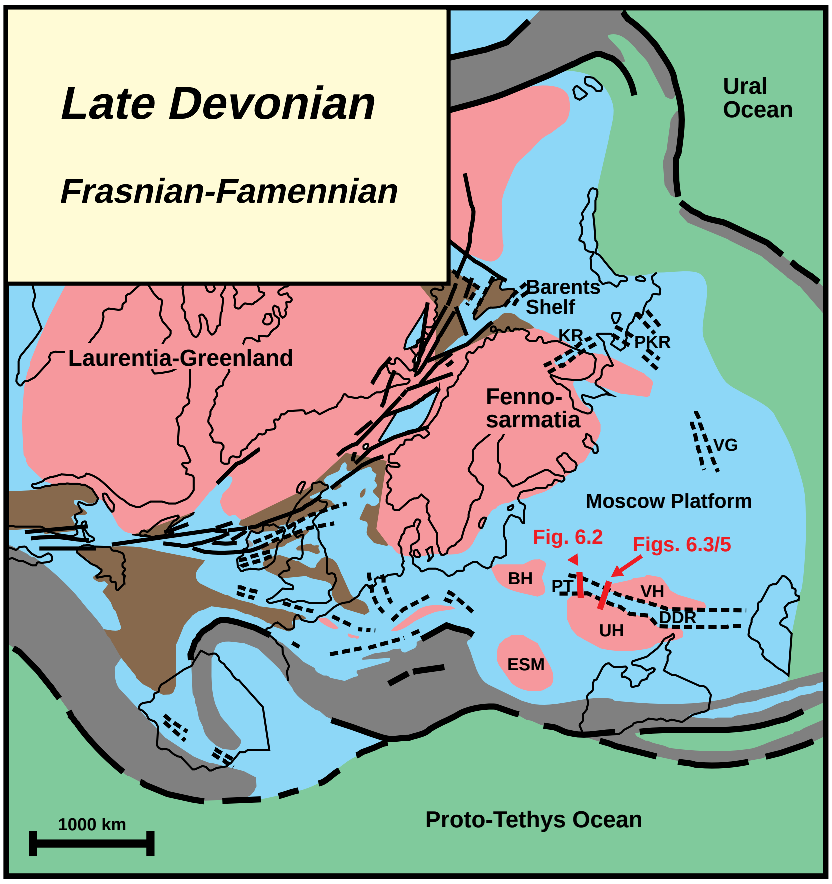


*Figure 6.1: Configuration of the peri-Atlantic continents during Famennian (from Ziegler, 1988). Pink: continental/cratonic areas; brown: continental/inactive Phanerozoic fold belt areas; grey: active fold belts; light blue: shallow water or terrestrial sedimen-tary basins; green: oceanic basins; BH: Belarussian High; DDR: Dniepr-Donets Rift ESM: East Silesian Massif; KR: Konto-zero Rift; PKR: Pechora-Kolva Rift; PT: Pripyat Trough; UH: Ukrainian High; VG: Vyatka Graben; VH: Voronezh High.*

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## Geological Background

### East-European Craton

The East-European Craton (EEC) forms the stable core of Europe; it extends from the Tornquist-Teisseyre zone to the Urals and from the Barents Sea to the Peri-Caspian Basin (Bogdanov and Khain, 1981; Fig. 6.1). The craton is fringed by orogenic belts, accreted during the Palaeozoic, and partly overprinted during the Alpine orogeny in the south. Large parts of this craton are concealed by sediments, ranging in age from Riphean to Recent and in thickness up to about 20 km. The sediment-covered onshore parts of the EEC are referred to as the East-European Platform (EEP), which consist of a superimposed system of sedimentary basins of different age and origin. These include flexural foreland basins fringing orogenic belts and basins developed in conjunction with repeated rifting cycles separated by periods of thermal subsidence and phases of intraplate compression. Preliminary correlations between the stress history of the EEC, the evolution of its sedimentary basins and lithospheric plate motions indicate that the kinematics of plate interaction controlled the evolution and subsequent partial destruction of the intracratonic, passive margin and foreland sedimentary basins (Nikishin et al., 1996). During the Late Precambrian, the EEC formed part of a Pangaea-type supercontinent from which it was separated at the transition to the Cambrian; it was sutured to Laurentia during the Caledonian orogenic cycle. Thus, during the Devonian and Carboniferous, the EEC and Laurentia formed part of a single continent, referred to as Laurussia. Whereas the Devonian and Early Carboniferous evolution of the European lithosphere was largely governed by rifting and wrench faulting, the North American Continent (NAC) was dominated by compressional stresses (Ziegler, 1989; 1990). This reflects major differences in the tectonic setting of the EEC and NAC, despite their forming part of one and the same megacontinent.

More detailed accounts of the main stages of the evolution of the EEC during Riphean and Phanerozoic times are found in Bronguleev (1985-1989), Garetsky (1990), Kuzmenko et al. (1991) and Milanovsky (1987).

