Strain state and crustal deformation in the central part of the ingul megablock of the Ukrainian Shield according to structural data on the Novoukrainka massif and the Subbottsy-Moshoryno fault zone

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The central part of the Ingul megablock of the Ukrainian Shield (US) is located between the Zvenigorod-Bratsk and Kirovograd fault zones, which is tectonically and metalogenically unique. That part of the US is the major section of a transregional fault belt that extends from the south to the north for 1000 km between the towns Kherson and Smolensk. This Kherson-Smolensk belt is represented by a set of submeridional faults and large intrusions, the Korsun'-Novomirgorod pluton of gabbro — anorthosites and rapakivi granites (KNP) and the Novoukrainka massif of trachytoid granites and monzonites (NU-massif) (Figure). They are divided by the latitudinal Subbottsy-Moshoryno fault zone (SMFZ). The NU-massif was intruded at ca. 2050—2035 Ma, while the KNP at ca. 1750 Ma.

The Novoukrainka massif and the Korsun'-Novomirgorod pluton. The structural research of the Novoukrainka massif is important to understand geodynamic processes in the lithosphere of the central part of the Ukrainian Shield and the formation of the Kirovohrad ore region with deposits and occurrences of uranium, lithium, gold, lead and zinc, copper, tin and silver [Granitoids ..., 1993; Starostenko et al., 2010].

Structural studies of the Ingul megablock were conducted in 2007—2009. Many features of crystalline rocks like dynamic http://www.multitran.ru/c/m.exe?a=110&t=1063694_2_1&sc=2 metamorphic mineral http://www.multitran.ru/c/m.exe?a=110&t=786494_2_1&sc=2 parageneses in cracks, zones of schistosity, cataclasis and mylonitization, spatial orientations of trachytoid textures, striation and furrows on sliding mirrors were investigated. As a result, stress conditions and the sequence of deformation events as defined by the interrelation of strain structures were obtained for the period between 2.05 and 1.75 Ga, which is isotopic age of the NU and KNP intrusions.

The formation and deformation in the NU-massif were connected with stress conditions, which caused the $\sigma_1\sigma_3$ planes both http://www.multitran.ru/c/m.exe?a=110&t=1929305_2_1&sc=228 subhorizontal and inclined. Generally, 67 % of studied fractures in the NU-massif are sub-vertical and 33 % are inclined (<70°).

The stress parameters for the NU-massif are close to those published by [Belichenko, Gintov, 1996] for the KNP i. e.: the Korsun' phase — compression (σ_1) 6/00[1], tension (σ_3) 276/00; the Gorodysche phase — compression (σ_1) 171/00, tension (σ_3) — 81/00 (Table). The preservation of strain during the time interval of ca. 250 Ma between the NU and KNP intrusions, when several deformation and fault stages occurred, is difficult to explain. We connect the early strain stage of the NU-massif to a strong EW extension of the lithosphere in the central part of the Ukrainian Shield along the future Kherson—Smolensk submeridional fault belt. This is a reason to separate the early stress phase in the NU-massif as the independent "Kherson–Smolensk" deformation stage, which repeated during the KNP intrusion after 250 Ma.

Since all faults before and after this event were shears [Gintov, 2005], there are no doubts that the Kherson-Smolensk fault belt was formed with a shear component, i.e. due to transtension. The orientation of compression axis of 8° deviates to the right from

[1] 6 — dip-azimuth / 00 — dip angle.

