Central Ukraine Uranium Province: The Genetic Model

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Tasks:

- Geological position
- Tectonic and structural control
- Mineral-forming stages:

- Mineralogy
- Elemental and isotopic geochemistry

- Regional model

Grade and tonnage

- *Average grade is low – from 0.05 to 0.20 wt% U*

The exhausted U deposits:

Zhovta Richka (18,900 t U)

Pervomaysk (11,000 t U)

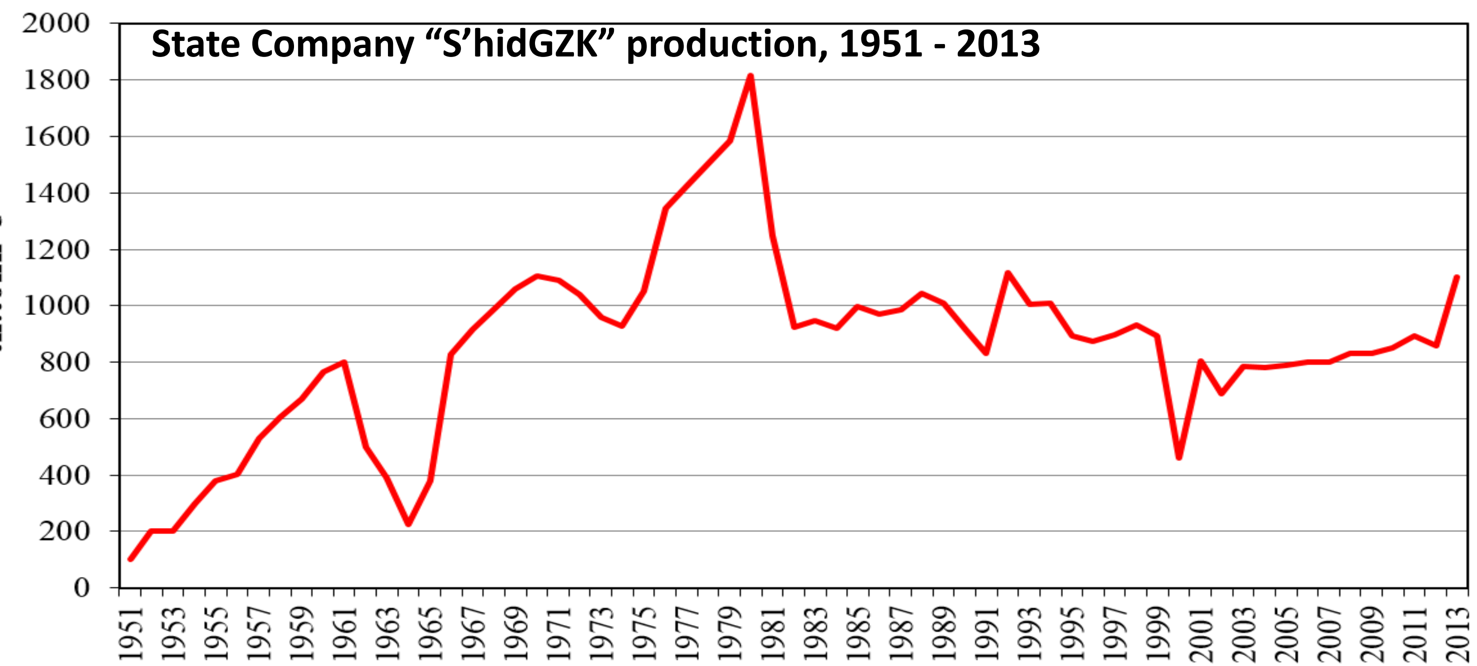
The deposits in mining:

Novokostantynivka U deposit (93,600 t U)

Michurynske (26,800 t U),

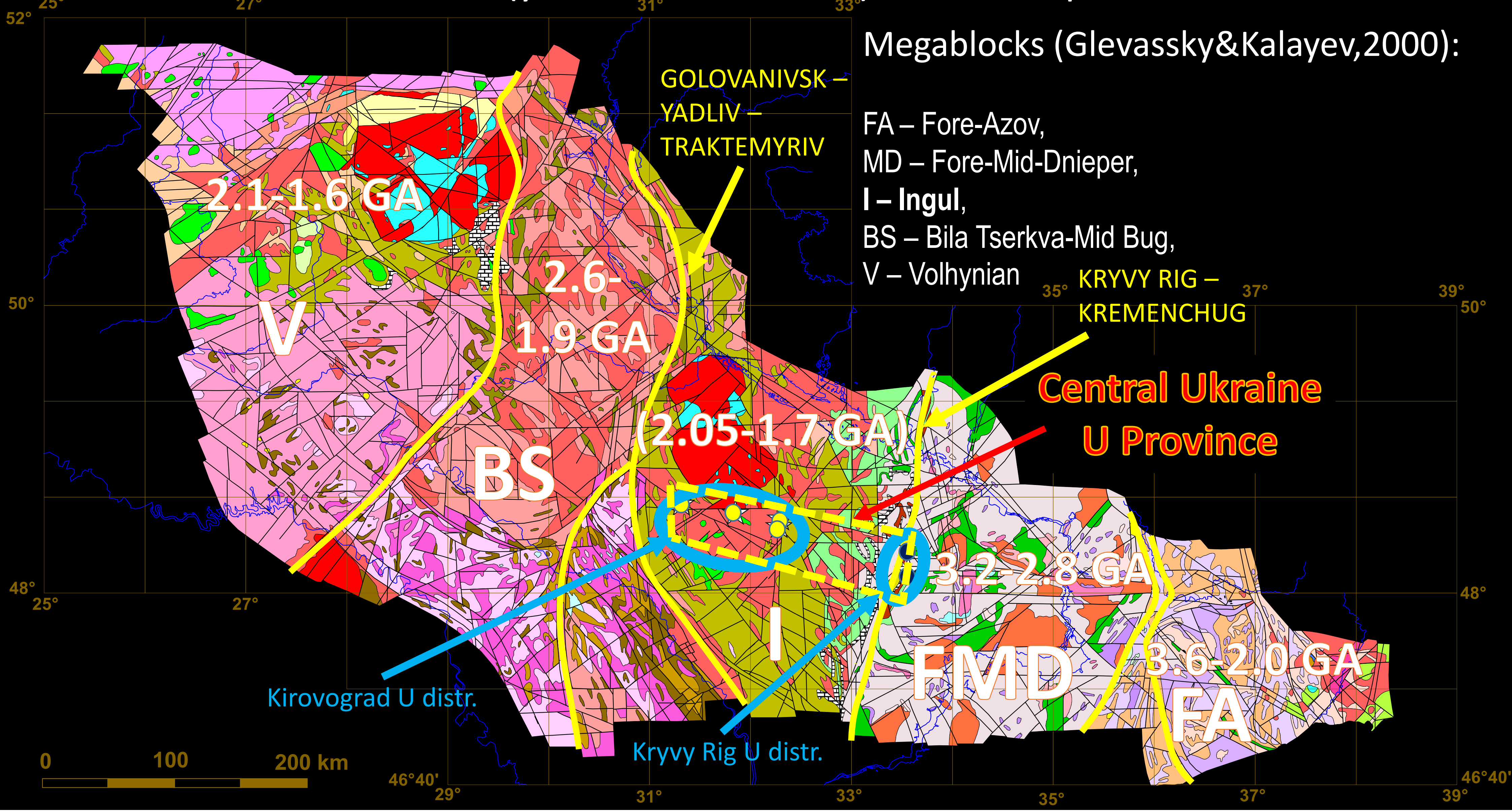
Centralne (60,000 t U),

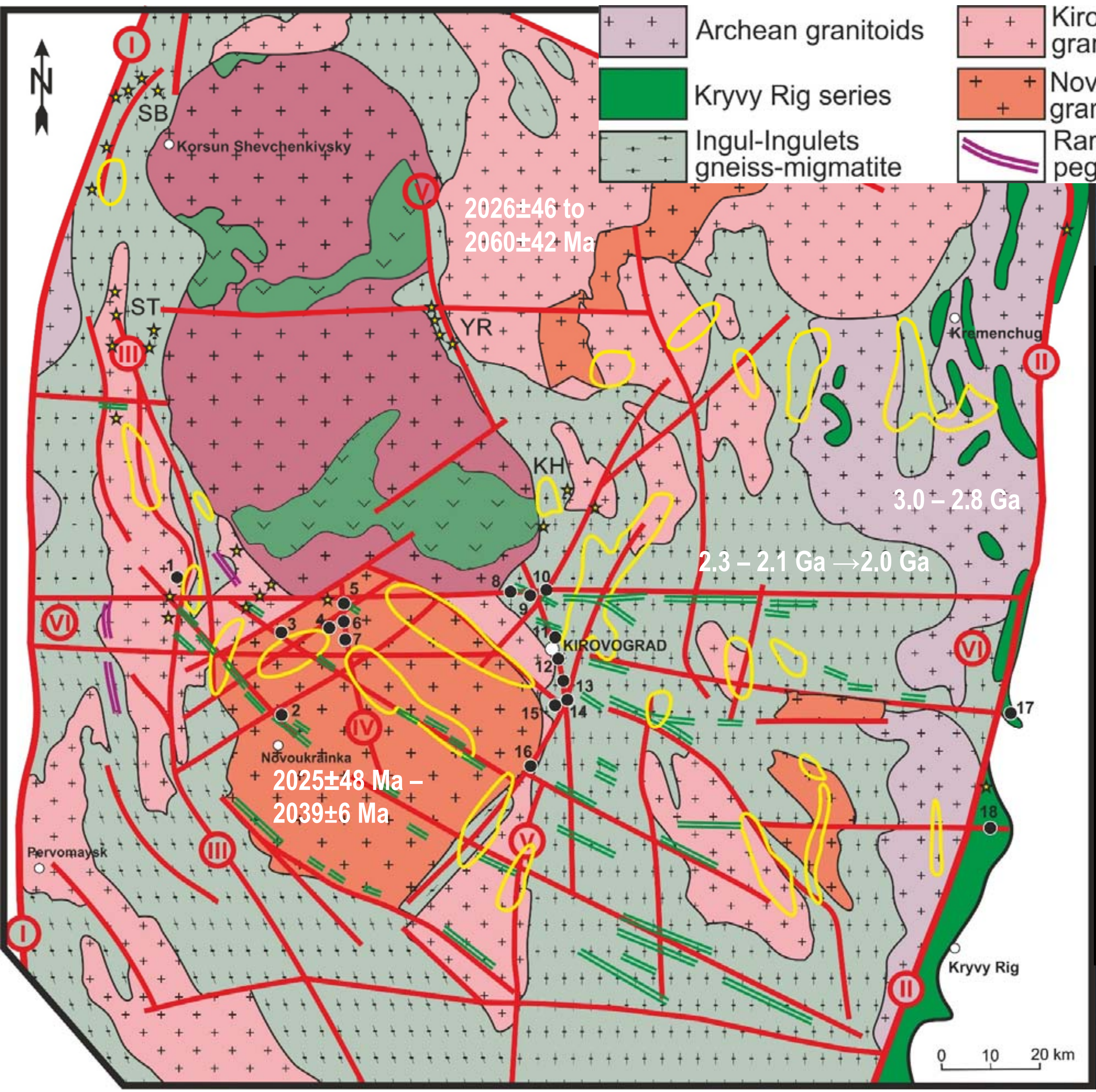
Vatutynske (26,000 t U)