### Pripyat-Dniepr-Donets Basin (PDD)

In order to assess the Devonian rifting processes on the EEC and to compare them with those of the Late Precambrian, GEORIFT focuses initially on the study of the PDD. In terms of size and thickness of its sedimentary fill this is the largest and best documented Late Palaeozoic rifted basin, not only of the EEC, but perhaps globally. The PDD is located in the southwestern part of the EEC (Fig. 6.1), striking in a southeasterly direction from Belarus through Ukraine, over a distance of c. 2000 km including its possible extension along the Karpinsky Swell in southern Russia. The Pripyat and Dniepr-Donets basins are major hydrocarbon provinces. The width of the rift varies between 60-70 km in the northwest and 140-160 km in

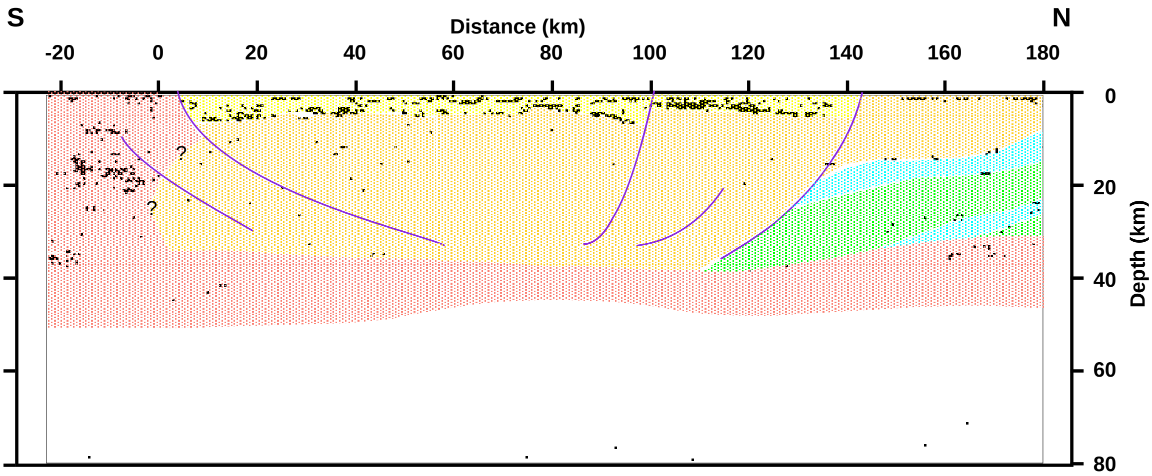


*Figure 6.2: Deep seismic reflection line VIII across the Pripyat Trough (modified from Juhlin et al., 1996). Yellow: Late Devonian and younger syn- and post-rift sediments of the Pripyat Trough; orange: undifferentiated crust of Palaeoproterozoic Andean-type magmatic belt; green/blue: undifferentiated juvenile Svecofennian crust subducted below the Andean-type magmatic belt; pink of upper-middle crust near the southern end of the profile: undifferentiated Ukrainian Shield crust with rapakivi and associated intrusions; pink of lower crust: crustal underplate younger than Palaeoproterozoic subduction and older than Devonian rifting.*

the southeast. Sediment thicknesses increase from about 2 km in the Pripyat segment of the rift to more than 20 km in its Donets sector. Devonian rifting was accompanied by major volcanic activity and the uplift of the flanking Ukrainian shield and the Voronezh massif, forming a large radius arch which is transected by the PDD. The PDD cross-cuts the structural grain of the Precambrian basement (Zaritskiy, 1992; Shchipansky and Bogdanova, 1996) and is segmented into the relatively shallow Pripyat, the much deeper Dniepr segment and the partly inverted Donets-Donbas basin.

*Crustal Structure*

Available data on the Dniepr-Donets rift include 13 Deep Seismic Sounding (DSS) transverse profiles, spaced 50-150 km apart, and one longitudinal profile. These are complemented by gravity and magnetic surveys (Chekunov et al., 1992). The crystalline crust underlying the sedimentary cover thins from 40-50 km under the rift flanks to 30-35 km and 20-25 km beneath the Dniepr and Donets segments of the rift, respectively. Whereas the Moho is pulled up by several km in the Dniepr segment, it is nearly horizontal in the mildly inverted Donets and the heavily inverted Donbas sectors. Within the rift zone, crustal velocities are heterogeneous and increase up to 7.1 km/s. A crust/mantle transition zone of variable thickness, characterised by velocities of about 7.6 km/s, overlies true upper mantle with a 8.0 km/s velocity (e.g. Ilchenko, 1996).

No crustal scale deep seismic-reflection profiles have been recorded across the Ukrainian part of the PDD. However, two such profiles are available for the Pripyat Trough, where they indicate that listric faults sole out in the reflective lower crust at depths of about 30 km (Garetsky and Klushin, 1989; Juhlin et al., 1996; Fig.6.2).

*Basin Fill*

The structural and stratigraphic architecture of the PDD is controlled by a network of industry-type reflection-seismic lines and a vast number of boreholes. In addition, 23 regional multichannel reflection-seismic lines, crossing the entire basin with a spacing of 15-35 km, were acquired in the Ukraine since 1985. These lines, which were recorded to maximum 12 s TWT, image the structure of the entire sedimentary fill of the basin and the configuration of the top of the Precambrian basement (Kivishik et al., 1991; 1993; Stovba et al., 1996; Fig. 6.3).

