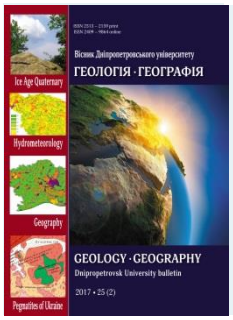

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The origin of megastructuresof the Ukrainian Shield in view of the magmatic plume concept

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Abstract. Internal tectonic structure of the Ukrainian Shield is currently seen as an association of megablocks (megastructures) divided by abyssal fractures. Within this region, six megablocks (megastructures) are differentiated: Volynski, Dnistrovo-Buzki, Rosynsko-Tikytski, Ingulski, Middle Prydniprovian and Pryazovian, the last of which is sub-divided by some researchers into two separate megablocks: Western Pryazovian and Eastern Pryazovian.Volynska, Ingulska, Middle Prydniprovian and Western Pryazovian megastructures of the Ukrainian Shield can be considered as such that formed as a result of abyssal magmatic plumes. The geological-structural position of these megastructures with obvious signs of influence of abyssal processes on their formation is in favor of this assumption. The structural-geological body of these megastructures is determined by granite-gneiss domes with the development (in some structures) in their central parts with large granitoid batholites of complex internal structure and a wide range of material composition, surrounded by synclinal- and graben-like trough structures composed of igneous-sedimentary formations metamorphized under greenschist and amphibolite facies conditions of regional metamorphism. The process of establishment of megastructures of the Ukrainian Shield, influenced by mantle plumes, didn't involve horizontal moves. The probable initiator of the following mantle plume was catastrophic sinking of a significant mass of cooled previous plume back into the mantle. This explains the time sequence of formation of megablocks of the Shield. Megastructures appeared as a result of complex multi-staged process that was similar to all of them, while the difference in age among rock complexes and certain difference in their structural position are not the criteria of different tectonic processes of the megastructure development. Conditionally, four stages of formation of megastructure resulting from the development of abyssal plume can be pointed out: *the first stage* is the rising of mantle magmatic plume from the depth; *the second stage*, intensive metamorphism of granite and basalt layers, partial melting with the formation of the above mentioned granite-gneiss domes and formation of compensation marginal troughs around them; *the third stage* is the formation of synclinorium around the domes, manifestations of intensive metamorphism of igneous-sedimentary rock masses, their ultramorphism with the formation of migmatites; *the fourth stage* is the establishing of the trough structures laid at the earlier stages with the formation of greenstone belts. At the final stage was an intensive bedding of multi-stage intrusives of two-feldspar granites.

Keywords: Ukrainian Shield,Volynska, Inguletska, Middle Prydniprovian and Western Pryazovian megastructures, gneiss granite dome-shaped structure,synclinorium, greenstone belt,plume structures

Походження мегаструктур Українського щита з точки зору плюм-концепції

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Резюме. Структурно-геологічне тіло Волинську, Інгульську, Середньопридніпровську і Західноприазовську мегаструктури Українського щита визначають гранітогнейсові куполи з розвитком (в окремих структурах) у центральних їх частинах великих гранітоїдних батолітів складної внутрішньої будови і широкого спектру речовинного складу, облямовані синклінально- і грабеноподібними троговими структурами виповненими метаморфізованими в умовах зеленосланцевої та амфіболітової фацій регіонального метаморфізму вулканогенно-осадовими утвореннями. Зазначені мегаструктури можна вважати такими, що утворилися внаслідок дії глибинних магматичних плюмів. На користь такого припущення свідчить геолого-структурна позиція цих мегаструктур з чітко вираженими ознаками впливу на їх формування глибинних процесів. Процес становлення мегаструктур відбувався під впливом мантійних плюмів і не передбачав горизонтальних переміщень. Мегаструктури є результатом єдиного для кожної із них складного багатостадійного процесу, а різновіковість породних комплексів і певні відмінності їх структурної позиції не є показником прояву різних тектонічних процесів розвитку мегаструктур.

Ключові слова:Український щит, Волинська, Інгульська, Середньопридніпровська і Західноприазовська мегаструктури, гранітогнейсові куполи, синклінорії, зеленокам'яні пояси, плюм-структури.

Introduction. The current research continues the author's research (Isakov, 2011- 1, Isakov,2011 - 2, Isakov, 2013) aiming to reconstruct the history of formation of the Ukrainian Shield crust in Middle and Late Archean and Early Proterezoic age, based on the magmatic plumes hypothesis (Hain, 1996). The authors show that separate megastructures of the Ukrainian Shield, Volynkska, Ingulska, Middle Prydniprovian and Western Pryazovian, in particular, have the same geological structure with thick granite-gneiss domes having the key structural and geological position, with the development in central parts of separate structures of batholites of complex internal structure with a wide range of material composition, surrounded by synclinal- and graben-like trough structures composed of igneous-sedimentary formations metamorphized under greenschist and amphibolite facies conditions of regional metamorphism. This similarity in geological structure of megastructures is obviously conditioned by congenial abyssal geological processes that most comprehensively can be explained using the criteria based on plume-tectonics concept.

A significant number of scientific and science-popular publications, ideas, hypothesis and concepts are dedicated to the question of the Earth formation, in general, and Earth crust in particular, at early stages of its development. At different steps of knowledge development, there were different and sometimes opposite views on the formation and tectonic development of the Earth crust. They are numerous, and firstly, they are: the concept of geotectonic, rotation hypothesis, rotation-fluid concept, pulsation and earth expansion hypothesis, ring-tectonic concept, global rotation tectonics, deep-seated differentiation concept, plate tectonics, plume-tectonics concept and many others (Hain, 1996, The planet Earth, 2004, Orovetski Yu. P., 1990, Dobretsov, 2011, Lobkivski, 2004, Gordienko, 2008, and oth.) Without deep analysis of these hypotheses, it should be noted that in the process of their development, undeniable facts have been established:

1) in the mantle, there occur continuous dynamic processes manifesting themselves in the circulation of heat gas condensate currents, and magma currents generated at different depths starting from the lower layer of the mantle at the boundary with outer core and finishing the asthenosphere;

2) these processes, and especially deep magmatic currents, make the basic moving force influencing the occurrence, development and formation of the main megastructures of the Earth crust;

3) gradual change in scale and power of the deep processes in the historical geological age starting from elementary low-powered but massive magmatic currents in Archean and Early Proterozoic era to highly-organized high-powered and whole-planet scale currents in Late Proterozoic and Phanerozoic era.

