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Pripyat Trough: Tectonics, geodynamics, and evolution

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Abstract. The Pripyat Trough is situated in the East-European Platform and is a part of the more extensive system of the Sarmatian-Turanian lineament. It is one of the most thoroughly drilled and seismically investigated oil-bearing basins of the paleorift type that are known in the ancient platforms. Its geological structure reflects the typical features of ancient rift basins and can be interpreted as the tectonic type of an oil-bearing paleorift. The tectonic style of the paleorift can be reconstructed from the structure of some markers, such as the surfaces of the basement, of the subsalt deposits, of the intersalt rocks, of the upper salt-bearing rock sequence, and of some other rocks residing in the upper parts of the sequence. The Pripyat Trough is characterized by the block tectonics of its subsalt deposits, by the block-fold tectonics of its intersalt deposits, and by the essentially fold tectonics of its upper salt-bearing and overlying deposits. The specific styles of the tectonic deformation of the subsalt, intrasalt, and suprasalt deposits suggest three structural zones, namely, the Northern, Central, and Southern zones. Proceeding from the results of deep seismic sounding, the Pripyat rift is interpreted as a zone of listric breaking which had enveloped not only the Pripyat Graben but also the adjacent areas of the Ukrainian Shield and Belorussian Anteclise, forming its shoulders.

1. Introduction

The Pripyat Trough is the westernmost sublatitudinal segment of the Pripyat-Donetsk Paleozoic Aulacogen which is situated in the old East-European Platform and is a part of the more extensive system of the Sarmatian-Turanian lineament [*Aisberg et al.,* 1971; *Garetskii,* 1976, 1979]. This trough is situated between the periclines of the Belorussia and Voronezh anticlines and the Zhlobin Saddle in the north and the Ukrainian Shield in the south. In the west the Polessie Saddle separates the Pripyat Trough from the Podlyas-Brest Basin and in the east the Bragin-Loev Saddle separates this trough from the Dnieper Trough (Figure 1). The latter has a length of 280 km and a width of 140–180 km. The Pripyat Trough has the following boundaries: the northern boundary at $52°59'$ N, the southern at $51°33'$ N, the western at $27°13'$ E, and the eastern at $30°49'$ E.

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The Pripyat Trough is one of the most thoroughly drilled and seismically investigated oil-bearing basins of the paleorift type that are known in the ancient platforms. Its geological structure reflects the typical features of ancient rift basins. It can be interpreted as the tectonic type of an oil-bearing paleorift. 66 oil fields have been found there, most of them being restricted to the Middle-Upper Devonian carbonate and terrigenous deposits and also to the late Proterozoic rocks. Since the year of 1990, the annual production rate has been about 2 million tons.

The main sources of information are the results of drilling 1350 holes in the Pripyat Trough (well-logging data, logs, and cores), the results of their processing in the form of the geological columns of the holes, their correlation along the profiles, the study of fracturing using the cores, the microscopic analyses of the rocks, and the recording of oil and gas contents of the rocks penetrated by the holes. The sources of geophysical information were the primary results of areal CDP seismic surveys, the results of deep seismic sounding (DSS+CDP), vertical seismic profiling (DSS+VSP), the results of analyzing potential gravity, magnetic, and thermal fields, the geoelectric parameters of the rocks using the re-

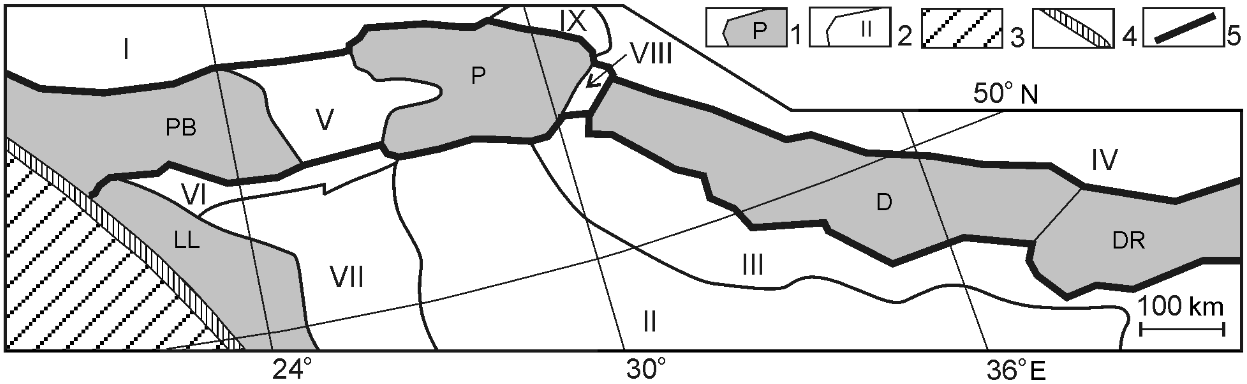


Figure 1. Schematic tectonic map of the southwestern part of the East European Craton. Structural features in the southwest of the craton: (1) Paleozoic sedimentary basins: (PB) Podlyas-Brest basin, including the following basins: (P) Pripyat, (D) Dnieper; (DR) Donetsk recent fold belt, (LL) Lvov-Lyublin fold belt; (2) other tectonic elements: (I) Belorussian anticlise, (II) Ukrainian Shield, (III) Ukrainian Shield slope, (IV) Voronezh anticlise slope, (V) Polessian Saddle, (VI) Lukovo-Ratnovo Horst, (VII) Volyn monocline, (VIII) Bragin-Loev Saddle, (IX) North Pripyat shoulder; (3) Middle European Plate; (4) Teisseir-Tornquist zone, (5) system of faults delimiting the Sarmatian-Turanian lineament.

sults of deep magnetotelluric soundings, and the combined interpretation of all geophysical data to derive geological and geophysical models for the solid crust and platform sedimentary cover.

The Pripyat Trough consists of a clearly expressed large graben and its North Pripyat shoulder. Its South Pripyat shoulder belongs to the Ukrainian Shield, from which the trough is separated by the South Pripyat marginal fault represented by a zone of normal faults measuring 2–6 km along the basement surface. The northern boundary of the trough in the west and of the graben in the east is marked by the North Pripyat marginal fault consisting of several en-echelon arranged normal faults varying from 2 to 4 km in total magnitude. In the east the northern boundary of the trough follows the Zhlobin and Malinovo-Glazov crustal faults separating the North Pripyat shoulder from the Zhlobin Saddle.

The sedimentary cover is as thick as 6 km there. The bulk of the rocks are Devonian and Carboniferous deposits which in the west of the trough rest on the Late Proterozoic (Riphean and Vendian) terrigenous sedimentary rocks. The oil-bearing, mainly carbonate, deposits of Devonian age are separated by two thick halogenic rock sequences.

The tectonic style of the paleorift can be reconstructed from the structure of some markers, such as the surfaces of the basement, of the subsalt deposits, of the intersalt rocks, of the upper salt-bearing rock sequence, and of some other rocks residing in the upper parts of the sequence. The Pripyat Trough is characterized by the block tectonics of its subsalt deposits, by the block-fold tectonics of its intersalt deposits, and by the essentially fold tectonics of its upper salt-bearing and overlying deposits [*Garetskii,* 1976]. The specific styles of the tectonic deformation of the subsalt, intrasalt, and suprasalt deposits suggest three structural zones, namely, the Northern, Central, and Southern zones.

Proceeding from the results of deep seismic sounding [*Aisberg et al.,* 1988; *Garetskii and Klushin,* 1987], the Pripyat rift zone was mapped. It is interpreted as a zone of listric breaking which had enveloped not only the Pripyat Graben but also the adjacent areas of the Ukrainian Shield and Belorussian Anteclise, forming its shoulders. The Pripyat Graben (the paleorift proper in the narrow sense) is separated by the North-Pripyat and South-Pripyat superregional listric faults from the shoulders located in the north and south. The North Pripyat shoulder includes a band, 35–40 km wide, with widely developed prerifting Riphean, Vendian, Lower and Middle Devonian, Lower Frasnian and synrifting Late Frasnian suprasalt and Late Frasnian, early Famenian intrasalt and late Famenian suprasalt deposits, all broken by faults into steps and covered by Triassic and Jurassic rocks, this allowing the inclusion of the North Pripyat shoulder into the Pripyat Trough. Its South Pripyat shoulder embraces a narrow zone (about 40 km wide) of the Ukrainian Shield and is bounded in the south by a marginal listric fault along which the crustal blocks did not experience any notable lowering. For this reason the South Pripyat shoulder does not include synrift deposits, the Quaternary sediments resting on the rocks of the basement and on the quasi-platform cover of the Ovruch graben-syncline. For these reasons the South Pripyat shoulder is not included into the Pripyat Trough. .

2. Basement Structure

All tectonic elements of the crystalline basement in the Pripyat Trough have a submeridional strike. These are (eastward): the Central Belorussian zone, Osnits-Mikashevichi volcano-plutonic belt, and Bragin granulite massif [*Aksamentova and Naidenkov,* 1992; *Konishchev,* 2001]. The first of them is composed of granite gneiss and extends in the westernmost part of the Starobin centrocline of the trough. The best represented is a volcanoplutonic belt which is composed of the relatively young igneous rocks of a metagabbro-diabase suite (2.02 Ga), a diorite-granodiorite-granite suite (2.0–1.97 Ga), and a quartz-sienite-granite suite (1.8–1.75 Ga). The belt is bounded by deep listric faults of Precambrian age: the Stokhod-Mogilev fault in the northwest and the Sushchano-Perzha fault in the southeast [*Aksamentova,* 2002]. The Bragin granulite massif occurs in the Bragin-Loev Saddle and in the southeast of the Pripyat Trough.

3. Stratigraphy of the Sediments

The platform cover of the Pripyat Trough consists of Late Proterozoic (Riphean and Vendian), Paleozoic (Devonian, Carboniferous, and Permian), Mesozoic (Triassic, Jurassic, and Cretaceous), and Cenozoic (Paleogene, Neogene, and Quaternary) deposits totaling 6000 m in thickness. They vary in origin, lithology, and thickness from 50 to 3500 m (Figure 2).

The sedimentary cover of the Pripyat Trough is divided by structural and azimuthal unconformities into several structural complexes: Lower Baikalian, Upper Baikalian, Hercynian, and Cimmerian-Alpine. The Lower Baikalian structural complex (Upper Riphean-Lower Vendian) is composed primarily of terrigenous red rocks in the Volyn-Orsha paleotrough of a NE strike, inherited from the tectonic elements of the basement. The same trends have been inherited by the structural features of the Late Baikalian time (Early Cambrian Vendian-Baltic), which are also represented by terrigenous rocks. These lithostructural units are overlain with a high azimuthal unconformity by Hercynian rocks.

The Hercynian rocks compose most of the platform cover and can be classified into the following structural units: Emsian-Middle Frasnian, Late Frasnian-Famennian, Late and Middle Carboniferous, Early Permian, and Early Triassic. The Cimmerian-Alpine Complex can be subdivided into a Late Triassic-Miocene and a Pliocene-Quaternary stage. In its turn, the Late Frasnian-Famennian stage, which dominates in thickness and developed under the complicated tectonic conditions of rifting, consists of several substages: Rechitsa-Evlanian, Livenian, Domanik-Petrikov, Lebedyan-Naidovian, Shatilki-Streshian, and Polessian substages. The bulk of this stage is occupied by two salt-bearing rock sequences (Late Frasnian and Middle Famennian) and by volcanic rocks replacing them in the east.

The main breaks in sedimentation and major stratigraphic unconformities are restricted to the tops of the Riphean, Vendian, Late Devonian (Semiluka Unit), Middle Carboniferous, Early and Late Permian, Triassic, and Jurassic rocks. These structural rock complexes, stages, and substages are separated by structural and azimuthal unconformities. The types of the rocks can be found in the names of the basic rock suites presented in Figure 2. The ages of the rocks are proved by their fauna, spores, and pollen. Field geologists often use the terms "subsalt sequence" (including all pre-Livenian Late Proterozoic, Middle Devonian, and most of the Frasnian rocks), "intrasalt sequence" (early Famenian), and "supersalt sequence" (Late Famennian-Quaternary).

The Emsian-Middle Frasnian stage was subdivided into the Emsian-Lower Frasnian and Middle Frasnian substages. The Emsian-Lower Frasnian substage is composed mainly of terrigenous rocks and combines two rock associations: (1) gray sulphate-carbonate terrigenous rocks (Vitebsk Horizon, Emsian Stage, Lower Devonian, and Pyarnu and Narov horizons of Eifellian stage of Middle Devonian) and (2) variegated terrigenous rocks (Polotsk Horizon, Givetian, Middle Devonian). The Middle Frasnian structural substage have been found to be represented by one formation, namely, by a gray marine carbonate formation (Sargaev and Semiluka horizons).

The Upper Frasnian-Famennian structural stage includes four substages: the Rechitsa-Evlanov, Evlanov-Petrikov, Lebedyan-Streshin, and Polessian stages.

The Rechitsa-Evlanov structural substage includes a variegated tuffite-clay-marl member (Rechitsa Unit), an alkaline ultrabasic to alkaline basaltic member, and a gray sulfate-carbonate member (Voronezh horizon and the lower part of the Evlanov horizon).

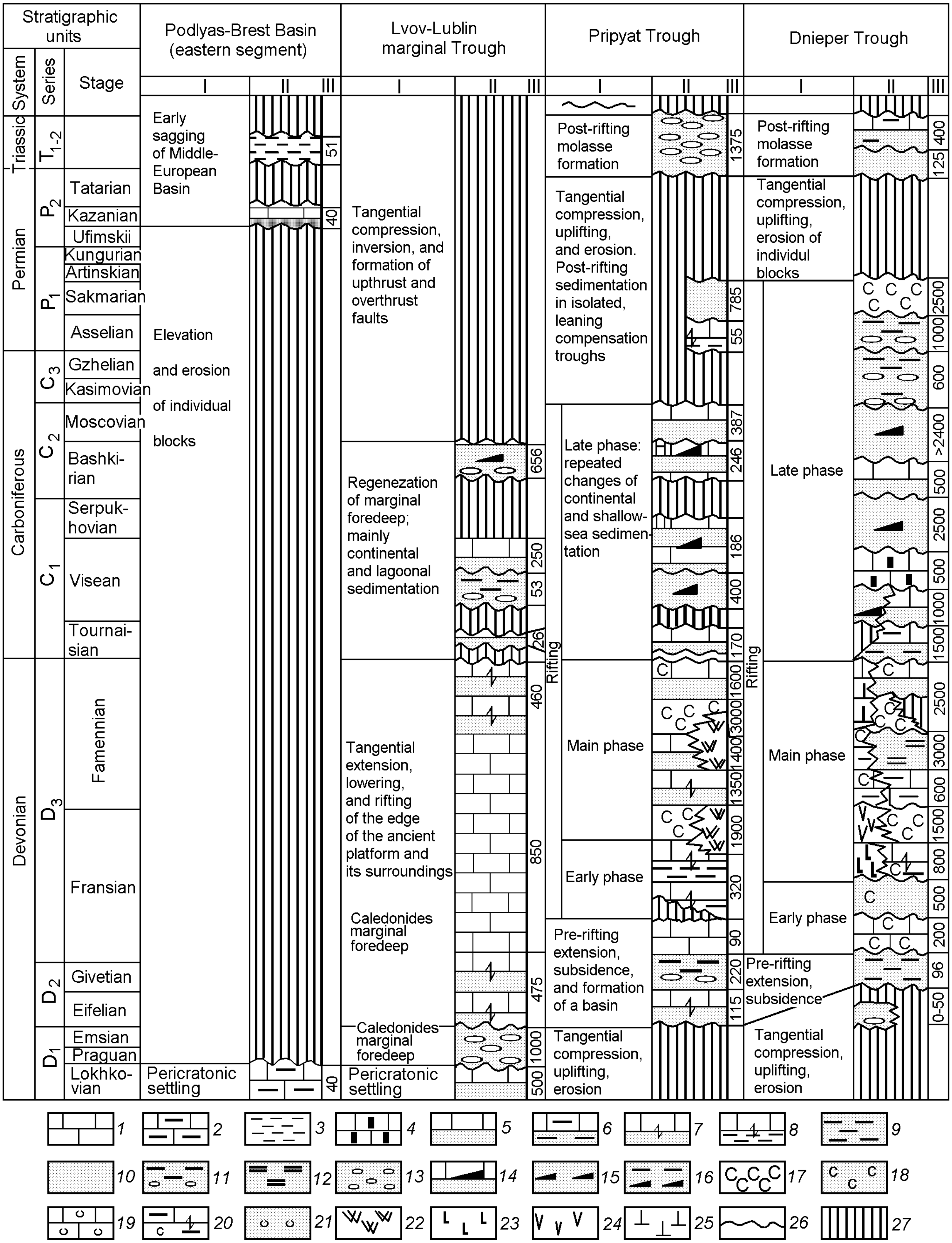
The Evlanov-Petrikov structural substage combines two rock suites: a halogenous halite unit (Evlanov unit in the lower part and Liven unit in the upper part) and a gray terrigenous sulphate-carbonate suite (intrasalt deposits, such as the Lower Famennian Domanovichi, Zadonsk, Elets, and Petrikov horizons). The latter suite consists of several subformations producing a horizontal sequence of flyschoid terrigenous-carbonate rocks in the south, domanikoid clays and carbonate rocks in the center, and rifting-related rocks in the north and west.

The Evlanov-Petrikov structural stage includes a unit of alkaline-ultrabasic and alkaline basaltic rocks, which consists of two rock sequences: the lower unit composed of Evlanov, Liven, and Domanovichi rocks, conjugated with the upper Evlanov part of the sulfate-carbonate rock sequences and with the halogenous halite sequence, and the upper rocks of the Elets unit, which replace the top of a terrigenous sulfate-carbonate unit.

The Lebedyan-Streshin structural substage is composed of the halogenous rocks of K-bearing halite rocks (Lebedyan, Ores, and Streshin horizons) and is replaced in the northeast by the upper rocks of an alkaline ultrabasic-alkaline basaltic rock unit. This rock unit consists of two subunits; the lower halite unit (Lebedyan horizon) and the upper K-bearing hallopelite-halite unit (Ores and Streshin horizons).

The Polessian structural substage includes the Devonian supersalt rocks in the volume of a gray shale-bearing carbonate-terrigenous rock unit.

The rocks of the Lower-Middle Carboniferous structural stage rest on the Upper Devonian rocks with a distinct stratigraphic erosional angular unconformity and are covered with an angular unconformity by Lower Permian and Mesozoic deposits. These rocks occur in the Pripyat Graben and in the Bragin-Loev Saddle, the lower rocks being widely developed in the Turov centricline, and the upper ones, in the northern part of the Bragin-Loev Saddle, filling synclinal zones and pinching out on the slopes of the swells, mainly as a result of numerous erosions [*Tostosheev,* 1988]. The Carboniferous


Stratigraphic units
System
Series
Stage
Podlyas-Brest Basin (eastern segment)
Lvov-Lublin marginal Trough
Pripyat Trough
Dnieper Trough
I
II
III
Triassic
T_{1-2}
Permian
P_2
Tatarian
Kazanian
Ufimskii
P_1
Kungurian
Artinskian
Sakmarian
Asselian
Carboniferous
C_3
Gzhelian
Kasimovian
C_2
Moscovian
Bashki-rian
C_1
Serpuk-hovian
Visean
Tournai-sian
Devonian
D_3
Famennian
Fransian
D_2
Givetian
Eifelian
D_1
Emsian
Praguan
Lokhko-vian
Early sagging of Middle-European Basin
Elevation and erosion of individual blocks
Pericratonic settling
Tangential compression, inversion, and formation of upthrust and overthrust faults
Regenezation of marginal foredeep; mainly continental and lagoonal sedimentation
Tangential extension, lowering, and rifting of the edge of the ancient platform and its surroundings
Caledonides marginal foredeep
Caledonides marginal foredeep
Pericratonic settling
Post-rifting molasse formation
Tangential compression, uplifting, and erosion. Post-rifting sedimentation in isolated, leaning compensation troughs
Rifting
Late phase: repeated changes of continental and shallow-sea sedimentation
Main phase
Early phase
Pre-rifting extension, subsidence, and formation of a basin
Tangential compression, uplifting, erosion
Post-rifting molasse formation
Tangential compression, uplifting, erosion of individul blocks
Rifting
Late phase
Main phase
Early phase
Pre-rifting extension, subsidence
Tangential compression, uplifting, erosion
51
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656
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53
26
460
850
475
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500
1375
785
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387
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186
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rock sequence includes the Tournaisian-Lower Visean, Upper Visean, Serpukhovian, and Middle Carboniferous structural substages.

The Tournaisian-Lower Visean structural substage is composed of two rock associations: gray-color carbonate and terrigenous rocks (Malevka and Lower Kizel horizons of Tournaisian age) and variegated terrigenous kaolinite- and coal-bearing rocks (Malinovka subhorizon and Bobrikov horizon of Visean age).

The rocks of the Late Visean-Serpukhovian structural substage have been mapped in individual synclinal zones of the Pripyat Basin and in the northern part of the Bragin-Loev Saddle. This substage includes one paralic gray-color coal-bearing carbonate-terrigenous rock formation.

The Middle Carboniferous substage combines two rock suits: a paralic mottled carbonate-terrigenous coal-bearing suit (Bashkirian Stage) and a variegated carbonate-terrigenous suit (Moscovian Stage).

The Lower Permian structural stage, represented by terrigenous sulfate- and carbonate-bearing rooks, is developed in the eastern part of the Bragin-Loev Saddle. This stage was found to include sporadical red halogenic K-bearing sand, anhydrite, and clay.

The rocks of the Lower-Middle Triassic structural stage are developed in the Pripyat Trough, in the Bragin-Loev Saddle, and in the area north of the latter. This stage is composed of mottled molasse-like rocks, subdivided into three units: a variegated sand-clay unit (Dudich formation, Indian Stage, Lower Triassic), a red terrigenous unit (Vystupovichi and Korenev formations of the Indian Stage, Lower Triassic), and a variegated carbonate-terrigenous unit (Lower and Middle Triassic Mozyr, Kalinkovichi, and Narovlya formations.

The Kimmerian-Alpine structural complex is represented by Late Triassic-Quaternary deposits occurring as typical syneclise orthocratonic deposits of a relatively small thickness with rapid paragenetic changes in a vertical sequence and forming a mantlelike, poorly deformed cover. In all areas of its occurrence this rock complex is subdivided into a Late Triassic-Miocene and a Pliocene-Quaternary structural stage divided by a pre-Pliocene unconformity.