The Late Devonian development was of typical rift type with high and laterally variable rates of downfaulting, a wide range of local depositional environments, intensive volcanism, and multidirectional tectonic movements. On the rift flanks, crystalline basement is overlain directly by Lower Carboniferous strata, suggesting that the pre-rift sedimentary layer was eroded during syn-rift flank uplift. The thickness of the Devonian syn-rift series, including massive halites, now involved in major diapiric structures, varies between a few hundreds of metres to 4 km (Fig. 6.4). Reactivation of pre-existing crustal discontinuities played a significant role in the localisation of volcanic centres. Frasnian and Famennian alkali basalts and their differentiates and pyroclastic rocks attain local thicknesses in excess of 2 km. The amount of melts generated is not compatible with the observed crustal

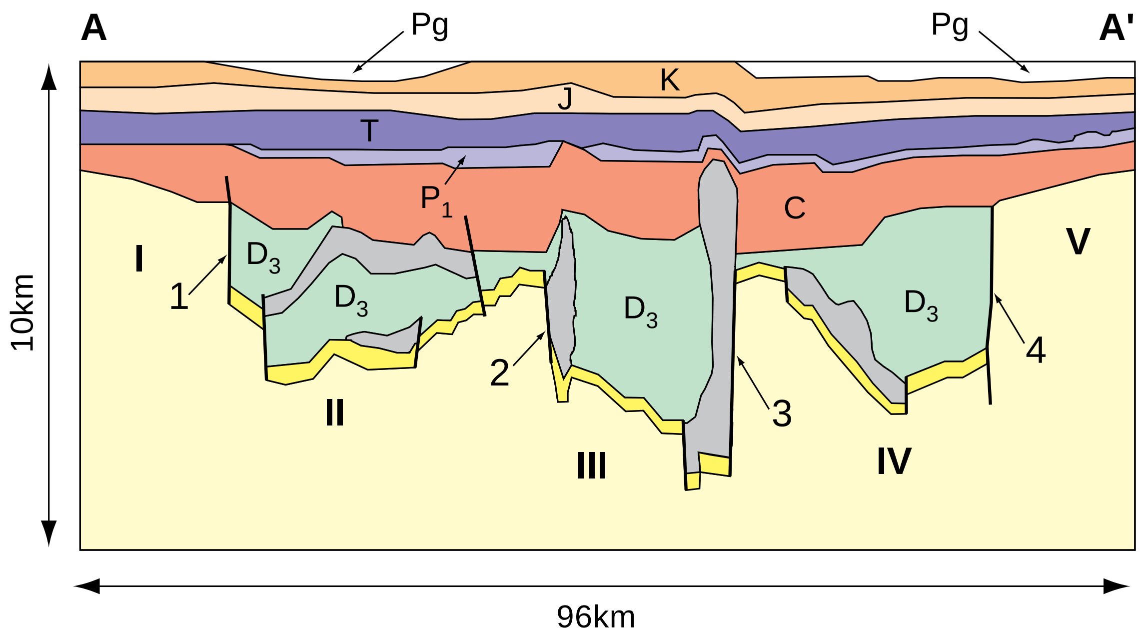


*Figure 6.3: Depth-converted and interpreted regional seismic reflection profile across the Dniepr-Donets Basin (from Stovba et al., 1996).*

stretching factors (Lyashkevich, 1987; Wilson, 1993; Kusznir et al., 1996; van Wees et al., 1996; Wilson and Lyashkevich, 1996).

Post-rift Carboniferous and Mesozoic sediments cover the rift flanks and increase in thickness towards the rift axis. Maximum thicknesses of the successions occur in the southern part of the axial zone of the basin and in the Donbas. The cumulative thickness of the Carboniferous sediments reaches 11 km, with the maximum depth of their base at about 15 km. The post-rift basin axis clearly coincides with the rift axis. The observed amount of post-rift subsidence is considerably greater than could be expected from a conventional stretching model (e.g. McKenzie, 1978). A number of post-rift tectonic reactivations occurred during the Carboniferous and Early Permian, most pronounced in the southeastern part of the Dniepr-Donets basin and in the Donbas, less pronounced in its northwestern parts and barely evident in the Pripyat Trough (e.g. Stovba et al., 1996). During the Permian the PDD was uplifted, with more than 2 km of erosion occurring on parts of the rift flanks. Basin inversion of latest Cretaceous or Palaeocene age is also observed. The uplift and inversion phases are thought to be related to the Uralian and Caucasus orogenies, respectively.

## General Evolutionary Model

During the evolution of the EEP, stress fields related to dynamic processes affecting the different margins of the EEC during its geological history propagated deeply into the craton. A sequence of more or less discrete cycles of intraplate compression and extension is evident. The orientation, polarity, and magnitude of stress changed repeatedly during the evolution of the EEP and governed the evolution of its basins, often by reactivation of pre-existing crustal discontinuities.

