МІНЕРАЛОГІЯ, ГЕОХІМІЯ ТА ПЕТРОГРАФІЯ

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L. Stepanyuk¹, Dr. Sci. (Geol.),
Corresp. Member NAS of Ukraine,
E-mail: stepaniuk@nas.gov.ua;
O. Hrinchenko², PhD (Geol.-Min.), Assoc. Prof.,
E-mail: alexgrin@univ.kiev.ua;
T. Dovbush¹, Researcher;
O. Ziultsle¹, PhD (Geol.), Senior Researcher;
N. Konoval¹, PhD (Geol.), Senior Researcher;
T. Mironchuk², PhD (Philol.), Assoc. Prof.,
E-mail: tatianakiev99@gmail.com;
¹Institute of Geochemistry, Mineralogy and Ore Formation of NAS of Ukraine,
34 Palladin Ave., Kyiv, 03680, Ukraine;
²Taras Shevchenko National University of Kyiv, Institute of Geology,
90 Vasylykivska Str., Kyiv, 03022, Ukraine

AGE SPAN FORMATION IN GRANITOIDS OF UKRAINIAN SHIELD

(Представлено членом редакційної колегії д-ром геол. наук, проф. О.В. Мумрохіним)

The paper discusses Berdychiv type granitoids that have always stirred up interest among researchers of the Ukrainian Shield. These rocks include minerals that are uncharacteristic of granites - cordierite, sillimanite, andalusite - and are closely related to rocks of the supposed substratum. At the same time, there still remain questions about the genetic nature of Berdychiv granites. Despite the fact that most researchers treat these granites as intrusive (anatectic) formations, there are other concepts according to which these granites are considered to be the products of metasomatic transformation (magmatic replacement) of primarily argillaceous and marly series of substratum.

The Stryzhavka open pit, which is located in the Upper Bug region of the Ukrainian Shield displays differently cataclised porphyry-like plagiogranitoids (predominantly, garnet-bearing varieties in its southwestern area, locally rock-forming potassic feldspar varieties), and garnet-bearing leucocratic granites similar to those of Berdychiv type granites.

The monazites of biotite-garnet granodiorite and biotite-garnet granite were dated by uranium-lead (U-Pb) isotopic dating method. The monazite of granodiorites is dated 2049,3±3,5 million years based on the upper intersection of concordia with discordia. Significantly lower values of age (about 15 million years younger) for the monazite selected from granite, approximating 2035,1±1,9 million years were established.

We assume it to be caused by prolonged crystallization of granitic melt and rather early crystallization of more basic granodioritic magma in comparison with granitic one. Thus, the duration of the granitoid formation uncovered in the Stryzhavka open pit exceeds 15 million years, which correlates accurately with the estimates for occurrence duration of the granitic melts, which gave rise to various granites of the Ukrainian Shield.

Keywords: Ukrainian Shield, Upper Bug, isotopic age, Berdychiv granite, monazite.

Introduction. Berdychiv type granitoids have always generated considerable interest among researchers, for these granites are closely associated with the rocks of the supposed substratum and contain minerals uncharacteristic of granites – cordierite, sillimanite, andalusite. Besides, the likely genetic nature of these granites still remains topical and poorly understood. Some researchers treat Berdychiv type granites as typical intrusive (anatectic) formations, while others consider them to be derived from metasomatic alteration (magmatic replacement) of primary argillaceous and marly depositions of the substratum. Also, surprising is the fact that chemical composition of these rocks type remains almost constant or similar over a large area of their distribution within the Dniester-Bug mega-block of the Ukrainian Shield. This can be treated as possible evidence that PT-conditions for crystallization are consistent or similar within various locations of Berdychiv type granites.

In 2013, the Stryzhavka open pit was ventured for field geological excursions in the course of scientific conference "Granitoids: conditions of formation and their ore-content". This open pit fully exposes possible varieties of Berdychiv type granitoids. During the conference run-up, rocks were sampled for laboratory research and relations between the established granite varieties were studied in detail. This paper shares laboratory findings on the monazite age obtained by uranium-lead dating of the monazites samples from Berdychiv type granitoids. The Stryzhavka open pit and its rock varieties outcropped are assumed to be attractive for geological excursions.

Paper aim. This paper is aimed at estimation of age span formation between early and evolved granitic varieties

of the Stryzhavka open pit, that typical of the most granitoid complexes of Ukrainian Shield.