It should be noted that the focused one-directional mass attack of low-powered magmatic currents aimed at the Earth crust first resulted in the formation of sialic continental crust, as well as in the appearance of asymmetry in the structure of the Earth crust, that is formation of two parts of the Earth crust – continental (quasi-Pangea) and its opposite – oceanic part (the larger part of the modern ocean floor), and we believe that these parts virtually didn't interact. Quite possibly, this initial asymmetry was influenced by the capture of the Moon, and its catastrophic impact on the Earth in the period of the interaction between the satellite and the planet while being within the critical distance of Roche limit. Similar concepts can be found in works by J.V. Smith (Smith, 1984) where he substantiates the most plausible period of the Earth capturing the Moon after 4.5bn years, and intermediate critical condition of the Moon location in relation to the Earth, as well as possible critical heating that must have changed the surface and the bowels of both bodies. The possibility of existence and development of oceanic crust over the whole period of geological time is indicated by W. Rubey (Rubey, 1955), however the followers of plate tectonics theory further criticized his concept (Smith,1984). A.M. Goodwin explains the appearance of quasi-Pangea, similar to that of the Moon, by a gigantic meteorite bombing (Goodwin, 1980) that occurred after the Earth crust formation, during the differentiation of sialic crust.

During Late Archean – Early Proterozoic era, under the corresponding differentiation of the mantle, the increase in the power of magmatic currents into the continental crust resulted in the development of greenstone belts whose structures already were trough-like, and were ancestors of the future oceans. Thus, greenstone period was of special importance in the formation of the Earth crust and the development of the planet dating back to the period when deep magmatic currents were not powerful enough to rupture the continents resulting in the formation of full-scale oceans; at the same time they already led to the formation of greenstone structures of different thickness and gneiss-granite domes.

The period of greenstone age in the history of the Earth is estimated by some researchers as 1200m years, at the same time it covers the period from 3700Mato 2500Ma (Sutton,1980), however from our point of view the development of magmatic mantle currents causing the formation of domes and development of trough structures lasted up to 2100m years, that is why in this period the formation of the main plume structures within con-

tinental crust took place. This is manifested in our research, the results of which are presented in this article. Further the increase in the power of plume currents and their gaining planetary scale resulted in the rupture of continental crust to form oceanic trenches and to trigger the processes of edge development of the newly formed continents, which conforms to the main principles of plate tectonics theory. This theory, therefore, is no more than a hypothesis explaining the activities of more powerful plumes.

Similar order of events can be observed in the works by D.M. Shaw (Shaw, 1980), where he suggests three stages of the Earth crust formation under the action of deep magmatic currents. At the first stage (Proto-Archean era), in the process of cooling, the primary solid scale was ruptured by a number of magmatic currents–volcanoes into small pieces, thus increasing its volume and area. Greenstone period can be considered as the second stage in which, according to D.M. Shaw, there started the process of increasing the thickness of continental plate and the formation of greenstone seams as primary oceanic basin. The third stage is the formation of full-scale oceanic basins with the manifestation of modern polarity in the interaction of craton and oceanic plate. The scheme is different only in the fact that D.M. Shaw (Shaw,1980) considered the Earth to be symmetrical, arguing in this with W. Rubey (Rubey,1955).

Based on the above mentioned concepts of the megastructure development within the continental crust in the greenstone period, below we present the formation scheme of megastructures of Ukrainian Shield in the Late Archean – Early Proterozoic era. It should be noted that from the point of view of plume-tectonic development of the Earth, Early Proterozoic era is associated with Archean era to a greater extent than with later eras.

General information and regionalization of the Ukrainian Shield. Ukrainian Shield is uplifted blocks with the outcrops of formations of Archean and Proterozoic era. It has submeridional strike in the Southern part of East European platform for more than 1000 km with maximum width of 300 km, encompassing seven megastructures: Middle Prydniprovian, Pryazovian (Western Pryazovian and Eastern Pryazovian), Ingulska, Rosynsko-Tikytska, Dnistersko-Buzka and Volynska (Fig.1).

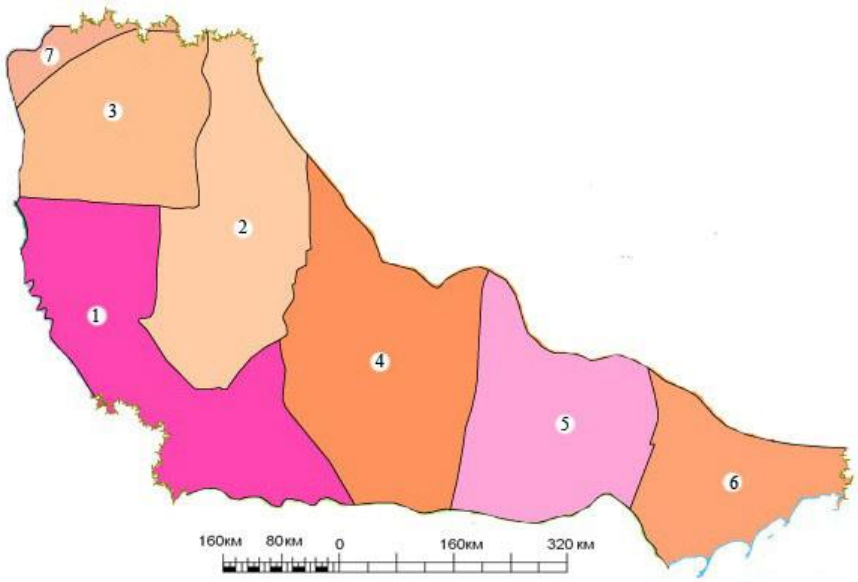

Fig. 1 Scheme of tectonic segmentation of the Ukrainian Shield**.**
1-6 –megastructures (megablock): 1 - Dnistersko-Buzka; 2 - Rosynsko-Tikytska; 3 - Volynska;4 - Ingulska; 5 –Middle Prydniprovian; 6 - Pryazovian. 7 - Volynsko-Dvinski belt.

Volynska, Ingulska, Middle Prydniprovian and Western Pryazovian megastructures can be considered as such that formed as a result of abyssal magmatic plumes. The geological-structural position of these megastructures with obvious signs of influence of abyssal processes on their formation is in favour of this assumption. The structural-geological body of the above mentioned megastructures is composed of granite-gneiss domes with the development (in some structures) in their central parts with large granitoid batholites of complex internal structure and wide range of material composition, surrounded by synclinal- and graben-like trough structures composed of igneous-sedimentary formations metamorphized under greenschist and amphibolite facies conditions of regional metamorphism. The analysis of reconstruction of the sequence of geological processes resulting in the for-

mation of these interrelated structures allows us to look at their formation from the point of view of the hypothesis of abyssal convective currents and magmatic plumes considered in (VSEGEI, 2004, Hain, 1996). Magmatic plume in each of the above mentioned megastructures was accompanied by the current of thermal energy in the correspondent time sequence of the development within lower and upper mantle, and shift of significant masses of mantle and crustal molten rock in the upper horizons of lithosphere, which played its role in the long-term development (hundreds of millions of years) and formation of almost all geological structures in megastructures. Thus, megastructures are the result of a complex multi-stage process that was common for all of them, and different age of rock complexes and certain differences in their structural positions do not indicate different tectonic processes of megastructure development.