Most of the Riphean aulacogens are superimposed on Archaean to Palaeoproterozoic sutures (e.g. Gorbatschev and Bogdanova, 1993). Although many Phanerozoic rifts were localised by palaeo-rifts and shear zones, others cross-cut such structures and the basement fabric. Sedimentary basins originating as rifts evolved during their post-rift stage into thermal sag basins. A number of these basins were compressionally deformed during subsequent orogenic events affecting the margins of the craton. Foreland basins are associated with the orogenic belts which fringe most of the margins of the craton; however, some of these basins were later destroyed during phases of regional uplift (e.g. Scandinavian Caledonian foreland). Intraplate compressional structures, often located far from the craton margins, generally involve the reactivation of pre-existing crustal discontinuities, such as old rifts and shear zones. Rifting activity was mainly associated with the loss of continental blocks from the margins of the craton, resulting in the opening of new Atlantic-type oceans; however, in some cases back-arc extension played a dominant role. Hot-spot activity may have contributed to the Devonian rifting phase.

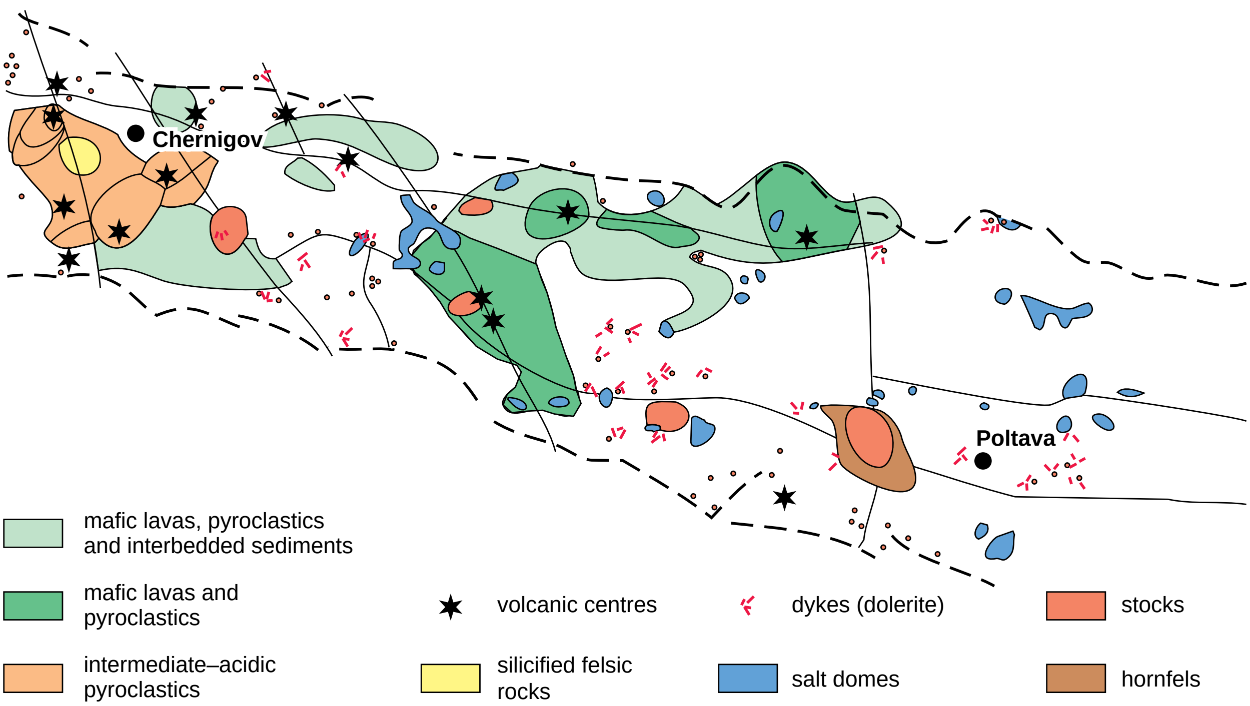


*Figure 6.4: Distribution of Frasnian and Famennian magmatic rocks in the PDD succession (after Wilson and Lyashkevich, 1996)*

Forward and reverse basin subsidence modelling studies (e.g. Kusznir and Ziegler, 1992) in the Pripyat and Dniepr segments of the PDD suggest that a large wavelength lithospheric uplift preceded or was contemporaneous with rift development during the Devonian and that the amount of extension was insufficient to account for the degree of Devonian volcanism in the basin (Kusznir et al., 1996; Fig. 6.5). This and new geochemical studies indicate that the potential temperature of the sublithospheric mantle increased during the Devonian, possibly in conjunction with the impingement of a rising mantle plume causing partial melting of the lithospheric thermal boundary layer. The widespread occurrence of Middle and Late Devonian volcanics and diatremes suggests that this phenomenon was not restricted to the PDD area but affected much of the EEC.