Objects and methods of research. To distinguish the ages and time span formation in granitoid varieties that can refer to Berdychiv type granitoids (also characterized as garnet-bearing granitoids uncommon to the Ukrainian Shield) uranium-lead isotopic systems are studied in the monazites selected from the biotite-garnet granodiorite (sample 14/13), which are outcropped at the western edge of the Stryzhavka open pit, and those selected from the biotite-garnet granite (sample P-2), which are located at the open pit southern edge.

Age is dated according to classical and widely used uranium-lead methodology. Accessory monazites are studied by U-Pb isotopic method on the laboratory equipment at the Department of Radiogeochronology of IGMOF, NAS of Ukraine. Multigrain fractions of monazite grains are selected manually under optical binocular. Selected samples (weighed amounts) are preliminary treated by chemical reagents according to modified technique published in papers (Krough, 1973; Scherbak et al., 1989). Uranium and lead contents are determined by using mixed ($U^{235}+Pb^{206}$) tracer.

Isotopic ratios are analyzed at multicollector static mode on 8-collector mass spectrometer MI-1201AT. Mathematical calculations are carried out applying Pb-DAT and ISOPLOT programs (Ludwig, 1989; 1990). Normalized age is in error by 2σ. To verify zircon metrological parameters standard, "IGMOF-1" is used (Bartnitsky et al., 1995).

The Stryzhavka open pit is located to the east of Zhytomyr-Vinnytsia motorway, to the south of Stryzhavka

village (Fig. 1). Among the main varieties of rocks uncovered by open mining, there are differently cataclased porphyry-like plagiogranitoids (south-western edge of the open pit), which predominantly include garnet and, rarely, potassic feldspar as rock-forming minerals, and also garnet-bearing leucocratic granites, which are very similar to Berdychiv type granites. Granitoids vary in composition depending on the content of quartz and garnet from pure granite to granodiorite. They are also characterised by different percentage of potassic feldspar and plagioclase presence.

The western edge of the Stryzhavka open pit indicates the presence of separately layered zones of greenish-gray

plagioclarnokites, and garnet-biotite granitoids (vinnytsite-like rocks). The latter include xenoliths of pyroxene-biotite crystalloschists and garnet-biotite gneisses. Locally, there occur Berdychiv type biotite-garnet granitoids - light gray, medium-grained, gneissic and indistinctly porphyric rocks. Among the granitoids, there are also found small-sized pyroxene crystalloschists (within 12 m). Morphologically, these are lens-shaped and rarely isometric bodies, which constantly show sharp and distinct contacts with host rock. In composition, biotite-garnet and biotite-hypersthene varieties are predominant among plagiogneisses.

Fig. 1. Stryzhavka open pit, satellite image. Location of granitoid samples studied geochronologically: 1 – sample 14/13, western edge of open pit; 2 – sample P-2, southern edge of open pit

Fig. 2. The Stryzhavka open pit, western edge. Location of sample 14/13

Berdychiv type biotite-garnet granites might also be found at the southern edge of the open pit, but these varieties of granites contain much less xenoliths and are more leucocratic in appearance. The detailed description of the Stryzhavka open pit and rock varieties distributed here might be found in the Excursion Guide (Stepanyuk et al., 2013).

Biotite-garnet granodiorite (sample 14/13, the Stryzhavka open pit) is gray unevenly granular cataclased rock which includes (%): 40–45 % plagioclase, 15–20 % quartz, 10–15 % potassic feldspar, about 10 % biotite, and about 5 % garnet. Among accessory minerals there are observed apatite, zircon, and monazite. The rock shows

porphyry-like structure with fine-grained granoblastic and local lepidogranoblastic groundmass. The texture is massive and slightly directive (Fig. 3).

The plagioclases are presented by strongly saussuritized porphyroblasts, small unaltered grains of groundmass and single isometric grains of strongly saussuritized plagioclase that occur within potassic feldspar aggregates.

Potassic feldspar may form both quite big (up to 4 cm in size) porphyroblastic grains that are intensively pelitized and rather small unaltered grains of rock groundmass.

Fig. 3 Granodiorite. Sample 14/13:

a – polished section image; b – image under microscope at crossed nicols

Quartz commonly forms small grains (0,1-0,2 mm) in rock groundmass. Rarely, mineral aggregates are composed of small quartz grains (1–2 mm) or aggregates which are supposed to be formed as a result of large grains disintegration.