Annual U production is 1.1 th. ton U from 4 U deposits

Central Ukraine U Province (yellow dashed line) on the map of Ukrainian Shield



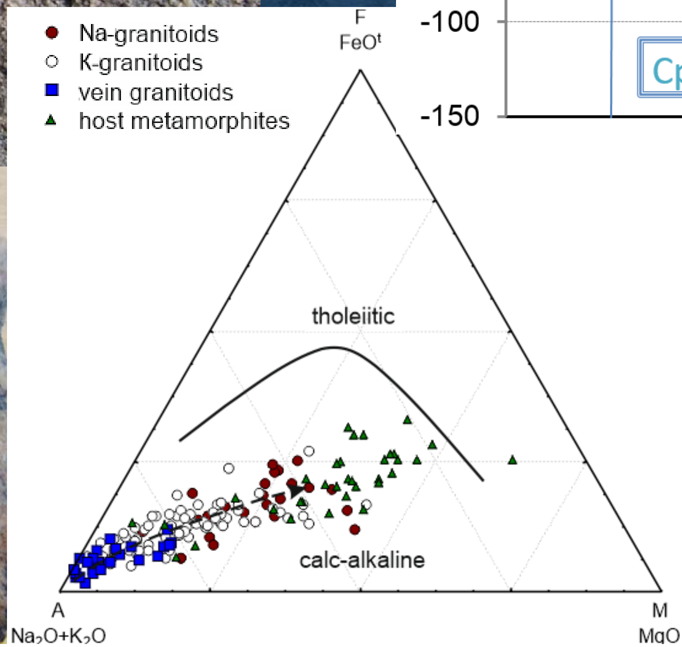


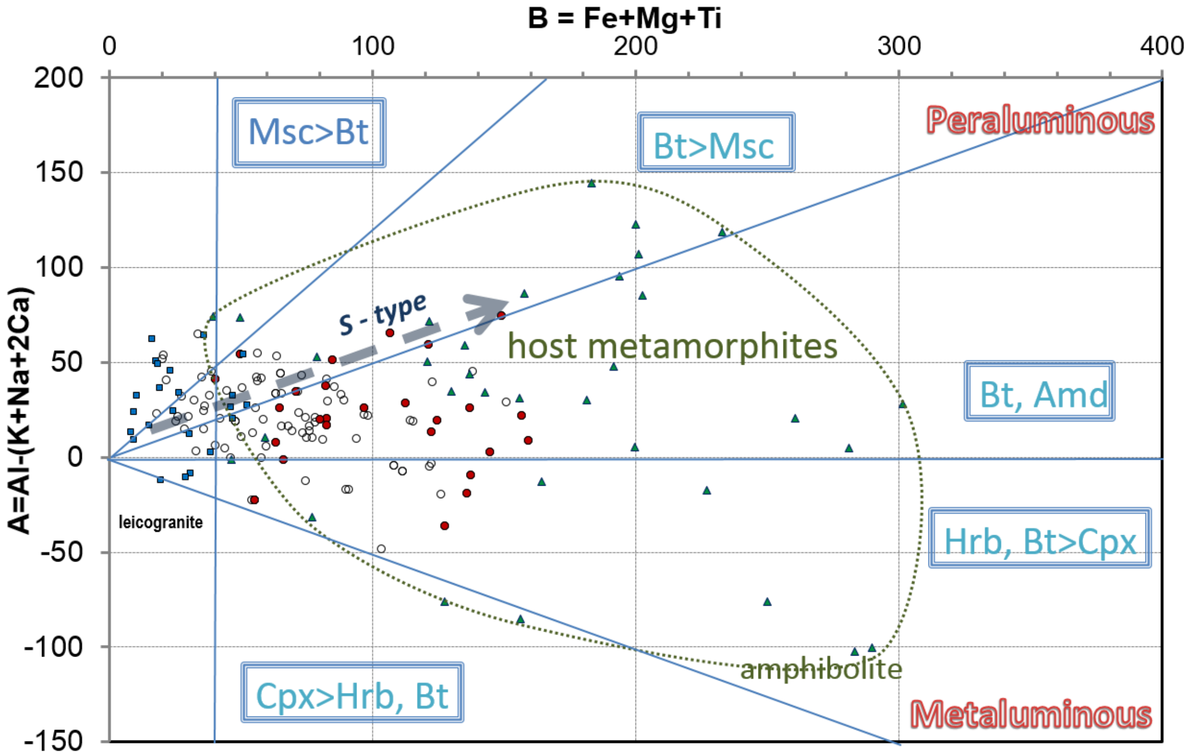
Geological map of the Ingul Megablock:

U deposits: (1) Vatutinske, (2) Partyzanske, (3) April, (4) Lisne, (5) Novokostantynivka, (6) Litne, (7) Dokuchayivka, (8) Schorsivka, (9) Pidgaytsi, (10) Severynka, (11) Central, (12) Michurinske, (13) Northern Konoplanka, (14) Southern Konoplanka, (15) Western Konoplanka, (16) Yuryivske, (17) Zhovta Richka, (18) Pervomayske.

U showing fields: ST – Stetsivske; SB – Steblivske; KH – Kohanivka; YR – Yarovske

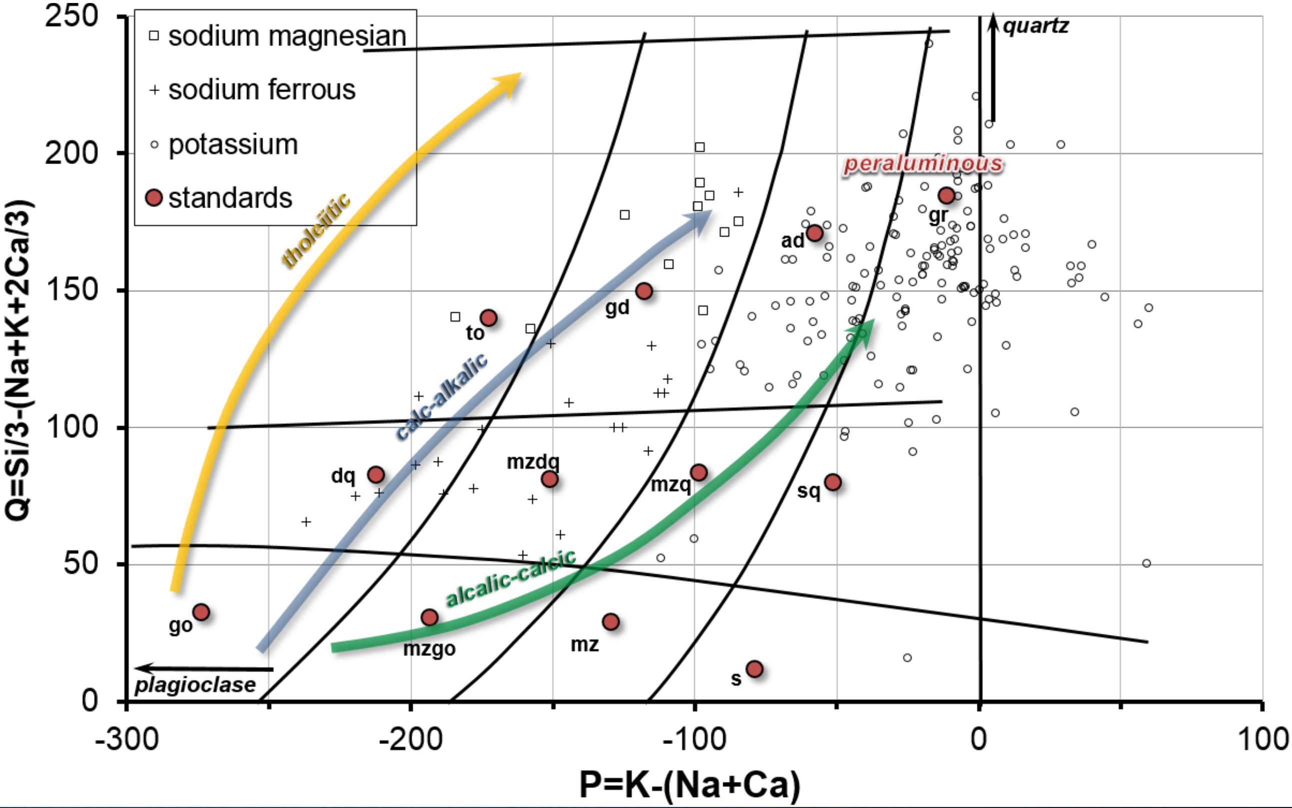
KIROVOGRAD GRANITOIDS



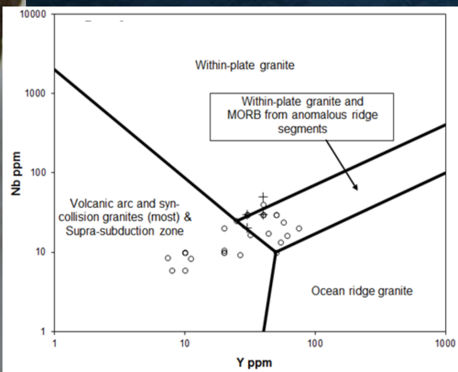


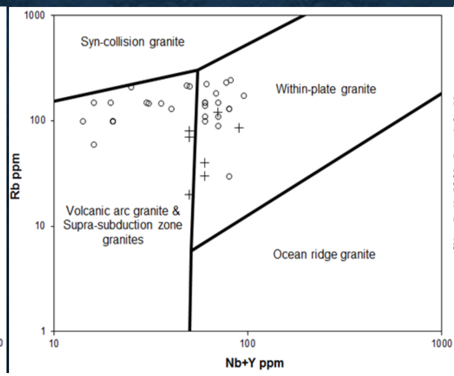
The granitoids are grey to rose-grey, fine- to medium-grained and porphyritic granitoids, garnet-bearing, with numerous restites of the host gneisses. Many bodies demonstrate a gradual transition from migmatized gneisses to the granitoids.

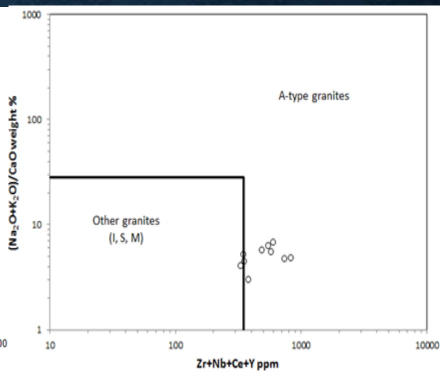
NOVOUKRAINKA GRANITOID COMPLEX

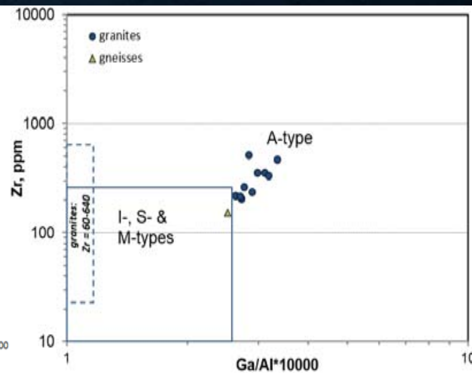


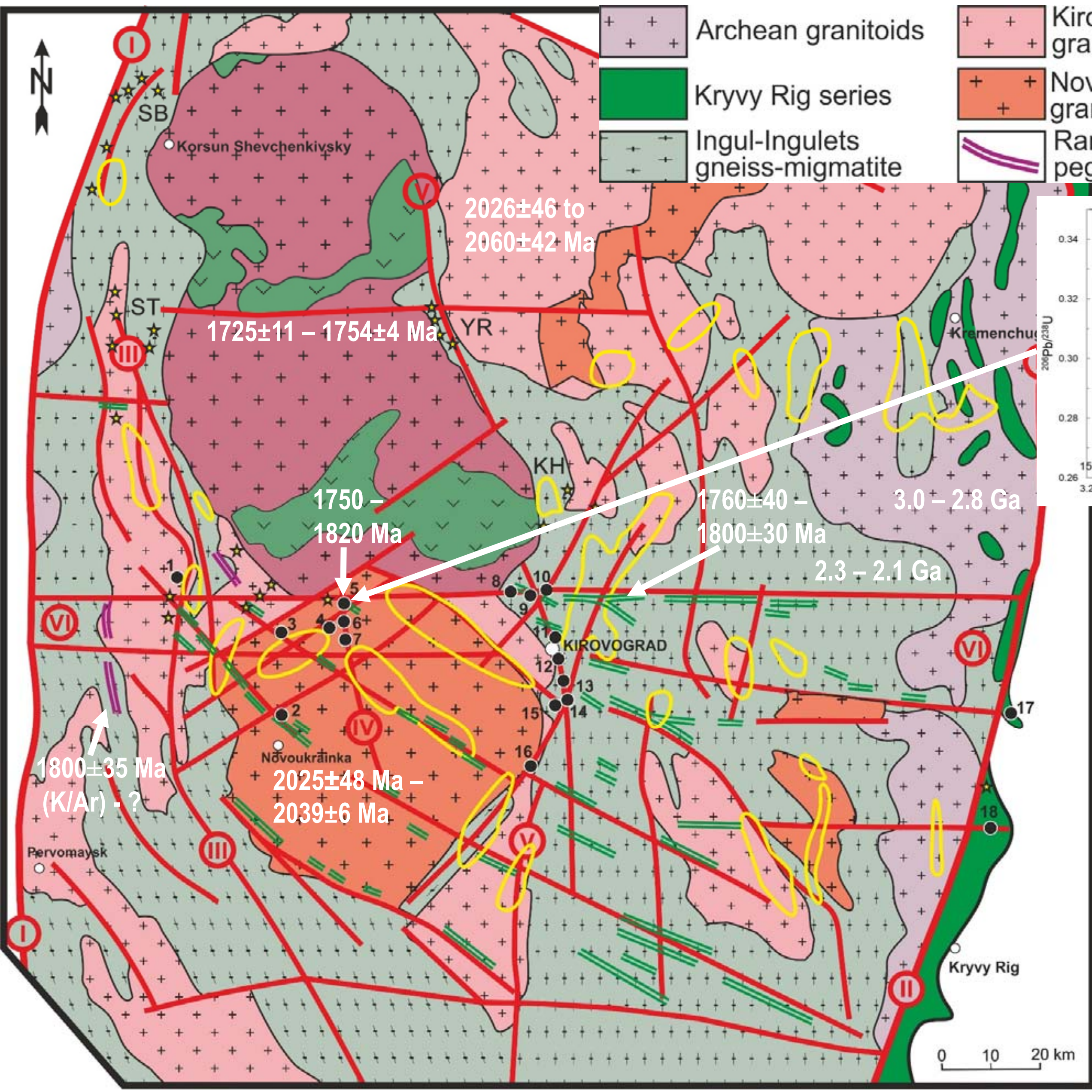
Red porphyritic coarse-grained primarily foliated garnet-biotite granites and adamelites composes 70-80 % of the complex. Geochemically, the Novoukrainka granitoids vary between S-type and A-type granites.