Yu.P. Orovetski, considering the concept of mantle diapir development, also point out the influence of mantle magmatic currents on the formation of megablocks of Ukrainian Shield (Orovetski, 1990). The presence of such diapirs is proved by the seismic observations data showing large non-uniformities originating from the mantle and cutting through the Earth crust (Orovetski, 1990). The process was named trans-crust anomaly. These anomalies in gravitational fields manifest themselves in the form of positive anomalies. O.K.Malinonvki, on the basis of calculation of gravity field indicators over Surska and Sofiivska greenstone structures, suggests singling out significant bodies of high density under these structures at the corresponding depth (oral statement), these structures, from our point of view, could be the remnants of mantle plume. The area of separate anomalies reached first tens of thousands square km (Orovetski, 1990).

Plume geochemical characteristics of komatiite and basalts of Kosivtsevska structure (Artyomenko,2010), pipe-like subjacent intrusives of Kolarivski complex that developed within Saltychanski granite-gneiss dome, the first of which ("Mriia") was discovered near Kolarivka v. in 1992 (Razdorozhny, 1999) – all these are direct evidences of the influence of magmatic plume on the formation of rock complexes of Ukrainian Shield. L.V. Shumlianski points out mantle origin of a range of magmatic formations of Volynski megablock (Shumlians'ki, 2012).

Based on the general principles of the plume-tectonic concept, we made an attempt to model the formation of megastructures of Ukrainian Shield under the influence of abyssal plumes. It should be noted, that in our opinion in Mezo-Neoarchean and Paleoproterozoic the formation of megastructures of the region was undergoing without significant horizontal shifts, on the contrary to the opinion of the advocates of plate tectonics believe. The occurrence of mantle plume could be caused by catastrophic sinking of a significant mass of cooled initial plume into the lower mantle. Its descend to probable depth of 2 900 km to the so-called "D" level, being the boundary between the lower mantle and the core, resulted in the disturbance of convection in the mantle and the core, which in its turn caused the mechanism of new mantle plume. Thus, on the contrary to S. Maruiama's and oth.'s opinion (VSEGEI, 2004, Hain, 1996), there is no necessity of crust plates sinking to a significant depth; while this role is played by the plumes themselves in the Archean-Paleoproterozoic era. This explains the distribution in time of formation of Ukrainian Shield megablocks, as well as their lens-like form.

Unlikeliness of development of significant (ocean) abyssal depths within Ukrainian Shield in Archean and Early Proterozoic era is caused, presumably, by the insignificant total energy of a separate magmatic plume that was sufficient only to form granite domes with granite batholites and small-scale trough-like trenches edging the domes. The formation process of each megastructure, belonging to Ukrainian Shield in particular, under the influence of magmatic plumes in the Archean and Early Proterozoic era differ in details, but are similar in principle, as evidenced by the analysis of their geological and structural framework and history of development.

The main factors of formation of megastructures of Ukrainian Shield. Based on the above considerations, we look at characteristics of four megastructures (Volynska, Ingulska, Middle Prydniprovia and Western Pryazovia) that are the clearest representatives of plume structures of Ukrainian Shield.

Western Pryazovian megastructure. Gradual mutually influenced development of the megastructure (Isakov, 2011 - 2, Isakov, 2013) respectively had its effect on the formation of its tectonic structures of higher order. Resulting from abyssal processes, there formed Vovchanski and Saltychanski middle granitoid-gneiss domes and compensation structures of surrounding Orichovo-Pavlogradski and Maloienisolski synclinorium are represented by a think isocline folding. Granite-gneiss domes composed of the formations of Western Pryazovian series of the Archean age, and heterogenous Saltychanski and Guliaipilski granite rock masses represented by plagiogranites, tonalites, diorites, and occasionally gabbro of Shevchenkivski and Obitochnenski complexes of Late Archean age (2.8Ma). Synclinorium structures, united in the central part into a common area composed of Vovchanska, Dragunska and Novopavlivska rock

masses of crystalline schist and gneisses of different composition of amphibole stage of metamorphism, and Central Pryazovian series of high-aluminous formation, whose age ranges from Early Archean to Late Proterozoic age, which suggests a complex structure of synclinores. Greenstone structures are located in the areas of joining synclinorium and uplifted domes, and form two subparallel segmented half-circle greenstone belts – Shevchenkivsko-Berestivski and Sorokinsko-Gaichurski belt with the total length of more than 250km. The former is composed of the following trough structures: Shevchenkivska, Fedorivska, Vovchanska and Dibrovska surrounded by Vovchanski dome: Pavlivskaand Berestivska trough structures within Maloianisolski synclinorium. Sorokynsko-Gauchurski greenstone belt is formed by Sorokinska and Dragunska trough structures surrounded by Saltychanski granite dome, as well as Kuibyshevska and Kosivtsivska trough structures surrounded by Guliaipilsky granite dome. Separate structures are up to 40km long and 1km to max 5km wide, formed by volcanic-terrigenous rocks of Osypenkivska series and Kosivtsivska and Ternyvatska rock masses of Meso-neo Archean with similar composition, metamorphized under greenstone to amphibolite facies of regional metamorphism. Along these structures, granite rock masses of Yanvarski and Saltychanski complexes whose age is estimated from 2.7 to 2.2Ma (Fig. 2).

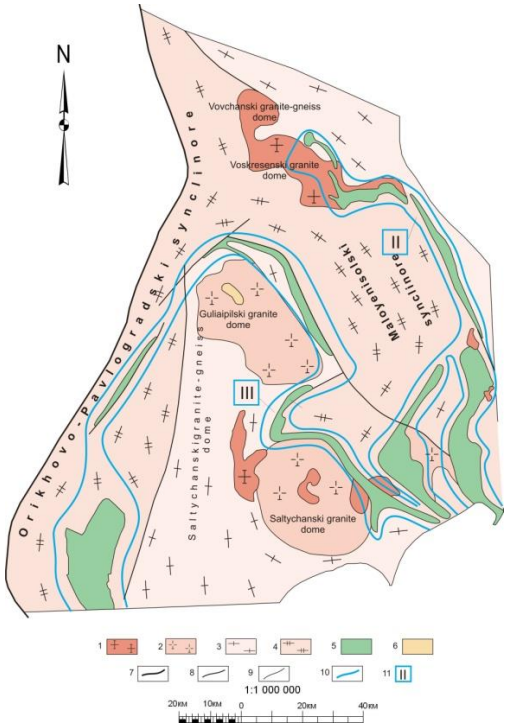

Fig. 2 Geological map of Western Pryazovia megastructure.
1 – two-feldspar granites of Dobropilski, Saltychanski and Yanvarski complexes; *2* – plagiogranites, tonalites of Shevchenkivski complex; *3* – metamorphic Western Pryazovian series and ultrametamorphic Novopavlivski complex of dome structures; *4* – metamorphic formations (Vovchanska and Dragunska), Central Pryazovian series and ultrametamorphic complexes (Remivski and Tokmatski) of sutural zones; *5* – metamorphized igneous-terrigenous complexes (Osypenkivska series and Novogurivska, Ternuvatska, Kosivtsivska formations) of trough structures of greenstone type; *6* – terrigenous complex esoffault-linesuperimposed structure (Guliapilskasuite); *7* – local abyssal fractures; *8* – other fractures; *9* – geological boundaries; *10-11* –greenstone belts: II – Sorokynsko-Gaichurski; III – Sorokynsko-Gaichurski;