Garnet forms sizable grains (2–5 mm) and locally occurs as intergrowths with biotite.

Biotite is presented by two varieties. The first one occurs as highly deformed flakes which show brown-yellow pleochroism and different degree of chloritization. The second variety occurs as small flakes of green color. It commonly forms aggregates with feldspars and quartz in rock groundmass which usually look like schlieren, lenses or bands.

The rock has the following chemical composition (wt. %): SiO₂ – 63,98, TiO₂ – 0,89, Al₂O₃ – 15,27, Fe₂O₃ – 1,88, FeO – 5,15, MnO – 0,13, MgO – 2,03, CaO – 2,28, Na₂O – 3,41, K₂O – 3,32, P₂O₅ – 0,06, S – 0,13, H₂O – 0,28, LOI – 0,88, Total – 99,69.

Monazites form two types of crystals: green-yellow transparent (about 5 %) and dark (almost black) non-transparent ones (about 95 %). There are gradual transitions between these two types. Black varieties of crystals have complex structure with transparent core and black opaque margin. Black crystals show cake-like morphology and are characterized by rounded contours. After treating monazites by weak solution of hydrochloric acid black, pitch-black crystal varieties became covered with white crusts.

In thin section the monazite crystals are found rather in rock groundmass than as inclusions in quartz or potassic feldspar.

The age of biotite-garnet granodiorite is determined by uranium-lead isotopic method on green-yellow crystals selected manually under binocular. The contents of uranium, lead and their isotopic ratio are determined by the weighed amount of several multigrain fractions of monazite, which are shown in Table 1.

Table 1

Uranium-lead content and isotopic composition of lead in monazites from Berdychiv type granitoids. Sample 14/13, Stryzhavka open pit

Fraction Mnz	Content (ppm)		Isotopic ratios					Age, Ma		
	U	Pb	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{207}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{208}\text{Pb}}$	$\frac{^{206}\text{Pb}_t}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}_t}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{206}\text{Pb}_t}$
1	5454	7881	1130	7,2474	0,37509	0,43260	7,5396	2317	2178	2048,5
2	6359	7879	9030	7,8413	0,38329	0,38215	6,6492	2086	2066	2045,6
2	6058	8097	16170	7,8548	0,34948	0,38638	6,7455	2106	2079	2051,6
3	5183	7922	10350	7,8345	0,28964	0,38438	6,7037	2097	2073	2049,7
3	5565	8329	11710	7,8431	0,29981	0,38643	6,7399	2106	2078	2049,9
2	5920	7863	7860	7,8174	0,34578	0,38054	6,6302	2079	2063	2048,0
2	4965	6826	28230	7,8753	0,34118	0,39076	6,8229	2126	2089	2051,8

Note. Correction in common lead according to Stacey and Kramers aged 2050 Ma. Monazite fractions: 1 – fine (0,04 mm) light green-yellow transparent crystals of isometric shape; 2 – green-yellow transparent cake-like crystals (0,04–0,05 mm) with small black inclusions; 3 – green-yellow transparent and semi-translucent crystals with many small black inclusions.

The age of monazites from granodiorite determined on top intersection of concordia with of regression line and

calculated on data shown in Table 1 makes 2049,3 ± 3,5 Ma (Fig. 4).

Fig. 4. U-Pb diagram with concordia for monazites from biotite-garnet granodiorite Sample 14/13, the Stryzhavka open pit

Biotite-garnet granite (sample P-2, the Stryzhavka open pit) is light grey inequigranular rock which includes (%): plagioclase – 35–40 %, quartz – 20–25 %, potassic feldspar – 20–24 %, garnet – 10 % and biotite – 5 %. Among accessory minerals, zircon, apatite and monazite are found.

Both granitoid varieties (samples) are quite similar in mineral composition and textural-structural features. The main difference is a proportion between rock-forming minerals. The light variety of granite includes mostly quartz and some biotite. Structurally, granitoids of both samples

look practically identical. Large porphyroblasts of feldspar, which are intensively altered by secondary processes, evince against the fine-grained groundmass comprised predominantly by quartz, feldspar, and locally green biotite.

Chemical composition is following (wt. %): SiO₂ – 69,42, TiO₂ – 0,10, Al₂O₃ – 14,99, Fe₂O₃ – 0,08, FeO – 3,57, MnO – 0,04, MgO – 1,20, CaO – 1,61, Na₂O – 3,33, K₂O – 4,70, P₂O₅ – 0,06, S < 0,02, H₂O – 0,06, LOI – 0,44, Total – 99,60.