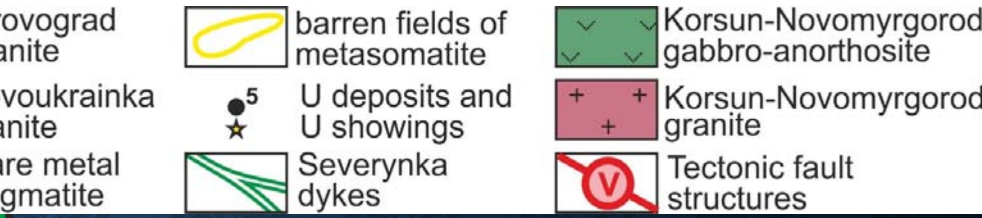


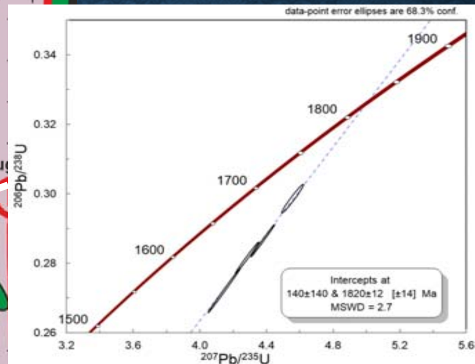










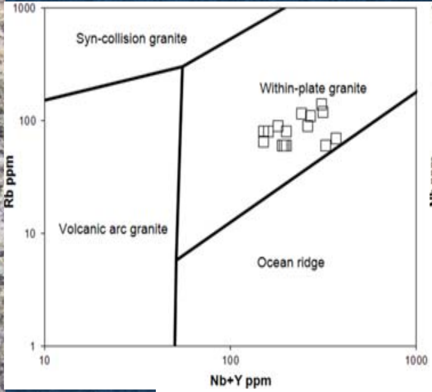


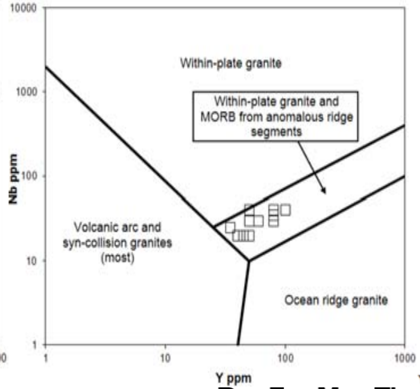
U deposits: (1) Vatutinske, (2) Partyzanske, (3) April, (4) Lisne, (5) Novokostantynivka, (6) Litne, (7) Dokuchayivka, (8) Schorsivka, (9) Pidgaytsi, (10) Severynka, (11) Central, (12) Michurinske, (13) Northern Konoplanka, (14) Southern Konoplanka, (15) Western Konoplanka, (16) Yuryivske, (17) Zhovta Richka, (18) Pervomayske.

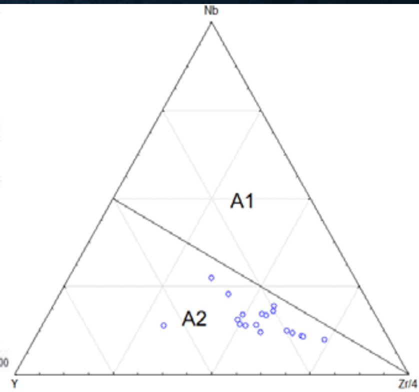
U showing fields: ST – Stetsivske; SB – Steblivske; KH – Kohanivka; YR – Yarovske

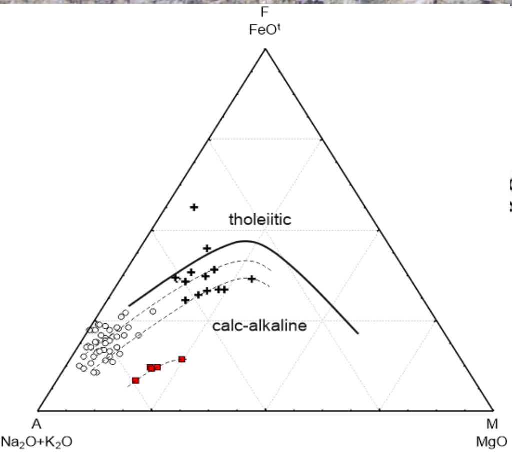
KORSUN-NOVOMYRGOROD RAPAKIVI GRANITE – GABBRO-ANORTHSITE COMPLEX

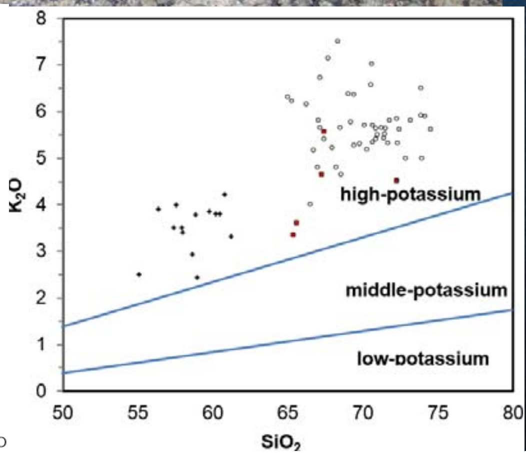
Rapakivi granite consists of anorogenic A2-type (average continental crust / island-type) ferrous high-potassium mostly metaluminous rapakivi granites and associated anorthositic rocks and mafic intrusions invaded the crust during decompression melting

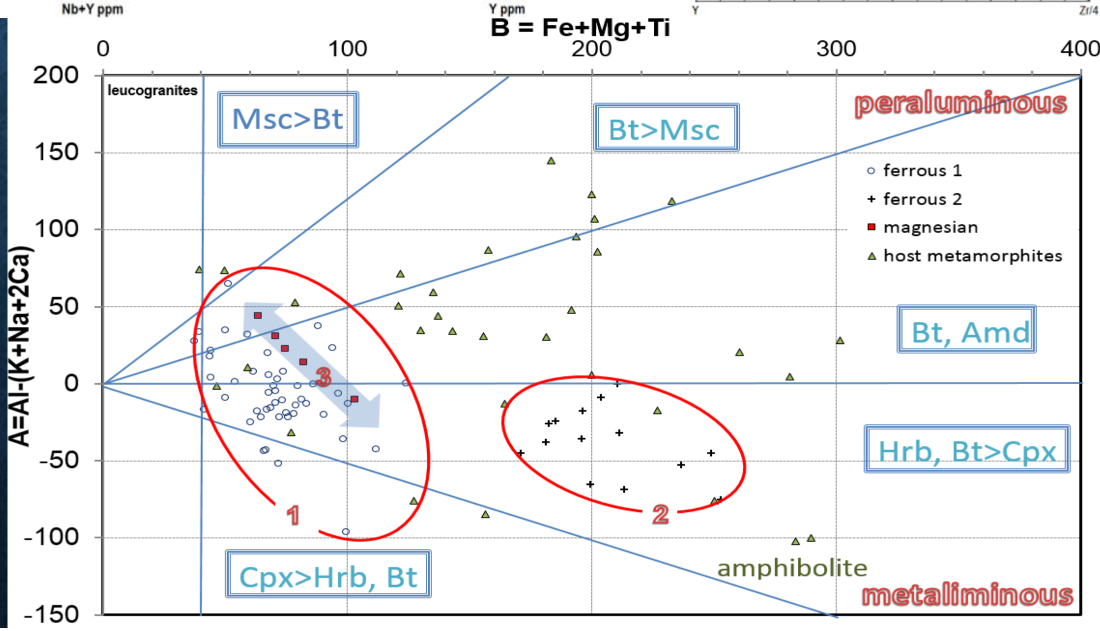












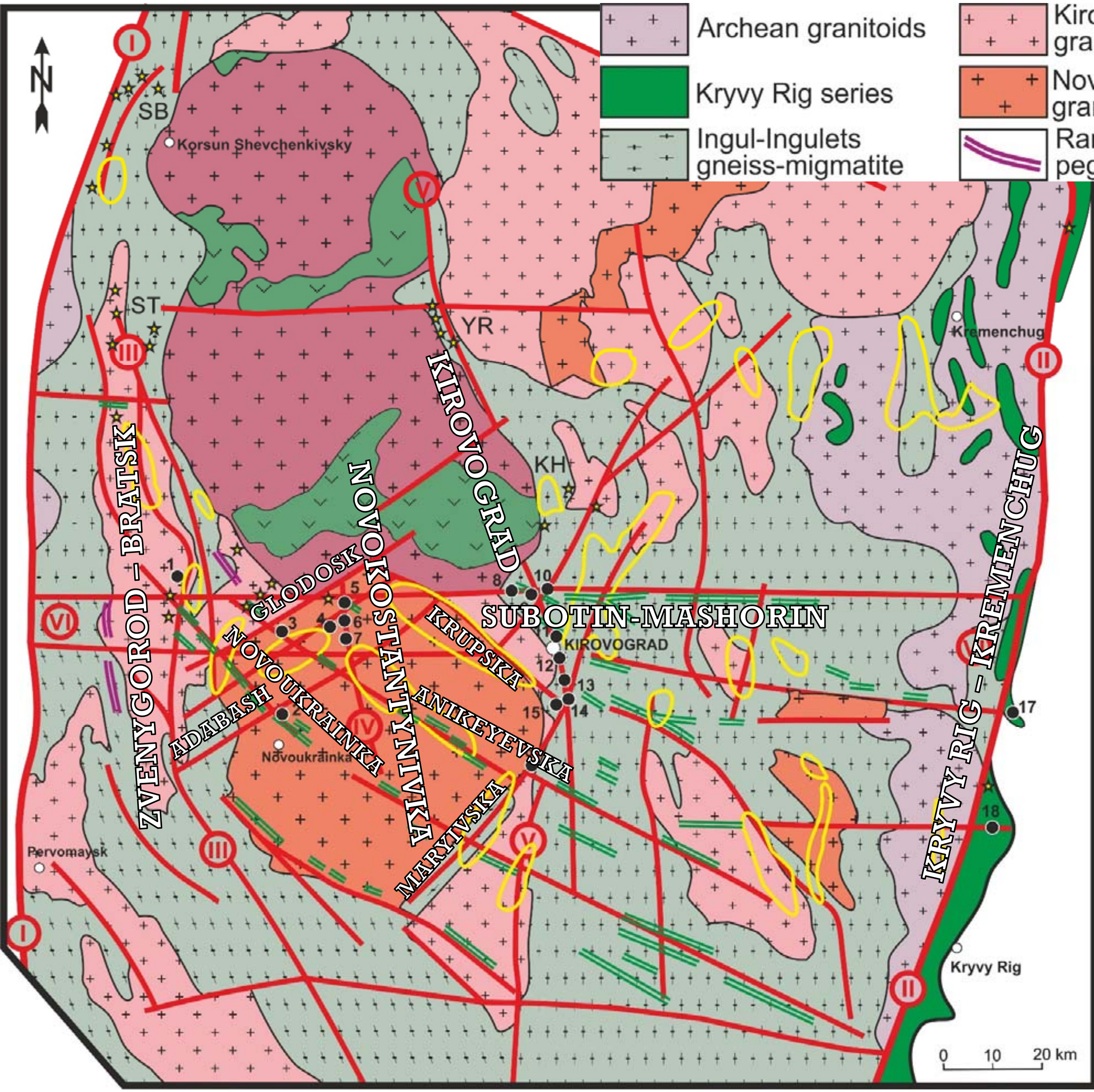
SUMMARY: GEOENVIRONMENT

- The Ingul megablock was activated with magmatism twice during complete consolidation:

1: between around 2,06 and 2.00 Ga due to regional anathexis and crustal melting.

2: between around 1.82 and 1.72 Ga during plume evolution at extensional tectonic regime from flowing out flood basalts reflected by the Severynka basic dykes between 1.8 and 1.75 Ga and decompression melting resulted in plume conduit (the Korsun-Novomyrgorod batholith) between 1.75 and 1.72 Ga.

- Na-metasomatites preceded or were in part synchronous with the first-stage plume regime reflected by the injection of the Severynka basic dyke and possible with the rare element pegmatite dykes (which are dated by non-precious K/Ar method (Nechayev, 2012)).



Geological map of the Ingul Megablock:

Crustal scale tectonic fault structures:

(I) Golovanivsk-Yadliv-Traktemyriv;
(II) Kryvy Rig–Kremenchug;
(III) Zvenygorod – Bratsk;
(IV) Novokostantynivka;
(V) Kirovograd.

U deposits: (1) Vatutinske, (2) Partyzanske, (3) April, (4) Lisne, (5) Novokostantynivka, (6) Litne, (7) Dokuchayivka, (8) Schorsivka, (9) Pidgaytsi, (10) Severynka, (11) Central, (12) Michurinske, (13) Northern Konoplanka, (14) Southern Konoplanka, (15) Western Konoplanka, (16) Yuryivske, (17) Zhovta Richka, (18) Pervomayske.