Four stages of formation of Western Pryazovian megastructure resulting from the development of abyssal plume can be pointed out (Isakov, 2011 - 2, Isakov, 2013)(Fig. 3):

the first stage is the rising of mantle magmatic plume from the depth, resulting in both direct influence and powerful heat flow on the earth crust, causing gradual rise of protocrust in the vicinity of modern Vovchanski and Saltychanski granite-gneiss domes with separation and intensive individual development of Western Pryazovian megastructure;

the second stage, a powerful heat flow caused intensive metamorphism of granite and basalt layers and resulted in their partial melting with the formation of the above mentioned granite-gneiss domes and formation of compensation marginal troughs around them, the troughs being filled by sedimentary and igneous sediments with further formation of Orihivsko-Pavlogradski and Maloenisolski synclinorium;

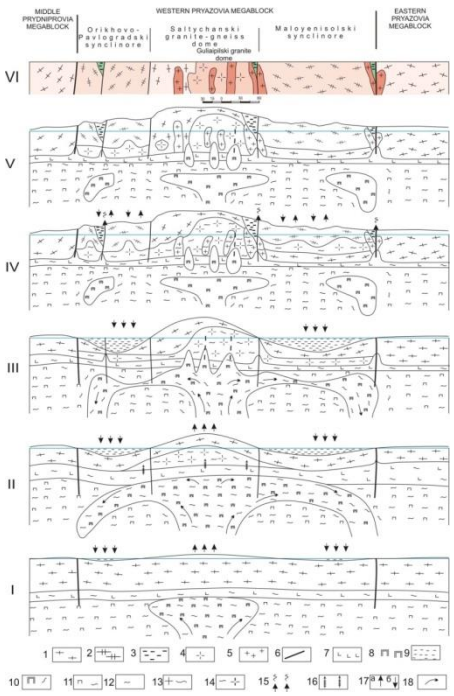

Fig. 3 Development scheme of Western Pryazovianmegastructures.

1 – megamorphic series (Western Pryazovian, Aulska) and ultrametamorphic complexes (Novopavlivski, Dnipropetrovski) of dome structures; *2* – metamorphic igneous-terrigenous rock masses (Vovchanska and Dragunska) and ultrametamorphic complexes (Remivski) of synclinore zones; *3* – metamorphied igneous-terrigenous complexes of trough structures (Osypenkivska series and Novogurivska, Ternuvatska, Kosivtsevska rock masses); *4* – plagiogranies, tonalites of Shevchenkivski complex; *5* - two-feldspar granites of Dobropilski and Yanvarski complexes; *6* – regional abyssal fractures; *7* – basalt layer (basalts, charnokite, two-pyroxene-crystall-slates); *8* – asthenospheric layer (half-molten, molten rock complexes of mafic composition); 9 – residual massifs of mantle plume; *10* – igneous-terrogenous formations of Vovchanska, Novopavlivska and Dragunska rock masses; *11* – mantle plume; *12* – molten basalt layer; *13* – plagiogranite magma; *14* – granite magma; *15* – volcanoes of the main magma; *16* – abyssal heat currents; *17* – vertical lithospheric movements; *18* – directions of mantle plume movement

the third stage is the formation of Orihivsko-Pavlogradski and Maloienisolski synclinorium around domes, manifestations of intensive metamorphism of formations of Novopavlivska and Vovchanska igneous-sedimentary rock masses, their ultramorphism with the formation of migmatites of Remivski complex. In the central parts of Vovchanski and Saltychanski granite-gneiss domes with some delay from Remivski ultrametamorphism there is an intensive bedding of granite batholites of Shevchenkivski complex, which evidently instigated a greater rise of the foundation. On the dome rims, simultaneously with their establishing, and, probably, after some insignificant time, resulting from compensation processes there was filling and intensive refilling of trough structures by igneous-sedimentary formations;

the fourth stage is the establishing of the trough structures laid at the earlier stages in the Western Pryazovian megastructure with the formation of greenstone belts. At the final stage was an intensive bedding of multi-stage intrusives of two-feldspar granites of Yanvarski, Dobropilski and Saltychanski complexes in the dome selvedge within trough structures.

The final touch in the formation of megastructures in the period of obviously full attenuation of plume activity, in the central part of Saltychansky granite-gneiss dome, was the formation of insignificant dips resulting in the formation of Guliaipilska brachystructure, as well as the development of lateral abyssal fractures that might be associated with the intrusion of alkali and carbonate magmas of Chernigivski complex into the upper layers of lithosphere.

Middle Prydniprovian megastructure is attributed to the category of specific lower Pre-Cambrian geostructural elements of the Earth crust – granite-greenstone areas (Bobrov,2002, Bobrov,2006,Yesypchuk,2000, Sivoronov,1983, Shcherbakov, 2005) or folded-dome greenstone belts (Salop, 1982) associated with large pegmatite provinces in other shields –Yilgarn in Australia, Winnipeg-Nipigon Abitibi in North America and oth. Megablock is characterized by relative time sequence of change of geological conditions similar

to the above provinces in the formation of rock complexes as well as their effect on the development and establishing of pegmatite fields.

Closely connected structural subdivisions (Fig. 4) take part in the formation of megastructure: 1) Saksaganski, Zaporizki, Piatyhatski, Demurynski, Slavgorodski and other granite-gneiss and migmatite-gneiss domes consisting of supracrustal formation of Aulska series and Dniprovski and Slavgorodsky plagiogranite-migmatite and enderbite-charnokitoid 2) Kryvorizko-Kremenchutski, Bazavlutski and Konsko-Bilozerski greenstone belts presented by Vysokopilski, Sortomlytski, Sofiivski, Verkhivtskivski, Surski, Zhovtovodski and other greenstone depressions of apo-volcanic formations of Konkska series and apo-sedimentary formations of Bilozerska series; 3) plagiogranites massives of Saksaganski and Surski complexes associated with greenstone structures; 4) polyphase granite massives: Demurinski, Mokromoskovski, Tokivski, Orilski and oth. associated with greenstone structures. Middle Prydniprovianmegastructure is a plume structure of the Ukrainian Shield by the structural framework and history (Isakov, 2013).