The Late Triassic-Miocene structural stage includes the following rock formations: gray terrigenous brown-coal rocks (Late Triassic, Lower (?) and Middle Jurassic including Callovian), gray terrigenous-carbonate (Callovian top and Oxfordian), gray terrigenous (Lower Cretaceous, including Albian), gray terrigenous-glauconite, phosphorite-bearing (Albian and Cenomanian), writing chalk (post-Cenomanian Late Cretaceous), gray terrigenous glauconite-bearing (Paleogene, Eocene, and Lower Oligocene), and variegated terrigenous rocks with brown coal (Late Oligocene to Miocene).

The Pliocene-Quaternary structural stage is represented by thin Pliocene lacustrine and alluvial and mainly by Quaternary glacial clastic rocks.

4. Platform Cover Tectonics

The Pripyat Trough is distinguished by a great variety of its structural forms which vary upward from one structural unit to another. As mentioned above, mainly block structures with some elements of bending forms are characteristic of the basement top and of the subsalt platform sediments. The lower salt-bearing and intrasalt deposits are deformed to block-fold structural features, while the upper salt-bearing and suprasalt deposits of Devonian, Carboniferous, Permian, Mesozoic, and Cenozoic age were deformed to folds.

Faults played the main role in the formation of the modern structural style of the basement surface and of the lower sediments in the Pripyat Trough. They can be classified into two main types: platform faults (which penetrated into the sedimentary cover) and basement faults (buried faults or those that had not reached the sediments). The platform faults of the paleorift had been formed mainly in Late Devonian time during the rifting phase. Some of the faults developed during both platform and basement evolution. In terms of their penetration depth they can be classified into mantle and crustal ones. In terms of the ranks of the tectonic elements bounded by them, they can be ranked into super-regional, regional, subregional, and local ones, and in terms

Figure 2. Correlation of Late Paleozoic tectonic events in the Pripyat Trough and those in the adjacent basins of the western part of the Sarmatian-Turanian lineament and Lvov-Lyublin marginal trough [*Aisberg et al.,* 2004].
(I) geologic events, (II) rock formations, (III) maximum thickness of the rocks. Sedimentary rocks: (1) carbonate rocks, (2) argillaceous-carbonate and carbonate-argillaceous rocks, (3) argillaceous rocks, (4) siliceous-carbonate rocks, (5) terrigenous-carbonate and carbonate-terrigenous rocks, (6) argillaceous-arenaceous-carbonate and argillaceous-carbonate-arenaceous, rocks, (7) terrigenous-sulfate-carbonate and sulfate-carbonate terrigenous rocks, (8) sulfate-carbonate-argillaceous and argillaceous-sulfate-carbonate rocks, (9) arenaceous-argillaceous rocks, (10) arenaceous rocks, (11) terrigenous rocks, (12) terrigenous-flyschoid rocks, (13) terrigenous molassic rocks, (14) paralic coal-bearing carbonate-terrigenous rocks, (15) terrigenous coal-bearing paralic rocks, (16) coal- and bauxite-bearing quartz-kaolinized rocks, (17) salt-bearing (halogenized) rocks, (18) salt-bearing terrigenous and mixed sedimentary-volcanic rocks, (19) volcanic-carbonate rocks, (20) tuffaceous clay-sulfate-carbonate rocks, (21) igneous (volcanic) rocks: (22) alkaline ultrabasic to alkaline basaltic rocks: (23) basalt, (24) andesite, (25) trachybasalt-trachyandesite-trachyrhyolite, (26) unconformity; (27) break in sedimentation.

of their structure and morphology, into listric and rectilinear ones, in terms of their kinematics, into concordant and discordant normal faults and shear faults, and in terms of their ranks, into major and minor faults. A remarkable feature of superregional and some regional listric faults of mantle origin (those extending deep into the mantle) is the fact that they form a divergent double or triple system consisting of the main fault and its satellites. The main fault usually becomes flatter with depth and reaches the Moho surface, whereas the second and third (attendant) faults pinch out before reaching the Moho discontinuity. The movements along these faults might have occurred simultaneously or at different periods of time, the major faults being usually characterized by an earlier reactivation.

Based on the deep crustal structure of the Pripyat Graben, and on the depths and ranks of the faults, this graben can be divided into two major structural elements, namely, the Northern zone of steps and the Internal graben, these elements being separated by the Chervonnaya Sloboda-Malodusha regional fault of mantle origin (Figure 3). The northern zone of steps is divided by the Rechitsa-Vishan subregional fault into second-order structural features: the Rechitsa-Shatilki and Chervonnaya Sloboda-Malodusha steps, the Starobin centriclinal depression in the west, and the Northern zone of side steps along the North Pripyat subregional mantle listric fault (Figure 4). The Internal Graben includes the following second-order structural units: the Petrikov-Khobna Zone of axial lowered highs and their periclines, the Zarechie-Velikoborie step located north of the axial line of the trough, and the Shestovichi-Skoloda and Narovlya-Elsk tectonic steps located south of the axial line of the trough. The western closure of the two latter is the Turov centriclinal depression. The South Pripyat subregional listric mantle fault is marked by the Southern zone of side steps. The second-order structural features of the Internal Graben are separated by subregional crustal faults.

The Northern zone of the steps is restricted by the Chervonnaya Sloboda-Malodusha regional fault in the south and by the North Pripyat superregional fault of mantle origin in the north. This zone includes two steps: the Chervonnaya Sloboda-Malodusha and Rechitsa-Shatilki steps with the northern dip of the basement surface and of the lower (subsalt) layers of the platform cover, separated by the Rechitsa-Vishan subregional mantle fault. The fault planes are inclined to the south. These faults are represented by fault zones including major and minor faults, which produce complicated scarps and fairly wide fracture zones (Figure 5).

The Chervonnaya Sloboda-Malodusha step is located in the southern part of the Northern step zone. The step is as long as 220 km in the latitudinal direction and has a maximum width of 25 km. The basement surface is a monocline dipping from -2000 to -6000 m to the north and northeast (Figure 6). The basement top and the overlying deposits begin to rise in the north in the vicinity of the Rechitsa-Vishan fault, the deep part of the step including synclinal zones of fault-related descendence. The Chervonnaya Sloboda-Malodusha high-magnitude (up to 2–3 km) listric mantle fault, bounding the step in the south, is accompanied by an attendant fault. A zone of fault-related highs, dissected by normal faults into numerous blocks, extends along these faults in the southern elevated part of the step. This zone is broken by normal faults into numerous blocks. Numerous local associated faults can be traced in the monoclinal step, arranged parallel to the step-forming crustal faults. The rocks rise stepwise from east to west along the submeridional faults.

The Rechitsa-Shatilki step is bounded in the north by the North Pripyat mantle listric fault, and in the south, by the Rechitsa-Vishan fault of the same type. It is 240 km long and varies from 10 to 25 km in width. The basement top plunges generally monoclinally from the south to the north from 2500–3000 m to 4000–6000 m. The southern elevated segment of the step is a complex scarp restricted in the south by a listric low-basement throw mantle fault, and by a high-throw listric accessory fault in the north, with a complex crush zone between them. The elevated block includes the Rechitsa-Vishan and Borisov-Drozdov Highs. The low-throw Ozemlya-Pervomaisk fault, which accompanies the Rechitsa-Vishan fault, complicates the structure of the central part of the step and controls the distribution of the linear zones of the fault-related highs.

The northern zone of flank scarps bounds the Rechitsa-Shatilki Step in the north and is a member of the North Pripyat marginal superregional mantle fault, being situated between this fault and the Glusk-Bereza fault (as its attending feature). This narrow (2–8 km) zone, more than 150 km long, is dissected by numerous normal faults into individual blocks. The depth of the basement top varies there from 2400 m in the Kovchitsa area to 5200 m in the Bereza area. The rocks composing these blocks dip west, east, and mostly south.

The Starobin centroclinal depression is the northwestern centrocline of the Pripyat Trough, where the Rechitsa-Shatilki and Chervonanya Sloboda-Malodusha steps are connected, and where the basement top rises as high as 500–1000 m or is lower. This step is broken by sublatitudinal and submeridional faults into blocks whose rocks are inclined mainly north, northeast, and east.

The graben rocks are dissected by crustal faults into second-order structural features. The latter show a complex structure, being dissected by sublatitudinal and submeridional strike-slip faults of different ranks into numerous blocks. The rocks show a distinct longitudinal and transverse structural zoning. The Azerets-Velikoborie and Shestovichi-Gostov crustal listric faults and the eastern segment of the Buinovichi-Gosta listric crustal faults and the eastern segment of the Buinovichi-Narovlya fault of the same type separate the zone of axial submerged highs and their periclines from the tectonic steps located in the north and south. This zone extends from the Mikashevichi-Zhitkovichi Horst in the west, being separated from it by the Mikashevichi transverse zone, as far as the Bragin-Loev Saddle in the east, and is intensively broken into blocks. The longitudinal axis is broken into individual links by transverse faults. Generally, the structural units of this zone plunge from east and west, opposite to one another. The longitudinal linear and isometric semi-oval structural features, such as rises and structural noses, are developed in

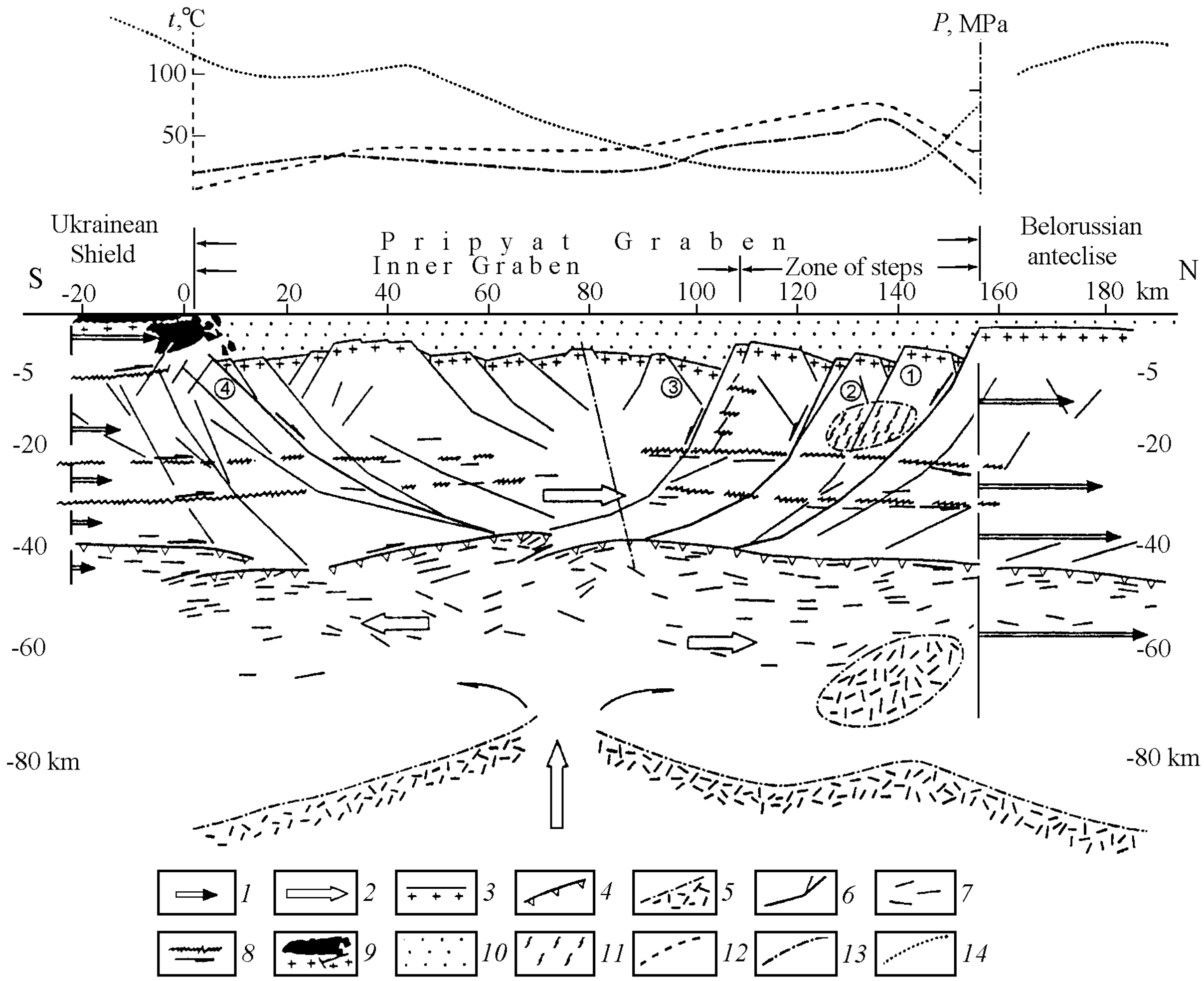

Figure 3. Generalized seismogeologic and geodynamic models of the section across the Pripyat paleorift along the VIII–VIII profile, compiled by R. G. Garetskii and S. V. Klushin: (1) vector of plate movements inside the lithosphere; (2) directions of the actions of forces: of the asthenospheric diapir (vertical arrow), of its constituents above the asthenosphere (horizontal arrows), and of the movement of the East European lithospheric plate; (3) basement surface; (4) Moho surface; (5) asthenospheric lenses and diapirs; (6) listric faults; (7) seismic reflector; (8) inferred boundaries of the slabs inside the lithosphere; (9) inferred overthrusts of the crystalline rocks of the basement over the sedimentary deposits; (10) sedimentary cover; (11) regions of fissured rocks; (12–13) temperature curves: (12) for a depth of 3 km, (13) for $P = P_{plate} - P_{water}$; (14) reduced G curve (recalculated for the level of 5 km above the ground surface (using I. V. Dankevich's data). The figures in circles denote the faults: (1) North Pripyat, (2) Rechitsa-Vishan, (3) Chervonnaya Sloboda, and (4) South Pripyat.

the west and east of the zone concerned, in the Petrikov and Khoiniki lowered noses. The central segment of the zone of the lowered protrusions, which is a segment of the Valava-Khatets transverse subsidence band, does not show any notable longitudinal structural zoning which seems to have been destroyed by the movements along the NE-striking faults. The basement top and subsalt deposits subside to the north and south from the axial part of the zone.

The Zarechie-Velikoborie step is located in the northern part of the internal graben between the Azerets-Velikoborie crustal and the Chervonnaya Sloboda-Malodusha faults. The step is as long as 210 km in the sublatitudinal direction with a width of 20 km; the bottom of its sediments plunges north there from 2500 to 6000 m.

Mapped south of the zone of the axial plunged highs, is the Shestovichi-Skoloda and Narovlya-Elsk steps, with the S-dipping tops of the basement and subsalt deposits, and the Southern complex zone of flank scarps, a member of the South-Pripyat marginal superregional fault.

The Shestovichi-Skoloda step is bounded in the north by the Shestovichi-Gostov crustal fault and, in the south, by the Buinovichi-Narovlya crustal fault with the fault planes dipping north. The step is bounded in the east by the Perzhana-Simonovichi basement fault, poorly expressed in

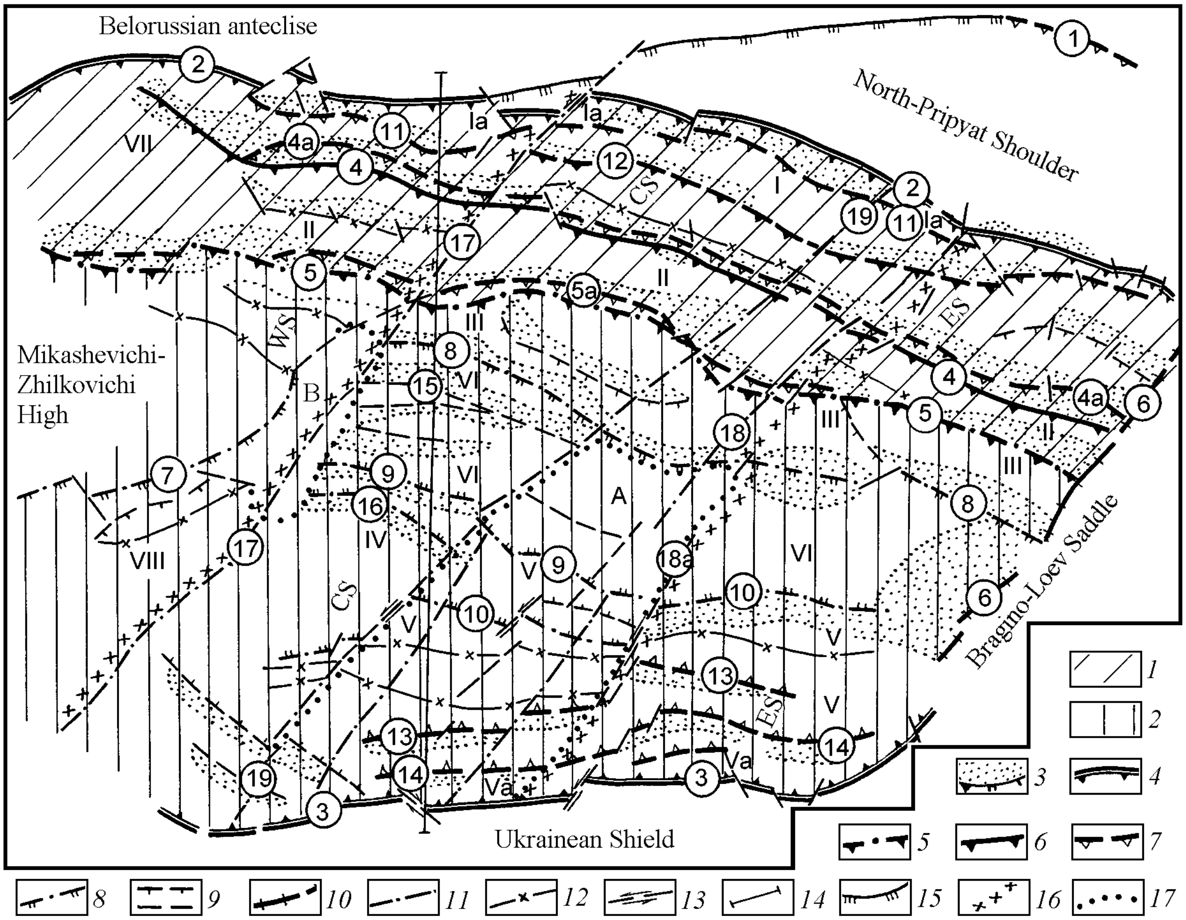

Figure 4. Schematic tectonic zoning of the surfaces of the basement and subsalt rocks in the Pripyat Trough, compiled by R. E. Aisberg, R. G. Garetskii, S. V. Klushin, A. M. Sinichka, and Z. L. Poznyakevich.

Longitudinal tectonic elements as second-order structures: (1) Northern zone of steps, (2) Internal Graben; 3d order structural features: (I) Rechitsa-Shatilka, (II) Chervonaya Sloboda-Malodusha, (III) Zarechnie-Velikoborie, (IV) Shestovichi-Skoloda, and (V) Narovlya-Elsk tectonic steps, (VI) Petrikov-Khobna Zone of axial plunged highs and periclines, (VII) Starobin and (VIII) Turov depressions; (3) 4th order structural features, such as, zones of linear fault-related highs; below-order structural features: (Ia) Northern zone of side steps, (Va) Southern zone of side steps; transverse tectonic elements: (WS) Western segment, (CS) Central segment, and (ES) Eastern segment; zones of mosaic highs: (A) Dubrovka-Valava, (B) Mikashevichi zone; faults: listric faults of mantle origin: (4) superregional, (5) regional, (6) subregional, (7) listric faults associated with main mantle faults; listric crustal faults: (8) subregional faults, (9) other faults; (10) crustal fault restricting the Pripyat Graben in the east; (11) basement faults marked by flexure-fault zones of the sedimentary cover and restricting transverse segments and structural features; kinematic types of the faults: (12) concordant normal faults and (13) shear faults; (14) DSS-CDP profile line; inferred outlines of (15) Pripyat Trough, (16) cross-cutting segments, and (17) transverse mozaic highs in the Pripyat Trough; faults (figures in circles): (1) Zhlobin, (2) North-Pripyat, (3) South Pripyat, (4) Rechitsa-Vishan main fault, (4a) Rechitsa-Vishan accessory fault, (5) Chervonnaya Sloboda–Malodusha main fault, (5a) Chervonnaya Sloboda-Malodusha accessory fault, (6) Loev, (7) Mikashevichi, (8) Azerets-Velikoborie, (9) Shestovichi-Gostov, (10) Buinovichi-Narovlya, (11) Glusk-Bereza, (12) Ozemlya-Pervomaisk, (13) Dubrov-Elsk, (14) Vystupovichi, (15) Kopatkevichi, (16) Skoloda, (17) Malyn-Turov, (18) Pervomaisk-Zaozernoe major fault, (18a) Pervomaisk-Zaozernoe accessory fault, (19) Perzha-Simonovichi fault.