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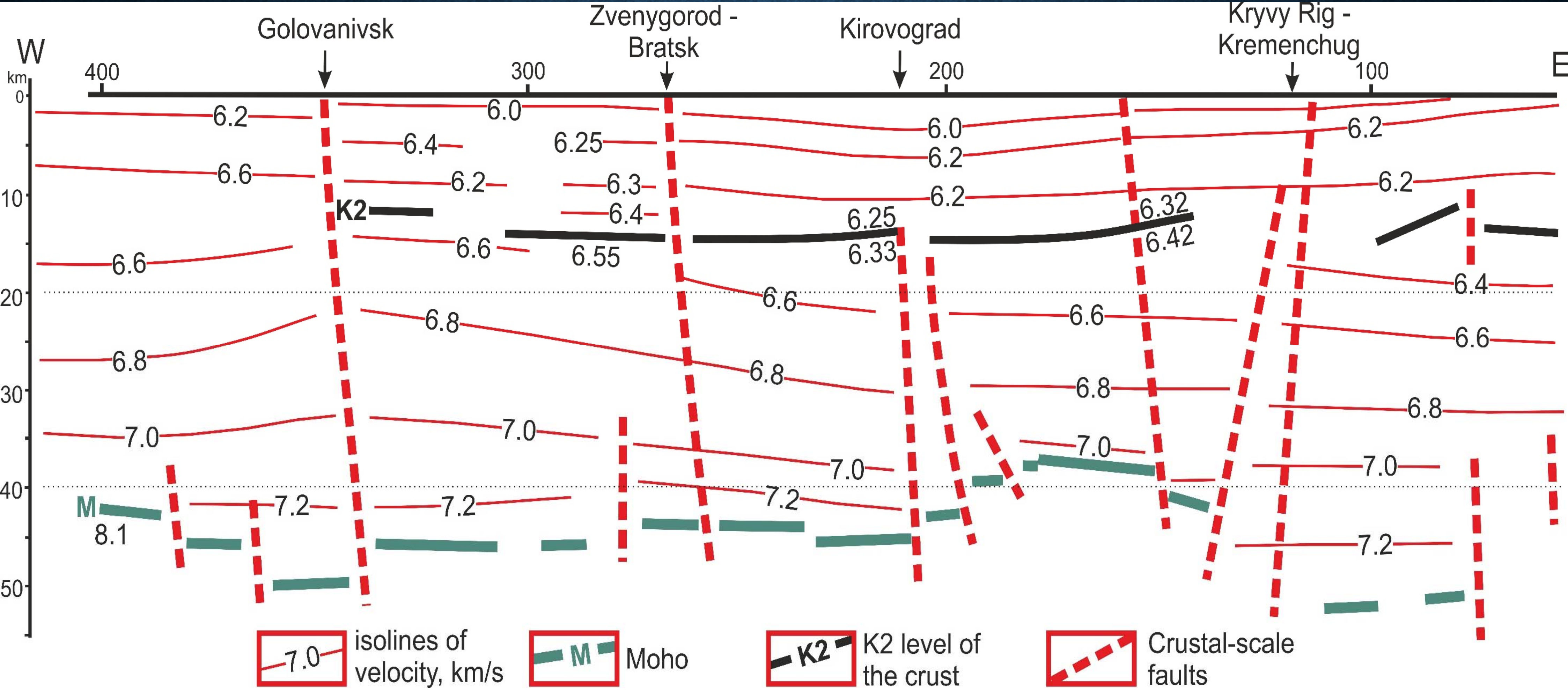
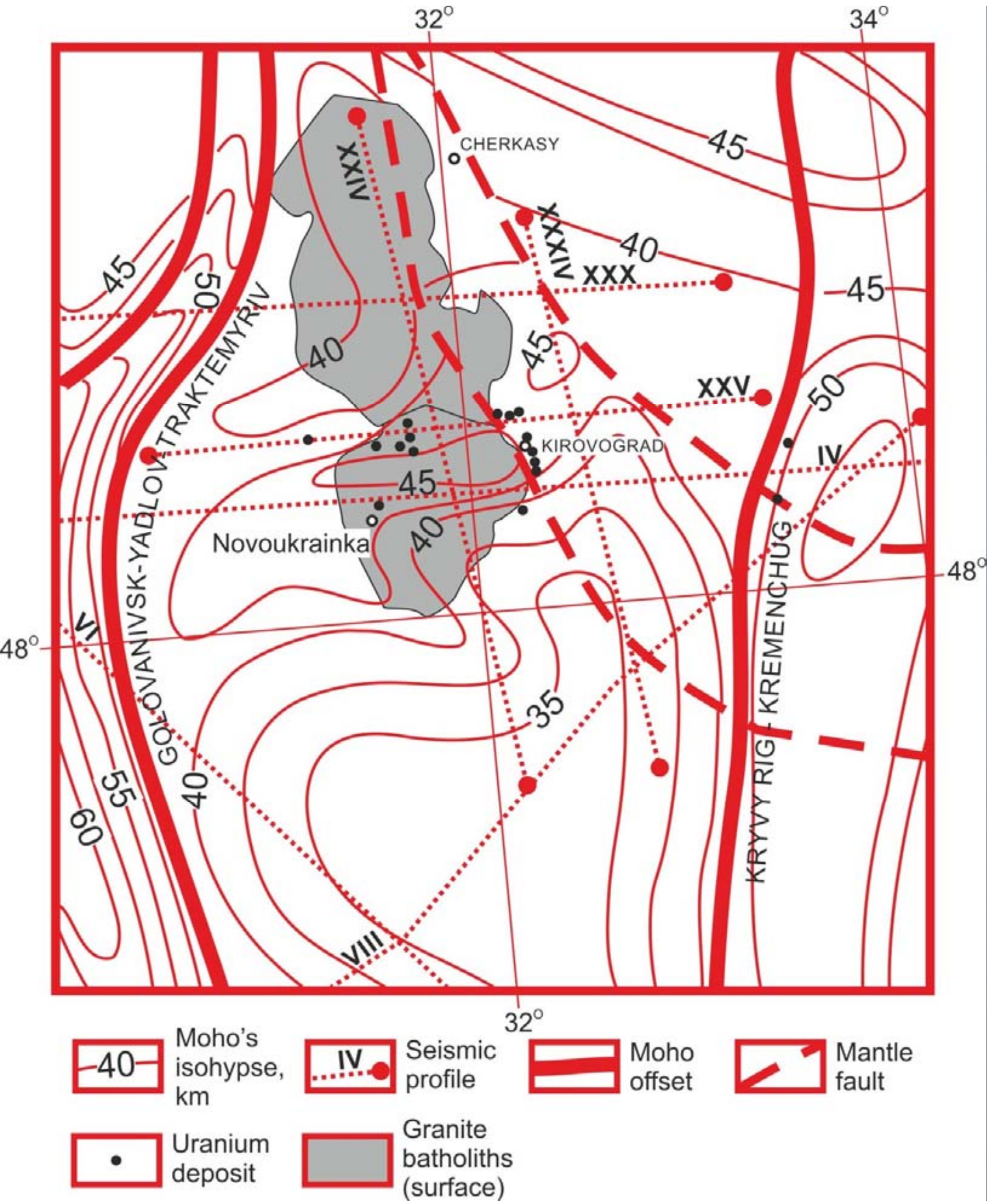
SEISMIC PROFILE IV:
modified after Sologub, 1986





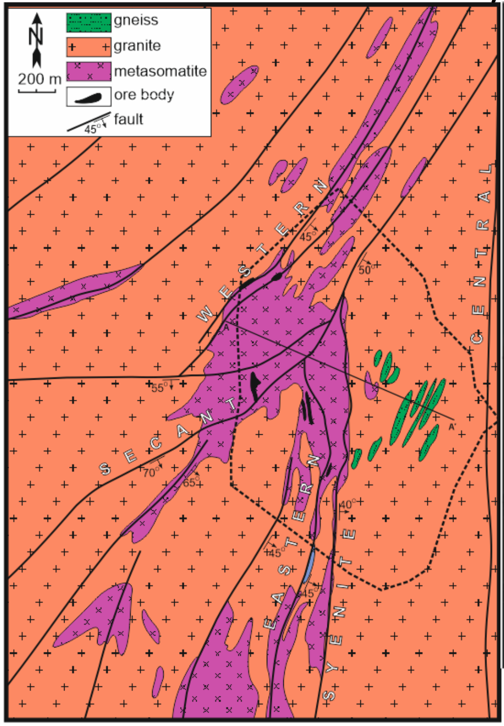
Moho position in the Ingul megablock (modified after Sologub, 1986).

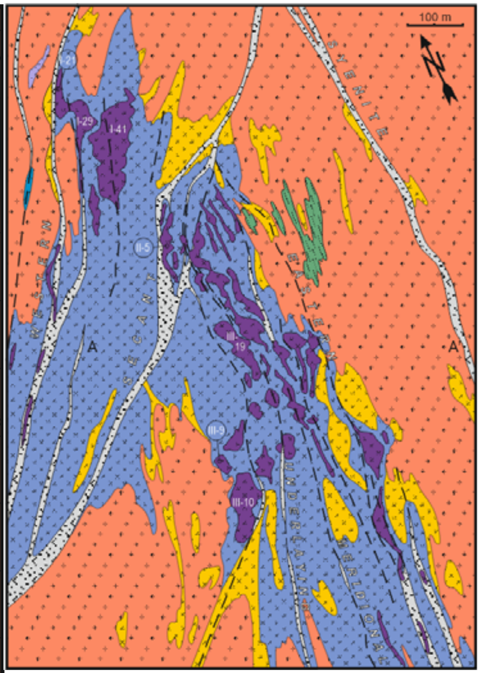
U deposits of the Kirovograd district spatially surround "mantle death" in the central part of the megablock (Starostenko et al., 2010): western slopes of the "mantle death" are gentle and shallower (43-44 km), but the eastern slopes are steep and deeper (43-46 km).

U deposits of the Kryvy Rig district trace the mantle offset along the eastern margin of Megablock from 40-45 km beneath the eastern margin down 47-50 km beneath the Fore-Mid-Dnieper megablock.

LOCAL STRUCTURAL CONTROL:

Novokostantynivka



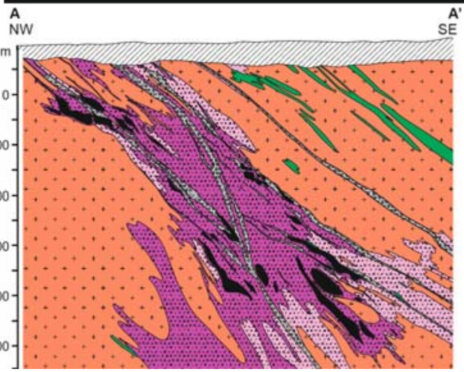


Metasomatites:

1. strongly fault-controlled
2. intermittently follow the major tectonic faults for up to several kilometers.
3. form extended (several hundreds meters) fields of alteration in the zones of intense brittle deformations developed at the places of the fault undulation where the major faults ramify into flower-like and echelon structures, locally was controlled by the host rock bedding.
4. gradually pinch out with depth.
5. vertical extent – from several hundreds meters to over 1 km

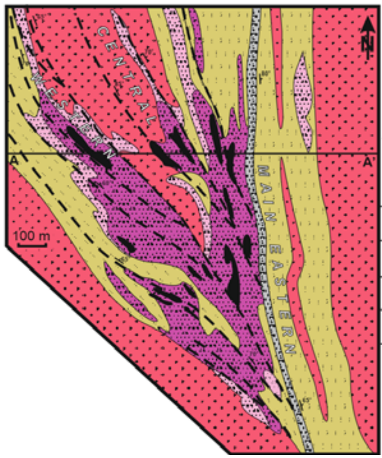
U mineralization:

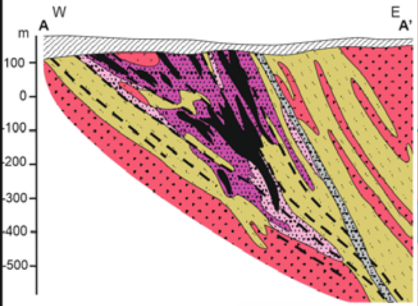
1. also fault-controlled;
2. forms a single or few ore zones following the brittle deformations in the fields of the extended Na-metasomatism.
3. U-bodies are shaped as lense-, plate-, pipe- and awkward bodies.