The lower boundary of Konkska series age is determined with the age of zircon from metavolcanites of Surska suite – 3170 Ma, and the upper boundary – with the age of zircon from plagiogranites of Surski complex – up to 2960 MA. The lower boundary of Bilozerska series age is determined with the age of zircon from metakeratophyre – 3000 Ma. The upper boundary of greenstone rock mass in general is determined with the age of the newest granites of Demurinski and Mokromoskovski complexes that break through it - 2850–2700 Ma (Shcherbak,2005)

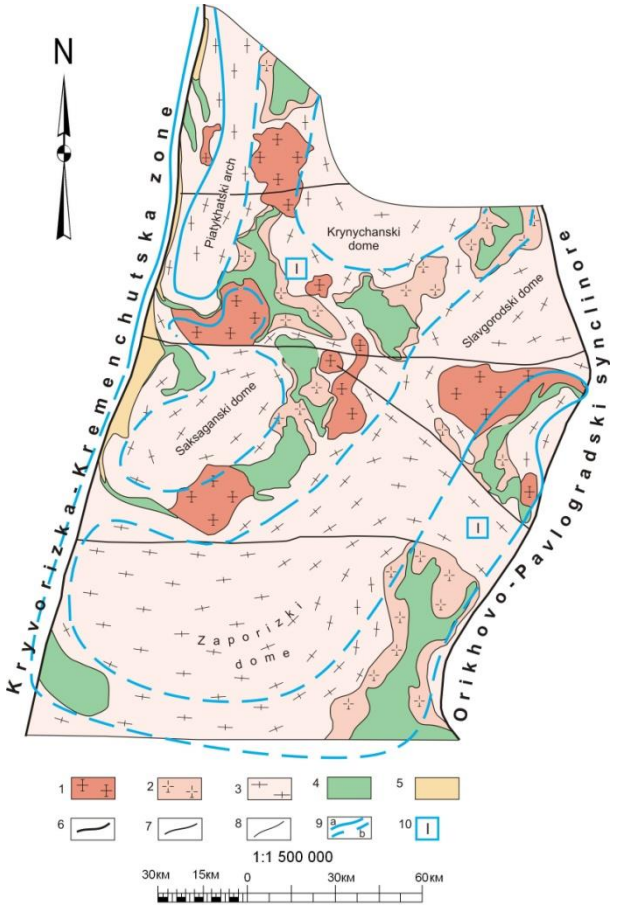

Fig. 4 Schematic geological-structural map of Middle Prydniprovia nmegastructures.
1 – two-feldspar granites of Demurski, Tokivski, Mokromoskovski complexes; *2* – plagiogranites, tonalites of Surski and Saksaganski complexes; *3* – metamorphic series (Aulska) and ultrametamorphic complexes (Slavgorodski and Dnipropetrovski) of dome structures; *4* – metamorphized igneous-terrigenous complexes of trough structures of greenstone type (Konkska and Bilozerska series); *5* – terrigenous complexes of fault-line superimposed structures (Kryvorizka series); *6* – abyssal regional fractures; *7* – fractures; *8* – geological boundaries; 9a,b-*10*–greenstone belts: I – Kryvorizko-Kremenchutski, Bazavlutski and Konsko-Bilozerski.

In its development, can be singled out four stages of structure formation (Fig. 5).

The first stage – under the influence of heat currents initiated by the plume, intensive heating up of continental crust, resulting in the initiation of ultrametamorphism centers.

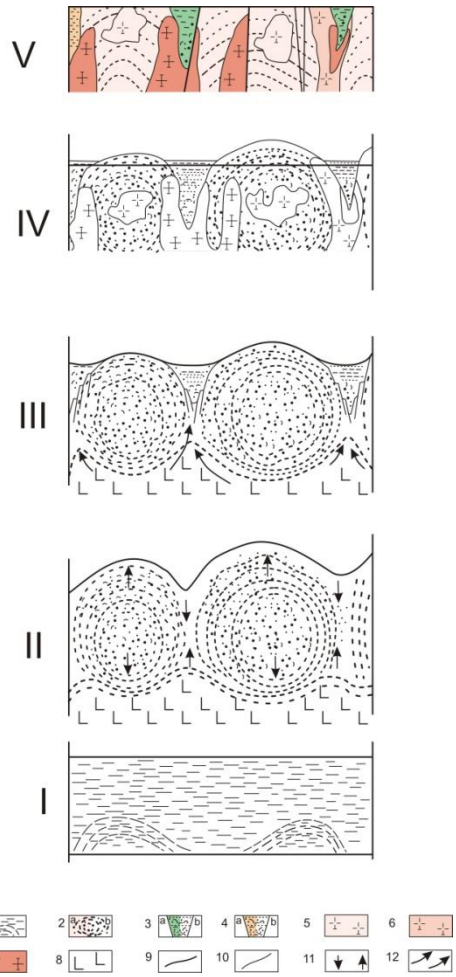

Fig.5 The scheme of development of pegmatite processes within the Middle Prydniproviamegastructures.
1 – igneous-terrigenous formations of Aulska series with the centers of genesis of ultramorphic areas; *2* – dome structures composed of metamorphic formations of Aulska series and migmatites of Dnipropetrovsk complex; *3* – trough structures of greenstone type composed of igneous-terrigenous formations of Konkska (*a*) and Bilozerska (*б*) series; *4* – trough structures of greenstone type composed of igneous-terrigenous formations of Konkska (*a*) and Bilozerska (*б*) series; *5* – palingenic plagiogranites of Dnipropetrovsk complex; *6* – intrusive plagiogranites of Surski and Saksaganski complexes; *7* – intrusive two-feldspar granites of Demurski, Mokromoskovski and Tokivski complexes; *8* – basalt layer; *9* – regional abyssal fractures; *10* – geological boundaries; *11* – directions of tectonic movements and stress; *12* – directions of movement of magmatic currents (basite and ultrabasite magmas).

*The second and third stages*are the intensive dome formation and establishing and formation of trough structures. The second period covers the time of establishing of dome structures accompanied by ultrametamorphic processes and the formation of charnokite-granulite and plagiogranite-amphibolite rock formations, as well as the establishing of trough structures; the third period is characterized by further development of dome structures, bedding of large plagiogranite massifs and intensive sinking of trough valleys that started to form around domes with the building-up of igneous-sedimentary rock masses. The events of this process can be imagined in the following sequence. Under the effect of intensive heat currents initiate by abyssal magmatic plume within the megablock, in its most active centers there started dome formation accompanied by ultrametamorphism and simultaneous granitoidmagmatism. At the flanks of ultrametamorphic domes and in intradome space there simultaneously started the formation of a set of trough warping that were quickly filled by ultrabasite and basite volcanic rock from the lower crust and deeper layers, as well as, probably from abyssal magmatic plume. Accumulated multi-kilometer rock masses, under the influence of thermal currents in the lower part, experienced the effect of high-temperature metamorphism with the manifestation of ultrametamorphism. The latter initiated the formation of centers of development of large magmatic reservoirs and building up of the crust in the places of their maximum development with the formation of dome structures. In addition, the formation of large quantities of molten masses in dome centers and vertical expanding of the domes initiated the inflow of molten sialitic mass from sides. As a consequence of the increase of the general mass of domes there occurred a certain sinking

of crust into the upper mantle layer on the area of its development. Accordingly, there formed weakened areas in earth crust away from the dome centers. There was a sort of granulation of the crust layer. Within the weakened areas there occurred compensation processes. They manifested in the formation of trough sags on the surface of the crust layer and rising mantle astenoliths opposite, being the source of ultrabasite and basite magma intensively bedding within trough sags by filling them. The stage of building up sedimentary rock masses finished.