No basin evolution model, based solely on a post-rift thermo-mechanical subsidence mechanism (e.g. McKenzie, 1978), can satisfactorily explain the thickness of the Carboniferous strata in the PDD, especially in the Donets part of the basin (e.g. van Wees et al., 1996). Mechanisms involving external tectonic stress and density changes in the crust and mantle may play a significant role during the post-rift evolution of basins (e.g. Ziegler, 1996). Cyclostratigraphic studies indicate that the dominant controls on basin infill during this time were tectonic in origin rather than glacio-eustatic (Dvorjanin et al., 1996).

Reflection seismic data indicate that during the Permian the basin flanks were uplifted, causing erosion of substantial amounts of Carboniferous strata. Dynamic processes controlling the underlying deformations, as well as regional phenomena such as the broad Permo-Triassic uplift of the western parts of the Baltic Shield, causing removal of the Caledonian foreland basin, remain unexplained. The lens of high velocity crust-mantle mix overlying the upper mantle identified in DSS data (Ilchenko, 1996) beneath the inverted Donets is similar to that observed beneath parts of the Permo-Triassic Polish Trough, which was inverted during the latest Cretaceous and Palaeocene (Guterch et al., 1986). Whether such zones developed during the rifting or the uplift stage is the subject of further investigations.

The development of crustal models, both for the non-inverted parts of the PDD and the inverted Donets-Donbas-Karpinsky zone, integrating wide-angle and new deep near-vertical reflection seismic data with gravity and magnetic measurements, is an essential requirement as an input for interactive basin modelling.

## Outstanding Features

The great thickness of the Late Palaeozoic succession in the PDD and the extensive data base in existence, as well as the recognised trends in the timing and intensity of deformation through the basin, facilitates the development of detailed integrated models of tectonic evolution and sedimentary infill. In combination with similar studies of the other basins of the EEP, a better understanding will be gained on the dynamics of rifting and on tectonic and non-tectonic processes influencing sedimentation.

Specific distinguishing characteristics of the PDD include:

1) Deposition of Devonian to Permian strata in a tectonic setting evolving from one of active crustal extension to thermal relaxation and ultimately to one of possibly active compressional deformation.
2) An extensive suite of syn-rift magmatic rocks and their geochemical, trace element and isotopic signatures providing information on mechanisms contributing to the generation of partial melts. These are derived from lithospheric and sublithospheric sources, with preliminary studies indicating that, during the Devonian, the potential temperature of the sublithospheric mantle rose significantly.
3) Strong evidence of important post-rift subsidence mechanisms other than thermal relaxation of the lithosphere; sufficient geological and geophysical controls are available for modelling a variety of potentially responsible tectonic processes.
4) Excessively thick Carboniferous shallow marine/terrestrial cyclothem successions allowing analysis of controlling mechanisms such as eustatic, tectonic, climatic, and orbital forcing factors.
5) Along strike variations in the degree of basin inversion, ranging from severe in the Donbas to insignificant in the Donets and Pripyat segments, providing a set of "snapshots" of basin inversion, with the available reflection seismic and well data permitting a quantification of inversion-related uplift and erosion and an opportunity to test dynamic models of inversion processes.
6) Extensive coalification data allowing high resolution analysis of the heat flow history of a rifted and partially inverted basin and assessment of temporal and spatial variations in heat flow and their effects on sedimentation.
7) Global importance as a site of Devonian and Carboniferous biostratigraphic age control warranting comparison with international time scales.

# GEORIFT RESEARCH

1. Configuration of the crust and mantle lithosphere beneath the PDD and its comparison with other rift basins of the EEC *(Kiev [IG, UG], Amsterdam [VU], Minsk [IGS, BelNiGri], Uppsala [U], Moscow [IPE, GEON, SG], Hannover [BGR]).*

A fundamental goal of GEORIFT is to explain the present-day geophysical characteristics of sedimentary basins and underlying crust and mantle - including neotectonic signatures - in terms of modelled processes of their geological (palaeotectonic) evolution. Specific activities include: 1) reinterpretation of the crustal and upper mantle structures of the Dniepr-Donets Rift by reprocessing DSS data, using ray-trace travel time inversion and other techniques; 2) tectonic interpretation of contrasting density and velocity models of palaeorift zones; and 3) reprocessing and reinterpretation of a deep reflection seismic profile across the Pripyat Trough. It is planned to construct revised crustal models of the Donbas basin and the Karpinsky swell to its southeast, based on reinterpretations of existing DSS, CMP, and potential field data. This involves filtering and wide-angle migration of newly digitised datasets in conjunction with the interpretation of CMP reflectors as well as ray-tracing and finally integration with geoid, topographic, and thermal data.