Echelon and flower-like

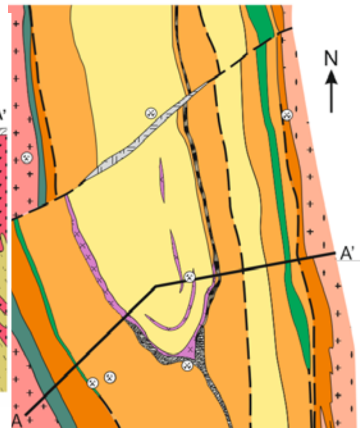
Michurynske

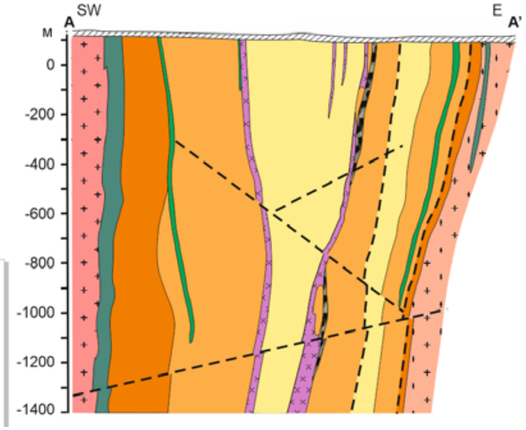




Flower-like

Zhovta Richka



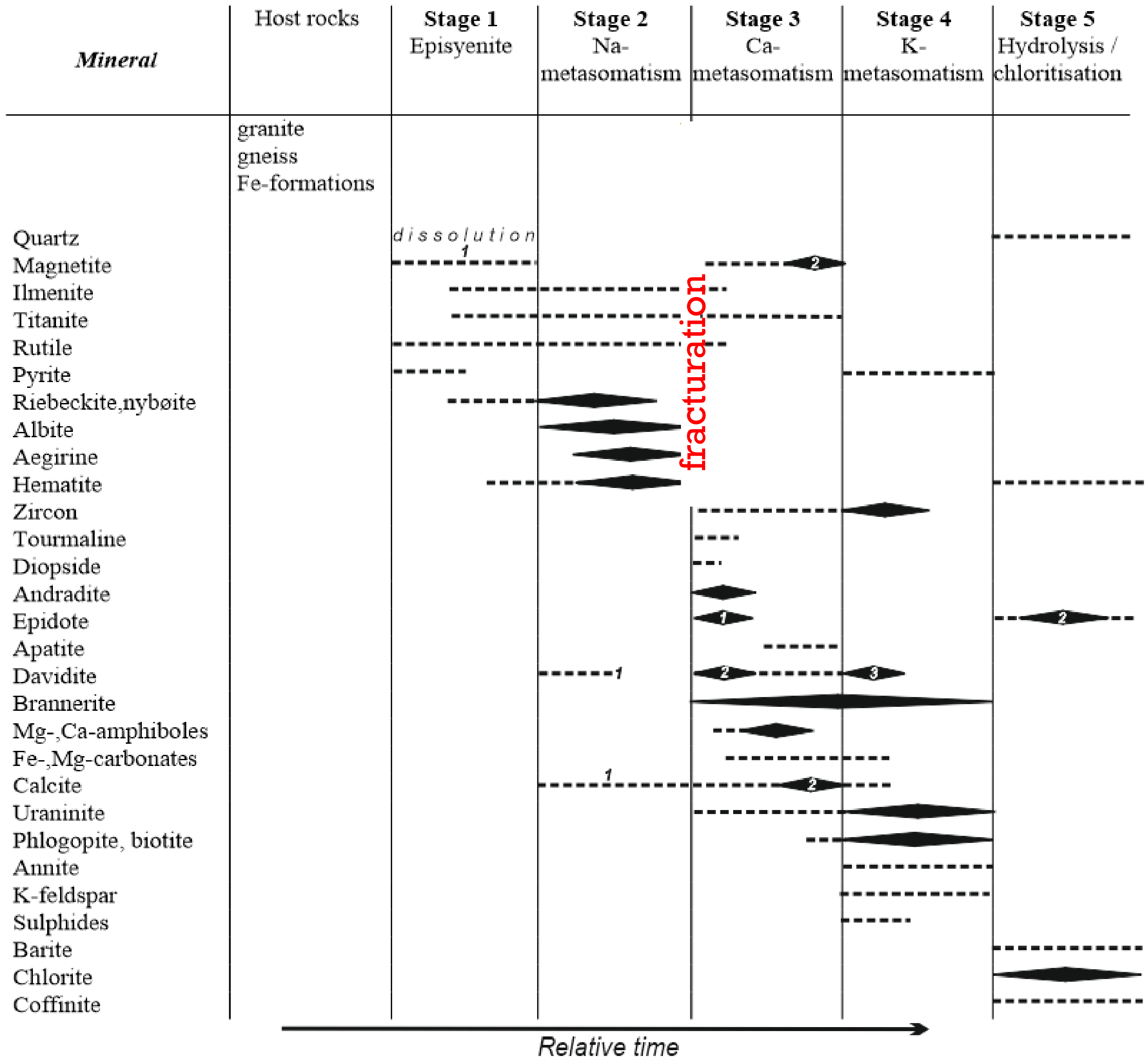


Fold(bedding)-controlled faulting

SUMMARY: TECTONIC CONTROL

- Na-metasomatism is a fault-controlled regional alteration reflecting the regional-scale hydrothermal process. With depth the metasomatites pinch out.
- The major U deposits of the CUUP are constrained by the Moho offsets characterizing lateral changes of the heat flow, P-T parameters and therefore representing the “week” zones both favorable for renaissance of faulting and crustal melting, and permeable for ascending fluids.
- The deposits are controlled by the extended zones of brittle deformations developed at fault intersections and undulations where the major faults ramify into an echelon and/or flower-like structures.

MINERAL-FORMING STAGES



Major parageneses:

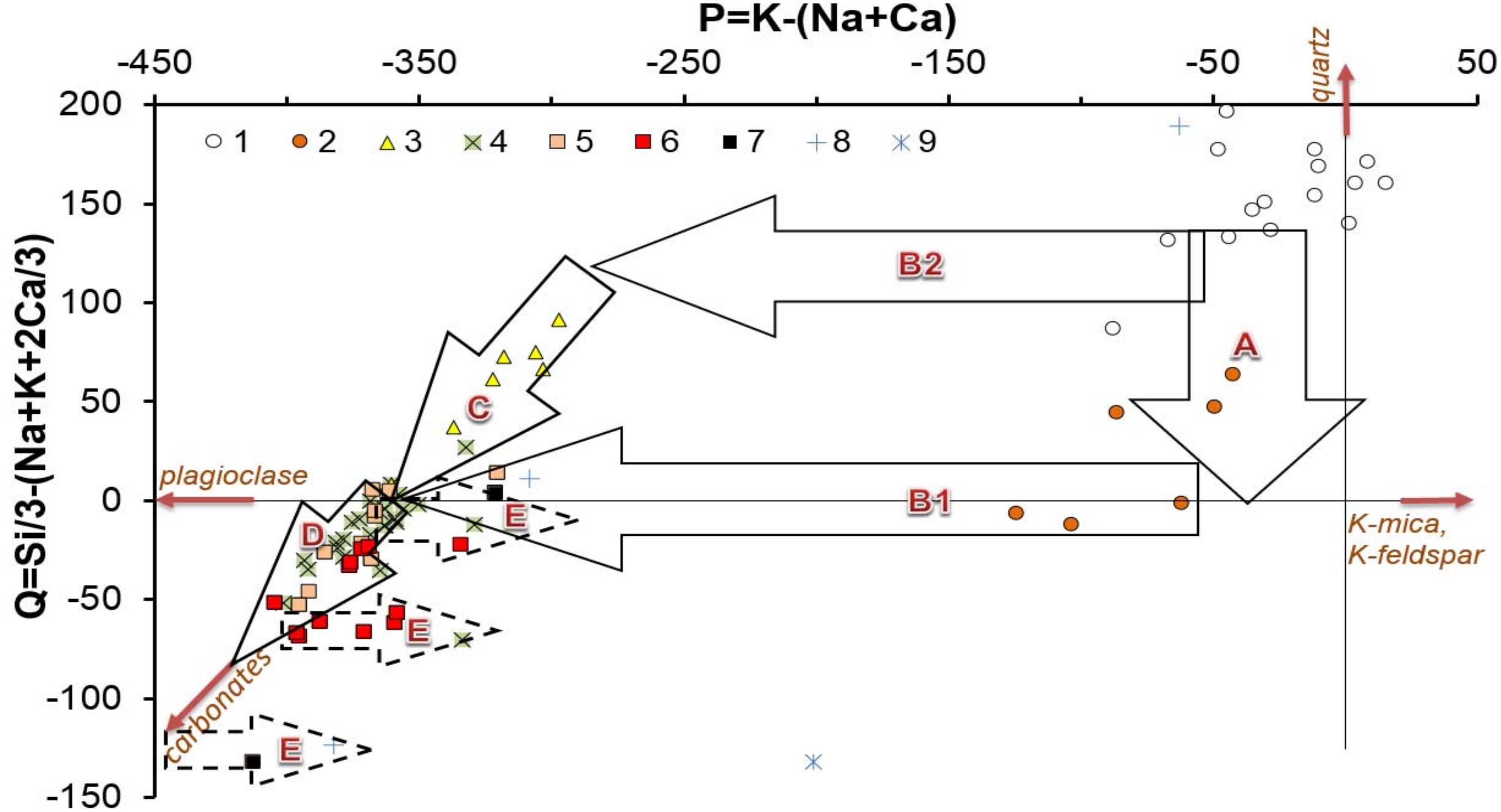
Stage 1: quartz-deficient host rocks

Stage 2: albite-aegirine-riebeckite

Stage 3: andradite-epidote-actinolite-calcite

Stage 4: calcite-phlogopite(biotite)-uraninite-brannerite

Stage 5: chlorite-epidote

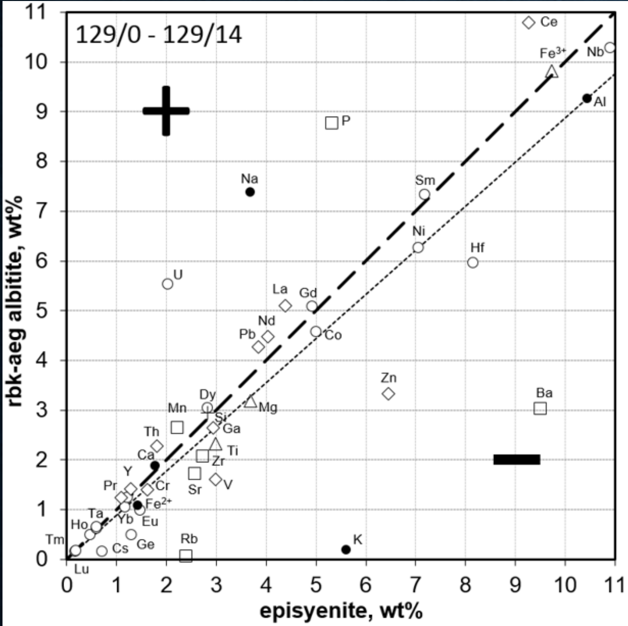


Arrows:
A: dequartzification;
B1, B2: two ways of albitization;
C: dequartzification of quartz albitites;
D: Ca-metasomatism;
E: K-metasomatism.

Evolution of the quartz content relative to the quantitative relation of K-feldspar and Na-Ca bearing minerals in the host rocks and metasomatites of the CUUP.

1: host granites, migmatite and gneiss; 2: episyenites; 3: quartz albitites; 4-7: albitites with U content: 4: < 0.09 wt %; 5: 0.09-0.2 wt %; 6: 0.2 – 2 wt %; 7: > 2 wt %; 8: aegirinites and riebeckitites; 9: U-mineralized iron-calcareous metasomatite of the Zhovta Richka deposit.

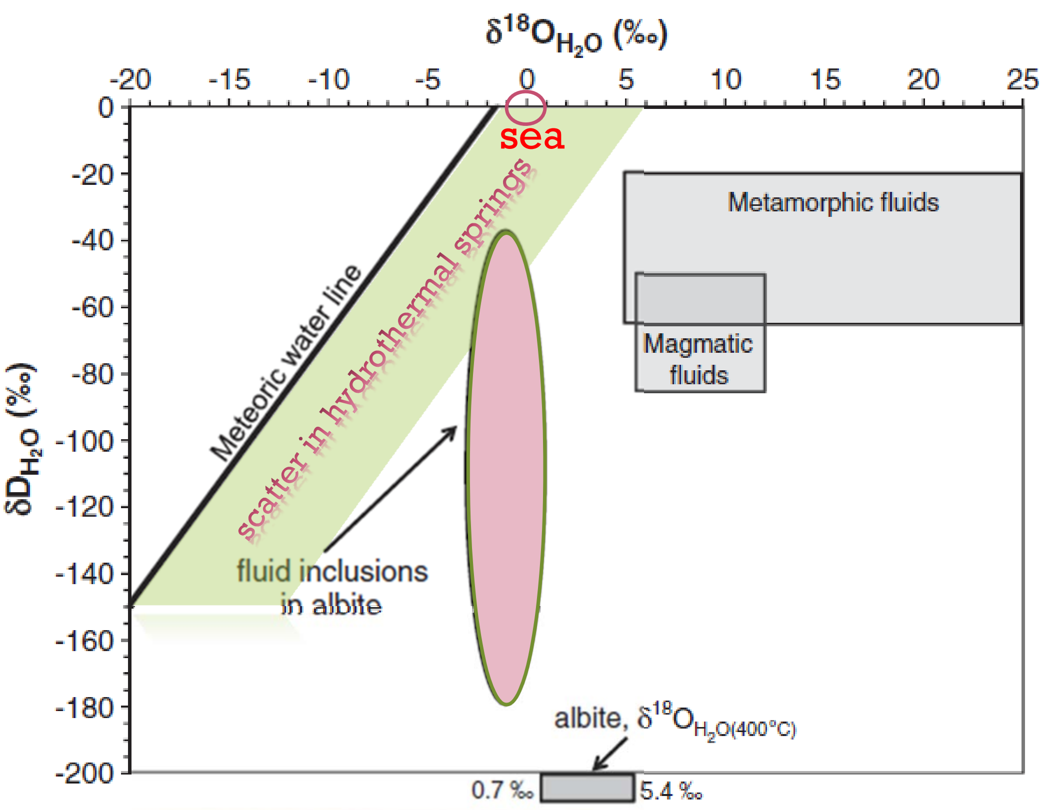
Na-metasomatism



Mass balance estimation demonstrates simple element exchange:
Deposition: Na, Ca and V   Removal: Si, K, Rb, Ba and Cs.
Fe^{2+} minerals were converted into Fe^{3+}-minerals (oxidizing fluids)

In the Fe-rich rocks also aegirinites and riebeckitites.