At the final stage of formation of dome granotoid structures and development of intradome tectonic zones were occurring simultaneously. Thus were formed Saksaganski, Piatyhatski, Zaporizki, Slavgorodski and other domes, and greenstone structures (Surska, Konkska, Verhivtsevska, Chortomlytska and oth.) that developed in their margins, forming Kryvorizko-Surski and Konkso-Bilozerski greenstone belts.

*The fourth stage*is associated with tectonostructural formation of greenstone structures and intensive bedding from magmatic chambers formed as a result of intensive heating, around basite-ultrabasite astenoliths and join canals, in marginal tectonic zones and within greenstone structures of plagiogranite and granite magmas. This led to the formation of massifs of plagiogranites of Surski and Saksaanski complexes during the first stage, and during the second stage – to high-differentiated granite intrusives of Demurynski, Mokromoskovski and Tokivski complexes.

Ingulska and Volynska megastructures. Key structural-geological position in the structure of these megablocks is taken by thick granitoid batholites of complex internal structure and wide range of composition. Analysis of restored sequence of geological processes causing their formation gives an opportunity to regard these megablocks based on the hypothesis of abyssal convection current and magmatic plumes (Isakov, 2011- 1, Isakov, 2013).

In the formation of ***Ingulska megastructure*** the following tightly connected structural unites take part: 1) Novoukrainski and Korsun-Novomyrgorodski plutons (magmatic dome); 2) the system of synclinore structures (Bratska and Pryingulska), their fringing; 3) Golovanivska and Kryvorizko-Kremenchutska inclining (suture, according to (Drannyk,2003, Geoinform, 2006) zones fringing the megablock (Fig.6).

Novoukrainski and Korsun-Novomyrgorodski plutons are located in the central part of Ingulski megablock, and form a certain dome-like structure. Migmatite-gneiss part of this dome-like structure is formed by the oldest ultrametamorphic formations of arch-like (partly aerial) apical part.

The system of synclinorium structures of the surrounding magmatic dome (Bratska – from the West, Pryingulska – from the East) make a common area uniting in its Southern part. They are composed of gneiss, crystalline schist and amphibolite of Ingulo-inguletska series, metamorphized in epidote-amphibolite and amphibolite facies of metamorphism. The internal structure of synclinorium is composed of a range of adjacent isoclinal and brachial anticlinal and synclinal folds intruded by granite formations of Kirovograd complex (and mainly uplifted in the form of small dome structures).

Golovanivska and Kryvorizko-Kremenchutska areas surrounding the megablock are most probably the slope of old megablocks, to some extent engaged in the processes going on in the main part of the megablock.

Isotropic age of granite formations ranges between 2.0 Ma (Kirovograd granites) to 1.75 Ma (granites of Korsun-Novomyrgorodski pluton).

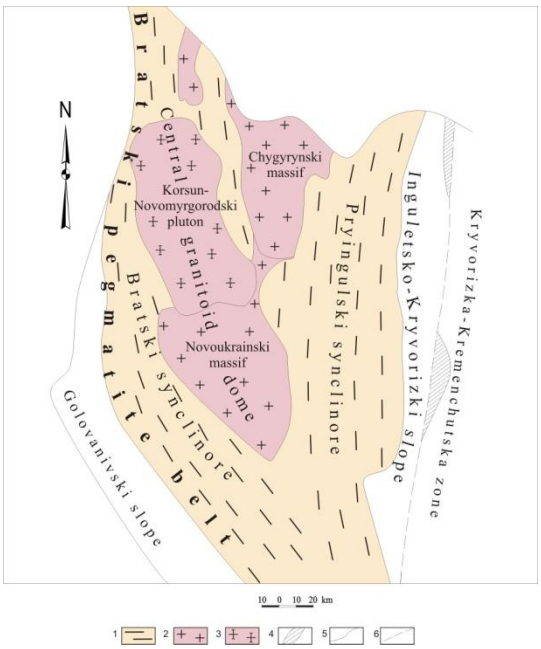

Fig. 6 Contour map of Ingulski megastructures.
1.Small-dome structure of Bratski and Pryingulski synclinoria formed by rock formations of Ingulo-Inguletska series and granites of Kirovograd complex. 2. Intrusive formations of Novoukrainski complex. 3. Intrusive formations of Korsun-Novomyrgorodski complex. 4. Metaterrigenous formations of Kryvorizka series. 5. Geological boundaries. 6. Fractures.

Within ***Bolynska megastructure*** there are singled out the tightly connected structural units: 1) Gorognytsko-Korostenski ultrametamorphic magmatic dome (Gorodnytsko-Yemilchynski granite-migmatite dome and Korostenski pluton); 2) the system of synclinoria structures forming Pivdenno-volynski synclinorium (Teterivski dip, after V.A. Riabenko, or Zhytomyrski synclinorium, after V.M. Klochkov); 3) Ovrutskagraben-synclinal with its Bilokorovytski and Vilchanski branches. Both by formation and age, the structure is close to the Ingulska one (Fig.7).

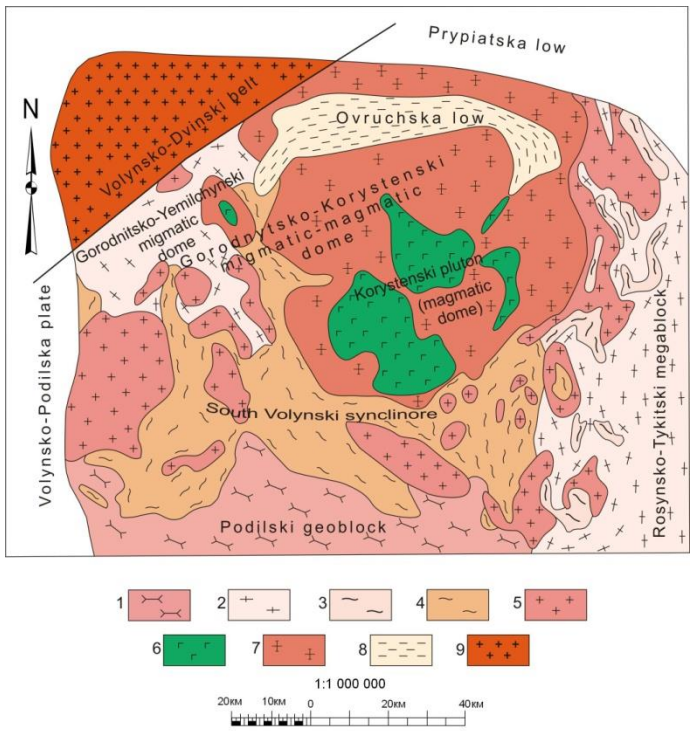

Fig. 7 Contour map of Volynski megastructures.
1 – migmatites and granites of Pobuzki complex; 2 – migmatites of Sheremetivski and Tetiivski complexes; 3 – rock complexes of Rosynsko-Tikytska series; 4 – rock of Teterivska series complex; 5 – granites of Zhytomyrski complex; intrusive formations of complex (6 – gabbro, 7 – granite); 8 – rock of Ovrutska series somplex; 9 – granites of Perzhanski complex.