Table 2

Uranium and lead contents, and isotopic composition of lead in monazites from granite of the Stryzhavka open pit. Sample P-2

Fraction Mnz	Content (ppm)		Isotopic ratios					Age, Ma		
	U	Pb	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{207}\text{Pb}}$	$\frac{^{206}\text{Pb}}{^{208}\text{Pb}}$	$\frac{^{206}\text{Pb}_t}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}_t}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}_t}{^{206}\text{Pb}_t}$
1	2663	8024	34250	7,9536	0,12138	0,37050	6,4094	2032	2034	2035,4
2	2629	8390	22220	7,9504	0,11262	0,36719	6,3441	2016	2025	2033,2
3	2721	8518	30120	7,9466	0,11720	0,37324	6,4598	2045	2040	2036,2
4	2621	8015	23280	7,9498	0,11935	0,37045	6,4023	2032	2033	2033,7

Note. Correction on common lead according to Stacey and Kramers aged 2050 Ma. 1–4 – light yellow transparent crystals of cake-like morphology size fractions. Fractions are selected by rolling down along oblique plane.

Fig. 5. U-Pb diagram with concordia for monazites from biotite-garnet granite Sample P-2, the Stryzhavka open pit

Monazites are generally presented by light yellow transparent crystals that show cake-like and rarely flattened morphology with lustrous surface and rounded edges.

The age of granite determined on monazite, which is indicated by the upper intersection of concordia with the regression line and quantified in Tabl. 2, makes 2035,1 ± 1,9 Ma (Fig. 5). Weighted average value of the age calculated according to isotopic ratio $^{207}\text{Pb}/^{206}\text{Pb}$ makes 2034,9 ± 3,8 Ma.

Conclusion. Thus, two varieties (samples) of granitoids collected in the Stryzhavka open pit have shown significantly different age dating. Such difference unambiguously specifies a fact that the monazites selected from granodiorite crystallized a little earlier (2049 Ma) than the monazites selected from granite (2035 Ma). This is supposed to result from much earlier crystallization of granodioritic melt or more prolonged evolution of granitic melt in comparison with granodioritic one. The whole period of granitoids crystallization (evolution) uncovered in the Stryzhavka open pit exceeds 15 Ma. This age is in good agreement with estimates on the possible period of granitic melt crystallization (evolution) typical of the most granitoid complexes in the Ukrainian Shield (Stepanyuk, 2017).

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Л. Степанюк¹, д-р геол. наук, член-кор. НАН України,

E-mail: stepaniuk@nas.gov.ua;

О. Грінченко², канд. геол.-мінералог. наук, доц.,

E-mail: alexgrin@univ.kiev.ua;

Т. Довбуш¹, наук. співроб.;

О. Зюльцле¹, канд. геол. наук, старш. наук. співроб.;

Н. Коновал¹, канд. геол. наук, старш. наук. співроб.;

Т. Мірончук², канд. філол. наук, доц.,

E-mail: tatianakiev99@gmail.com;

¹Інститут геохімії, мінералогії та рудоутворення НАН України,

пр. Палладіна, 34, м. Київ, 03680, Україна;

²Київський національний університет імені Тараса Шевченка,

ННІ "Інститут геології", вул. Васильківська, 90, м. Київ, 03022, Україна

ВІКОВИЙ ІНТЕРВАЛ ФОРМУВАННЯ ГРАНІТОЇДІВ УКРАЇНСЬКОГО ЩИТА

Розглядається гранітоїди Бердичівського типу, які завжди викликали інтерес багатьох дослідників Українського щита. Дані породи містять нетипові для гранітів мінерали – кордиєрит, силіманіт, андалузит і тісним чином пов'язані з породами можливого субстрату. Усе ж ще залишається відкритим питання щодо генетичної природи бердичівських гранітів. Незважаючи на той факт, що більшість дослідників відносять граніти бердичівського типу до інтрузивних (анатектичних) утворень, існують й інші припущення, згідно з якими ці граніти розглядаються як продукти метасоматичного перетворення (магматичного заміщення) первинно глинисто-мергелистих товщ субстрату.