Isotopic geochemistry of albitite

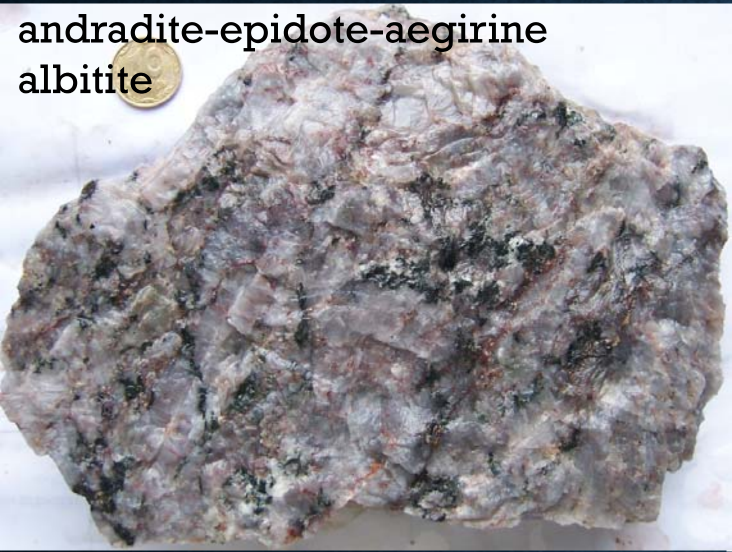


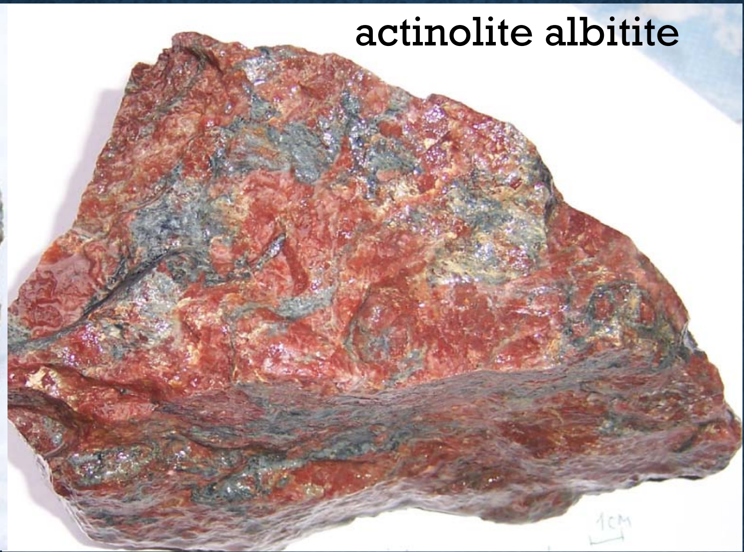
H2O of fluid inclusions from albitites:
$\delta D = -180.0$ to -38.0‰,
$\delta^{18}O = -3.1$ to 0.7‰
(Vetstein and Scherbak, 1981; Fomin and Deminov, 1990)

characterize surficial waters, in part equilibrated with the host rocks

Maximum temperature was estimated up to 450-500°C from:
* ductile deformation of feldspar;
* riebeckite thermometry (**Sinitsyn et al., 1988**)

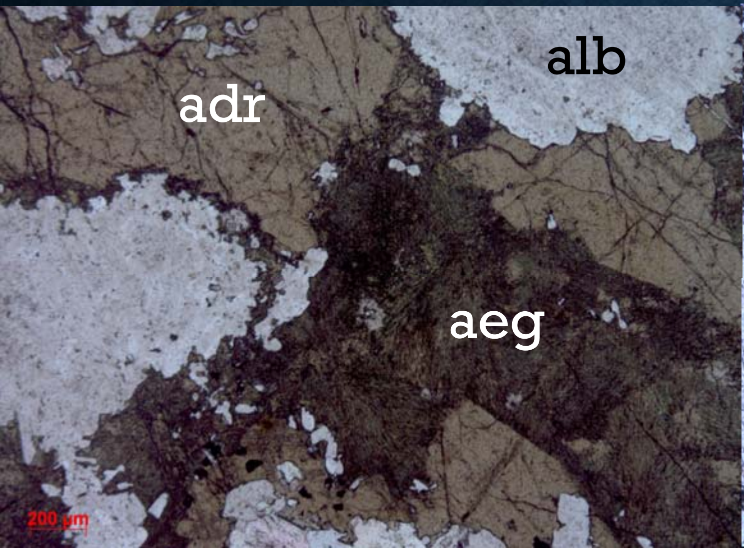
Ca-metasomatites



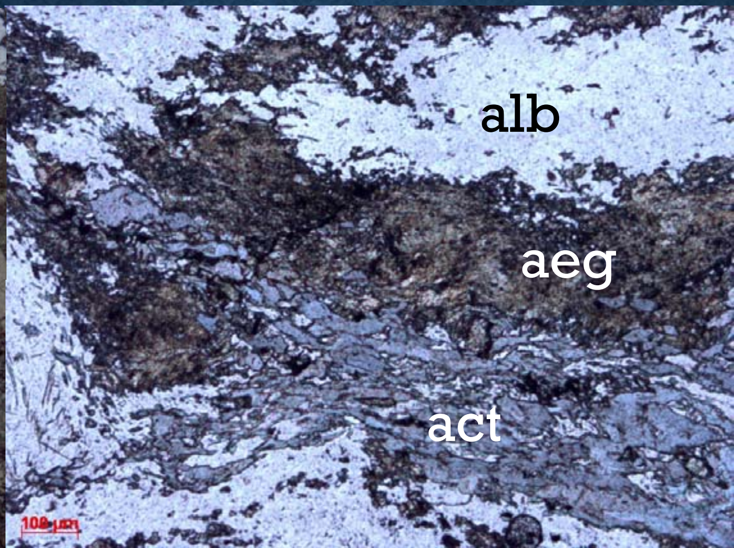


act - actinolite
adr - andradite,
aeg – aegirine,
alb – albite

Locally contain U mineralization



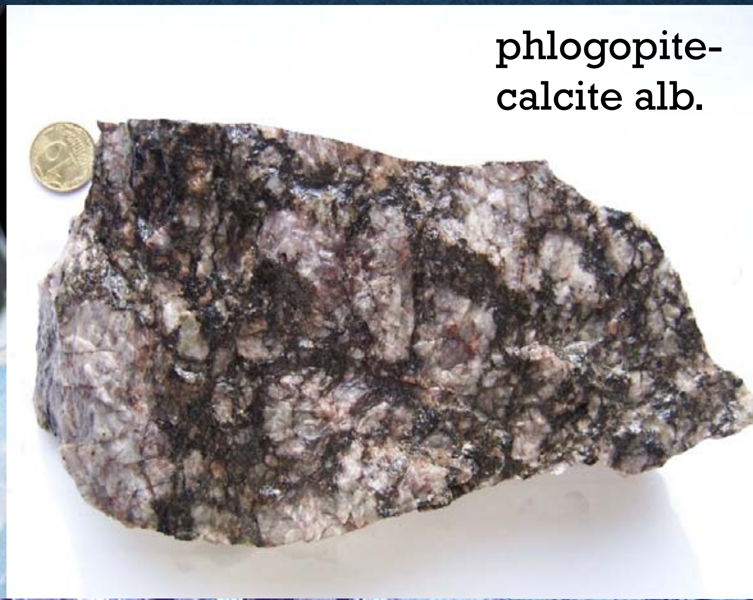
andradite replaces aegirine

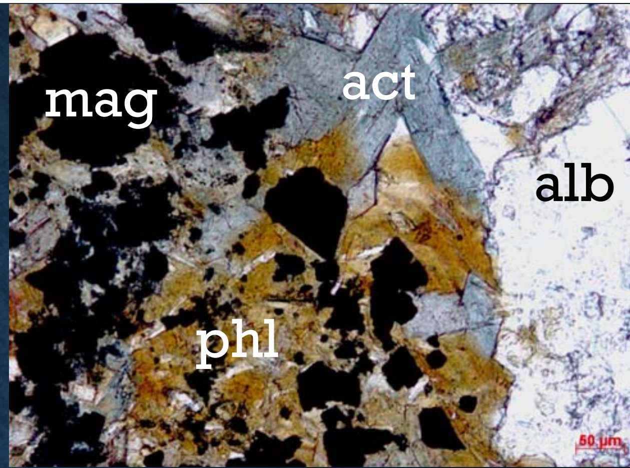


actinolite replaces aegirine

Maximum temperatures of Ca-metasomatism were estimated at 300–360°C from andradite crystallization in modern hydrothermal fields.

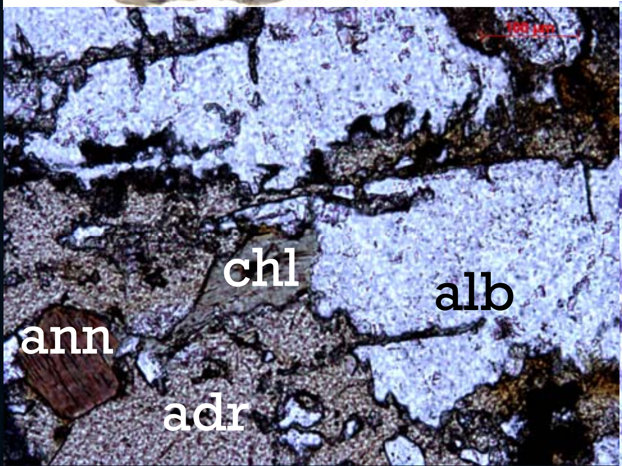
K-metasomatites



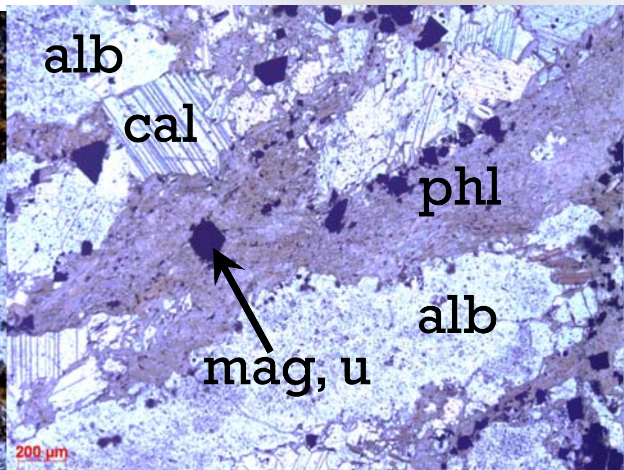


phlogopite replaces actinolite

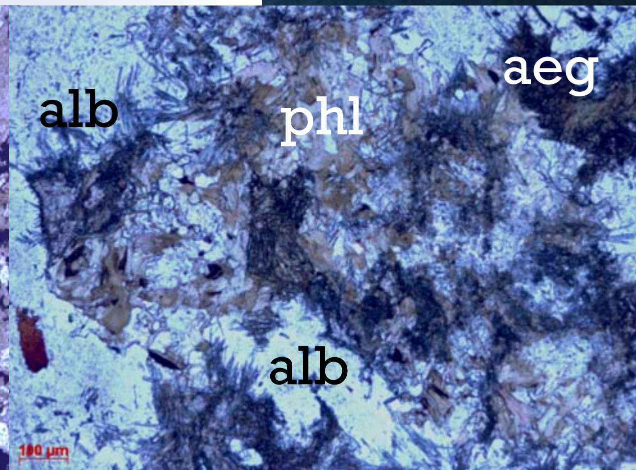
act - actinolite
adr - andradite,
aeg – aegirine,
alb – albite,
ann – annite,
cal – calcite,
chl – chlorite,
mag – magnetite,
phl – phlogopite,
u - uraninite



annite pseudomorphs andradite



phlogopite-calcite alb.

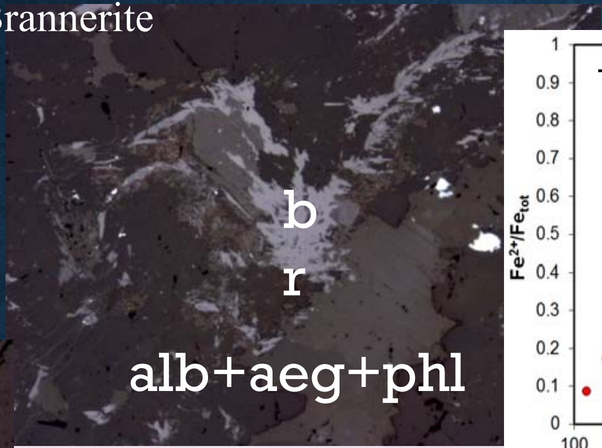


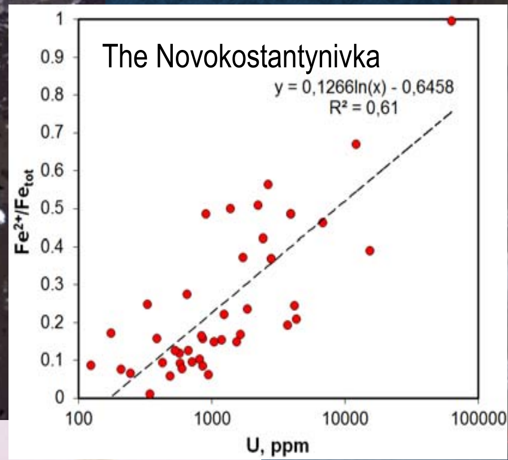
phlogopite replaces aegirine

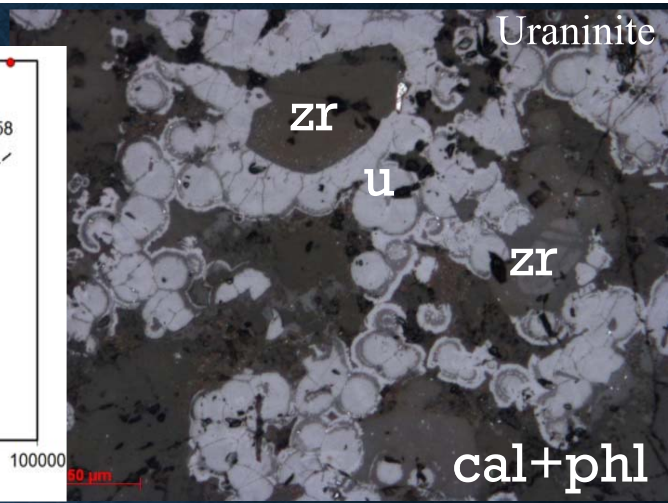
K-metasomatism: < about 200°C from fluid inclusion homogenization in calcite from calcite-phlogopite paragenesis