2. Basement provinces *(Lund [U], Moscow [SU, SAOG, GIN, GEON], Murmansk [RAS], St. Petersburg [VSEGEI], Kiev [IG, IGS, IGMO], Minsk [IGS], Vilnius [LIG], Utrecht [U]).*

The Precambrian basement of the EEC crops out in the Baltic Shield, the Voronezh Massif, and the Ukrainian Shield and has been reached by numerous boreholes drilled through the sedimentary cover of the EEP. Available results suggest that the EEC consists of the composite Fennoscandian, Volgo-Uralian and Sarmatian terranes. These terranes, each of which includes Archaean and Proterozoic crustal elements, were assembled in Palaeoproterozoic times. In most cases, the sutures between terranes coincide with Riphean aulacogens. Later compressional structures also generally involve reactivation of pre-existing crustal discontinuities, indicating that the analysis of the relationship between the fabric of the Precambrian crust and the structure and geometry of the superimposed sedimentary basins is imperative. A better definition of the basement provinces of the EEC is being obtained by analysing core material from boreholes (petrology, geochemistry, radiometric dating) and by mapping their structural fabric on the basis of detailed aeromagnetic and gravity maps and by integrating results of available reflection and refraction seismic data.

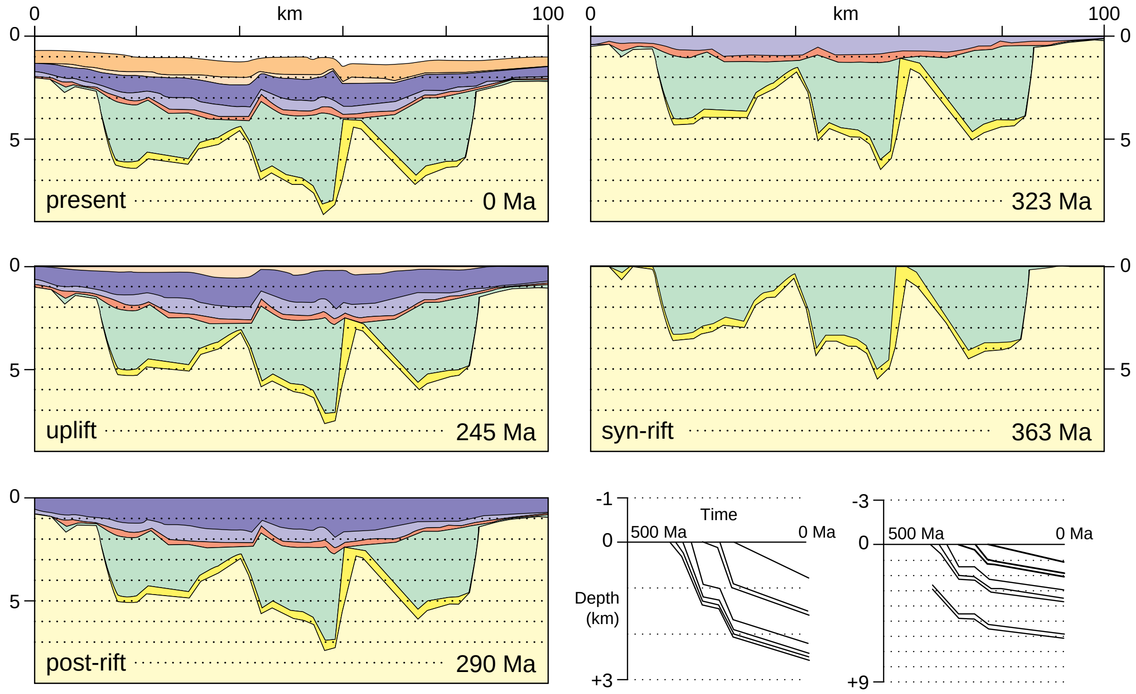


*Figure 6.5: Syn- and post-rift models of the stratigraphy and crustal structure of the Dniepr basin (after Kusznir et al., 1996).*

3. The PDD rift viewed from a mineralisation perspective *(Kiev [GP, IGS, IGMO], Minsk [IGS], Utrecht [U]).*
The Donets segment of the PDD is endowed with a variety of metal deposits amongst which mercury and antimony are of particular significance. Gold and diamond are known to occur, but no detailed records are available so far. In western Europe it is thought that the mechanisms underlying the emplacement of such mineral deposits involve post-orogenic gravitational instability leading to subcrustal lithospheric detachment, the consequent advection of asthenospheric mantle to higher levels, increased heat flow and fluid activity in the crust and often bimodal magmatism with the result that mercury and antimony and most probably also gold may be derived directly from the mantle. Deep-reaching faults and shear zones are likely to have provided the pathways for mineralising fluids. Devonian magmatism involved the intrusion and extrusion of alkaline mafic and ultramafic magmas during the rift stage. Permo-Triassic trachy-andesitic plugs are known just south of Donets. A study is being undertaken of the relations between mineralisation, magmatic activity, deep structures, rift development and inversion.

4. Timing and magnitude of uplift of shields and basement massifs *(Amsterdam [VU], Chernigov [USGI], Moscow [SU]).*
For areas lacking a sedimentary cover, such as on the Kola Peninsula, the Voronezh Massif and the Ukrainian Shield, fission track data is to be acquired to determine the timing and possible magnitude of their uplift, as far as this cannot be constrained by provenance and sedimentological studies of adjacent basins. Fission track data are only available for the Swedish Caledonian foreland; these indicate its uplift around the end of the Permian, thus suggesting that several kilometres of Old Red Sandstones once covered much of the Baltic Shield. The analysis of palaeosoils could provide further constraints for palaeogeographic reconstructions.