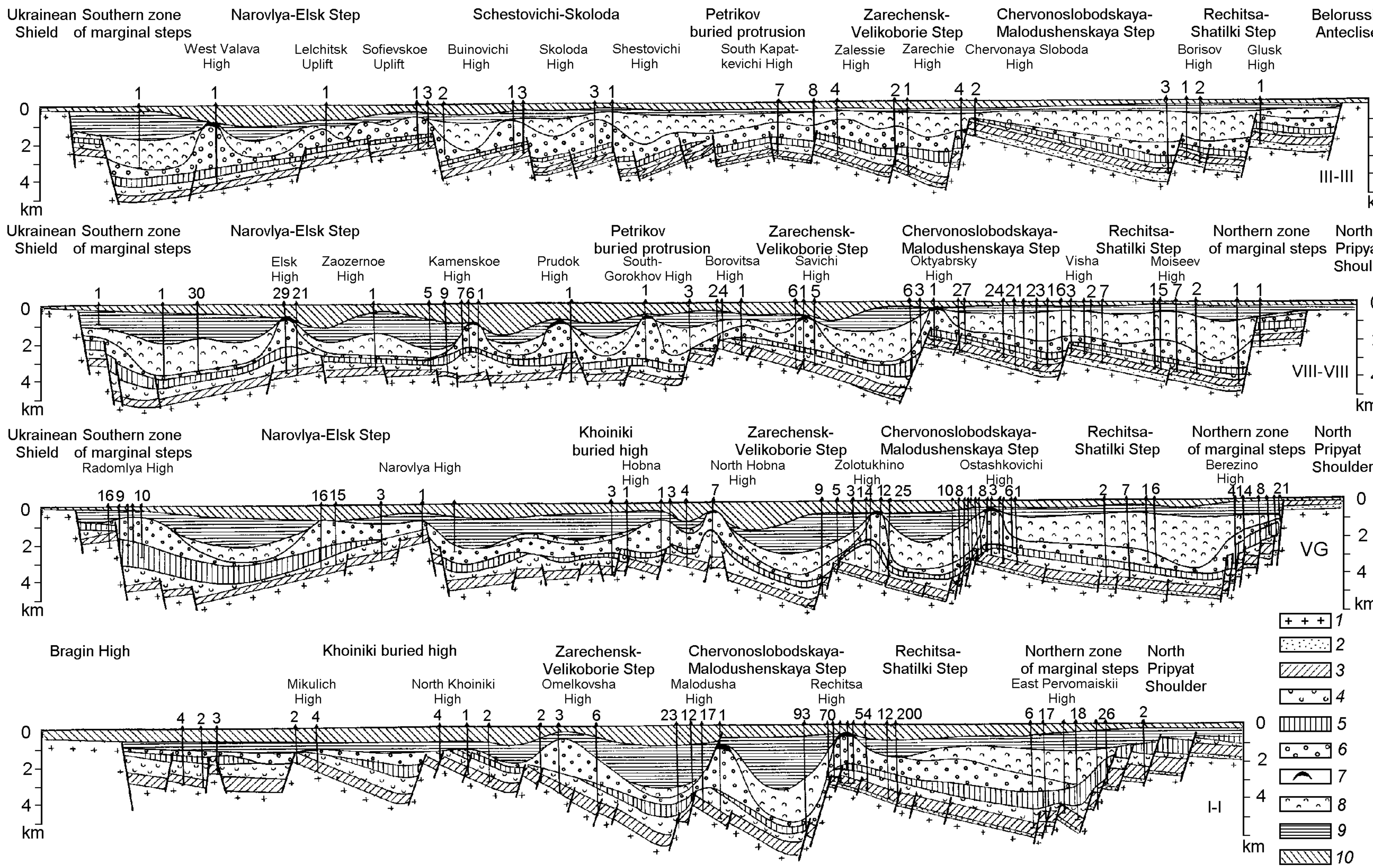

Figure 5. Geologic sections across the strike of the Pripyat Trough along the regional profiles III–III, VIII–VIII, VG, and I–I, plotted by *Konishchev* [2001] using the results of geophysical work and drilling done by the production companies “Belgeologiya” and “Belorusneft” (using the data of B. M. Arkhipov, R. N. Gomon, N. V. Gridasov, I. D. Kudryavets, A. I. Shlychkov, and others). Deposits: (1) Archean and Early Proterozoic, (2) Riphean and Vendian, (3) subsalt Devonian, (4) lower salt-bearing Evlanov-Liven, (5) intrasalt Zadonian-Petrikovian, (6) halite subsequences, (7) caprock breccia, (8) clay-halite subsequences, (9) supersalt Devonian, Carboniferous and Permian rocks, (10) Mesozoic and Cenozoic rocks (see Figure 8 for the locations of the profile lines).

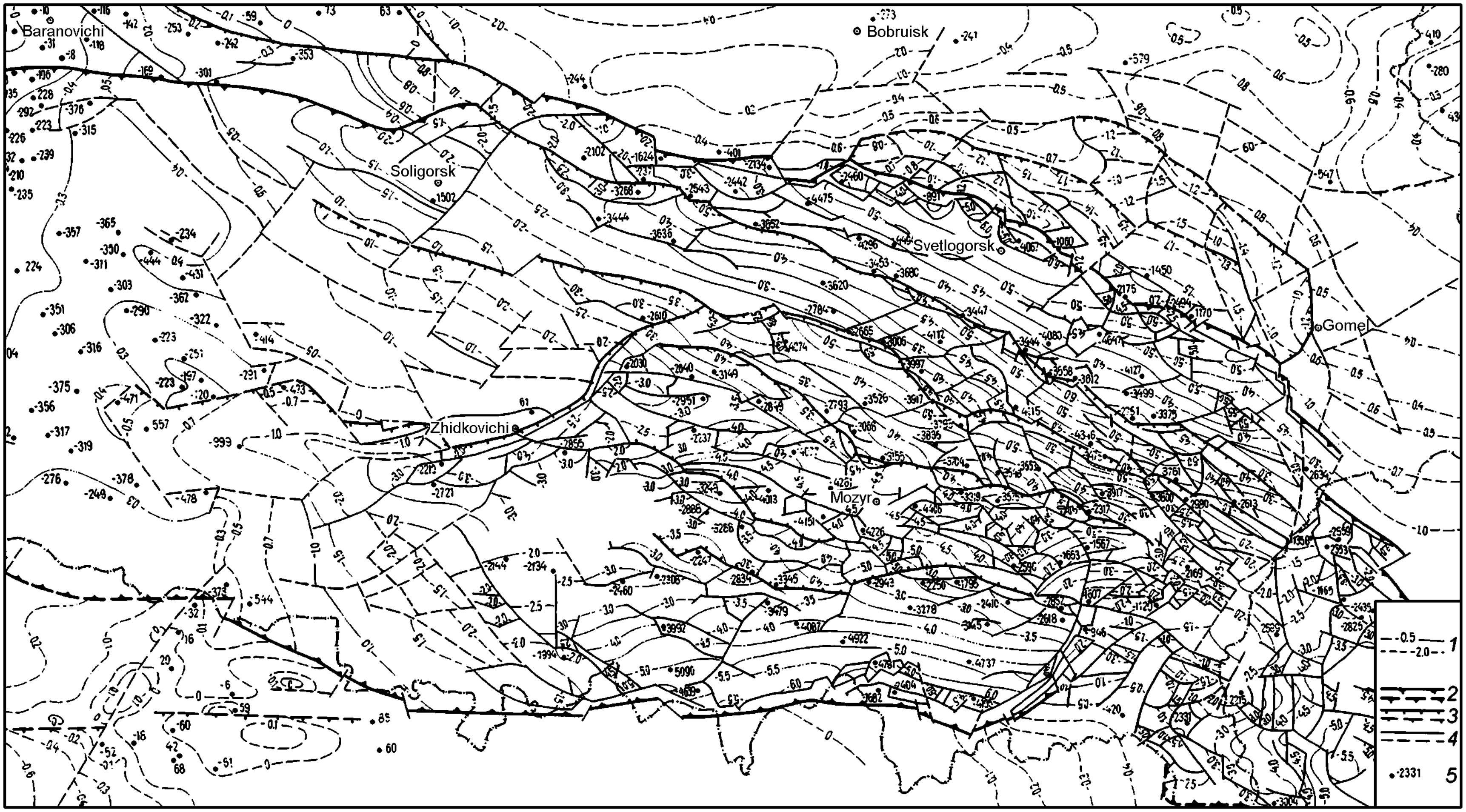

Figure 6. Structural map of the basement surface in the Pripyat Trough, plotted by T. A. Starchik [*Konishchev,* 2001] using the drilling and geophysical data of "Belgeologiya" and "Belorusneft".
Companies: (1) basement surface contour lines: (a) proved, (b) inferred; (2) marginal faults of the Pripyat Graben: (a) proved, (b) inferred; (3) step-forming faults: (a) proved, (b) inferred; (4) local faults: (a) proved, (b) inferred; (5) holes and absolute depths of the basement top.

the platform cover as a flexure-fault zone. The step is as long as 100 km in the sublatitudinal direction and is as wide as 10 to 20 km with its basement surface plunging southward from 2000 to 5500 m.

The Narovlya-Elsk step bounds the Buinovich-Narovlya crustal fault, some segments of which are displaced by transverse submeridional strike-slip faults, the southern boundary of the step being the Vystupovichi mantle fault. The maximum length of the step is 150 km, the maximum width is 35 km, the top of the basement there plunging southward from 1800-3000 m to 6000 m. The central part of the Narovlya-Elsk step shows the Dubrovka-Elsk low-magnitude (100–200 m) crustal fault which is a by-product of the South-Pripyat superregional mantle fault. This fault is divided by transverse shears into individual segments.

The Turov centriclinal depression is located in the southwestern part of the trough between the South-Pripyat marginal fault in the south and the Mikashevichi fault in the north. In its limits the Narovlya-Elsk and Shestovichi-Skoloda steps close, and the basement surface rises westward.

The southern zone of flank scarps is located between the South Pripyat fault and the Vystupovichi fault associated with it. This is a complex crush zone, broken by numerous normal faults into individual blocks with the differently dipping basement surface. This zone extends in the latitudinal direction for a distance of 170 km with a width of 3–8 km.

In addition to this latitudinal zone, the Pripyat Trough shows some transverse (diagonal or submeridional) zoning which is controlled by submeridional (mainly NNE) direction, which are reflected in the platform sediments as flexure-fault zones. Four large transverse faults of preplatform origin have been recorded. These are the Malyn-Turov, Pervomaisk-Zaozernyi, Perzhana-Simonovichi, and Loev faults. The latter was active also during the platform stage. The two former faults divide the Pripyat paleorift into several tectonic elements, namely the Western, Central, and Eastern segments, the Loev fault separating the trough from the Bragin-Loev Saddle (see Figure 4). These segments differ from one another in their geologic histories, sedimentation, in the rates of the erosion of their Riphean, Vendian, and Paleozoic rocks, in subsidence rate, and in the present-day structure.

The Malyn-Turov fault separates the western segment from the central one. It extends along the eastern margin of the Mikashevichi-Zhitkovichi High and separates the Turov and Starobin centriclinal depressions from the remaining part of the Pripyat Graben, which is distinguished by many specific features of its structure. The sediments grow more deformed east of the fault, in particular, the super salt deposits grew thicker in connection with the growing thickness of halite and more active halokinezis.

The Pervomaisk-Zaozernoe Fault extends in the northeastern direction from the East Greben area in the south, crosses the Zaozernoe, Pritok, Tishkov, and Pervomaisk areas and emerges to the Gorodok-Khatets step (North Pripyat shoulder), separating the Central segment from the Eastern one. This fault is represented by its individual breaks in the sediments.

The Central segment includes the Valava-Khatets transverse band of lows, which is controlled by the Perzhana-Simonovichi NE-trending fault and serves as the main transverse axis of the Pripyat Depression. The salt-bearing features of this band tend to change their sublatitudinal trends to submeridional ones. Another characteristic feature of this band is the mosaic distribution of its local block highs that had formed in areas of the transection of the longitudinal and transverse faults. The transverse zoning is best expressed in the Vnutrennii Graben.

The combination of the sublatitudinal tectonic zones of rift origin with the superimposed submeridional zonal pattern produced a variegated range of tectonic elements of different orders.

In addition to the second-order steps and ledges, described above, there are third-order structural features, such as the zones of fault-related highs and lows The following fault-related highs have been mapped in the elevated parts of the blocks along the regional and subregional faults, both step-forming ones and complicating the steps (southward): Bereza, Cherna, Pervomaisk, Aleksandrov, Shatilki, Rechitsa-Vishan, Borisov-Drozdov, North Kalinovka, Chervonnaya Sloboda, Rudnaya, Malodusha, Kopatkevichi, Gorokhov, Omelkovshcha, Shestovichi, Skoloda, Kamensk, Buinovichi, Narovlya, Lelchitsa, Elsk, and Vystupovichi highs. The zones of fault-related lows are (southward): Bereza, Rechitsa, Chervonnaya Sloboda, Malodusha, Shestovichi, Skoloda, Narovlya, and Vystupovichi.

Mainly local block highs are developed in the basement top and in subsalt deposits in the zones of fault-related highs. The most numerous are local highs representing a monocline or a poorly expressed hemianticline restricted to the elevated limb of the fault and bounded by a fault curve (Vishan, Borisov, Rechitsa, Zarechie, Bobrovichi, Azerets, Nezhin, Narovlya, and other highs). Another type of the block structures is a monoclinal block (or an occasional poorly expressed hemianticline), bounded by normal faults both updip and along the strike of the rocks (Ostashkov, Oktyabrsk, North Domanovichi, Ozemlya, Pervomaisk, Zolotukha, Nadvina, Savichi, North Khoiniki, and other features).

One of the most widespread types of subsalt highs is a small triangular monoclinal block pressed between two faults converging to produce a corner. The examples are the Kuzmichev, Kazimirov, Yurovka, Borichev, West-Valava, and other highs. Some local highs are monoclinal or slightly curved intermediate fault-zone blocks compressed on all sides by faults (Kalinovka, Marmovichi, North Narovlya, and others). Some local structural features have the forms of a half-anticline or a half-dome, bordering the fault and located in the elevated (Aleksandrov and Barsukov highs) or in the downthrown (South Vishan, South Ostashkov, Dudich, and other highs) fault sides. Some local structural features have the form of fault-related anticlines of a wholly closed contour (Drozdov, Rukhov, Glusk, Borshchevsk).

The near-fault depressed zones include local synclines, brachyanticlines, troughs, and structural bays, broken by faults and pressed to them. They are often inscribed in fault- plane curves, and are sometimes restricted by faults from one or two flanks.

The block-fold structural features of the lower salt-bearing (Frasnian) and intrasalt (Famennian) rock se-

Figure 7. Structural map of the upper surfaces of the Zadonian-Petrikovian deposits of the Pripyat Trough, compiled by T. A. Starchik [*Konishchev*, 2001] using the drilling and geophysical data of the Belgeologiya and "Belorusneft" companies: (1) zones devoid of intersalt deposits and the faults bounding (2) Pripyat Graben and (3) steps and protrusions; (4) local faults; (5) contour lines of the tops of intersalt deposits, m.

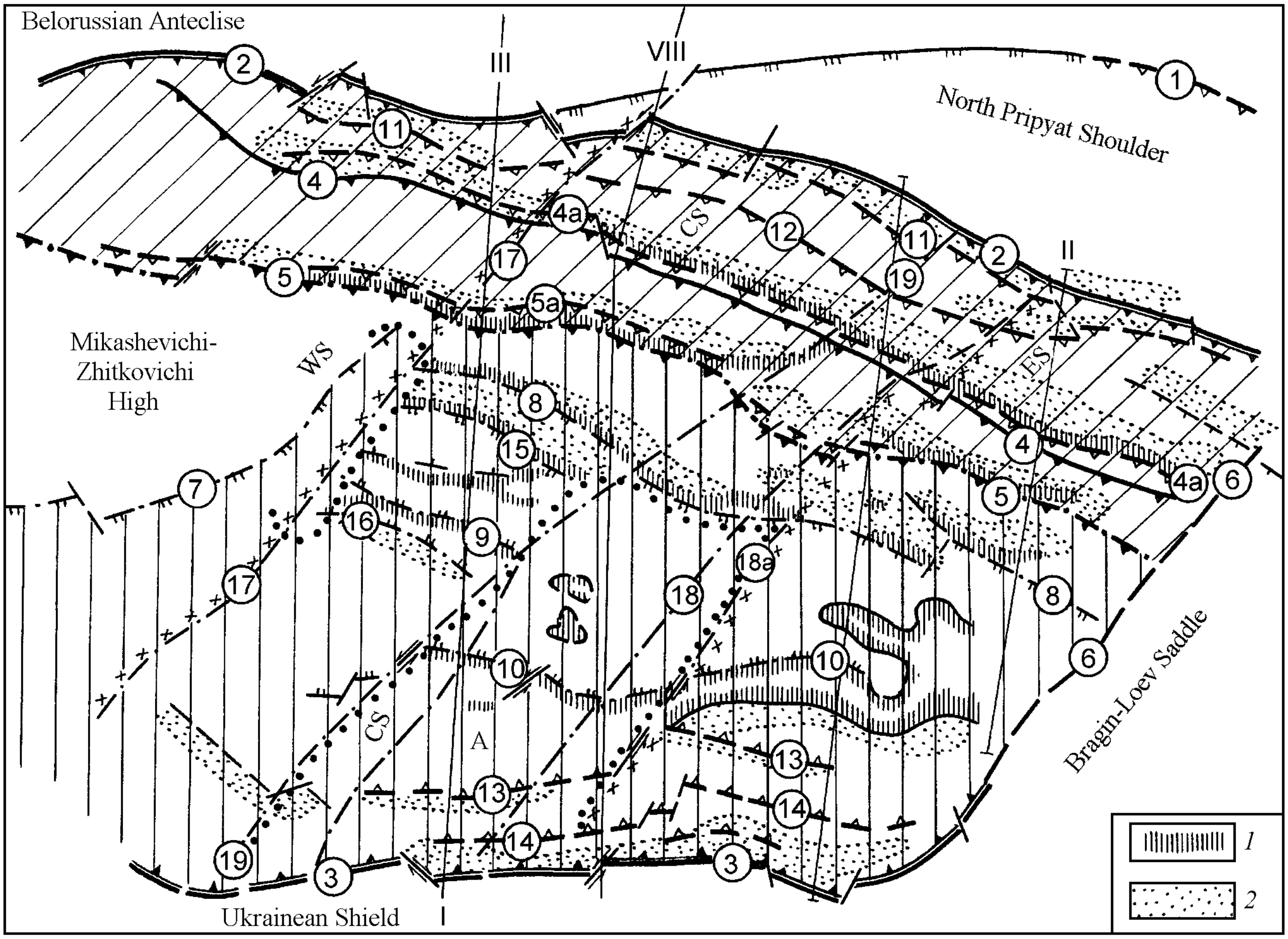

Figure 8. Schematic tectonic map of the intersalt rocks in the Pripyat Trough, compiled by R. E. Aisberg, R. G. Garetskii, S. V. Klushin, A. M. Sinichka, and Z. L. Poznyakevich [*Konishchev,* 2001]: (1) zones and areas of no or highly thin intersalt deposits; (2) zones of linear highs. See Figure 4 for the other symbols.

quences (Figures 7 and 8) inherit in a significant manner the structural style of the basement and subsalt rocks (see Figure 6). The rearrangement of the structural pattern in the lower salt-bearing rocks was caused by salt tectonics in the Central Segment and by the attenuation of many small faults over the entire area. For this reason the main changes in the structural styles of the lower-salt and intrasalt rock sequences occurred in local areas in contrast to the salt-bearing rocks.

The following regularities have been discovered. The anticlines that had developed in the intrasalt deposits occur above the fault-bounded blocks with monoclinal subsalt deposits. The tops of the intersalt anticlines are usually displaced as far as 1–3 km from the most elevated parts of the subsalt blocks down the dips of the rocks. The uplifts of this kind are scarce (Rechitsa, Ostashkovichi, Vishan, and some others.); they are usually located in the elevated parts of the steps.

The intrasalt deposits were found to be discordant relative to the subsalt deposits in the downthrown sides of large normal faults. Where the subsalt deposits dip in a monoclinal manner toward the faults, the intrasalt deposits rise in the same direction as a result of the highly growing thickness of the lower salt-bearing rock sequence. The examples are the South Ostashkovichi, South Oktyabrsk, and South Domanovichi areas.

The anticlines in the intersalt deposits may be located in the down-thrown limbs of normal faults above a monocline composed of subsalt deposits (North Kalinovka area), and also above the faults in the subsalt deposits, which attenuate as early as in the lower salt-bearing rocks (Savichi, West Zolotukha, East Pervomaisk, and other highs). The anticlines of the lower salt deposits often coincide in map view with the monocline of the subsalt bed (Zolotukha, Skrygalovo, Kamensk, and East Elsk highs). The anticlines of this kind have been produced by salt tectonics.