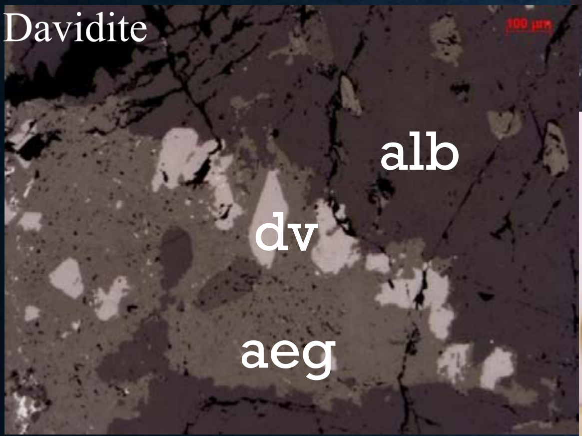
U-minerals:

disseminated,
veinlet-disseminated,
replace Fe-minerals,
U content depends on Fe^{2+}

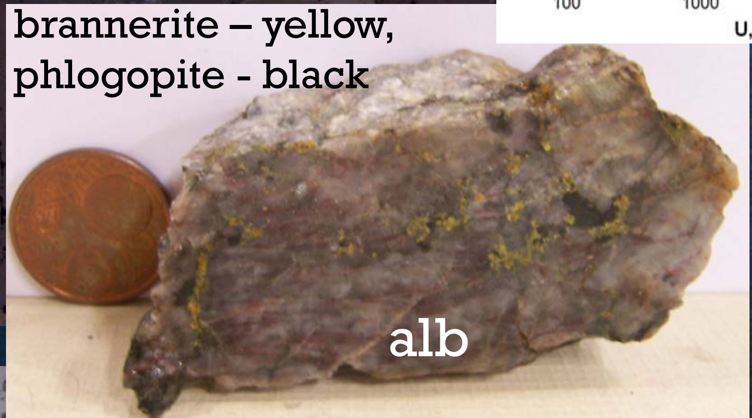


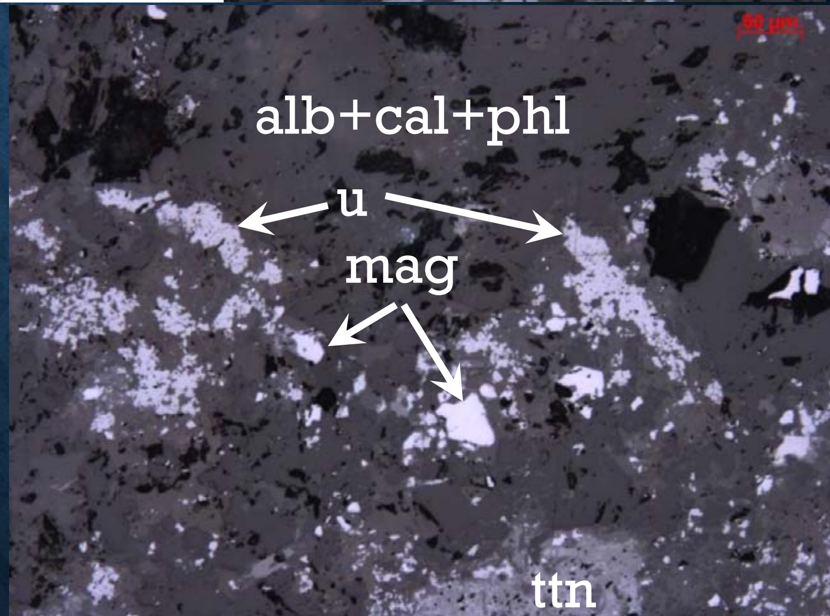


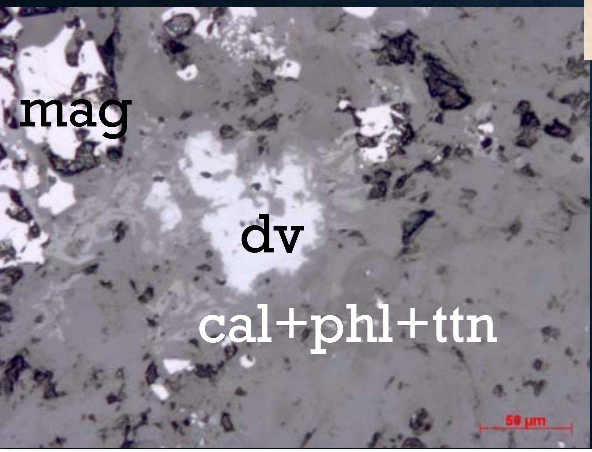


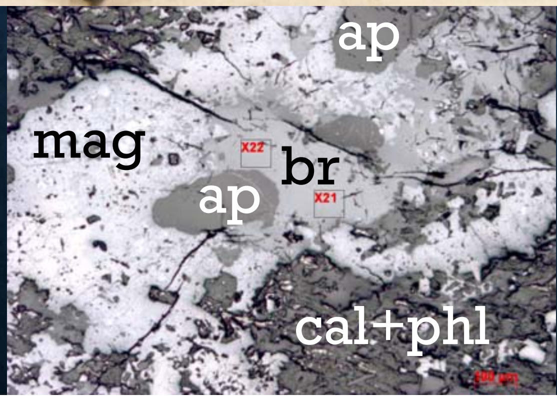


brannerite – yellow,
phlogopite - black



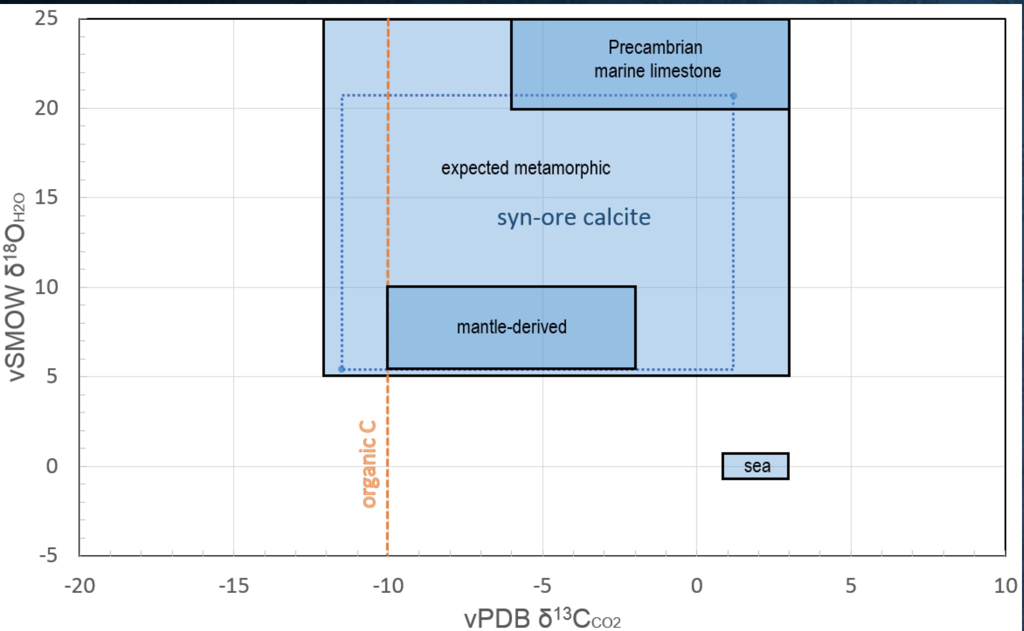






aeg – aegirine, ap – apatite, br – brannerite, cal – calcite, dv – davidite, mag – magnetite, phl – phlogopite, ttn – titanite, u - uraninite

ISOTOPIC COMPOSITION (CA-METASOMATISM)

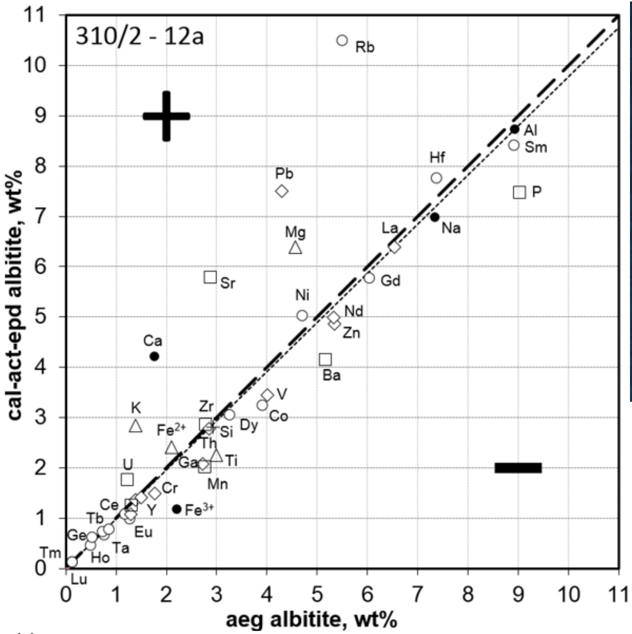


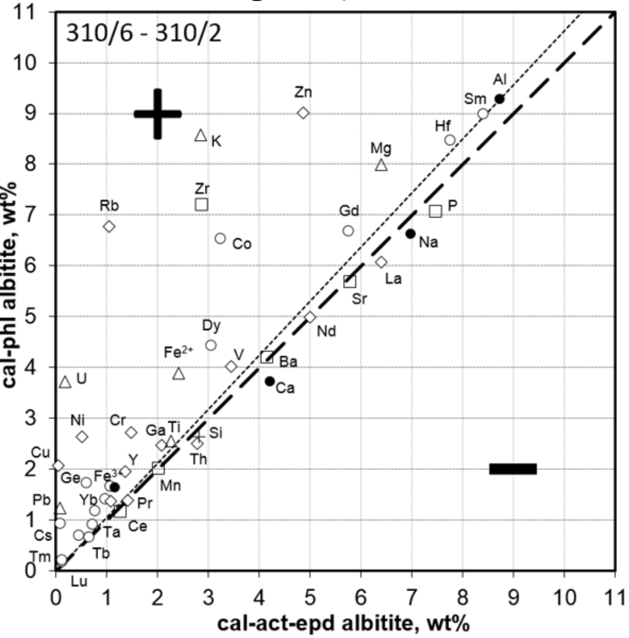
Syn-ore calcite:
$\delta^{13}C = -0.8..\ -13.5‰$)
$\delta^{18}O = 10.7..\ 26.0‰$
reflect diverse metamorphic source of carbon.

Initial $^{87}Sr/^{86}Sr$ in calcite = 0.7152±2…0.7271±2 (Scherbak, 1982), indicates the fluids derived from the various sources rich in ^{87}Sr.

$^{87}Sr/^{86}Sr$ in apatite from the ore = 0.7092 (Stepaniuk et al., 2012)
exceeds the values characterizing either 1.8 Ga mantle (0.701-0.702) or oceanic water (0.703-0.706) (different models by Flament et al., 2013).
These values are either equivalent or mostly less than $^{87}Sr/^{86}Sr$ ratio of 0.72409±2 of the host granites characterize fluids derived from the lower to upper crust source less enriched in ^{87}Rb in comparison with the granite.