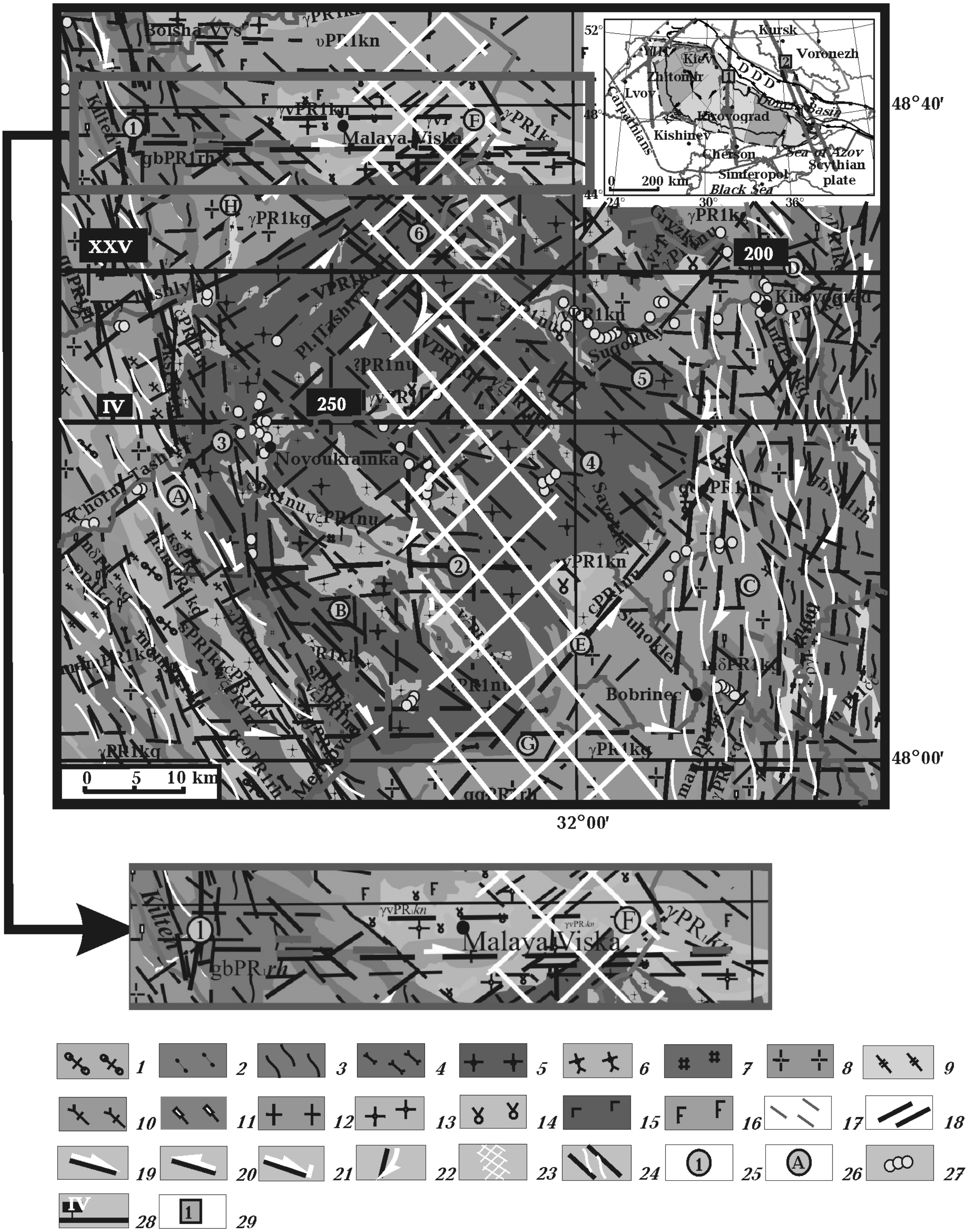

Fig. 1. Structural map of the central part of the Ingul block [as based on Kirovgeologiya' and the authors' data]. *Ingulo-Ingulets series: 1* — gneisses and biotite-cordierite schists (gcoPR_1rh); *2* — gneisses and garnet-biotite schists (ggPR_1rh); *3* — biotite gneisses (gbPR_1rh); *4* — pyroxene and biotite-pyroxene orthogneisses (sPR_1kk). *Novoukrainka complex: 5* — host granites and migmatites with biotite and garnet porphyroblasts (ãPR_1nu); *6* — host granites and migmatites with pyroxene-biotite porphyroblasts (čPR_1nu); *7* — monzonites and quartz monzonites (vξPR_1nu). *Kirovograd complex: 8* — granite and migmatite (γPR_1kg); *9* — composite gneisses (m^1PR_1čč); *10* — plagioclase migmatites and granites (mamPR_1kg); *11* — porphyroblastic plagioclase migmatite (mδPR_1kg); *12* — aplite granite and pegmatite (ñãPR_1kg). *Korsun'-Novomirgorod complex: 13* — ovoid rapakivi granite (γrPR_1kn); *14* — hybrid rocks (gabbro-monzonites, quartz monzonites) (γvPR_1kn); *15* — gabbro, gabbro-norites, norites, gabbro-diorities, gabbro-anorthosites (vPR_1kn); *16* — anorthosites (labradorite) (uPR_1kn); *17* — dykes of

the direction of this belt by 15°. This suggests a right-lateral shear component of general deformation.

During some stages transtension could pass to transpression, because the emplacement and crystallization of the granite bodies took place under side compression.