A special type of relations between intrasalt and subsalt structural features is represented by the swells of intersalt deposits, possibly of rift origin, and their local thinnings (inferred local erosions) located in the monocline of the subsalt

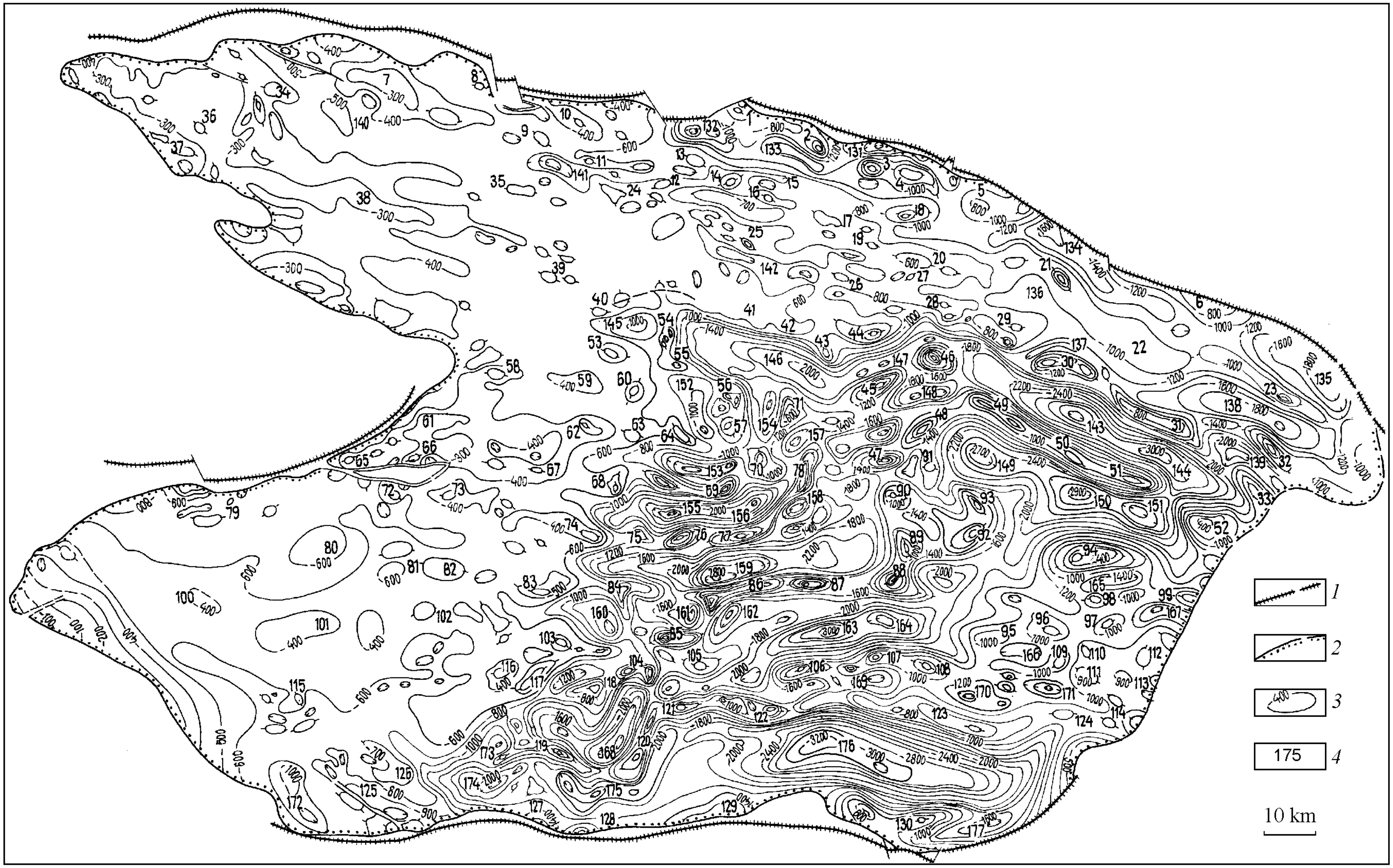

Figure 9. Structural map of the surface of the Famennian salt-bearing rocks compiled from the results of drilling and geophysical surveys of the "Belgeologiya" Survey and the "Belorusneft" Association [*Konishchev,* 2001].
(1) marginal faults of the Pripyat Graben, (2) boundaries of Famennian salt-bearing rocks, (3) contour lines of the Famennian rock top, (4) numbers of local structural features. Local highs: (1) Kovcha, (2) Knyshevich, (3) Sudovits, (4) Iskrs, (5) Bereza, (6) Ozersha, (7) Drozdov, (8) Osovets, (9) East Drozdov, (10) Glusk, (11) Kholopenichi, (12) Malyn, (13) Ozemlya, (14) Moiseevskoe, (15) Northern Cherna, (16) Cherna, (17) Kormyanskoe, (18) Nolcha, (19) Zal'in, (20) Shatilki, (21) Pervomaisk, (22) East Pervomaisk, (23) Aleksandrov, (24) Borisov, (25) Vischan, (26) Marmovichi, (27) Davydov, (28) Sosnovka, (29) Ostashkov, (30) Tishkov, (31) Rechitsa, (32) Vasilevichi, (33) Vetkhino, (34) Darasa,

(35) North Kalinovskoe, (36) Pokrovskoe, (37) Starobin, (38) Nezhin, (39) Chervonaya Sloboda, (40) Koshevichi, (41) Oktyabrsk, (42) North Domanovichi, (43) Kazan, (44) Korenevo, (45) South Domanovichi, (46) Pritok, (47) Smaglovo,(48) Rudnya, (49) Zolotukha, (50) Vedricha, (51) Malodusha, (52) Vyshemirovo, (53) Zarechie, (54) Komarovichi, (55) Dubnyak, (56) West Savichi; (57) Bobrov, (58) East Kuzmichev, (59) Zalesie, (60) Kopatkevichi, (61) Selyutich, (62) South Kopatkevichi, (63) Rybkhoz, (64) West Gorokhov, (65) Ostra, (66) Brinev, (67) North Shestovichi, (68) Konkovichi, (69) Ptich, (70) Gorokhov, (71) Savichi, (72) Naida, (73) Petrikov, (74) Shestovichi, (75) Skrygalov, (76) Mysha, (77) Prudok, (78) Azerets, (79) Veresnitsa, (80) Turov, (81) Pererov, (82) Sudibor, (83) Skoloda, (84) Kazimirov, (85) Makhnovichi, (86) Kamensk, (87) Mozyr, (88) South Avtyuka, (89) Avtyuka, (90) Dudich, (91) Lozkovo, (92) Khobna, (93) North Khobna, (94) Omelkovshcha, (95) West Khoiniki, (96) Khoiniki, (97) East Khoiniki, (98) North Khoiniki, (99) Maiskoe, (100) Gubarev, (101) Gorki, (102) East Simanovichi, (103) Buinovichi, (104) Anisimovskoe, (105) Zaozernoe, (106) Kustovnitsa, (107) Narovlya, (108) Tulgovichi, (109) South Khoiniki, (110) Mikulichi, (111) Lyudva, (112) Lyuban, (113) Rudakov, (114) Ostroglyad, (115) Sologubovo, (116) Velikopolie, (117) Lelchitsa, (118) Sofievka, (119) West Valava, (120) Valava, (121) Nikolaev, (122) Elsk, (123) East Elsk, (124) Strelichev, (125) Milashevichi, (126) Borovskoe, (127) Novokhutorskoe, (128) Medveda, (129) Vystupovichi, (130) Mikhailov; synclines, brachysynclines, and troughs: (131) North Sudivitsa, (132) South Kovcha, (133) South Knyshev, (134) North Pervomaisk, (135) North Aleksandrov, (136) South Pervomaisk, (137) North Tishkov, (138) North Vasievsk, (139) North Vetkhino, (140) South Drozdovskaya, (141) West Borisov, (142) South Vishan, (143) South Tishkov, (144) South Rechitsa, (145) North Zarechie, (146) South Kazan, (147) West Pritok, (148) South Pritok, (149) South Zolotukha, (150) South Malodusha, (151) South Barsukov, (152) West Bobrovichi, (153) North Ptich, (154) West Savichi, (155) North Skrygalov, (156) North Prudok, (157) North Azerets, (158) South Azerets, (159) North Kamensk, (160) North Buinovichi, (161) West Kamensk, (162) South Kamensk, (163) North Kustovnits, (164) North Narovlya, (165) South Velikoborie, (166) South Khoiniki, (167) South Maiskoe, (168) West Valava, (169) South Narovlya, (170) West Tulgovich, (171) North Strelichev, (172) West Milashevichi, (173) East Drozdov, (174) East Borovsk, (175) South Valava, (176) South Elsk, (177) East Mikhailov.

bed. Mapped in the northwestern part of the basin were the structural elements enveloped into the late intrasalt deposits including organic structures.

The Late Fammennian salt-bearing rocks show a transition from the block-plicative style of the sediments to the purely plicative one (Figure 9). This was associated with the attenuation of the bulk of high-magnitude and all low-magnitude faults and with the active halokinesis of the upper salt-bearing rocks. The structural features mapped using the surface of these rocks (domes, brachyanticlines, structural noses, troughs, synclines, and structural bays) can usually be combined into extensive swells and synclinal zones of sublatitudinal strike. The swells are located in the elevated parts of the steps and are restricted mainly to the raised segments of the steps, whereas the synclinal zones tend to the lowered parts of the steps.

The Paleozoic deposits overlying the salt-bearing deposits generally inherit the structural style of the surface of the Late Famennian salt-bearing rocks, most of the structural forms flattening up the rock sequence.

The Mesozoic-Cenozoic rocks compose the Pripyat-Dneiper (Ukrainian) Sineclise and inherit most of the local structural features of the Paleozoic upper salt-bearing sequence and super-salt rocks.

5. Igneous Rocks

The Late Devonian volcanic rocks mapped in the Pripyat rift zone outline the Pripyat paleovolcanic region. This zone is a western link of the extensive (1200 km) volcanic belt in the southwest of the East European Craton, associated with the formation in Late Devonian of the intraplate Pripyat-Donetsk aulacogen. The igneous rocks of the Pripyat paleovolcanic region occupy an area of about 2000 km^2, their total thickness being 2.0–2.3 km.

The igneous rocks of the Pripyat Trough have been classified as an alkaline ultrabasic-alkaline basaltic rock sequence [*Gonshakova et al.,* 1968]. These rocks have been fairly well studied in terms of their petrography, facias, manifestation forms, vertical and horizontal zoning, and geodynamics of magmatism [*Aisberg et al.,* 1999a, 1999b, 2001; *Gonshakova et al.,* 1968; *Korzun,* 1974; *Korzun and Makhnach,* 1977]. At the present time two fields of these rocks have been mapped (Figure 10). The major field occupies the northeastern part of the Pripyat graben, the Bragin-Loev Saddle, and the adjacent shoulder of the paleorift. The rocks occur as two thick sequences: the late Frasnian Evlanov-Liven rocks with the greatest thickness of 1900 m and the early Famennian Elets rocks, up to 1400 m thick, which are conjugated horizontally with sedimentary rocks of the same age. The igneous rocks are represented by lava, lava breccias, and tuff, all being the products of central and fissure-type volcanic eruptions. These are intermediate, basic, and ultrabasic rocks: subalkalic and alkalic trachite, trachybasalt, nephelinite, leucitite, limburgite, and ankaratrite-picrite. Apart from the volcanic rocks proper, numerous layered intrusions (sills and possibly dikes), represented by syenite porphyry, porphyry picrite, vogesite, and shonkinite, have been found by drilling in the

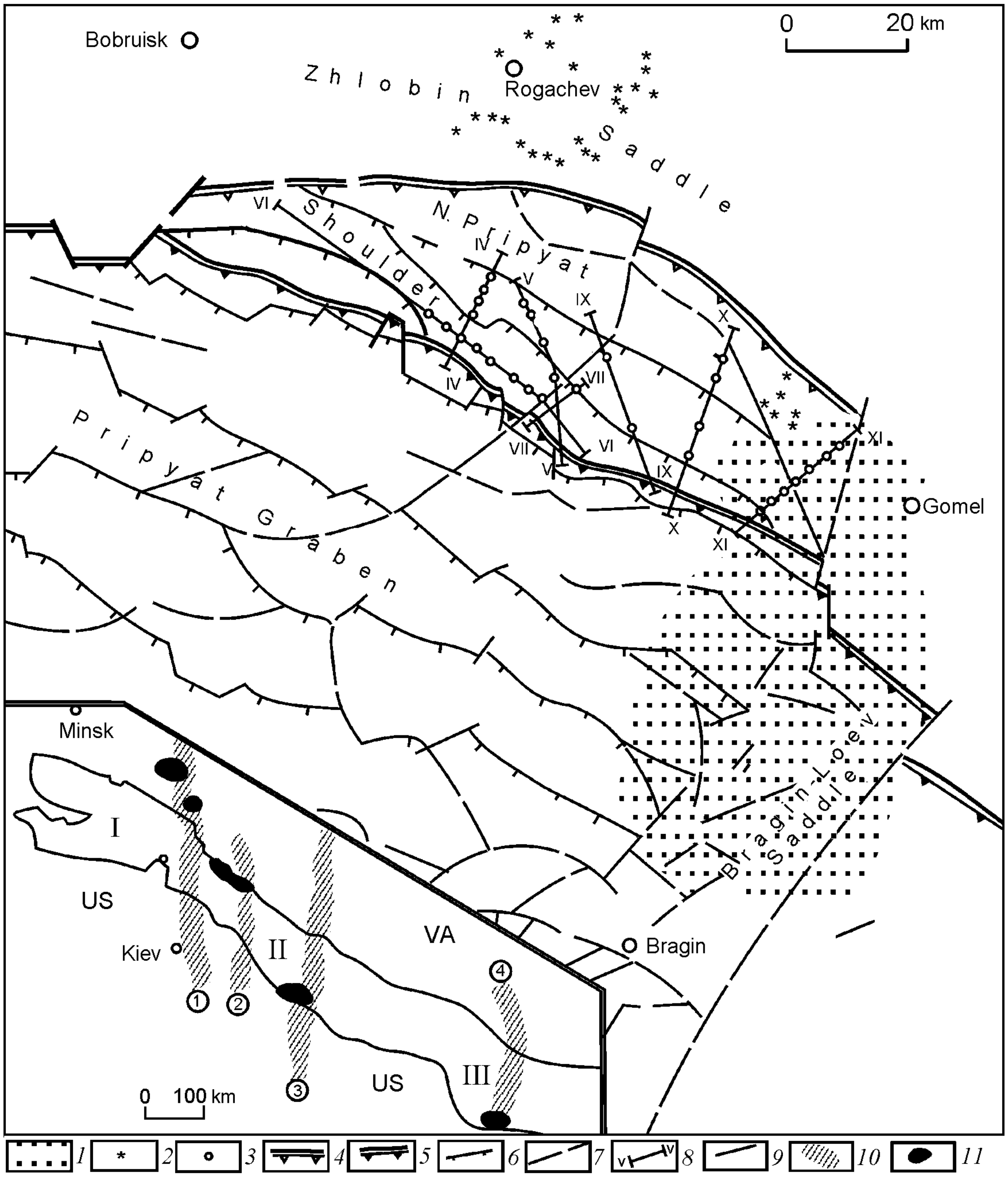

Figure 10. Schematic map of the Late Devonian volcanic rocks of the Pripyat rift zone [*Aisberg et al.,* 2001].
(1) The area of Late Frasnian-Famennian volcanic rocks in the Pripyat Trough; (2) explosion pipes found by drilling (after N. V. Veretennikov, V. P. Korzun, E. A. Nikitin et al.); (3) subvolcanic bodies proved by seismic data (after S. V. Klushin et al.); the faults bounding: (4) the Pripyat Trough, (5) the Pripyat and Dnieper grabens, (6) the steps of the Pripyat Trough; (7) other faults; (8) seismic profiles. The inset map shows the areas of Frasnian alkaline ultrabasic igneous rocks in the Pripyat-Dnieper aulacogen (PDA) (after [*Lyashkevich,* 1987] with our additions): (9) PDA marginal crustal faults, (10) zones of old pre-Late Proterozoic transverse crustal faults (figures in circles): (1) Odessa, (2) Znamenka-Piryatin, (3) Krivoi Rog, (4) Kalmius-Aldar); (11) areas of alkaline ultrabasic rocks. The tectonic elements shown in the inset map are (VA) Voronezh anticlise, (US) Ukrainian Shield. The Pripyat-Donetsk aulacogen includes: (I) Pripyat Trough, (II) Dnieper-Donetsk Trough, and (III) Donetsk Foldbelt.

vicinity of volcanoes in the Middle and Late Devonian sedimentary rocks.

Another field of Late Devonian volcanic and igneous rocks has been found in the area of the North Pripyat shoulder and in the zone of its junction with the Zhlobin Saddle. The early alkaline ultrabasic rocks, recording the initial phase of rifting, occur there as diatrems. Geophysical surveys discovered about 100 pipe-type anomalies, 30 of them have been proved by drilling to be diatrems containing occasional small diamond crystals [*Nikitin et al.,* 1999].

The Upper Frasnian and Lower Famennian volcanic rocks have a similar structure and a similar propagation (Figures 11 and 12). The analysis of the volcanic material in both rock sequences revealed several facies zones: a vent and near-vent facies, an effusive-explosive facies, a sedimentary facies, and a volcanic sedimentary facies. The vent and near-vent zones are related to central-type volcanoes. The effusive-explosive zone embraces the areas bordering the central- and fissure-type volcanoes. The latter two facies zones combine the rock sequences which include interbeds of volcanogenic and normal sedimentary rocks in varying per cent proportions.

During the late Frasnian time the volcanic activity was associated with central- and fissure-type volcanoes, which produced mainly intermediate rocks (subalkalic and alkalic trachite, trachybasalt, and syenite porphyry), represented in explosive, effusive, vent, and subvolcanic facies. One hole exposed a nephelinite sheet, this suggesting the potential activity of a fissure volcano erupting alkali-basalt lavas.

More diverse rocks, represented by intermediate, basic, and ultrabasic varieties (see Figure 12), were erupted in Early Famennian time, yet they preserved their facies and alkaline character (see Figure 12). Individual through- and central-type volcanoes continued to act and produced, during two phases of volcanic activity, the largest volcanic edifices which periodically rose above the sea level. Some central-type volcanoes were regenerated to volcanoes of fissure type and, vice versa: some fissure volcanoes changed to central-type ones. Some volcanoes did nor resume their activity in Early Famennian time, yet new volcanoes appeared. The pyroclastic products of the central-type eruptions of some volcanoes propagated for distances of tens of kilometers from them to produce sequences and interbeds of volcanic tuff of mainly mixed basaltoid-trachyte composition. The lava flows seem to have traveled not farther than 10 km from the vents. Depending on the compositions of the erupted material, there are zones of leucitite, nephelinite, or trachite lavas with the predominance of one of them. Lavas of ultrabasic composition (limburgite and ankaratrite-picrite) occur in smaller volumes, mainly in the western periphery of the paleovolcanic area. On the whole, with the general areal mosaic distribution of the petrographically varying volcanic rocks of the second phase of volcanic activity, there is some regularity in their distribution. More abundant in the central part of the region are the rocks of intermediate (trachitic) composition, the southern and western periphery being more abundant in basic (nephelinite) and ultrabasic rocks.

Another distinctive feature of the Pripyat paleovolcanic region is the abundance of intrusive rocks exposed by drill holes, which had been intruded into the sedimentary rocks mainly in the pre-Evlanian part of the Devonian. In terms of their morphology they occur as layered intrusions (sills). The maximum number of sills recorded in one hole is 27. The vertical thickness of these intrusive bodies varies from a few centimeters to dozens of meters. Some of them may be subvertical stocks or dikes. The maximum thicknesses of the intrusions penetrated by the holes are as great as 300–700 m (the holes ceased to be drilled in the intrusive rocks).

Most of the intrusions lie in the Givetian and Lancian (Frasnian) rocks, their second peak being restricted to the Rechitsa-Voronezh (Frasnian) part of the rock sequence. Single intrusions have been recorded in the Vitebsk-Narovlya (Emsian and Eiphelian) and in the Sargaevo-Semiluka (Frasnian) deposits. Areas with a great number of sills in the hole sequences were found to coincide with the zones of the greater thickness of the subsalt effusive-tuffaceous rocks. This may be an indirect evidence of the synchronous emplacement and genetic relationship of a great number of intrusions with the Frasnian phase of volcanism, although this process continued undoubtedly in the Early Famennian. This is proved by the intrusive sheets recorded by drill holes in the sedimentary rocks of the Zadonian stage, and also by seismic data. The seismic time sections available for the northern shoulder of the paleorift show that the depth of the penetration of the intrusions varies from the top of the basement to the Famennian rocks. It is possible that the volume of these intrusive rock bodies of volcanic origin at the upper levels of the consolidated crust is significantly greater than the volume of the magmatic formations in the platform sedimentary cover, as it is supposed for most of the old and recent continental rifts.

Of great interest is the vertical and horizontal zoning in the igneous rocks of the Pripyat paleovolcanic region. This concerns the development of vertical and horizontal zoning of the igneous rocks in the Pripyat paleovolcanic area. This is particularly pertinent to the time migration of the initial phase of igneous activity from the periphery to the center of the Pripyat Trough.

The oldest igneous rocks associated with the beginning of the Pripyat paleorift formation are individual diatrems mapped in the junction zone between the North Pripyat shoulder and the Zhlobin Saddle. They are dated Early Rechitsan (beginning of late Frasnian). The earliest intrusions have been dated Late Voronezhian-Early Evlanian (middle phase of the Late Frasnian [*Kruchek and Obukhovskaya,* 1997]. At the same time volcanic and magmatic activity began in the Pripyat Graben and Loev Saddle as late as the Evlanov-Liven time (end of the Late Frasnian).

This migration of the early igneous activity in space and time agrees with the stages of the graben formation caused by mantle diapirism. This regularity has been reported using the example of the structure and evolution of many continental rift zones and confirmed by the results of kinematic modeling. Extensive areas, much greater than the width of the future Pripyat Graben, were subject to destruction.

Migration of volcanism toward the center of this structural feature continued also in the area of the graben itself. The maximum thickness of the Late Frasnian volcanic rocks

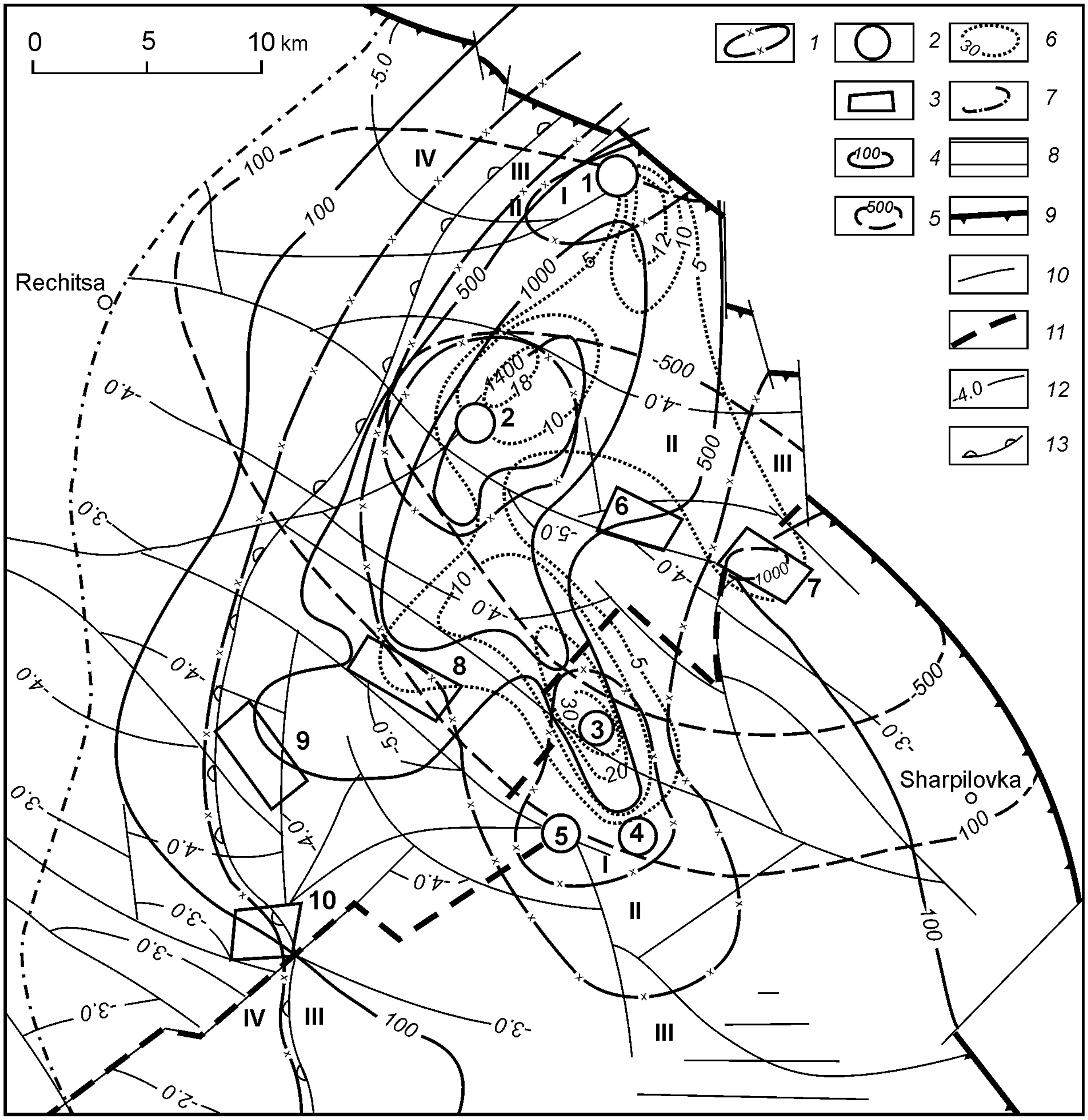

Figure 11. Distribution of volcanic rocks in the Eifelian-Frasnian deposits of the Pripyat rifting zone [*Aisberg et al.*, 2001].