characterize diverse metamorphic source

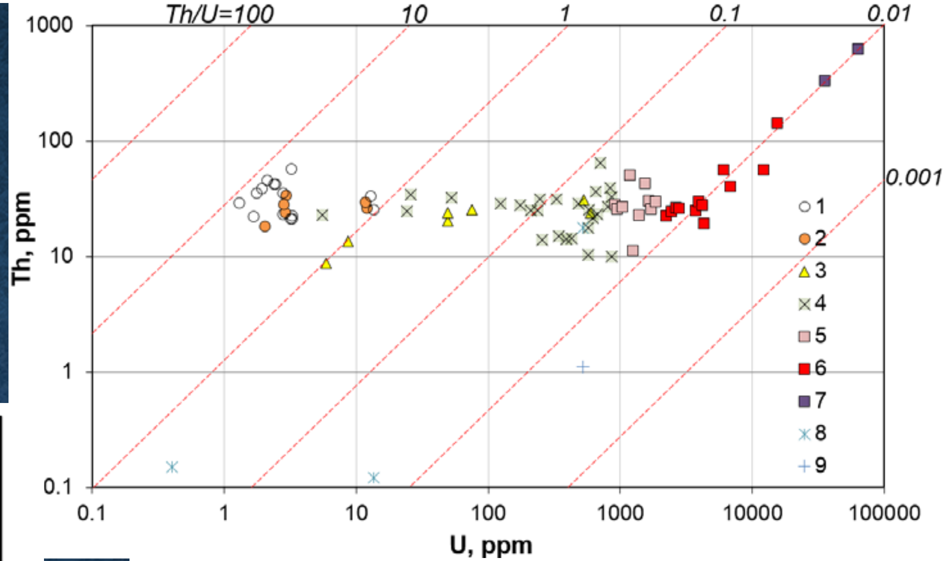


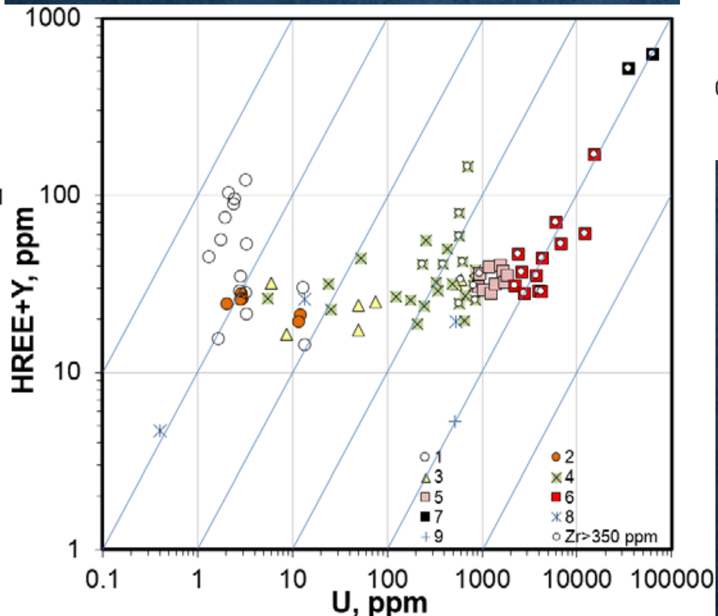


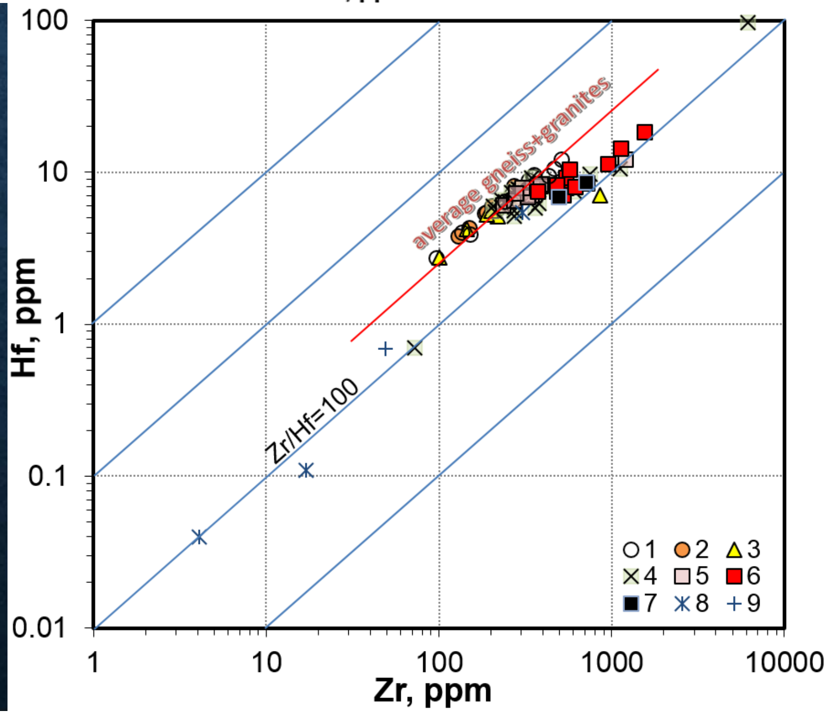
Ca-metasomatites

Removal: Na, Si, Al and V.

Accumulation: Ca, Sr, Mg, Fe^{2+}, U







K-metasomatites

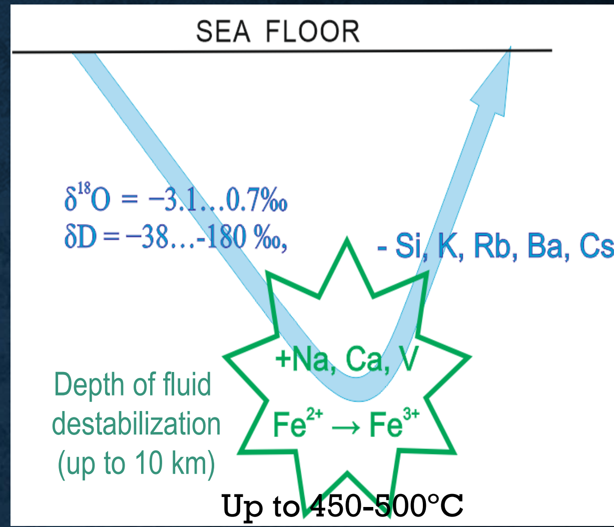
Removal: Na, Si, Al, V, Fe, Ca.

Accumulation: K, Mg, Rb, Cs, F, U, Zr, Th, Y, REE, increasing Zr/Hf ratio

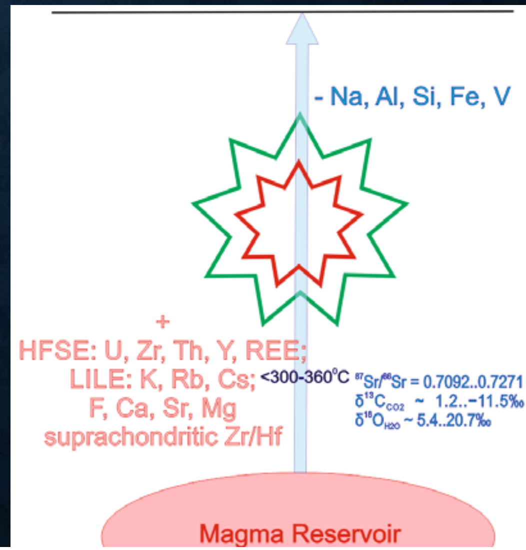
SUMMARY: MINERAL-FORMING STAGES

- The U-mineralized metasomatites of the CUUP resulted from five stages of the hydrothermal alterations. U-bearing K-Ca metasomatites are superimposed on Na-metasomatites.
- Na-metasomatites were formed due to interaction of surficial Na-dominant solutions (seawater) with the host rocks.
- From isotopic characteristics of the minerals, K-Ca metasomatism was resulted from the invasion of new fluids derived from the metamorphic source.
- A complex of accumulated incompatible elements including HFSE (U, Zr, Th, Y and REE) and LILE (K, Rb, Cs) during crystallization of F-bearing minerals (phlogopite, biotite, tourmaline), and the increased Zr/Hf ratio in the ore, suggest a deeply seated differentiated granitic source.
- U mineralization during crystallization of calcite-phlogopite suggest that carbonate-uranil and carbonate-fluorine-uranil complexes were the major transport medium for U in the mineralizing solution. The major reaction of U deposition was a reduction of uranil-ion by Fe^{2+} oxidation.

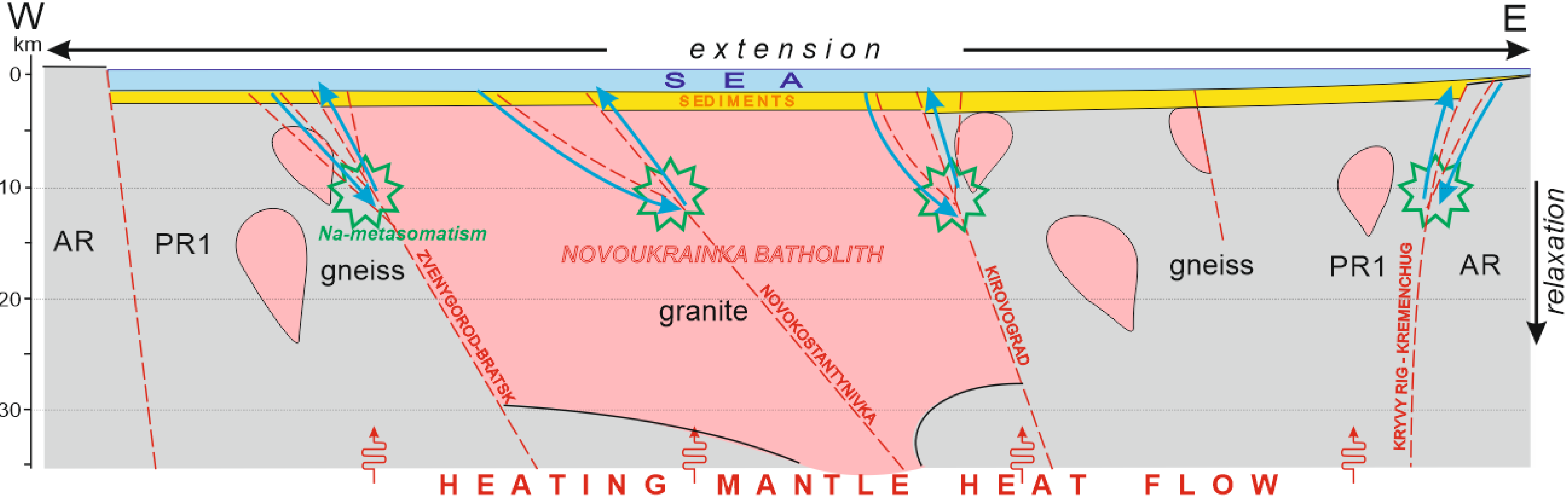
Na-metasomatism



K-Ca-metasomatism

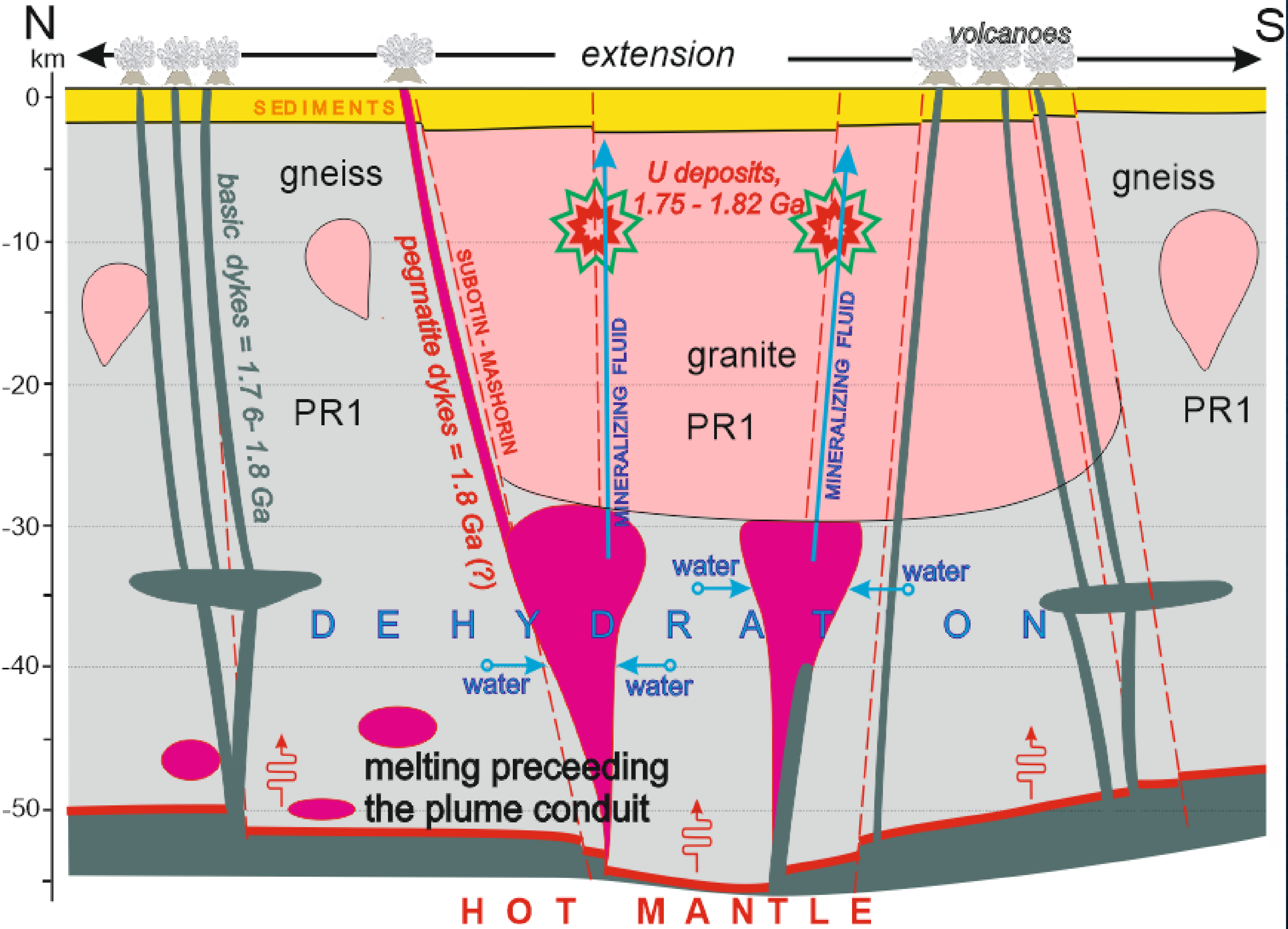


REGIONAL TECTONIC MODEL: NA-METASOMATISM



Na-metasomatism occurred during extensional tectonic regime stimulating seawater infiltration along “week” zones deep in the Earth crust, in the beginning of the regional injections of the basic dykes during the enhanced mantle melting. The basic dyke swarms indicate flowing out flood basalts preceding decompression melting resulted in plume conduit.

REGIONAL TECTONIC MODEL: CA-K-METASOMATISM



The mineralizing fluids were derived from the magmatic sources which would form through the high-temperature dehydration melting of the deep-seated metamorphic rocks. Also, the Novoukrainka batholith could provide a sheet stimulating a crustal melting. With cooling and solidification they were fractionated, saturated by water and eventually emanated the mineralizing hydrothermal solutions which tunneled the crustal scale tectonic faults and reacted with chemically contrasting Na-metasomatites.