5. Geodynamics of intraplate magmatism *(Leeds [U], Minsk [IGS], Lvov [NASU], Kiev [UGC], Moscow [SU, IMGRE], Amsterdam [VU], London [U]).*
Numerous magmatic provinces are recognised within the EEC; these include flood basalts, rift-related volcanism, alkaline intrusions, kimberlite fields and dyke swarms. The main periods of intraplate magmatism are Riphean, Vendian, Devonian, Early Permian, Triassic, and Cretaceous. The general lack of isotope ratio and trace element analyses prevents a clear understanding of the depth of magma generation and of geodynamic processes governing partial melting (passive lithospheric extension, mantle plume activity, back-arc extension, subduction-related magmatism). Detailed studies of the geochemical and Sr-Nd-Pb isotopic characteristics of the most primitive (ultra)-mafic magmatic rocks have been undertaken. They concentrate mainly on rocks emplaced during the Late Palaeozoic in the PDD and other rift basins and seek to determine magma source regions and magma generation conditions. The results allow interpretation of the geodynamic processes controlling the production of partial melts and to evaluate the significance of magmatic activity during intracratonic rifting.

6. Palaeogeographic-palaeotectonic mapping *(Moscow [SU, AG], St. Petersburg [VSEGEI], Basel [U], Minsk [IGS], Murmansk [RAS], Kiev [GP, UG], Chernigov [USGI], Warsaw [PAS]).*
The Late Precambrian and Phanerozoic evolution of the EEC, with links to the Tethyan, west- and central-European and Arctic-North Atlantic domains, has been reconstructed, documented and will continuing updating in a sequence of palaeogeographic-palaeotectonic and isopach maps covering the entire craton. These provide an update of the Vinogradov (1969) Geological Atlas of the USSR, particularly concerning the deep basins for which much new data are available. The compilation scale is 1:10 million and mapping methods and a legend similar to the Geological Atlas of Western and Central Europe of Ziegler (1990) have been adopted. Palaeoenvironments and clastic transport directions will be identified, erosional and depositional basin edges distinguished, and palaeoreconstructions of basin outlines attempted. For major unconformities, subcrop and onlap maps will be constructed. These, together with the palaeogeographic-palaeotectonic maps, will permit an assessment of the scope and dynamics of lithospheric deformations. Preliminary results indicate that major changes in sedimentary basin distribution, and the dynamic process governing their evolution, mirror changes in intraplate stress regimes and correlate with major plate reorganisations.

7. Structure and chronostratigraphy of sedimentary basins of the EEP *(Moscow [SU, SOGA, CSBR, AG], Jaroslavl [NEDRA], Kostroma [KG], Murmansk [RAS], St. Petersburg [VSEGEI, VNIGRI, VNIIO], Minsk [IGS], Kiev [UG], Chernigov [USGI], Amsterdam [VU], Basel [U]).*
The structural and sedimentary architecture of the different basins are being analysed on the basis of well data, reflection seismic lines, and existing seismo-stratigraphic interpretations. It will be documented in a set of regional structural and stratigraphic cross-sections including chrono-lithostratigraphic diagrams. The area to be covered embraces the entire EEP, extra-Alpine western and central Europe, the Barents Sea and the Peri-Caspian Basin. Dynamic processes governing the evolution of the individual basins (e.g. rifting, thermal sag, passive margin, inversion, foreland basin, etc.) will be evaluated by means of 1D and 2D subsidence analyses and step-wise palinspastic reconstructions.

8. Stratigraphic record of relative sea level changes in the EEP *(Moscow [SU, PIN, GIN], St. Petersburg [VSEGEI, VNIGRI], Kiev [UG], Chernigov [USGI], Amsterdam [VU], Utrecht [U], Nancy [U]).*
The Late Precambrian and Phanerozoic sedimentary record of the individual basins of the EEP is being analysed and compared in terms of relative sea-level changes. Sea-level curves are being compared with data available from other cratons in an attempt to discriminate between the contribution of eustatic and tectonic components in the observed relative sea-level fluctuations. Preliminary studies indicate for the slowly subsiding Moscow syneclise and the rapidly subsiding Dniepr-Donets basin that cyclicity correlates with that established in western Europe and North America. However, due to a large spatial variability in cyclicity amplitude, tectonic processes must be involved. Detailed studies along two profiles in the PDD - through Lower Carboniferous strata in the Dniepr basin and through Middle-Upper Carboniferous strata in the Donbas basin - will be undertaken. A modelling study has begun that seeks to integrate basin fill ("quantitative dynamic stratigraphy") and tectonic basin evolution models in order to study the interactions of tectonic and non-tectonic processes influencing the development of sedimentary sequences.

9. Structural interpretation of regional seismic reflection profiles of the PDD *(Kiev [UG], Amsterdam [VU], Liverpool [U], Basel [U]).*
The Dniepr-Donets basin is crossed by more than twenty regional (>100 km long) reflection seismic profiles imaging the basin fill and the upper crust. These data are being interpreted in terms of key tectonic issues such as the control and relationship of basement structure with basin formation, timing and propagation of rifting phases, relationships between halokinesis and tectonic processes, and the timing and style of inversion-induced structures.