(1) boundaries of the lithofacies zones of volcanic rocks: (I) vent and near-vent rocks, (II) effusive-explosive rocks, (III) volcanic sediments, (IV) sediments volcanic; (2) central type volcanoes: Shcherbovskii (1), Aleksandrovskii (2), North-Mikhalkovskii (3), Mikhalkovskii (4), West Mikhalkovskii (5); (3) fissure-type volcanoes (Borshevskii (6), Mirnyi (7), Vasilievskii (8), Vetkhinskii (9), Nadvinskii (10). The contour lines show (4) the total thickness of Evlanov-Domanovichi (Late Frasnian) volcanic rocks, m; (5) the total thicknesses of intrusive rocks in pre-Evlanov Devonian deposits, m; (6) equal amounts of sills in the pre-Evlanov Devonian rocks, m; (7) western limit of intrusive bodies; (8) area of Frasnian undifferentiated volcanic rocks in the Dnieper-Donetsk Trough; faults: (9) Northern marginal fault of the Pripyat and Dnieper-Donetsk Trough; (10) other faults; (11) western boundary of the Bragin-Loev Saddle; (12) structure contour lines of the synrift rocks (bottom of the Rechitsa-Loev Saddle), km; (13) eastern boundary of salt interbeds in the late Frasnian rocks.

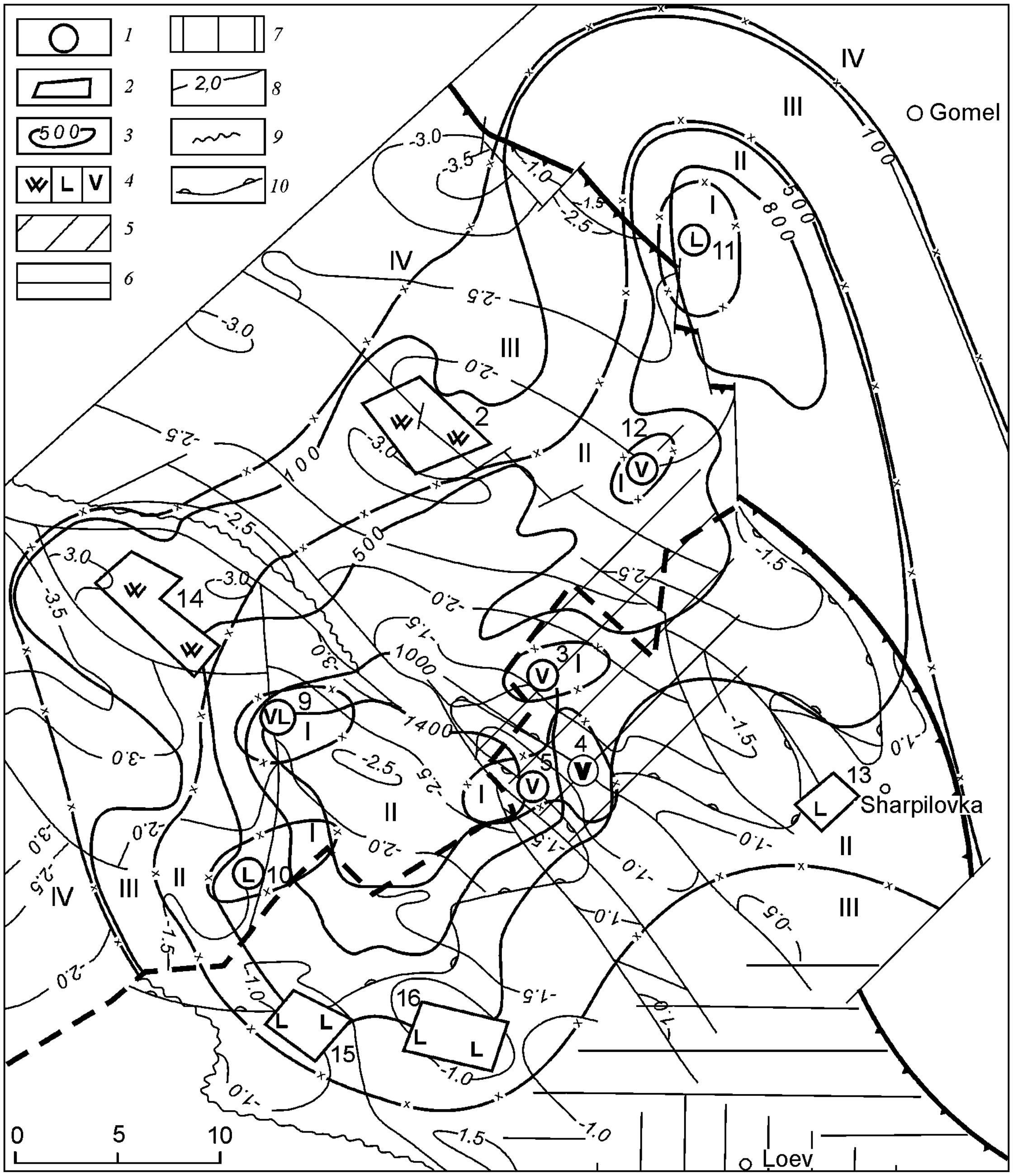

Figure 12. The distribution of lower Famennian volcanic rocks in the Pripyat rift zone [*Aisberg et al.,* 2001].
(1) central-type volcanoes: Vetkhin (9), Nadva (10), Gomel (11), East Borshchevskii (12); (2) fissure volcanoes: Aleksandrov (2), Sharpilov (13), West-Vetkhinskii (14), Yastrebovskii (15), Loev (16); (3)'contour lines of the total thicknesses of the Elets volcanic rocks, m; (4) predominant composition of the volcanic rocks: (a) ultrabasic, (b) basic, (c) intermediate; (5) area of Zadonsk volcanic rocks: areas of volcanic rocks in the Dnieper-Donetsk Trough; (6) undifferentiated Upper Devonian rocks (inferred); (7) Lebedyan-Polessian (Late Famennian) rocks; (8) contour lines of the surface of the Lower Famennian intersalt rocks, km; (9) boundary marking the absence of intersalt deposits; (10) eastern limit of the Famennian salt-bearing rocks. See Figure 12 for the rest of the legend.

tends to the northern part of the graben (see Figure 11), while the field of the Lower Famennian thickest volcanic rocks is located southward (see Figure 12). The boundary of the area with Famennian volcanic cones passes much more south compared to that of the Frasnian ones.

Some trend in the change of the composition of the Late Frasnian volcanic rocks can be seen in the same direction, from the northern periphery to the center of the Pripyat paleorift. The earliest (Early Rechitsa) diatremes and those most remote from the paleorift axis include explosion pipes filled with xenogenic tuff breccias of alkaline ultrabasic and alkaline basaltic rocks. The ingenous rocks of Evlanov-Liven age, developed in the North Pripyat shoulder in the direct vicinity of the Northern marginal fault, have been classified as subalkalic basic and intermediate rocks [*Veretennikov et al.,* 2000]. The compositionally variable volcanic rocks of the Pripyat Graben and Loev Saddle are dominated by intermediate rocks (trachyte). Thus, the composition variation trend of the early (Frasnian) phase of volcanism can be classified as a peculiar lateral series transverse to the paleorift axis. The dominant rock varieties change gradually from ultrabasic to basic and to intermediate rocks from the periphery to the center.

The rocks of the second (Early Famennian) stage of the volcanism do not show any expressed lateral zoning in their composition. The growth of the petrographic variety of the igneous rocks was controlled by the growing space and time destruction of the crust in the Pripyat rift zone. As a more and more branching network of faults (magma routes) was formed, the initial alkaline ultrabasic magma (parental for all igneous rocks of the region) experienced differentiation in intermediate chambers at varying depths. This controlled the great variety of ultrabasic, basic, and intermediate rocks over the entire area of their development, which is characteristic of the second (Early Famennian) phase of the volcanic activity.

The igneous activity, associated with the formation of the Pripyat-Donetsk aulacogen, tended to be restricted discretely to the areas of its intersection with old crustal faults. This fact is mentioned by all geologists dealing with this region. The intersections of crustal faults of different ages in the geodynamic extension environments were zones of high crustal permeability. In the Pripyat Trough, alkaline ultrabasic rocks and alkaline basalts are developed in the area where the zone of the dynamic effect of the Northern marginal fault is intersected by the Yadlov-Traktemirovo old submeridional fault, or by the Odessa (after A. V. Chekunov) crustal fault.

Our synthesis of the data available for the Late Devonian igneous rocks of the Pripyat Trough and the adjacent areas suggests that the volcanic rocks developed in this region are characteristic of the typical continental rift zones proposed by *Ramberg and Morgan* [1984]. The indications of rift-related magmatism in the Pripyat Zone are the rocks of high alkalinity, including ultrabasic alkaline rocks; the various kinds of their origin, including explosive eruptions, and the numerous intrusions in the platform sediments at different levels of the consolidated crust, as well as the migration of volcanic activity from the periphery to the axial part of the rift.

The potential discovery of a new diamond-bearing province in the Belorussian territory is associated with the ultrabasic and alkaline rocks in the Pripyat rift zone [*Nikitin et al.,* 1999]. The reasons for this are the findings of diamond crystals in some explosion pipes, and the discovery of more areas with pipe-type anomalies, in addition to the known ones, from the results of an aeromagnetic survey in the North Pripyat rift shoulder.

Moreover, the igneous activity contributed to the formation of oil deposits in the Devonian sediments of the Pripyat Basin. It manifested itself in the formation of oil traps, associated with atoll-type hydrocarbon traps in atoll-type organic structures in the Zadonsk and Petrikov rock horizons above the volcanic cones. Oil pools have been discovered in these traps in some areas. Good prospects are associated also with some unconventional hydrocarbon traps including volcaniclastic interbeds with good reservoir properties and top and side screens composed of poorly permeable effusive and intrusive rocks. There is another aspect of a relation between magmatism and oil content. The intrusion of high-temperature magmas and hydrotherms might have contributed to the high heating of the surrounding rocks and to the intensification of oil formation even in the areas with shallow petroleum-generating rocks.

6. Crustal Structure of the Pripyat Trough

Much information for the lithosphere to depths of 100–120 km has been obtained from deep CDP seismic surveys along the profiles III, VIII, XXII, and XXXIII cutting across the Pripyat Trough across its strike (Figure 13), and from the geological and geophysical surveys carried out along a geotraverse run in the framework of the Eurobridge International Project.

The seismic records showed fairly distinct coherent lineups of reflection waves throughout the Earth's crust and upper mantle top, this suggesting their significant layering (Figures 14 and 15).

Fairly good reflections are associated with the basement top which had been studied fairly well using various modifications of the seismic method and crossed by numerous drill holes [*Garetskii,* 1979; *Garetskii et al.,* 1986]. A series of longitudinal (sublatitudinal) and more rare transverse (submeridional and diagonal) faults with magnitudes of 2–5 km break the basement into blocks, this producing tectonic steps. The steps are inclined to the north in the northern part of the basin, and to the south in the southern one (see Figure 5).

The most intensive reflections were recorded at times of 13–16 s, which correspond to the depths of 35–45 km, and locally to a depth of 55 km. These are multiphase interference-wave packages with subhorizontal and slightly inclined coherence events were interpreted to be associated with the transition zone from the crust to the upper mantle, known as a zone of crust-mantle mixture [*Sollogub,* 1982]. The upper boundary of the zone was found to be fairly distinct and was interpreted as the Moho surface using the refraction data available. The analysis of the spectral characteristics of re-

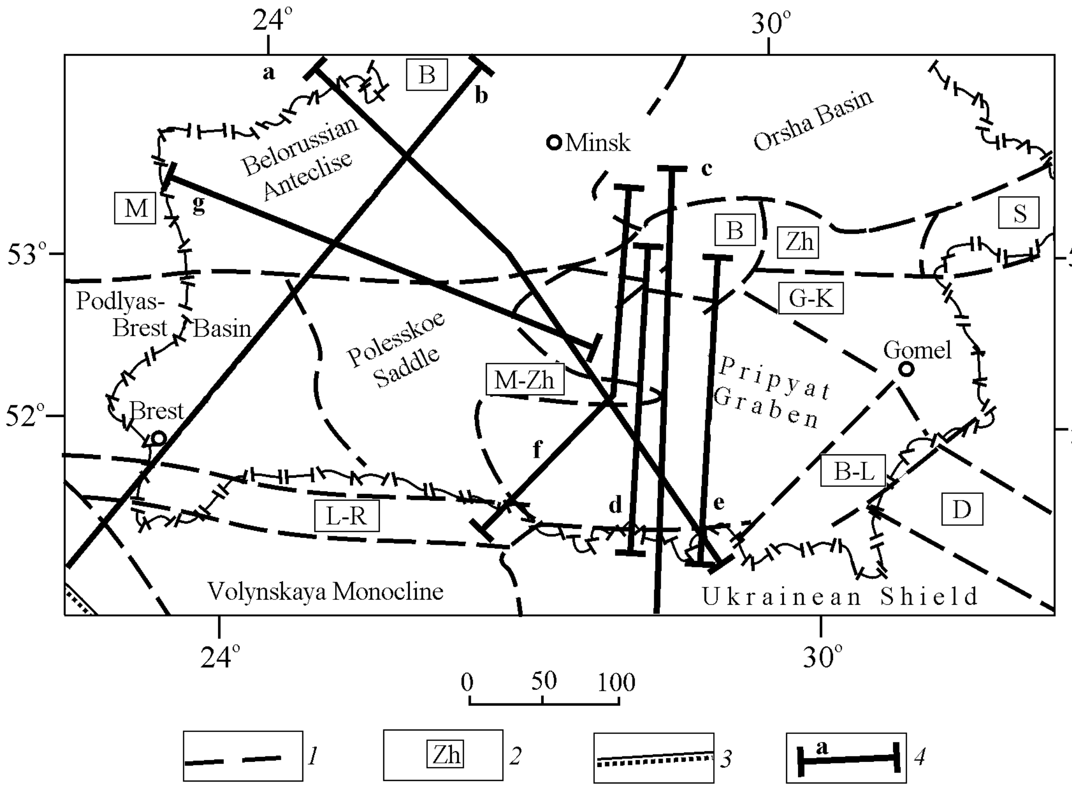

Figure 13. Map showing the location of DSS profiles in the territory of Belorussia.
(1) outlines of the platform structural features; (2) names of structural features: (M) Mazura, (M-Zh) Mikashevichi-Zhitkovichi, (S) Surazh, and (B) Bobruisk buried highs; (L-R) Lukov-Ratno Horst, (V) Volozhinskii and (D) Dnieper grabens, (B-L) Bragin-Loev Saddle, (Zh) Zhlobin Saddle, (G-K) Gorodok-Khatetsa Step; (3) Teisseira-Thornquist Zone; (4) DSS profiles and their names: (a) Eurobridge/96, (b) Celebration, (c) Eurobridge/97, (d) DSS-CDP III–III, (e) DSS-CDP VIII–VIII, (f) DSS-CDP XXII–XXII, (g) Grodno-Starobin.

flected waves, based on the results of the frequency and time transformations of seismic records using a velocity model of the rocks, revealed that the thicknesses of the crustal and mantle layers varied from 60 to 200 m. The lower boundary of the zone was found to be less contrasting. The thickness of the crust and mantle rocks varies from 5 to 10 km, this zone being thinnest under the central part of the paleorift, and thickest under the marginal faults and the adjacent areas of the Ukrainian Shield and Belorussian Anteclise. Some thinning of this zone has been recorded farther northward.

Some individual, less intensive reflections, recorded below the zone of a crust-mantle mixture, mark subhorizontal boundaries. The intensity of the reflections decrease, and coherent lineups become more rare. This suggests a decline in the thin-layered acoustic differentiation of the rocks and their higher heterogeneity. The maximum recording time of these reflections is below 18–22 seconds in different segments of the profile, these recording times corresponding to the depths of 60–65 km.

The acoustic differentiation of the rocks can be inferred from the velocities predicted from the results of the pseudoacoustic transformation of the records of vertical seismic profiling [*Garetskii et al.,* 1986; *Klushin et al.,* 1989]. Some local anomalies have been observed against the general growth of velocities from 6 km s^{-1} near the surface of the basement to 8.8 km s^{-1} in a depth interval of 80–90 km (see Figure 15).

A zone of high vertical velocity gradients was recorded in a depth interval of 35–45 km. This zone coincided with a region of the concentration of high-contrast reflectors, supposed to be associated with a crust-mantle transition zone. Here, velocities grow with depth from 7 to 7.6 km s^{-1}, the velocity gradients being as high as 75 m s^{-1} per 1 km, with the average gradient being 30 m s^{-1} per 1 km in the studied part of the rock sequence. It appears that the refracted waves and the critical reflected waves interpreted to be associated with the Moho surface during deep seismic sounding originate in this layer.

Some local anomalies with low interval velocity values have been recorded. The anomalies were interpreted as wave guides associated with zones of low-density rocks. The lower subhorizontally extending anomaly with a depth of 80–90 km can be caused by the partial melting of the rocks in the form of an asthenospheric lens or an asthenospheric diapir.

The lenticular anomaly recorded in a depth interval of 60–70 km also seems to be associated with partial melting. Proceeding from the model proposed by *Ringwood* [1961], it

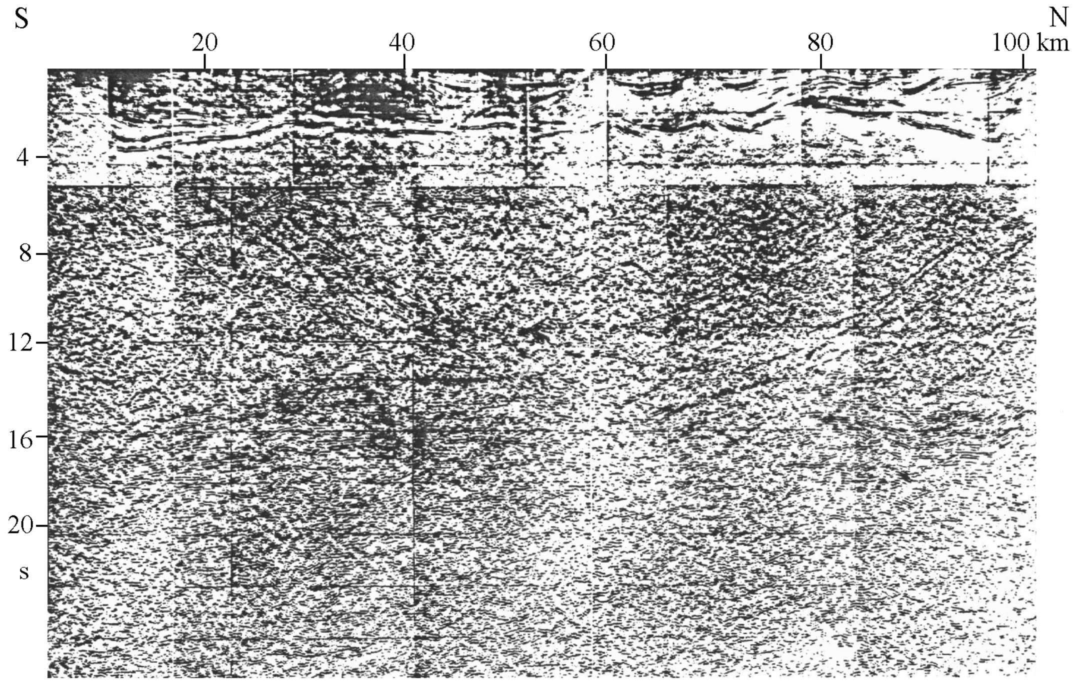

Figure 14. DSS-CDP time section along Profile VIII–VIII across the southern segment of the Pripyat paleorift [*Garetskii and Klushin,* 1989]. The section shows listric faults that form the South-Pripyat bowl-shaped inner graben, the tectonic steps of the basement surface and the lower platform cover, and the structure of the latter with salt domes.

can be supposed that this anomaly is produced by some independent homogeneous body that had been detached from the asthenosphere. This supposition is supported by the growth of the heat flow from 30–40 mW m^{-2} in the center of the trough to 80–90 mW m^{-2} above this anomaly [*Parkhomov,* 1985].

Low-velocity anomalies have been recorded also at depths of 20 and less kilometers. It is believed that they were caused by low-density regions associated with tectonic fracturing. The misaligned seismic records were used to locate regions where low density had been caused by the tectonic formation of fracturing. In most cases these regions are located in areas where faults with opposite dips intersect. The depths of these regions are less than 20 km deep. For this reason in can be assumed that fissure-type low-density regions extend as far as this depth. It is difficult to locate the upper boundary of these regions. It appears that it can be located both below the basement surface (approximately above the 10-km level) or underlie it directly. The totality of tectonically fractured blocks can be interpreted as an extensive spatially heterogenous layer in the upper crust [*Klushin et al.,* 1989].

A great number of inclined sites with the simultaneous significant decrease of the subhorizontal ones have been found in the Earth crust above the zone of mixed crustal and mantle rocks.

The inclined grounds tend to be grouped in the rock sequence and produce isolated narrow zones with the distinctly ordered reflecting elements. It is characteristic that the dips of these grounds and those of the zones themselves grow more horizontal with depth. Some groups of these flat grounds have been correlated with regional faults in the basement top and lower sediments and traced into the lower crust and a crust-mantle rock zone, growing flatter there up to getting subhorizontal and pass into the above – mentioned grounds of the zone itself. It follows that the layering of the crust and of the crust-mantle mixture is genetically common and has the same tectonic origin.

In addition, there are groups of ordered grounds with a smaller penetration depth into the crust (usually less than 20 km), which also correlate well with the faults in the basement top and in the lower sediments.