The general development of Ingulska and Volynska plume-structure are similar and conditioned by the following sequence of geological events (Fig. 8, 9).

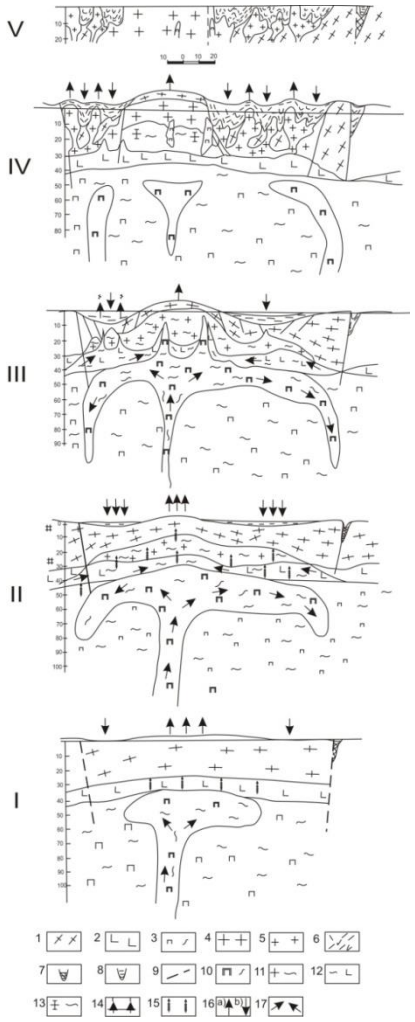

Fig. 8 Development scheme of Ingulskimegastructures**.**
1.-Granite layer of earth crust (migmatites, granite-gneiss, crystal-schist); 2.- Basalt layer (basalts, charnokites, two-pyroxene crystal-schist); 3.- Asthenospheric layer (half-molten, molten rock complexes of basic, ultrabasic composition); 4.- Granites of Novoukrainski complex; 5.- Granites of Kirovogradski complex; 6.- Rock complexes of Ingulo-inguletska series; 7.- Archean Kryvorizko-Kremenchutski trench filled with greenstone rock; 8.- Rock complexes of Kryvorizka structure; 9.- Abyssal fractures; 10.- Mantle magmatic plume (magma of ultrabasic composition); 11.- Granite magma; 12.-Basic magma; 13.- Residual reservoir of granite magma that further formed Korsun-Novomyrgorodski pluton; 14.- Volcanoes of basic magma; 15.- Direction of movement of high-temperature heat current caused by mantle plume; 16.- Directions of vertical movements of earth crust: a) rising; b) dipping; 17.- Directions of movements of abyssal currents.

The first stage is the rising from the depth of magmatic plume that caused powerful heat current and gradual rising of the main granite dome. Powerful heat current also resulted in intensive metamorphism of granite and basalt layers and their partial melting;

The second stage is the continuation of rising from the depth and spreading to the width of megastructure of mantle magmatic plume. Heat current caused intensive melting of granite and basalt layers. These two processes resulted in further rising of the main granite dome and formation of compensation edge dips that started to fill with sedimentary and igneous sediments;

The third stage is the formation of a huge magmatic reservoir filled with differentiates of granite, basite and ultrabasite magmas, and their intrusion into the surface layers of lithosphere with the development of acidic and basic volcanism and acceleration of formation of large dips around the main granite dome, the dips being filled with sedimentary-igneous sediments which further formed Ingulo-Inguletska and Teterivska series, accordingly;

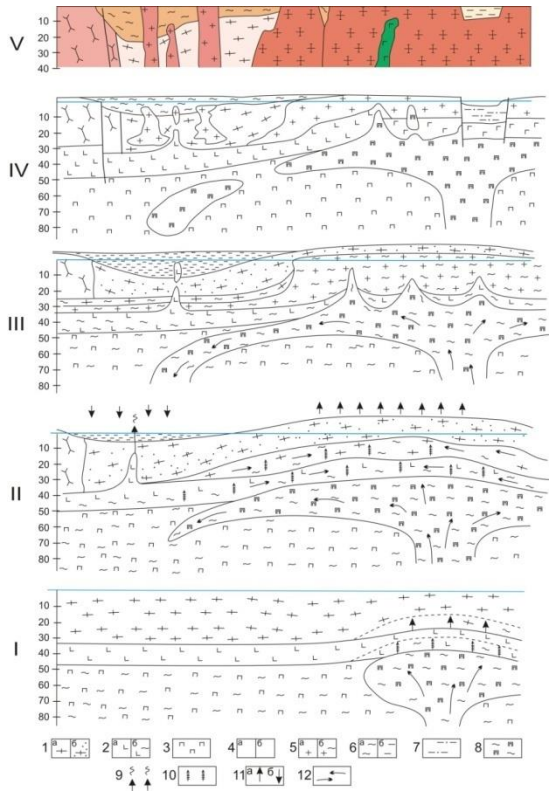

Fig. 9 Development scheme of Volynski megastructures.
1 – a) Granite layer of earth crust (migmatites, granite-gneiss and schist); b) partial melting (superimposed migmatization) of granite layer. 2 – a) Basalt layer (basic basalts and schist); b) molten layer (basic magma). 3 – Astenospheric layer (half-molten and molten rock formations of basic and ultrabasic composition. 4 –Rock formations of magmatic plume: a- ultrabasic abyssal rocks; b- magma of ultrabasic abyssal rocks. 5 – Granites of Zhytomyrski and Korostenski rock masses.Magma forming the granites of Zhytomyrski and Korostenski massifs. 6 – a) Rock complexes of Teterivska series; b) igneous-sedimentary rocks forming rock complexes of Teterivska series. 7 – rock complexes of Ovrutska series. 8 – Mantle magmatic plume. 9 – Volcanoes of basic magma. 10 – High-temperature heat currents caused by mantle plume. 11 – Directions of vertical movements of earth crust: a- rising, b- dipping. 12 – Directions of movement of magmatic currents.

The fourth stage is extinction of the activity of magmatic plume and its influence on geological processes within megablock. Along with it there increased the influence of lithospheric pressure on megablock in general and the formed magmatic part in particular. This caused general pit-like fault of surface, differentiation of magmatic part and intrusion of differentiates into upper layers of lithosphere with residual formation of central granite domes, with intrusion of significant amount of magmatic mass into near-surface layers within Ingulski megablock, and formation of large massifs of Novoukrainski and Chygyrynski domes and a set of small domes composed of granites of Kirovogradski, Novoukrainski and Zhytomyrski complexes and other small massifs of different composition within synclinoria structures. It should be noted that intensive formation of domes cause metamorphism of rock mass of sedimentary-igneous rocks of Ingulo-Inguletska and Teterivska series and their crumpling with the formation of a range of synclinal folds in intradome space;

The fifth stage is the upheaval of residual magma of abyssal magmatic environment in subsurface part of domes and the formation of Korsun-Novomyrgorodski and Korostenski plutons.