10. Integrated modelling study of the PDD basin and other sedimentary basins of the EEP *(Kiev [IG, UG], Minsk [IGS], Amsterdam [VU], Liverpool [U], Moscow [SU, CSBR]).*
Quantitative tectonic subsidence and basin evolution models are being applied along a suite of closely related 2D transects across the PDD basin. Activities include flexural backstripping and reverse modelling of basin architecture through the syn- and post-rift phases of basin development, forward modelling using the flexural cantilever and other methods, and investigation of multiple thermo-extensional and compressional tectonic events during basin evolution. Such models, which predict basin stratigraphy through time, must be consistent with palaeothermometric inferences from the sedimentary and magmatic basin fill and the observed lithospheric characteristics, and are to be integrated with quantitative models of the basin fill processes.

11. Influence of intralithospheric and lithosphere-asthenosphere processes on basin dynamics - geophysical and geological constraints and modelling *(Moscow [CSBR, IEPT, GEON, SG, IPE], Amsterdam [VU], Leeds [U], Kiev [IG]).*
The constraints inherent to the geological and geophysical data available for the PDD permit the development of a new generation of tectonic basin models, with greater attention to issues such as dynamic linkage and feedback of brittle and ductile deformations with thermo-isostatic evolution of the lithosphere, non-thermal subsidence mechanisms including phase transformation processes in the upper mantle, and global processes. The continued development of new generations of modelling tools is fundamental for the comparison of the PDD and other basins of the EEP and the definition of the response of the craton to changing tectonic settings and stress systems.

12. The inverse problem of basin stratigraphy modelling using the Dniepr-Donets basin as a case example *(Amsterdam [VU], Kiev [IG, UG], Montpellier [U], Zürich [ETH]).*
This project aims at developing a new approach to tectonic modelling of basin evolution by using inverse modelling techniques to discriminate rigorously between the different tectonic processes that are involved in rift basin evolution. These include heterogeneous crustal and mantle attenuation during rifting, rheological controls on lithospheric necking localisation, in-plane stresses, flexure, and rift reactivation.

13. Thermal history of the Dniepr-Donets basin *(Chernigov [USGI], Kiev [UG], Utrecht [U], Basel [U]).*
Coal and dispersed organic matter from the Devonian-Carboniferous-Permian basin fill will be investigated for their palaeothermal signals. In this way, temporal and spatial variations in palaeothermal gradients will be placed into the framework of thermal tectonic events. These are to be assessed in the context of the palaeotectonic and palaeogeographical evolution of Europe during the Late Palaeozoic. Organic petrological analysis is to refine initial concepts of temporal and spatial variation in palaeo-heat flow in the PDD basin. Moreover, the timing and extent of Palaeozoic and Mesozoic inversion events and associated erosion will be determined. This may lead to a better understanding of the thermal metamorphism and prediction of hydrocarbon generation.

14. Neotectonics, present stress, and dynamics of the EEC *(Moscow [SU, CSBR], Potsdam [GFZ], Karlsruhe [U], Amsterdam [VU]).*
This project aims at a compilation of a neotectonic map at a scale of 1:10 million in conjunction with the acquisition and collation of present-day stress data (from in situ measurements, seismicity, and physiographic studies) in co-ordination with the ongoing relat-

ed ILP projects. One important objective, beyond the characterisation of the present-day intracratonic stress field, is to model neotectonic deformations numerically.

15. New deep seismic and ancillary geophysical studies of the PDD *(Kiev [UG, IG], Minsk [IGS, BelNiGri], Moscow [IPE, GEON, SG], Amsterdam [VU], Uppsala [U]).*

In consultation with ongoing, national programmes of geophysical data acquisition on the EEC, new purpose-designed near-vertical reflection, seismic refraction, and magnetotelluric soundings are seen as essential to solve some of the outstanding problems of basin geodynamics on the EEC. In the framework of the outlined GEORIFT objectives and research programme, key targets are the Donbas region of the PDD and the adjacent southern margin of the EEC. Several globally fundamental issues related to intra–cratonic rifting and the post-rift evolution and deformation of sedimentary basins, and global plate reconstructions in the Late Palaeozoic can be addressed in this area. These include Moho evolution and magmatic processes during rifting and lithospheric extension and lithospheric controls on basin inversion processes. Additionally, GEORIFT participants will collaborate fully in the EUROBRIDGE project where it involves acquisition of essential crustal and upper mantle velocity controls from wide-angle seismic data across the Pripyat Trough.

16. Synthesis and 4-Dimensional modelling of the evolution of the EEC *(Amsterdam [VU], Basel [U], Minsk [IGS], Kiev [IG], Moscow [GIN, CSBR, SU], Toronto [U], Halifax [U]).*

A synthesis and joint analysis of all data gathered by GEORIFT will permit 4-dimensional computer modelling of the evolution of the EEC during Riphean and Phanerozoic times and numerical modelling of its major sedimentary basins. A comparison of the response of the EEC and other cratons to changing stress regimes will be made.

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