The combination of all inclined and curvilinear breaks is a system of normal listric faults [*Garetskii and Klushin,* 1987, 1989]. During the rift formation the crust was broken in the listric manner as a result of the lithospheric extension. Its blocks sagged along the fault planes. In the course of their subsidence the wedge-shaped blocks moved toward the extension center, their upper subhorizontal planes tipped over in the opposite directions at the expense of the rotation components of the displacements , caused by the listric breaking of the crust. The blocks of the latter collapsed along the fault planes. In the course of the subsidence the wedge-shaped blocks moved toward the extension center, their upper subhorizontal planes overturned in opposite directions at the expense of the rotation component of the displacements, caused by the curvilinear sliding planes. This explains the rises of the basement blocks facing the paleorift center and the inclination of their surfaces in opposite directions. All

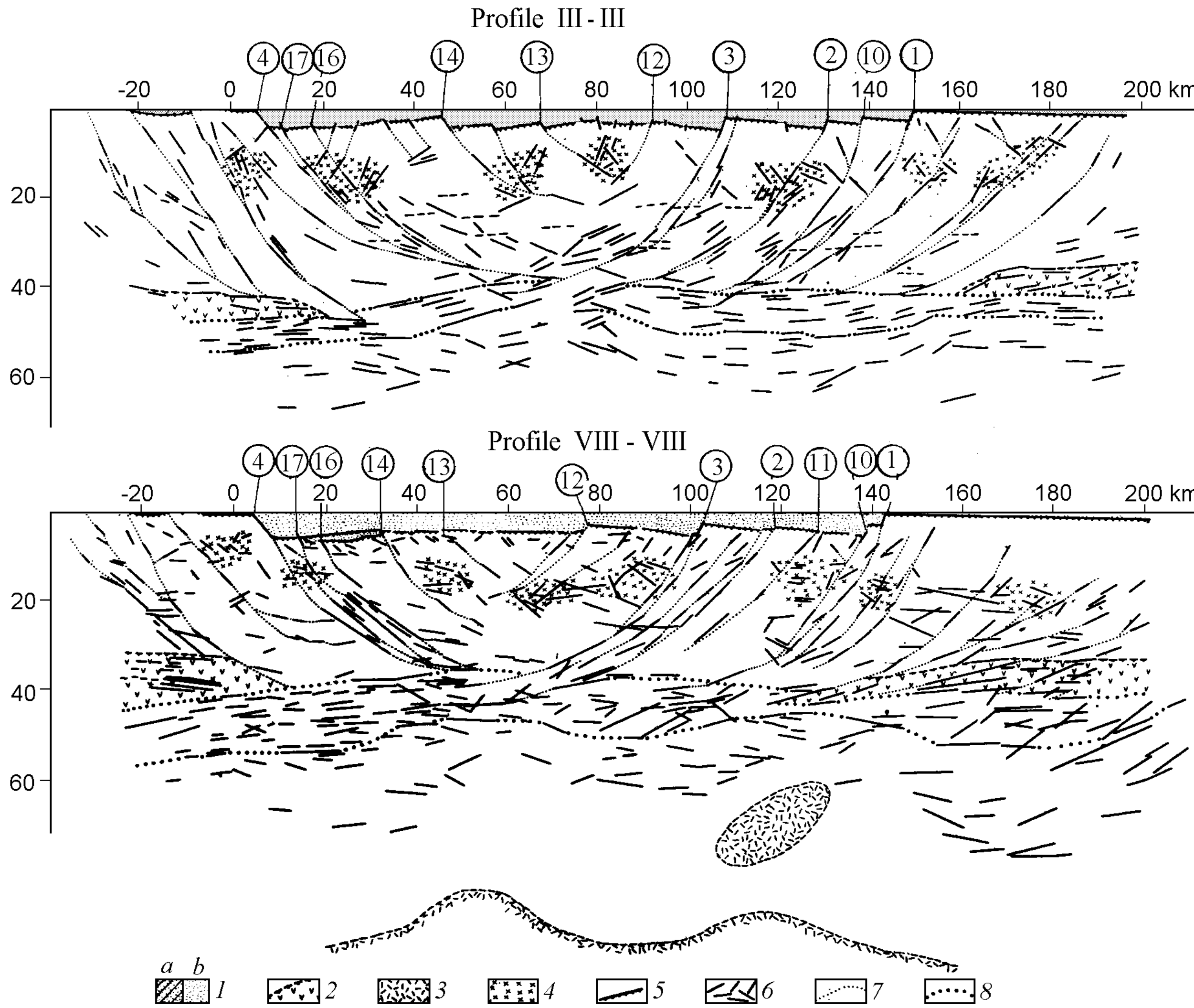

Figure 15. Seismological sections across the Pripyat Paleorift along profiles III–III and VIII–VIII [*Garetskii and Klushin,* 1989].
(1) Platform sedimentary cover: (a) Lower Riphean, (b) Upper Riphean-Anthropozoic; (2) clinoforms in the lower crust and their contours; (3) waveguides; (4) low-density zones assumed to be associated with tectonic fracturing; (5) basement surface; (6) reflectors; (7) listric faults; (8) Moho surface and the bottom of a mixed crust-mantle zone.

listric faults are accompanied by normal faults cutting the top of the basement and the lower sediments. The rotation of the block surfaces in different directions from the rift center was accompanied by the formation of faults that grew wider upward, that is, the upper part of the crust grew wider than the bottom of the lithosphere. This produced more listric and rectilinear breaks feathering the deep-root faults. Smaller blocks slipped off along the breaks.

In terms of their penetration depth into the lithosphere the listric faults can by classified into the mantle faults that reached the Moho surface and even penetrated into the crust-mantle transition zone and the crustal faults that did not reach the upper surface of the mantle. The mantle and crustal faults, represented by normal faults in the basement top, bound the large tectonic steps of the paleorift and control its basic longitudinal (sublatitudinal) zoning. The normal fault magnitudes are as great as 2–5 km. These major faults are, in turn, complicated by more shallow feather breaks which separate smaller tectonic elements (monoclines and zones of rises and submergences) of the same longitudinal orientation. The feather faults may have counter or single-direction dips. As has been mentioned above, the latter are usually referred to as faults that accompany the major ones or as accessory faults.

The longitudinal faults attenuate gradually in the western direction as the paleorift becomes less expressed. Here, the magnitudes of the normal faults decrease to 1 km and less, their depths being restricted to the crust. The lower part of the crust, less than 30 km thick, where the faults become more flat, is characterized, in contrast to the central segment of the paleorift, by a clearly expressed subhorizontal tectonic layering. This part of the section is represented in seismic records by extensive lineups. Reflections from the Moho surface and from the boundaries in the crust-mantle layer are also clearly expressed and, compared to the crustal reflections, are much more intense.

This description and the cross-sections presented in Figure 15 show a clearly expressed asymmetry in the crustal structure of the Pripyat paleorift. This manifests itself in the asymmetry of the system of four main listric faults of mantle origin: only one of them, the South-Pripyat one, has a northern dip of its fault plane. The three others dip to the south, the fault plane of the first of them being more gentle than those of the latter. There is a substantial difference in the structure of the southern and northern segments of the paleorift, the inner graben being a large bowl-shaped crustal block. The step zone is represented by two smaller wedge-shaped blocks. Asymmetry is characteristic also of the deeper zones of the lithosphere: the very steep dip of the Moho surface in the southern direction and the gentle one in the northern.

The asymmetry of the deep structure of the Pripyat paleorift is reflected both in the tectonic elements of the sedimentary cover and basement surface, and in the specific paleostructural evolution and in the lithology of the Upper Devonian-Triassic rocks, as has been reported earlier [*Aisberg et al.,* 1976].

To sum up, the crustal profiles (see Figure 15) show two Moho surfaces [*Aisberg et al.,* 1988; *Garetskii and Klushin,* 1987, 1989, 1994]: the upper Moho surface (shown by a special line in the figure) and the lower Moho_1 surface (located 5–20 km deeper, bounding the layer of a core-mantle mixture, distinguished by a great number of reflectors). The Moho surface in the central segment of the Pripyat Trough resides at depths of 34–35 km in the northern part, at a depth of 40 km in its northern segment, and in a depth interval of 45–48 km in the southern. In the parts of the trough bordering its sides the lower crust includes clinoforms located at the Moho-boundary and wedging out toward the trough. The southern clinoform is interpreted as a potential thrust.

The territory of the Pripyat Trough is characterized by the crust of the lowest density (2.88 g cm^{-3} and less), whereas the crust under the neighboring Bragin-Loev Saddle is composed of highly dense rocks (>2.96 g cm^{-3}). The lithosphere under the Pripyat Trough in the western part of the East European Craton shows a minimum thickness and is outlined by the contour lines of 150 to 100 km, the thickness of the asthenosphere being as great as 100–120 km [*Konishchev,* 2001].

7. Geodynamics and Evolution

By analogy with modern continental rifts, distinguished by a specific prerifting evolution period [*Razvalyaev,* 1988], the formation of the aulacogens was also preceded by an aulacogen preparation prehistory.

The late aulacogens, which seem to have been the members of a world rift system [*Zonenshain et al.,* 1990], began to form at the end of the Middle and Late Devonian as a result of the extension associated with the opening of the Paleotethys ocean and with the events in the Ural Paleoocean, these aulacogens being the members of the World rift system.

The stages of the Pripyat Trough evolution have been established in fair details [*Aisberg et al.,* 2004; *Garetskii,* 1976]. The Variscan period of this trough evolution began with the formation of the margin of the southwestern side of the Moscow Syneclise (the prerifting syneclise substage of insignificant extension during the Middle Frasnian time). However, even during that time structural features began to form in the sediments, initially of a sublatitudinal (Pripyat) strike, which later, during the subrifting stage, developed as the tectonic elements of the Pripyat Trough (buried highs, zones of fault-related highs). The southern boundary of the paleorift inherited the position of the pre-platform fault and controlled the onset of the reactivation of movements along the future South Pripyat marginal fault. The closing phase of the pre-rift syneclise evolution was marked by the quiet conditions of tectonic planation. This is proved by the persistent thickness of the Sargaevo-Semiluka deposits underlying the rift rocks, as well as by the absence of coastal facies in the peripheral parts of the basin [*Golubtsov,* 1974; *Uriev and Anpilogov,* 1977]. Beginning from the later half of the Sargaev time, almost no clastic (clay) material was supplied to the shallow-sea basin of carbonate accumulation. This situation seems to be indicative of the deep peneplanation and low stand of the surrounding land, rather than of the significantly remote shoreline, which can be interpreted to be indicative of the absence of any forerift domal rise.

The syneclise substage was replaced in Late Frasnian time by a rifting substage which can be subdivided into the following stages: initial downwarping, corresponding to the rift generation and to the early destruction of the lithosphere (onset of Late Frasnian to Voronezh-Evlanov time); the stage of maximum downwarping, rifting culmination, and the main destruction of the lithosphere (end of Late Frasnian to Famennian time); the final downwarping, rifting attenuation, and the end of the lithosphere destruction (Early and Middle Carboniferous); general uplifting and compression (Late Carboniferous to Early Permian); stabilization, rifting and residual extension dying-off (Late Permian-Middle Triassic). The Pripyat-Dnieper suprarift syneclise was being developed since the Late Triassic.

The time of the most active destruction of the Pripyat paleorift lithosphere coincided with alkaline-ultrabasic volcanism, the maximum magnitudes of normal and strike-slip faults, the formation of uncompensated basins and their subsequent filling with Frasnian and Famennian salt-bearing rocks. It should be mentioned that the extension processes, which operated in the late Devonian at the southern and eastern margins of the East European Platform, adjacent to the Paleotethys and Ural Paleoocean, favored the wide development of uncompensated troughs and basins [*Garetskii et al.,* 1990], namely, the Pripyat and Dnieper ones, restricted to the aulacogens of the same names, the vast Caspian Basin, the Umetov-Linevskii; the Pechora and Kama-Kinel system of troughs, partially coinciding with the Pechora-Kolva, Varandei-Adzva, Kazhim, Kaltasy, and Sernovodsk-Abdulino aulacogens.

The extension of the Pripyat Paleorift varies from 9.3 to 13 km, that is, about 10% of its width, like in the cases of many modern rifts, and the duration of the main destruction phase was 8.5 million years. It follows that the average spreading rate was 0.11–0.16 cm year^{-1}, while the instantaneous spreading rate was 0.2–0.3 cm year^{-1} [*Aisberg,* 1986].

The good knowledge of the platform sediments and the crust in the Pripyat paleorift allowed the development of geodynamic models using this rift as an example. One of them was reported by *Garetskii and Klushin* [1989]. In terms of this model an asymmetric system of crustal listric faults was formed in the crust as the lithospheric plate moving to the north above the rising asthenospheric diapir was broken into an asymmetric system of listric crustal faults. Crustal listric faults were formed because the crust was divided into two layers: the upper more brittle layer (roughly as deep as 20 km), which is highly faulted and includes regions of low density associated with dense tectonic fissures, and the more brittle lower part penetrated by more scarce listric faults of mantle origin and including waveguide lenses associated with partial rock melting. A zone of dense tectonic slabs originated at the contact of the crust and upper mantle. The structural asymmetry of the Pripyat Trough and its transverse zoning can be explained by the simultaneous operation of several forces (see Figure 3): (1) a horizontal force causing the movement of the lithospheric subplate along the lithosphere-asthenosphere contact; (2) a vertical force directed upward into the region of the asthenospheric diapir under the middle of the depression, and (3) extension forces directed to different sides from the center, and also the forces of gravitational attraction (not shown in the figure). The actions of these forces created conditions where the southern extended segment of the subplate slowed down, whereas the movement of the northern segment accelerated. As a result of friction arising during the sliding of the lithospheric plates along the subhorizontal faults, the rates and amounts of horizontal movements of the upper plates in the southern part of the subplate turned out to be higher than those in the lower ones, and the former plates rode over the latter. The northern part of the subplate shows an opposite pattern. Because the extension had been caused by the intrusion of the diapir, the area north of it is a weak zone (divergence area), and the area south of it is a compression zone (convergence area). This model suggests the existence of overthrusts in the zones of the southern and some other listric faults with the northern dip of the fault planes. In particular, the wave pattern in the southern segment of the trough is interpreted as the gentle thrusting of the basement of the Ukrainian Shield over the sedimentary (subsalt) rocks of the Pripyat Trough or, on the contrary, as the underthrusting of the lower lithospheric plates under the upper ones, north of the North Pripyat Fault.

Another alternative model has been proposed by R. E. Aisberg and T. A. Starchik, based on the tectonic mechanism of listric fault formation, developed by E. M. Shishkin and T. Yu. Shishkina [*Aisberg et al.,* 1991]. The essence of this mechanism is the fact that, like any other

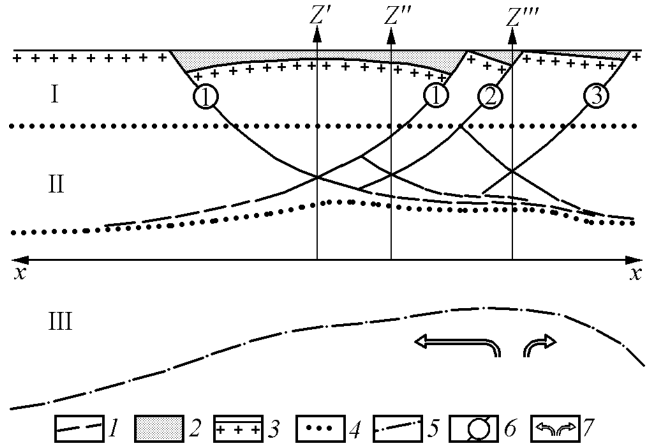

Figure 16. Development of deep faults in the continental crust under the conditions of subhorizontal extension in the case of tensile forces acting primarily in one direction. Compiled by E. I. Shishkin and T. Yu. Shishkina [*Aisberg et al.,* 1991]. (1) Crustal fault, (2) ground surface subsidence area filled with loose sediments; (3) boundary of the modified position of the pre-rift ground surface; (4) boundaries of the areas with different types of deformation; (5) conventional depth limit of the region of plastic deformation; (6) numbers of fault generations; (7) extension directions; (I) region of brittle deformation; (II) region of mixed-type deformation; (III) region of plastic deformation: z', z'', and z''' denote successive changes of the z-axis position in the zx plane.

disjunctive features, listric faults are initially formed as flat fault planes and acquire their characteristic "bucket shaped" (listric) forms during the subsequent stages of evolving deformation because of the ability of the lower crustal layers to experience plastic friction along with brittle destruction.

Depending on PT conditions, three main rheologic zones are distinguished in the lithosphere, namely, a zone of mainly brittle deformation, a zone of mixed-type deformation, and a zone of plastic deformation of dislocation type, which agrees with the ideas of the rheologic layering of the crust and lithosphere. The zone of plastic deformation seems to be restricted to the upper mantle. The generation and subsequent development of crustal faults, including their transformation to listric faults, takes place in a zone of mixed deformation. The intensive development of plastic deformation at the lower levels of mixed deformation and its absence in the upper layers of this zone resulted in the different flattening of the resulting fault planes. As a result, the profile of these faults acquired a listric form in the cross-section (Figure 16).

The specific geodynamic mechanisms of the formation of intracontinental rifts were also controlled by the configuration of the zone where the source of extension was located, by variations in the spreading rate of the asthenolith material, and by variations in the rheologic properties of crustal regions not only in the vertical but also in the horizontal direction. The use of these specific features in the case of the Pripyat Trough, in terms of the chosen geo-

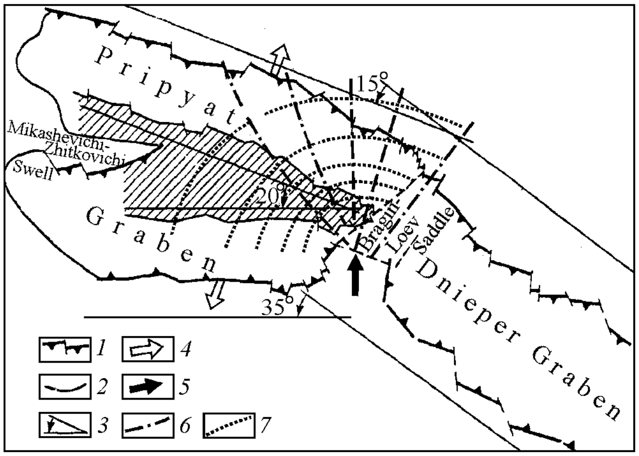

Figure 17. Interpretation of the tectonic environment in the Pripyat Paleorift in terms of the forward-rotation movement of the Internal Graben block, constructed by T. A. Starchik and R. E. Aisberg.
(1) Marginal faults of the Pripyat-Donetsk aulacogen; (2) western boundary of the Pripyat Paleorift; (3) the angle and direction of the inferred rotations of the North Pripyat and South Pripyat marginal faults relative to those of the Dnieper-Donetsk aulacogen; (4) the vector of the main extension stress of the paleorift; sketch of the dynamic effect of the Bragin stamp; (5) vector of active force and the trajectories of the compression (6) and extension (7).

dynamic model, allowed us to explain the mechanism of the formation of normal and shear faults and to associate the existence of "islands" with the interrupted rifting process of the Mikashevichi and Bragin protrusions. The correlation of the real seismological model of the Pripyat Trough with the tectonophysical models based on the unidirectional action of external extension forces suggest the conclusion of their good agreement. The formation of a structural feature of this kind can be explained by the relatively stable position of the Northern Zone and by the active movement of the Internal Graben block southward (Figure 17).

The use of our geodynamic models of paleorift formation is important for estimating oil and gas prospects. During the rift graben formation the main type of stress was of a pulling-apart kind, which produced normal faults in the platform sediments and facilitated the formation of oil- and gas-promising structural features.

The most important disjunctive boundaries in the paleorifts are longitudinal normal listric faults of mantle and crust level. They control not only the deep crustal structure but also the character of faults in the upper layers of the Earth crust. The origin and evolution of deep crustal faults involved the formation of numerous minor normal faults both in the basement and in the sediments of a paleorift, which controlled the main structural features of oil- and gas-bearing rocks. Each crustal listric fault produced a dynamic effect on a certain zone in the platform sedimentary cover. Fields of destroyed rocks were formed in the zone of the dynamic effect of a fault. Various oil-promising fold-block, block-fold or fold structural features are the objects of oil prospecting.

The horizontal rheologic heterogeneity of the basement caused a great effect on the conditions of the formation of paleorift basins. In particular, it controlled the transverse tectonic and, in the long run, the oil petrology zoning of paleorifts. It is known that during pre-Hercynian time the rocks of the region were structured (fractal), this manifesting itself as a system of pre-rift faults of different strikes, as a lateral and vertical heterogeneity of the rheologic properties of crustal areas, and as many other features. Under these conditions, even where extension operated on one side of a rift zone, displacements along listric faults in pre-Hercynian blocks might differ in magnitude and might cause movements along some transverse faults which might be relatively "passive" at that time. These movements might be not only of the normal fault type, but also of the shear type, especially where all of the four blocks bordering the intersection angle between the transverse and longitudinal faults moved over different distances.

As mentioned above, the source of shear deformation must have been outside of the rifting zone. The type of this source might have been the effect of tangential forces acting from the more mobile crustal zones surrounding the East European Craton in the south and southwest, associated with the formation of the Tethys Ocean. The model suggested by *Voronov* [1991] seems to provide a convincing explanation of the principles of shear tectonics. Its essence is the fact that the external effect of the lateral force from the outside onto a flat platform-type plate produces an equal counter effect. These effects constitute a couple with a certain momentum which must inevitably initiate the rotation of the whole plate. Yet, taking into account the block structure of rigid platforms (cratons), the total couple of forces with a rotation moment will break into a certain number of pairs in accordance to the rotation trend of each block, separated from the neighboring one by a zone of strike-slip fault formation.

This pattern of horizontal rotation fits the angular curvature of the Pripyat and Dnieper segments of the paleorift, which measures 15°–17° in the system of the northern marginal faults, and about 35° in the system of the southern marginal faults. The Pripyat segment was formed in the conditions of the left-lateral rotation of large basement megablocks, and the Dnieper segment, in the conditions of the right-lateral rotation of large basement megablocks. As a result, both structural units look in the horizontal plane as peculiar wedge-shaped pull-apart faults with the angle of 20° [*Aisberg et al.,* 1991]. In the case of the Dnieper Trough this angle is 8°–10° [*Chekunov,* 1976]. This counter rotation produced an impressed wedge, the Bragino stamp block, intruded into the paleorift body from the south (see Figure 17). It was an area where the region of maximum transverse compression was produced in the boundary areas and was later redistributed to the zone of the paleorift extension. The Bragin block is restricted in the west and east by the abrupt breaks of the South Pripyat and South Dnieper marginal faults turned under toward the troughs. It is natural to assume that with this mechanism of the block movements the areas of these breaks were strike-slip faults:

with a left-lateral displacement in the Pripyat Trough and a right-lateral displacement in the Dnieper one.