This finished the formation of Ingulska and Volynskamegastructures, and further denudation processes led to the opening of magmatic (Novoukrainski, Korsun-Novomyrgorodski and Korostenski complexes) massifs forming domes, as well as earlier synclinore structures surrounding them formed of metaigneous-sedimentary sediments of Ingulo-Inguletska and Teterivska series and complicated by small domes formed of granitoids of Kirovogradski and Zhytomyrski complexes.The above considerations about the development of magmatic plumes within the Ukrainian Shield are generalized in the Table

Table. Development stages of the Ukrainian Shield megastructures formed under abyssal magmatic plumes

Main phases of magmatic plume development	Main influencing factors of plume on the lithosphere	Development stages of the Ukrainian Shield megastructures formed under abyssal magmatic plumes				Generalisation
		Archean age		Proterozoic age		
		Middle Prydniprovian megastructure	Western Pryazovian megastructure	Ingulska megastructure	Volynska megastructure	
phaseVI– post-plume	Decrease in heat current, increase in lithostatic pressure	Not evident	Formation of failures in central parts of the dome, resulting in the appearance of brachistructures (Guliaipilska) and lateral abyssal failures with the intrusion of alkali and carbonate magma (Chernigivski complex)	Not evident	Formation of failures in central parts of the dome, resulting in the appearance of Ovrutska graben-syncline with its Bilokorovytska and Vilchanska branches	Under lithostatic pressure, in the centre of the dome failures are likely to occur resulting in the formation of brachistructures and lateral failure zones with abyssal magma intrusion
phaseIII– final, plume attenuation	Localization of heat and magmatic currents	Completion of greenstone structures and granite-gneiss domes formation. Intrusion of granites into greenstone zone with the formation of Demurski, Mokromoskovski, Tokivski and Orilski rock mass	Intensive filling with volcanic-sedimentary rocks with further formation of greenstone trough structures that further resulted in the occurrence of Shevchenkivsko-Berestivski and Sorokynsko-Gaichurski belt along the central dome perimeter. Embedding of intrusive granites of Yanvarski and Saltychanski complexes into greenstone structures zone.	Formation of Novoukrainski and Korsun-Novomyrgorodski granite plutons in the centre of the dome.	Formation of Korostenski granite pluton in the centre of the dome	For Archeanmegastructures: completion of greenstone structures formation. Embedding of granite intrusions in greenstone structures. For Proterozoic megastructures: formation of granite pluton in the centre of the dome
phaseII - principal, intensive development of plume	Intensive heat and magmatic current	Formation of Saksaganski, Zaporizki, Piatyhatski, Demurski, Slavgorodski and other granite-gneiss domes, intrusion of magmatic currents into intradome zones, and formation of Vysokopilska, Chortomlynska, Sofiivska, Verhivtsivska, Surska, Konkska and other trough structures	Establishing of central granite-gneiss dome (Vovchanski and Saltychanski fragments) and formation of compensation marginal troughs with further metamorphism of the accumulated rock masses with the formation of synclinore structures (Orihivsko-Pavlogradski and Maloienisolski synclinoria).	Establishing of noname central granite-gneiss dome, and formation of a large magmatic reservoir in its centre. Formation of compensation marginal troughs around the dome with further metamorphism of the accumulated rock masses with the formation of Bratska and Pryingulska synclinoria structures.	Establishing of central Gorodnytsko-Emilchynski granite-gneiss dome, and occurrence of a large magmatic reservoir in its centre. Formation of compensation marginal troughs around the dome with further metamorphism of the accumulated rock masses with the formation of Pivdennovolynski synclinorium.	Establishing of the central dome or a range of granite-gneiss domes, and formation of compensation marginal troughs around the them with further metamorphism of the accumulated rock masses with the formation ofsynclinore structures or trough greenstone structures
phaseI - initial, uplifting of magmatic plume	Intensive heat current	Intensive metamorphism and ultrametamorphism of the crustal layer, formation of central domes, and the initial stage of their uplifting	Intensive metamorphism and ultrametamorphism of the crustal layer, formation of central domes, and the formation of the centre, and the initial stage of uplifting of the median dome	Intensive metamorphism and ultrametamorphism of the crustal layer, formation of the centre and initial stage of uplifting of the median dome	Intensive metamorphism and ultrametamorphism of the crustal layer, formation of the centre and initial stage of uplifting of the median dome	Metamorphism and ultrametamorphism of crustal layer, formation of the centre (centres), and the initial stage of uplifting of the median dome (domes)

Conclusions.

1. Magmatic mantle currents that resulted in the formation of plume-structures of the Ukrainian Shield belong to one series of deep mass transfer that has been in action ever since Pre-Archean era. In the first stage (Proto-Archean era), in the cooling

process, the primary unstable crust was being ruptured by a large number of magmatic currents close to the surface – volcanoes – into fine pieces, thus increasing its volume and area; during greenstone period, now influenced by mantle magmatic currents, greenstone seams were being formed as ancestors of oceanic basins. The third stage is the development of pan-magmatic mantle currents that resulted in the formation of full-scale oceanic basins in Late Proterozoic and Phanerozoic era.

2. In the period between 3100Ma and 1750Ma, the action of magmatic currents on the Earth mantle within the Ukrainian Shield caused discrete gradual formation of plume structures within its boundaries. These processes resulted in the development of a range of megastructures that are similar in structure, but practically not interconnected –Middle Prydniprovian and Western Pryazovian megastructures are of Middle and Late Archean, and Volynska, Ingulska are of Early Proterozoic era. The period of formation of Early Proterozoic megastructures is estimated as 250 Ma (2000-1750 Ma), and Archean, accordingly as 325 Ma (3175-2850) and 300 Ma (2900-2600 Ma), however here there is a scatter in the age data from 3130 to 2200 Ma, which is unlikely.

3. The main components of the above mentioned megastructures are thick gneiss-granite domes, or batholites of complex internal structure framed by synclinoria and graben-like trough structures composed of metavolcanic-sedimentary formations metamorphized under the condition of greenschist and amphibolite facies of regional metamorphism.

4. The process of establishment of megastructures of Ukrainian Shield, influenced by mantle plumes, didn't involve horizontal moves. The probable initiator of the following mantle plume was catastrophic sinking of a significant mass of cooled previous plume back into the mantle. This explains the time sequence of formation of megablocks of Ukrainian Shield.

5. Megastructures appeared as a result of complex multi-staged process that was similar to all of them, while the difference in age among rock complexes and certain difference in their structural position are not the criteria of different tectonic processes of the megastructure development.

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