The Subbottsy-Moshoryno fault zone (SMFZ). The latitudinal Subbottsy-Moshoryno fault zone extends for 200 km within the Ingul megablock, between 48°34.5′ and 48°45.5′ north (see Figure). 750 structural measurements were carried out in 53 sites. Our results show that the SMZF faults are steep, dipping between 70 and 90°. There is evidence of the shear nature of the SMZF such as the mainly sublatitudinal http://www.multitran.ru/c/m.exe?a= 110&t=1057518_2_1&sc=2 flat-dipping (30—55°) cracks, and thrusting in 3 % cases. Furrows and striatiuon on rare sliding mirrors indicate both right- and left-lateral slip components along sublatitudinal and submeridional structures. The presence of right-lateral and left-lateral R- and R′-shears almost everywhere agrees with this kinematics [Gintov et al., 2008].

Table sums up the structural characteristics of the Novoukrainka massif and of the SMFZ and deformation stages for the period of 2.05—1.75 Ga.

Major stages and phases of deformation in the central part of the Ingul megablock of the Ukrainian Shield

Stage	Phase	Axes of stress		Type of stress	Deformation	Age, Ga
		σ_1 compression	σ_3 tension			
Krivoi Roh	Krivoi Roh	70/30	320/30	compression	Slip reverse fault	≥2.05
Kherson-Smolensk	Kherson-Smolensk	8/00	278/10	tension	transtension	2.05
Kirovoghrad	Kirovoghrad	48/00	318/00	compression	Transtension (right lateral shear)	1.9
Kirovoghrad	Lelekovka	3/00	273/05	compression	Transtension (right lateral shear)	1.9
Kirovoghrad	Bobrinets-Zhivanovka	62/05	330/35	compression	Transtension (right lateral shear)	1.8—1.9
Korsun'-Novomirgorod	Korsun'	6/00	96/00	tension	Transtension	1.75
Korsun'-Novomirgorod	Gorodysche	171/00	81/00	tension	Transtension	1.75
Korsun'-Novomirgorod	Kompanievka	90/00	360/00	compression	Transtension (right lateral shear)	1.75
Subbottsy-Moshoryno	Subbottsy-Moshoryno	134/00	45/00	tension	Transtension (right lateral shear)	~1.75
Subbottsy-Moshoryno	Adzhamka	47/00	317/00	compression	Transtension (right lateral shear)	~1.75

diabases, lamprophyres (β PR_1—PR_2); *18* — en echelon and elementary shears (kinematic indicators for the initial stage); *19* — right-lateral shear; *20* — left-lateral shear; *21* — slip-normal fault; *22* — slip-reverse fault *and thrust*; *23* — Kherson-Smolensk transregional belt; *24* — folding along faults; *25* — faults (Kirovgeologiya's data) (1 — Novopavlovka—Yaroshevka, 2 — Devladovo—Butovo, 3 — Adabashev, 4 — Nerubaevo—Lozovatsk, 5 — Shestakovka—Voroshilovka, 6 — Novokonstantinovka); *26* — fault zones, letters in circles are (A — Zvenigorodka-Bratsk, B — Novoukrainka, C — Kirovograd, D — Lelekovka, E — Mar'evska, F — Subbottsy-Moshorino, G — Bobrinetsy, H — Gladossk); *27* — sites of structural studies; *28* — profiles of DSZ (deep seismic zoning) IV and XXV (200 and 250 — picket numbers); *29* — deformation zones are shown on the right up map of the US (1 — Kherson-Smolensk belt, 2 — Donetsk-Bryansk belt).

Conclusion. The obtained results confirm the earlier idea [Gintov, 2005] about a strong extension of the lithosphere in the central part of the Ukrainian Shield which took place ca. 1.8 Ga ago. At this time the Shield was divided by the submeridional Kherson-Smolensk intracratonic fault belt, 60—70 km wide. The phases of transtension were interrupted by transpression phases, however extension predominated. This defined the emplacement both the Novoukrainka and Korsun'-Novomirgorod pluton.

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Computer modeling of nonlinear dynamic processes in structured geophysical media

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In different kinds of deformation processes practically all rocks reveal specific properties such as nonlinearity, hysteresis, dilatancy and dependence on the rate of deformation. These nonlinear properties are usually attributed to the structural constitution of the materials and to the processes taking place on contacts of structural elements: crystals, grains, granules, etc. The experiments with neutron diffraction [Darling et al., 2004] confirm the dependence of the non-classical properties of sedimentary rocks (sandstones, marble and limestone) on the deformation processes of small material volumes near bonds and contacts, inhomogeneous stresses in the grains and the pore space available for grain motion. For the explicit study of this dependence the computer simulation of dynamic deformation processes in the structured medium has been performed.

The structured medium is modeled by the discrete system of 2D deformed elements (grains). Three types of grain interaction: a) elastic, b) viscoelastic and c) elastoplastic are considered. The

Fig. 1. The grains massif.