The analysis of the structural pattern of the junction zone revealed the general diagonal displacement of the Pripyat rift segment to the north relative to the Dnieper segment along the above-mentioned right-lateral strike-slip fault which seems to be have been the major fault in the hierarchy of the strike-slip faults in this segment of the Earth's crust. The compression along the fault developed in terms of a simple pattern: in the north it "complimented" the extension in the northern segment of the Pripyat Trough, in the south it "complimented" the extension in the southern segment of the Dnieper Trough. In terms of its dynamics this strike-slip fault differs from a classical one by the fact that this fault terminates abruptly at its both ends being transformed to a tectonic element of another type, namely, to a tear fault, resembling a transform fault.

The redistribution of compression was different in the area where the South Pripyat marginal fault deviates abruptly at the contact with the Bragin Protrusion. The horizontal displacement along this left-lateral strike-slip fault in the south also terminates in the extension zone of the Pripyat paleorift as a transform-type fault and can be visually traced only as far as the latitude of the Buinovichi-Narovlya fault. Further northward it seems to have no its visual logic continuation, this suggesting the diffusion of the horizontal displacement in this direction. Considering that the total vector of the application of forces from the Bragin block was directed toward the Pripyat Trough (see Figure 17), the stress was mainly discharged in its territory.

8. Evolution of the Pripyat Trough and the Adjacent Late Paleozoic Sedimentary Basins in the Southwestern Part of the Sarmatian-Turanian Lineament

The Hercynian stage left a particularly notable trace in the structure of the platform cover in the western part of the Sarmatian-Turanian Lineament including the Pripyat and Dnieper troughs and the Podlyas-Brest Basin. As demonstrated above, rifting-related processes caused the formation of the modern structure of the Hercynian rocks in the Pripyat and Dnieper troughs and in the Bragin-Loev Saddle. The system of latitudinal faults bounding the Pripyat rift graben has been traced in fragments westward as far as the Teisseir-Thornquist Line. The above-cited faults predetermined the combination of genetically different platform-cover tectonic elements of different ages, such as the Podlyas-Brest Basin and the Pripyat-Donetsk Aulacogen (PDA) [*Aisberg and Levkov,* 1987]. The Podlyas-Brest Basin is a Caledonian structural feature, although it acquired its present-day sublatitudinal fault limitation during the Hercynian evolution period.

The Hercynian evolution of the Earth's crust in the southwestern part of the East European Platform was affected by Late Proterozoic geologic events. It is known that many of the Devonian rifts were inherited from the Late Proterozoic ones. For instance, the central and southeastern parts of the Dnieper Trough inherited the position of the Ripheanvendian (?) paleorift. The Pripyat segment of the Pripyat-Donetsk Aulacogen extends parallel to and at some distance from the Ovruch sublatitudinal graben-syncline filled with late Proterozoic rocks. However, the rifting processes operating in the Pripyat Zone were superimposed over the Volyn-Orsha Riphean-Early Vendian paleotrough, over the Middle Devonian margin of the Moscow Syneclise, or directly on the Archean-Early Proterozoic basement which had not been involved in any significant tectonic and thermal reworking during a period of 650–800 million years. It appears that the lateral rheologic heterogeneities of the crust in the Pripyat-Donetsk Aulacogen controlled, along with the other tectonic and paleogeodynamic factors, the differences in the evolution of the Pripyat and Dnieper paleorifts.

The general background of the tectonic evolution of the Pripyat-Donets Aulacogen was the gradual migration of the processes of intracontinental rifting from east to west along the old, obviously, transform-type fault zone remobilized during the Hercynian time. This activity was initiated by the regional tectonic events that took place at the southern margin of the East European continent in connection with the opening of the Paleo-Tethys Ocean [*Zonenshainn et al.,* 1990]. Our comparative analysis of the evolution of the individual links of the aulacogen showed that this trend had been responsible for the substantial difference in the evolutions of the Pripyat and Dnieper troughs and of the Donbass Basin. In the case of the Pripyat troughs these differences seem to have been controlled also by the effects of the synchronous tectonic processes that had operated in the surrounding of another, southwestern, margin of the platform.

The break-up of the crust in the Pripyat-Dnieper linear zone caused the rise of the asthenosphere and the formation of mantle asthenoliths there. This is proved by the crustal and Moho-surface structure found from deep seismic measurements in the Dnieper and Pripyat paleorifts [*Garetskii and Klushin,* 1987; *Ilchenko,* 1997]. A crust-mantle transition zone, as thick as 5 km, has been traced under the Donetsk segment (Primorsk-Svatovo profile). The upper boundary of this zone with a longitudinal wave velocity of 8.0 km s^{-1} shows a protrusion at a depth of 38 km and plunges to a depth of 40–44 km under the Ukrainian Shield and the Voronezh Anteclise and to a depth as great as 55 km in the regions of their slopes. The crustal structure of the Pripyat Basin has been discussed in detail in Section 6.

Our comparative correlation and estimation of geodynamic events in the Pripyat and Dnieper paleorift basins and in the Podlyas-Brest basin of the Sarmatian-Turanian lineament (including the Lvov-Lyublin marginal basin) were based on structural and formation analyses (see Figure 2). The estimates of geodynamic events in the Pripyat and Dnieper paleorift basins, reported by different investigators show substantial differences [*Aisberg,* 1986; *Arsirii et al.,* 1993; *Chekunov,* 1994; *Gavrish,* 1989; *Konishchev,* 1999; *Lukin,* 1997; *Stovba and Maistrenko,* 2001]. This can be explained by the different understanding of the various mechanisms of intracontinental rifting, including its stages, the time of the rifts' life, the structure of paleorift basins, etc. The treating of rifting only as a process of rift-valley formation contradicts the understanding of rifting dynamics, where the relatively short intervals of intensive high-velocity downwarping, faulting, magmatism, and maximum heat intensity were followed by the gradual attenuation of dynamic activity and by the relaxation of the initial heating of the Earth's crust, which were accompanied by the associated processes of basin formation. During this activity the synrifting deposits, including the late ones, might have been "splashed out" beyond the rift graben to remain on the rift shoulders, as happened during the formation of the Pripyat and Dnieper paleorifts.

During the Hercynian time the processes of basin formation began to operate as early as during the prerifting stage and were restricted to the boundary between the Early and Middle Devonian (see Figure 2). Small isolated basins, not deeper than a few tens of meters, were formed in the Dnieper Basin during the Eifelian time. Sand and clay began to accumulate there during the Givetian time and attained a thickness of 100 m. *Lukin* [1997] called this phase as a "prerift horst-type magmatic phase". The period of basin formation in the area of the Pripyat Trough was longer in time, compared to the Dnieper one, and continued from the Eifelian to the Middle Frasnian time, when terrigenous to carbonate rocks accumulated there, totaling 425 m in thickness.

In the Dnieper Trough a rifting phase began in the Early Frasnian time when volcanic and carbonate rocks, as well as the overlying volcaniclastic rocks, accumulated during the early stage of rifting, measuring 200 and 500 m in thickness, respectively. Compared to this trough, rifting in the Pripyat Trough began somewhat later (during the early half of the Late Frasnian time) with the accumulation of a sulfate-bearing dolomite-limestone-marl sequence attaining a thickness of 320 m. The indications of the rifting onset in both troughs were the appearance of basic igneous rocks, and also the more active subsidence and the growing intensity of differentiated movements along the system of the newly formed and inherited faults with magnitudes as large as tens of kilometers.

The main rifting phase in the Dnieper Trough embraced the late Frasnian and Famennian time of the Devonian Period, when a vertical sequence of rocks, including salt-bearing and volcanic rocks, accumulated to measure 2500–3000 m in thickness [*Lukin,* 1997]. This rock sequence is characterized by the formation of various block structures, tectonic movements of different directions, igneous activity, and the growing rate and magnitude of subsidence.

In the Pripyat Trough the main rifting phase began, like the early one, slightly later than in the Dnieper Trough, namely, during the Evlanovian-Livenian period of the late Frasnian time, and ended in both troughs approximately simultaneously at the boundary of the Devonian and Carboniferous periods, and is characterized by a roughly similar set and thickness of the rock formations. The maximum downwarping rate (sediment accumulation) was 175-433 m per million years for the late Frasnian time, and 784–1293 m per million years for the Famennian time [*Konishchev,* 1999]. Generally, this phase is characterized by the formation of high-magnitude strike-slip faults, uncompensated downwarping, high magmatism and halogenesis, fold-block structure, high heat flow, and thin crust [*Aisberg et al.,* 1991; *Garetskii,* 1976; *Garetskii and Klushin,* 1987].

The high Late Devonian igneous activity in the aulacogen reflects a correlation between the intraplate and continental-margin events in the southwest of the platform. Volcanic rocks are developed in the territories of the Pripyat and Dnieper troughs, in the folded Donbass region, and in the southeastern slope of the Voronezh Anteclise, where basalt flows record rifting processes at the shoulders of the aulacogen. The volcanic rocks of this extensive (1200 km) belt are represented by several igneous rock formations, classified using the ratios and dominance of similar rock groups [*Korzun,* 1974; *Lyashkevich,* 1987]. Their distribution in the vertical sections of the above-mentioned structures and in the lateral direction from east to west, the petrochemical differences in the rocks of the same type (tholeiite basalt composition, alkalinity factor, etc.), as well as the time, duration, and intensity of the earliest igneous activity in the Pripyat-Donetsk paleorift, describe the migration of the rifting activity from east to west. The igneous activity began at the time between the Middle and Late Devonian in the east, in the zone where the Donbass area contacts the Azov crystalline massif [*Gonshakova et al.,* 1968]. The earliest traces of volcanic activity are known also in the central and northwestern areas of the Dnieper Trough, as an admixture of volcanic rocks in the Late Givetian-Early Frasnian sedimentary rocks. The earliest igneous activity in the Pripyat Trough began later, at the boundary between the Middle and Late Frasnian.

Two main volcanic phases in the Dnieper Trough were of Late Frasnian and Late Famennian age. The bulk of the volcanic rocks accumulated in the central segment of the trough in the first phase, during the Voronezh-Evlanov time, and during the Semilukian time on the Belaya Tserkov High [*Lyashkevich,* 1987]. Igneous activity was shorter in the Pripyat Trough and has been dated Late Frasnian (Evlanov-Liven) and Early Famennian [*Korzun,* 1974].

The volcanic rocks developed in the aulacogen are the rocks typical of continental rift zones [*Ramberg and Morgan,* 1984; *Seyfert,* 1991]. The Devonian volcanic rocks of the Donbass area, with their typomorphic evidence, show a complete set of indicators of the geodynamic environment of intracontinental rifting [*Zonenshain and Kuzmin,* 1993]. The indications of rift-related magmatism found in the Pripyat paleovolcanic area prove its tectonic position in the region of the lateral attenuation of rifting activity; there are no tholeitic basalts, and no acid differentiates of an alkaline rock association [*Aisberg et al.,* 2001].

As the relatively short main rifting phase had terminated in the Dnieper Trough in Late Devonian time, many rifting-related processes did not cease but continued to operate during tens of million years, attenuating gradually and growing more intense in some periods of time, including the areas of the trough shoulders, also involved in the rifting process. These processes included not only disjunctive tectonics, represented by normal extension faults, but also high downwarping rates and large rock thicknesses comparable with those of the main rifting phase [*Gavrish,* 1989; *Gavrish and Ryabchun,* 1981]. Igneous activity continued as well, as indicated by the paragenesis of silicic rocks and metabentonite, by the mineralogy and geochemistry of the rocks in the Tournaisian-Early Visean rock sequences and by the presence of tuffaceous sandstones and ash interlayers in the limestones of the Middle- Upper Carboniferous terrigenous coal-bearing rocks in the Dnieper Trough and in the Donbass area [*Gavrish,* 1989].

The rocks that had accumulated in the Dnieper Basin during the Carboniferous and Early Permian included paralic coal- and salt-bearing rock sequences measuring many hundreds to a few thousands of meters [*Lukin,* 1997] in thickness, which are comparable with the thickness of the Devonian rocks of the main rifting phase. Our calculation of the maximum average rate of subsidence (sediment accumulation) throughout the Carboniferous-Early Permian time yielded a value of 75–350 m per million years, which is merely 2–3 times lower than the value for the main Late Devonian rifting phase (400–700 m per million years). We compared the subsidence rate and thickness of the Carboniferous deposits in the Dnieper Trough with the Moscow Basin, a syneclise tectonotype, and found a difference to be roughly an order of magnitude higher. The total thickness of the Carboniferous deposits in the central and southern parts of the Moscow Basin varies merely from 450 to 600 m [*Velikovskaya,* 1977].

In the Pripyat Trough the late-rifting sedimentation took place during the Early and Middle Carboniferous epochs when 170–400 m of carbonate-terrigenous and coal-bearing rocks had accumulated. This growing decline of the subsidence magnitude was replaced in the Late Carboniferous by the regional rise of the territory and by the completion of the rifting process in the Pripyat Trough.

Generally, beginning from the Carboniferous, the evolution dynamics of the Pripyat and Dnieper basins, and especially of the Donetsk Basin, was notably different. Since that time, the evolution of the Pripyat Trough was much more in common with the Lvov-Lyublin marginal trough, rather than with the Dnieper genetically similar trough [*Aisberg and Starchik,* 2002].

The Middle Devonian-Middle Carboniferous sagging in the Pripyat link of the aulacogen, which operated under the conditions of regional time-varying extension, was interrupted in the Late Carboniferous and Early Permian by general compression, regional rising, and a break in the sedimentation [*Aisberg,* 1986]. In Late Carboniferous time the process of regional rising involved the Bragin-Loev Saddle and the northwestern part of the Dnieper Trough. The central and southeastern parts of the latter continued to experience subsidence at a rate of 75 m per million years, which was accompanied by the accumulation of red molasse-like rocks as thick as 600 m. During the Early Permian epoch the difference between the formation of the Pripyat Trough and the Bragin-Loev Saddle grew more contrasting compared to the middle and southeastern segments of the Dnieper Trough. Red terrigenous copper-bearing and halogenic rocks continued to accumulate to the thicknesses of 1000 and 2500 m, respectively, in the latter [*Lukin,* 1997]. The Hercynean complex is absent in the Middle Devonian-Lower Permian rock sequence in the Podlyas-Brest Basin in most area of the territory. Thus, the correlation of the Middle Devonian-Lower Permian rocks from the Dnieper Trough to the Podlyas-Brest Basin shows a directed reduction of the synrifting (especially late-rifting) Hercynean deposits of the aulacogen from east to west and their absence in the Podlyas-Brest Basin (see Figure 2).

Of interest in this respect is the tectonic position and orientation of the structural features concerned relative to the mobile belt of the Transeuropean suture zone and the Middle European Foreland conjugated with it, located in the Lvov-Lyublin marginal trough [*Aisberg and Starchik,* 2002]. The Dnieper graben extends at an angle of 25°–30° to this graben, is at a distance of >600 km from it, and is separated from it by the stable Ukrainian Shield. The Pripyat Graben and the Podlyas-Brest Basin are oriented at an angle of 45°–50° and are located at a distance of >300 km (Pripyat Graben) or are conjugated with it (Podlyas-Brest Basin).

The evolution of the adjacent Central European territory in Devonian and Early Carboniferous time took place, according to P. Ziegler's data [*Ziegler,* 1990], against the background of the subduction of the Paleo-Tethys oceanic plate to the north under the Lavrussia plate. As a result of the regional extension caused by this process, complex systems of back-arc rift basins were formed (Renohercynian, Saxonian-Tyuringian) up to the opening of some of them to become mini-oceans. The Eastern links closing these systems were the Lower and Upper Silesian and Lyublin basins. The Lyublin and Upper Silesian basins were open to the southeast toward the Paleo-Tethys Ocean. The evolution of the Central European basins was controlled by the repeated changes of the high and low back-arc extension (up to local compression phases), which was replaced by regional compression, associated with the closure of the Paleo-Tethys Ocean, by the end of the Early Carboniferous time.

At the boundary between the Early and Middle Devonian some areas of the mobile belt concerned, including those in the east, in the area of the Malopolie Massif, experienced collisions (inversion of the Caledonian miogeosyncline in the terminology of *Vishnyakov et al.* [1990]). These events were accompanied by the formation of the Lvov-Lyublin marginal trough filled with red molasse and molassoids. The final phase of the Caledonian stage affected the adjacent territory of the East-European Platform, including the Pripyat Trough and Podlyas-Brest Basin in the form of tangential compression, regional rising, and no sedimentation (see Figure 2). In the area of the Podlyas-Brest Basin, this activity continued almost throughout the Hercynian period of time.

During the Middle-Late Devonian period of Hercynian time the southwestern margin of the East European Platform developed under the conditions of general extension and sedimentation in the basins of the Lvov-Lyublya marginal basin and the in Pripyat-Donetsk rift-related trough. During the Early-Middle Carboniferous the Lvov-Lyublin Basin was formed as a marginal negative structural feature in front of the southwestern surrounding of the craton regenerated by the Hercynian movements [*Vishnyakov et al.,* 1990]. Like the Pripyat Trough, the Lvov-Lyublin Basin experienced an abrupt decline of block movements along the faults and the accumulation of coal-bearing rocks with comparable values of their thicknesses (up to 1000 m in the former and up to 850 m in the latter). At the Middle and Late Carboniferous boundary the extension was replaced by inversion and tangential compression, which was imprinted in numerous linear strike-slip thrust faults in the eastern side of the Lvov-Lublin Trough, which affected also the Carboniferous rocks. The whole of this territory was a land from the end of the Carboniferous to the beginning of the Jurassic.

At the boundary between the Middle and Late Carboniferous compression propagated, with some lagging, as far as the Pripyat Trough where it was superimposed over the late stage of the attenuating rifting. This activity accelerated the complete degradation of the rifting conditions, and the Pripyat Trough experienced, as mentioned above, regional rising and a break in sedimentation in the Late Carboniferous to Early Permian. During the latter time mainly argillaceous deposits accumulated up to a few dozens of meters in the most depressed areas, and salt-bearing sediments, which compensated the sagging caused by the halokinesis of the Devonian salt, accumulated in the narrow fore-Skoloda zone. It appears that compression affected also the Bragin-Loev Saddle and the northwestern centrocline of the Dnieper Trough. At the same time intensive sagging and the accumulation of coal- and salt-bearing deposits of a fairly large thickness continued in the central and southeastern parts of the trough. Here, the conditions of tangential compression, uplifting, and erosion grew stable much later, namely, at the boundary between the Early and Late Permian.

To sum up, the degree of the dynamic effect of the Middle European Foreland on the southwestern edge of the craton in the Late Paleozoic expressed itself in the specific evolution of the individual links of the Pripyat-Donetsk aulacogen. This activity was favored by the immediate vicinity of the Pripyat Trough to the pre-Middle European Foreland and by the distant position of the Dnieper Trough and its protection by the Ukrainian Shield from the effects of the lateral pressure from the mobile Variscan Belt of Central Europe. It was only in the Donetsk Basin that the effect of this pressure was extremely high, yet only from the south, and its source was the Scythian Hercynides.

9. Mineral Resources

Many kinds of useful minerals are associated with the paleorift structural features of the Pripyat type. These are oil- and gas-bearing rocks which are most rich and promising in the late aulacogens. Oil and gas resources were restricted in them to the main evolution period. These are multiform deposits located in faults, folds, reefs, lithologic and stratigraphic traps, etc. The example of the Pripyat Trough shows a close relationship between the location of oil deposits and the deep structure and geodynamics [*Aisberg et al.,* 1988].

Large potassium and rock-salt deposits are associated with the sediments of the Paleozoic rifts (Pripyat and Kempendyai troughs). Suffice it to remind that the Starobin deposit of the Pripyat Trough produced about 50% of potassium fertilizers in the former USSR. The most rich K contents are restricted to synsedimentation synclines and troughs. Restricted to the paleorifts of the Pripyat type are oil shale, dawsonite (aluminum and sodium carbonate raw material), mercury, as well as brines with high concentrations of Br, Sr, Li, I, and many other elements. Their rocks contain also fresh, mineral and thermal water, the latter being suitable for energy production. Also known in these paleorifts are rare and rare earth placers.

The modern data on the mineral resources of the Pripyat Trough have been summarized in the book *Khomich et al.* [2002]. The main useful minerals of the Pripyat paleorift having a commercial value and being worked are oil and potassium and rock salts. The other material promising for commercial mining are brown coal, oil shale, bauxite-lawsonite ore, and others.

Petroleum. The Pripyat oil- and gas-bearing basin (PGB) is situated in the area embracing mainly the Pripyat Graben, Loev Saddle, and a part of the North-Pripyat shoulder. Commercial oil is restricted to the Devonian subsalt terrigenous and carbonate, intersalt and upper salt-bearing rock units, and also to upper Proterozoic deposits. By the present time 181 oil pools have been discovered in 66 oil deposits: 13 pools in upper salt-bearing rocks, 69 pools in intersalt deposits, 87 pools in subsalt carbonate rocks, 10 in subsalt terrigenous rocks, and 2 in Late Proterozoic rocks. In addition, gas and gas-condensate deposits have been discovered in the Krasnoselskii Field. Prospecting and exploration of hydrocarbon deposits in the Pripyat oil and gas basin have been carried out since 1952, and exploration, since1965. According to the latest estimation of hydrocarbon prospects in the Pripyat Basin, the latter contains 192 million tons of unexplored and roughly estimated oil reserves. The total volume of the recoverable oil reserves of commercial categories ($A+B+C_1$) in the Pripyat Trough has been estimated recently as 172 million tons, the oil recovered being 110 million tons.

Although the newly discovered oil fields in Belorussia are small, the average daily production rate in new production wells is declining, and the amount of oil difficult to recover is growing, yet, considering the well-developed infrastructure of the region, it is economically worthwhile to continue oil exploration. The total period of exploration activities for oil in the Pripyat Trough included a significant volume of regional and detailed seismic prospecting work. By the present time 1350 reservoir evaluating, prospecting and exploration wells have been drilled in the major oil-promising areas.

The territory of the Pripyat oil and gas basin includes the Northern oil- and gas-bearing area and three promising oil- and gas-bearing areas: Central, Southern, and Loev. The boundaries between the Northern, Central, and Southern areas are controlled by the Chervonnaya Sloboda-Malodusha and Narovlya faults. The ranking of the Loev area as an independent object of oil and gas exploration was associated with its tectonic position, namely, its location in the Loev Saddle between the Pripyat and Dnieper troughs, and also with a significant difference between the oil-promising rocks there. The western boundary of the Loev oil and gas promising area is a crustal fault of the same name.