Стрижавським кар'єром, який розташований у регіоні Верхнього Побужжя Українського щита, нерівномірно розкриті катаклазовані порфіроподібні плагіогранітоїди (гранатемісні різновиди – переважно в південно-західній частині кар'єру та локально – різновиди з породотвірним калишпатом) і гранатемісні лейкократові граніти, які є подібними до гранітів бердичівського типу.

Уран-свинцевим ізотопним методом було визначено вік монацитів з біотит-гранатового гранодіориту і біотит-гранатового граніту. Вік монациту з гранодіориту, який був розрахований за верхнім перетином конкордії з дискордією, становить $2049,3 \pm 3,5$ млн років. Істотно менші значення віку (майже на 15 млн років молодше) було отримано для монациту з граніту – $2035,1 \pm 1,9$ млн років. Цей факт, на наш погляд, обумовлений тривалою кристалізацією гранітного розплаву й відносно ранньою кристалізацією більш основної гранодіоритової магми порівняно з гранітною. Таким чином, загальний період (тривалість) формування гранітоїдів, розкритих Стрижавським кар'єром, перевищує 15 млн років, що добре узгоджується з оцінками тривалості існування гранітоїдних розплавів, які спричинили формування різноманітних гранітоїдів Українського щита.

Ключові слова: Український щит, Верхнє Побужжя, ізотопний вік, бердичівський граніт, монацит.

Л. Степанюк¹, д-р геол. наук, член-кор. НАН України,

E-mail: stepaniuk@nas.gov.ua;

А. Грінченко², канд. геол.-мінералог. наук, доц.,

E-mail: alexgrin@univ.kiev.ua;

Т. Довбуш¹, науч. сотр.

О. Зюльцле¹, канд. геол. наук, ст. науч. сотр.;

О. Коновал¹, канд. геол. наук, ст. науч. сотр.;

Т. Мирончук², канд. филол. наук, доц.,

E-mail: tatianakiev99@gmail.com;

¹Інститут геохімії, мінералогії та рудообразовання НАН України,

пр. Палладіна, 34, г. Киев, 03680, Украина;

²Киевский национальный университет имени Тараса Шевченко,

УНИ "Институт геологии", ул. Васильковская, 90, г. Киев, 03022, Украина

ВОЗРАСТНОЙ ИНТЕРВАЛ ФОРМИРОВАНИЯ ГРАНИТОИДОВ УКРАИНСКОГО ЩИТА

Рассматриваются гранитоиды Бердичевского типа, которые всегда вызывали интерес многих исследователей Украинского щита. Данные породы содержат нетипичные для гранитов минералы – кордиерит, силлиманит, андалузит и тесным образом связаны с породами предполагаемого субстрата. В то же время, все еще остаются открытыми вопросы относительно генетической природы бердичевских гранитов. Несмотря на тот факт, что большинство исследователей относят граниты бердичевского типа к интрузивным (анатектическим) образованиям, существуют и другие представления, согласно которым эти граниты рассматриваются как продукты метасоматического преобразования (магматического замещения) первично глинисто-мергелистых толщ субстрата.

Стрижавским карьером, который расположен в регионе Верхнего Побужья Украинского щита, в различной степени раскрытые катаклазированные порфировидные плагиогранитоиды (гранатемещающие разновидности – преимущественно в юго-западной части карьера, и разновидности с породообразующим калишпатом – локально) и гранатемещающие лейкократовые граниты, сходные с гранитами бердичевского типа.

Уран-свинцевым изотопным методом был определен возраст монацитов из биотит-гранатового гранодiorита и биотит-гранатового гранита. Возраст монацита из гранодiorита, который был рассчитан по верхнему пересечению конкордии с дискордией, составляет $2049,3 \pm 3,5$ млн лет. Существенно меньшие значения возраста (почти на 15 млн лет моложе) были получены для монацита, выделенного из гранита – $2035,1 \pm 1,9$ млн лет. Это, на наш взгляд, обусловлено продолжительной кристаллизацией гранитного расплава и относительно ранней кристаллизацией более основной гранодiorитовой магмы по сравнению с гранитной. Таким образом, продолжительность формирования гранитоидов, раскрытых Стрижавским карьером, превышает 15 млн лет, что хорошо согласуется с оценками продолжительности существования гранитоидных расплавов, которые обусловили формирование различных гранитоидов Украинского щита.

Ключевые слова: Украинский щит, Верхнее Побужье, изотопный возраст, бердичевский гранит, монацит.