The oil- and gas-bearing objects of the next rank are zones and areas of oil and gas accumulation. In their integrated form, they combine all zones and areas of oil and gas accumulation in more or less extensive structural features and lithofacies elements of the Pripyat Trough, which had controlled the conditions for oil concentration in pools and deposits of different genesis and morphological expression. 26 oil and gas accumulation zones have been mapped.

The local objects of oil accumulation are fold-block, block-fold, and fold structural features. The lithofacies barriers of the same ranks are produced by systems of organic structures, sand accumulation bodies, lithologic replacement or wedging zones, and volumetric ratios between oil reservoirs and fluid-resisting rocks in one reservoir.

A particular role in the formation of oil bodies, as well as of oil and gas accumulation regions, was played by faults of different genesis, kinematic type, and magnitude. On the one hand, the system of mantle and crustal faults, producing a dense network of minor faults in subsalt and intrasalt sediments, was a main network for deep crustal heat flow which is very important for stimulating the heat sources in sedimentary rocks and for the process of oil formation. On the other hand, the faults acting under certain conditions created, directly or indirectly, a natural barrier for the migration of hydrocarbons, localizing them in structural or nonstructural traps in particular zones and localities. Finally, faults might have been the routes used by hydrocarbons for their vertical migration, or might have caused the destruction of preexisting oil pools.

The main parameters of the faults, such as their magnitudes, the types of contacts between the reservoirs and fluid-resisting rocks along the fault, the kinematics and density of faults have been taken into consideration in mapping the Devonian oil- and gas-bearing rocks in the Pripyat oil and gas basin. The paleogeodynamic data available for this region characterize, along with the fault system, the synrifting geodynamic environment of oil formation and accumulation, namely, the environment of intensive downwarping controlled by the faults of different types, in the conditions of crustal extension. The indicators of synrifting pressure are the graben extension vector, the direction of the Bragin Block movement, the deformation ellipses and the orientation of the normal stress axes of the Pripyat Graben and Bragin-Loev Saddle, the direction of the horizontal movements of the blocks, the micrograbens of extension, and others. The paleogeodynamic conditions, most favorable for hydrocarbon formation, accumulation, and preservation, had existed in the territory of the northern oil and gas basin [*Aisberg et al.,* 1999a, 1999b].

Special conditions for the localization of potential oil pools have been proposed by V. N. Beskopylnyi for the Upper Proterozoic deposits and weathering crust of the basement, this being a new element in estimating the potential oil and gas prospects of the pre-Phanerozoic oil- and gas-bearing deposits and of the weathering crust in the basement of the Pripyat and other oil and gas provinces of the East European Platform.

The low content of organic matter in the Upper Proterozoic rocks served earlier as a basis for the negative estimation of oil and gas prospects in these rocks, although some investigators (A. S. Makhnach, N. V. Veretennikov, and others) inferred the formation of oil pools there by way of oil migration from the Devonian productive rocks.

The discovery of commercial oil deposits in the Vendian rocks in the Rassvet block of the Tishkov oil field (in 1997) and in the Rechitsa oil deposit (in 1998) stimulated more active work aimed to estimate the oil and gas prospects of the Late Proterozoic deposits in the Pripyat Trough. V. N. Beskopylnyi revised the drilling results in all wells, which had entered the Late Proterozoic rocks, plotted a map of the equal thicknesses of these deposits, located areas promising for finding potential lithostructural oil traps in the zone where the Vendian deposits pinch out, and estimated the prospects of locating hydrocarbon deposits in the Late Proterozoic rocks in the areas where subsalt oil deposits had been discovered earlier. This work resulted in plotting a map for the prospects of finding new oil deposits in the Upper Proterozoic rocks.

Repeated attempts were made to find oil in the crystalline basement of the Pripyat oil and gas basin. Several holes were drilled in the Northern oil and gas region to penetrate the basement to a depth of 600–800 m from its surface for the purpose of finding and studying low-density rock zones. Several low-density rock zones were located in the basement by well logging in the zones of this type with a basement porosity of 0.1–1.1% were discovered by well logging. Water flows of 0.09 to 138 m^3 day^{-1} were obtained from these wells (at depths of 350–450 m below the basement surface). The chemical composition of the water was close to that of the water in the subsalt deposits of the Pripyat Trough. The results of the CDP seismic recording along 12 key profiles to depths of 5–7 km helped to trace 2–4 strong reflection horizons which are believed to be associated with the zones of subhorizontal low-density zones in the basement

Another trend of studying the oil-gas prospects of the basement and searching for oil deposits was associated with the study of the weathering crust to a depth of a few dozens of meters below the top. As reported by V. N. Beskopylnyi, the crust of weathering consists of three vertical zones: a lower desintegration zone, a middle leaching zone, and an upper hydrolyzed zone. The former two may contain oil reservoirs, and the latter one (zone of hydrolysis) may serve as a cap rock. The reservoir characteristics of desintegration and leaching zones may be fairly high. According to some data, porosity is 8–14%, being as high as >20% in some zones. The reservoir properties of the weathering crusts in the Pripyat oil and gas basin were poorly studied using core samples, yet, the combined analysis of the well-logging and drilling data allows one to identify these zones with a fairly high degree of certainty. Apart from the argillized rocks, the rocks of the zones of hydrolysis might have served as cap rocks above petroleum reservoirs in the eastern part of the territory, where Late Proterozoic rocks and Middle Devonian argillaceous-sulfate rocks are absent. Like in the case of the Late Proterozoic rocks, the basement weathering crusts are most promising, in terms of finding oil pools in subsalt deposits.

Rock Salt. Rock salt deposits are restricted to three stratigraphic levels in the Devonian rocks: the Eifelian salt-bearing rock sequence, not more than 70 m thick, the Late Frasnian sequence, as thick as 1100 m, and the Middle Famennian rock sequences, as thick as >2500 m (in salt domes). The local Lower Permian salt-bearing deposits, restricted to individual troughs in the middle of the Pripyat Trough, are as thick as 700 m.

The Famennian rocks are of main practical interest in terms of their salinity and the number and the purity and quality of the rock salt units. These rocks are developed over an area of more than 26 thousand square kilometers. This rock sequence includes two groups of facies. In the stratigraphic volume of the Lebedyan Horizon it is known as a Famennian halite subformation [*Vysotskii et al.,* 1988]. The depth of its roof varies from 365 to 4715 m with the thickness varying from 50 to 3350 m, the maximum thickness has been traced in the salt domes. This subformation is distinguished by the fact that merely halite is present out of chloride minerals. It composes rock salt members up to 100 m thick, which alternate with saltless rocks.

The upper group of the facies, mapped in the stratigraphic volume of the Oresa and Streshin horizons, is usually referred to as a K-bearing subformation. Its main value is potassium salt, represented by sylvinite and carnallite, with halite being the dominant mineral, so that the rock salt of this type can also be an object of mining. The rock salt was discovered in early 1941. At the present time three rock salt deposits have been commercially explored, namely, Davydov, Mozyr, and Starobin. The two latter are being mined.

The rock salt reserves are almost unlimited, their volume only in the halite subformation being 10.5 thousand cubic kilometers. The most convenient for mining by underground leaching are relatively shallow and thick salt domes with large reserves of good-quality materials. More than 100 salt domes have been mapped, the resources in each being 1 to 10 billion tons.

Potassium salt. Potassium salt deposits are restricted to three salt-bearing rock suits: Late Frasnian, Middle Famennian, and Lower Permian [*Vysotskii et al.,* 1988].

The Late Frasnian potassium salt is restricted to the rocks of the Liven Horizon where four deposits, 1 to 19 m thick, occur in the western part of the Pripyat Trough. They consist of red sylvanite. About 2.8 billion tons of potassium salt accumulated during the late Frasnian period of salt accumulation.

A potassium-bearing body is restricted to the lower part of the Lower Permian salt-bearing formation in the fore-Skoloda synclinal zone, where the K-bearing minerals are as thick as 55 m. These are carnallite, kieserite, and bischofite, and possibly K-sulphate salts. About one million tons of K and K-Mg salts had accumulated in the Pripyat Trough during the Early Permian time.

Only the Famennian K-bearing subformation, which occupies an area of 19 thousand sq. km, is of commercial value. Its thickness is 50–100 to 2670 m, the average value being 980 m. The greatest thicknesses are found in the synclinal zones, this subformation being often absent in local dome-shaped bodies. A specific feature of this subformation is its potassium horizons composed of sylvanite and less abundant carnallite (in the north and northwest of the basin), with the total ore reserves of about 200 billion tons of potassium salt (30 billion tons of K oxide). Potassium salt occurs in many-stage ore bodies. By the present time 62 potassium salt horizons, ranging from 0.5 to 40.0 m in thickness have been discovered in a depth range of 350–4026 m. The largest deposits are Starobin (mined now) and Petrikov.

Brown coal. The coal-bearing formations of the Pripyat Trough are restricted mainly to the continental rocks of Early and Middle Carboniferous, Middle Jurassic, and Neogene ages. The largest coal occurrences in the Carboniferous deposits are restricted to the rocks of the Visean and Bashkirian stages and are associated with two rock formations [*Azhgirevich et al.,* 1974]. These are variegated terrigenous kaolinite- and coal-bearing rocks and paralic, variegated coal-bearing carbonate-terrigenous rocks. Coal layers occur in synclinal zones, varying from one to several tens in number and from a few centimeters to 1.3 m in thickness. The coal-bearing formation of the middle crust is restricted to the Bukcha Depression in the southwestern part of the trough where the rocks have been classified into three coal-bearing rock sequences. The Middle Jurassic coal-bearing rocks are restricted to the Bukcha Depression in the southwestern part of the trough, where there are three coal-bearing rock sequences. The main (Bathonian) rock sequence was found to contain 1 to 21 coal seams and coal-bearing rocks with a total thickness of 20–22 m in a depth interval of 70 to 285 m. However, the commercial coal is associated only with the Neogene rocks of the Brinev Formation in the western part of Pripyat Basin. The initial material had been accumulating mainly in tidal (marsh) peat bogs [*Azhgirevich,* 1981]. The largest deposits are the Zhitkovichi, Brinev, and Tonezh ones with the commercial reserves of tens of million tons in each. The deposits consist of several seams residing at depths of 14-15 to 130 m and varying from 15 to 20 m in thickness.

Oil shale is restricted in the Pripyat Trough to the Late Famennian–Early Carboniferous (Tournaisian) rocks of a clay-marl shale-bearing formation in a basin more than 10 thousand sq. km in area with the total predicted resources of 8780 million tons. The oil shale is restricted to depths of 50–600 m with the thickness of its individual layers varying from 0.5 to 3.0 m. The geometry of the oil shale seams was controlled by the synsedimentation growth of local structural features and post-sedimentation faults.

Bauxite-lawsonite ores are restricted to the Bobrikov Horizon of the Visean rocks as a constituent of a variegated terrigenous kaolinite-coal suite. A bauxite deposit of the same name has been discovered in the Zaozernoe Area, the maximum content of bauxite in the rock being as high as 63%. The thickness of the ore bodies varies from 1.0 to 7.5 m, their depths ranging between 370 and 900 m. The commercial ore resources there have been estimated as 182 million tons. This orebody is restricted to the turtle back slope of the interdome structure.

As to the other mineral resources, we can mention commercial water represented by chloride brine saturating the Devonian intersalt and subsalt and Late Proterozoic deposits of the Pripyat oil basin, and containing bromine, iodine, lithium, and other elements.

References

Azhgirevich, L. F. (1981), *Cenozoic Brown Coal Formation of Belorussia,* 206 pp., Science and Technology Publ., Minsk.

Azhgirevich, L. F., L. M. Paler, and N. A. Savchenko (1974), Paleozoic shale and coal-bearing rocks in the Pripyat Trough, *Geology and Geochemistry of Fuel Minerals, 38,* 82–91.

Aisberg, R. E. (1986), Geodynamic evolution of the Pripyat paleorift, *Dokl. AN BSSR, 30,* (5), 460–463.

Aisberg, R. E., and E. A. Levkov (1987), Hercynian fault systems in Belorussia, *Dokl. AN BSSR, 31* (4), 343–345.

Aisberg, R. E., R. G. Garetskii, C. V. Klushin, et al. (1988), The tectonics of oil-bearing rocks in the Pripyat paleorift and its relationship with the deep crustal structure, *Sovetskaya Geologiya*, (12), 3–14.

Aisberg, R. E., and T. A. Starchik (2002), Effect of stresses in the marginal plates on the development of Hercynean structures in the south of Belarus, *Doklady NAN Belarusi, 46,* (1), 107–110.

Aisberg, R. E., R. G. Garetskii, and A. M. Sinichka (1971), Sarmatian-Turanian crustal lineament, in *Problems of Theoretical and Regional Tectonics,* pp. 41–51, Nauka, Moscow.

Aisberg, R. E., R. G. Garetskii, and T. A. Starchik (1999a), Geodynamic model of the Vendian and Devonian magmatism in the south of the East-European Craton, in *Tectonics, Geodynamics, and Processes of Magmatism and Metamorphism, Proc. XXXII Tectonic Conference,* vol. 1, pp. 31–35, GEOS, Moscow.

Aisberg, R. E., R. G. Garetskii, and T. A. Starchik (1999b), Geodynamics and mineragency of Belorussian paleorifts, *Dokl. NAN Belarusii, 43,* (3), 92–95.

Aisberg, R. E., R. G. Garetskii, and T. A. Starchik (2004), Correlation of Late Paleozoic tectonic events in the basins of the southwestern margin of the East European craton and its surroundings, *Geotectonics,* (1), 51–62.

Aisberg, R. E., V. N. Beskopylnyi, T. A. Starchik, and T. H. Tsekoeva (2001), Geodynamic conditions for Late Devonian magmatism in the Pripyat rifting zone, *Otechestv. Geology,* (3), 61–65.

Aisberg, R. E., R. G. Garetskii, V. Z. Kislik, and V. B. Okushko (1976), The dissymmetric evolution of the Pripyat Trough, *Dokl. AN BSSR, 20,* (2), 154–157.

Aisberg, R. E., E. I. Shishkin, T. Yu. Shishkina, and T. A. Starchik (1991), Geodynamic model of the Pripyat paleorift basin, *Geophys. J., 13,* (3), 17–20.

Aksamentova, N. V. (2002), *Magmatism and Paleogeodynamics of the Osnitsk-Mikashevichi Volcano-Plutonic Belt,* 176 pp., Institute of Geology, National Academy of Belorus, Minsk.

Aksamentova, N. V., and I. V. Naidenkov (1992), *Geological Map of the Crystaline Basement of Belorus and Adjacent Territories,* Scale 1:1 000 000, Explanatory Note, Kiev.

Arsirii, Yu. A., B. P. Kabyshev, V. I. Savchenko, and A. K. Tsypko (1993), Evolution, interrelation, and oil-gas regularities of individual elements in the western segment of the Sarmatian-Turanian Lineament, in *Rifting and Oil-Gas Content,* pp. 65–76, Nauka, Moscow.

Chekunov, A. V. (1976), On the spreading and rotation of crustal blocks in the course of the formation of the Dnieper-Donetsk aulacogen, *Geol. J.,* (1), 123–127.

Chekunov, A. V. (1994), On the geodynamics of the Dnieper-Donetsk rift (syneclise), *Geophys. J., 16* (3), 3–17.

Gavrish, V. K., and L. I. Ryabchun (1981), *The Genesis and Oil and Gas Prospects of Marginal Deep Faults in the Dnieper-Donetsk Rifts,* 161 pp., Naukova Dumka, Kiev.

Garetskii, R. G., (Ed.) (1976), *Tectonics of Belorussia,* 176 pp., Science and Technology Publ., Minsk.

Garetskii, R. G., (Ed.) (1979), *Tectonics of the Pripyat Trough,* Minsk.

Garetskii, R. G., and S. V. Klushin (1987), Crustal structure of the Pripyat Paleorift, *Doklady AN SSSR, 297,* (6), 1438–1442.

Garetskii, R. G., and S. V. Klushin (1989), Listric faults in the Pripyat paleorift, *Geotectonika,* (1), 48–60.

Garetskii, R. G., and S. V. Klushin (1994), The specific crustal structure and paleogeodynamics of the Pripyat Trough, in *Paleogeodynamics of Oil and Gas Basins in the East European Platform,* pp. 20–40, Monograph, Oil and Gas Institute, Belorussian Acad. Nauk.

Garetskii, R. G., L. G. Kiryukhin, N. N. Kapustin, and V. S. Konishchev (1990), *Uncompensated Troughs in the East European Platform,* 102 pp., Science and Technology Publ., Minsk.

Garetskii, R. G., A. M. Boborykin, V. A. Bogino, V. A. German, et al. (1986), Deep seismic sounding in the territory of Belorussia, *Geophys. J.,* (4), 3–8.

Gavrish, V. K. (Ed.) (1989), *Geology and Oil and Gas Prospects of the Dnieper-Donetsk Basin: Crustal Structure and Geotectonic History,* 208 pp., Naukova Dumka, Kiev.

Golubtsov, V. K. (1974), The stratigraphy of the Sargaev and Semiluki deposits in the Pripyat Basin, *Problems of Regional Geology in Belorussia,* pp. 77–113, Monograph, Science and Technology Publ., Minsk.

Gonshakova, V. I., M. D. Boichuk, N. V. Buturlinov, et al. (1968), Alkaline ultrabasic to alkaline basaltic magmatism in the zone of junction between the Big Donbass and the Ukrainian Shield, *Izv. AN SSSR, Ser. Geol.,* (9), 3–15.

Ilchenko, T. V. (1997), Some aspects of the evolution of the Dniper-Donetz paleorift (from DSS data), *Geophysical Journal, 19,* (3), 69–81.

Khomich, P. Z., et al. (Eds.) (2002), *Mineral Deposits of Belorussia, published on the occasion of the 75th anniversary of the BelNIGRI Institute,* 528 pp., Minsk.

Klushin, S. V., R. G. Garetskii, and S. A. Veres (1989), The use of a reflection survey to study the Earth crust and upper mantle in Belorussia, *Geophys. J.,* (5), 3–17.

Konishchev, V. S. (1999), Tectonics and sedimentation rate in the Pripyat Trough, *Proc. Beloruss. Academy, 43,* (1), 95–98.

Konishchev, V. S. (Ed.) (2001), *Geology of Belorussia,* Monograph, Institute of Geology, 856 pp., Belorussian Academy of Sciences, Minsk.

Korzun, V. P. (1974), Late Devonian alkaline volcanics in the Pripyat Trough, in *Tectonic Problems in the Pripyat Trough,* pp. 178–183, Science and Technology Publ., Minsk.

Korzun, V. P., and A. S. Makhnach (1977), *Late Devonian Volcanic Rocks in the Pripyat Basin,* Science and Technology Publ., Minsk.

Kruchek, S. A., and T. G. Obukhovskaya (1997), Detailed stratigraphy of Devonian deposits in the Zhlobin Saddle and adjacent areas in connection of searching for mineral deposits, in *Mineral Resources of Belarus Republic: State and Prospects,* pp. 19–21, Science and Technology Publ., Minsk.

Lukin, A. E. (1997), *Lithogeodynamic Factors of Oil and Gas Accumulation in Aulacogens,* 219 pp., Naukova Dunka, Kiev.

Lyashkevich, Z. M. (1987), *Magmatism in the Pripyat-Dnieper-Donetsk Paleorift,* 176 pp., Naukova Dumka, Kiev.

Nikitin, E. A., V. A. Drozdov, L. V. Shtefan, et al. (1999), Estimation of diamond content in Belorussian territory, in *Prospects of Finding Diamonds in Belorussia,* pp. 24–33, BelNIGRI, Minsk.

Parkhomov, M. D. (1985), Heat Flow in the Pripyat Trough, in *Seismic and Geothermal Studies in Belorussia,* pp. 124–130, Science and Technology Publ., Minsk.

Ramberg, I., and P. Morgan (1984), Physical characteristics and evolution trends of continental rifts, in *Tectonics. Proc. 27th International Geological Congress,* vol. 7, pp. 78–109, Moscow.

Razvalyaev, A. V. (1988), *Continental Rifting and its Prehistory,* 191 pp, Nedra, Moscow.

Ringwood, A. E. (1961), *Composition and Petrology of the Earth's Mantle* (in Russian), Mir, Moscow.

Seyfert, K. K. (1991), Plate tectonics, mantle plumes, and magma formation, in *Structural Geology and Plate Tectonics* (in Russian), vol. 3, pp. 72–156, Mir, Moscow.

Sollogub, V. B. (1982), The Earth's crust in the Ukrainian, *Geophysical Journal,* (4), 3–34.

Stovba, S. N., and Yu. P. Maistrenko (2001), Late Devonian extension of the Earth's crust as one of the factors responsible for the formation of heterogeneities in the crystalline rocks in the sides of the Dnieper-Donetsk Basin, *Geophys. J., 23,* (6), 67–74.

Tolstosheev, V. I. (1988), *Devonian and Carboniferous Suprasalt Deposits in the Pripyat Trough,* a monograph published, 150 pp., Science and Technology Publ., Minsk.

Uriev, I. I., and A. P. Anpilogov (1977), *Undersalt Devonian Rocks of the Pripyat Trough,* 150 pp, Science and Technology Publ., Minsk.

Velikovskaya, E. M. (1977), *Carboniferous Deposits of the Russian Platform,* pp. 176, Nauka, Moscow.

Veretennikov, N. V., V. P. Korzun, A. S. Makhnach, and A. G. Laptsevich (2000), Late Devonian volcanic rocks of the Gomel structural bridge, *Dokl. NAN, Belarus, 44,* (5), 107–109.

Vishnyakov, I. B., G. M. Pomyanovskaya, and L. E. Filshtinskii (1990), Lvov-Lyublin Paleozoic Basin, in *Geotectonics of the Volyn-Podolia Region,* pp. 169–177, Naukova Dumka, Kiev.

Voronov, P. S. (1991), Principles of strike-slip tectonics and the rotation forces of the Earth, in *Tectonic Shears and Their Role in the Formation of Mineral Deposits,* pp. 9–19, Nauka, Moscow.

Vysotskii, E. A., R. G. Garetskii, and V. Z. Kislik (1988), *Potassium-Bearing Basins of the World,* 387 pp., Science and Technology Publ., Minsk.

Ziegler, P. A. (Ed.) (1990), *Geological Atlas of Western and Central Europe* (second and completely revised edition by P. A. Ziegler), 2nd ed., The Netherlands.

Zonenshain, L. P., and M. I. Kuzmin (1993), *Paleogeodynamics,* 190 pp., Nauka, Moscow.

Zonenshain, L. P., M. I. Kuzmin, and L. M. Natapov (1990), *USSR Plate Tectonics,* Book 1, 328 pp., Book 2, 334 pp., Nedra, Moscow.

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