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# Xenotime-(Y) from granitic pegmatites of the Monatsitovaya mine, Aduisky massif, Middle Urals (chemical composition and age)

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## Abstract

***The relevance of the work*** is due to the need to improve the chemical dating method as applied to high-uranium and high-thorium accessory minerals, which are difficult to study using isotopic research methods.

***The purpose of the work*** is to study the chemical composition of accessory xenotime from granite pegmatites of the Monatsitovaya mine (western part of the Aduisky massif) and determine its age.

***Research methodology.*** A quantitative analysis of the chemical composition of monazite was performed on a CAMECA SX 100 electron probe microanalyzer (IGG Ural Branch RAS, Ekaterinburg). Measurement conditions: accelerating voltage 15 kV, current 250 nA, electron beam diameter 2 μm. The pressure in the sample chamber is $2 \times 10^{-4}$ Pa. The spectra were obtained on inclined wave spectrometers, the intensity measurements were carried out along the analytical lines: Y *Lα*, Si *Kα*, (TAP crystal analyzer), U *Mβ,* Pb *Mα*, Ca *Kα*, Th *Mα*, P *Kα* (PET), Yb *Lα,* Dy *Lα*, Er *Lα*, Gd *Lα*, Lu *Lα*, Sm *Lβ* (LiF). The overlap of peaks of spectral lines was taken into account, which is extremely important in the quantitative determination of lead content (the Y $L\gamma_{2,3}$ и Th $M\zeta_{1,2}$ lines are superimposed on the analytical Pb *Mα* line). The pulse accumulation time at the peaks of analytical lines was twice as long as for the background and was 60 s for Th, 40 s for U and Pb, and 10 s for other elements. When conducting research, linear experimental design was used to vary the time of measuring the intensities of the *Mβ* line of uranium, *Mα* lines of thorium and lead. The calculated detection limits are 345 ppm for U, 283 ppm for Th, 65 ppm for Pb, 205 ppm for Y.

***Results.*** It has been established that xenotime belongs to the yttrium variety and is characterized by an increased content of uranium ($UO_2$ up to 8.8 wt. %) and thorium ($ThO_2$ up to 4.5 wt. %). According to the results of chemical dating (based on 32 analyses), xenotime-(Y) shows a weighted average age of 276 ± 7 Ma (MSWD = 0.54). When constructing the dependence ($ThO_2$+$UO_2^{eq}$) – PbO, the points fall on one isochron. Calculating the age using the isochron slope angle gave a dating of 276 ± 12 million years (MSWD = 0.94).

***Conclusions.*** The obtained age values for the xenotime are in good agreement with the dating of the pegmatoid granites of the Krutikhinsky massif, which is located on the western contact of the Aduisky granite massif and relatively close to the Monatsitovaya mine. It is quite possible that some pegmatites in the western part of the Aduisky massif were formed as a result of the formation of the Krutikhinsky massif.

***Keywords*:** xenotime-(Y), chemical dating, granite pegmatites, Monatsitovaya mine, Aduisky massif, Middle Urals.

## Introduction

The method of chemical U–Th–Pb dating has been known for quite a long time; abroad it is often used as a rapid non-isotopic method for determining the age of accessory U–Th-containing minerals with a size of at least 5–10 microns. This method is of interest to geologists for its simplicity in sample preparation, high speed, low cost of analysis, and good agreement with isotope dating. It is mainly applied to monazite, which is more widespread in nature, and only in rare cases to other radioactive minerals [1, 2]. In this case, it is most difficult to date yttrium phosphate – xenotime, since serious difficulties arise in determining lead using the *Ma*-line due to spectral overlap with the yttrium line [3–5]. In [6], the effect of superposition of the Y *Lγ*-line on the Pb *Ma*-line was analyzed on synthetic $YPO_4$; extrapolation to the yttrium content in monazite of the order of 2 wt. % shows that the superposition of lines in phosphates can lead to an overestimation of the lead content by a maximum of 30 ppm, which in turn leads to an increase in the calculated age. This paper presents the results of a study of accessory xenotime from granite pegmatites of the Monatsitovaya mine, located in the western part of the Aduisky massif.

**Geological position and structure of the Monatsitovaya mine in the Aduisky massif.** In recent years, a number of new pegmatite mines have been discovered in the Aduisky granite massif [7]. A large number of them were found 6–7 km north of the village of Ozernoye (located south of the city of Rezh) and in its vicinity [8]. This area is rich in ceramic pegmatite mines, in the largest of which at the beginning of the last century (1925–1927) prospectors mined feldspar for the ceramic industry. Lump feldspar was mined from the upper fractured parts of the mines to a depth of 2–3 m in workings up to 4–30

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m long and transported on carts to the river and then to the Rezh station. In total, about 1000 tons of feldspar were mined [9].

The Monatsitovaya mine is located on the northwestern edge of the Chistoye swamp, approximately 4 km southwest of the village of Ozernoye and 5 km west of the Kostousovo railway station (Fig. 1). The reference from the GPS navigator is N 57°17′34.2′′, E 61°08′96.6′′. In 1971 V. A. Gubin (now deceased) found large monazite crystals, up to 1.5 cm in size, in an unnamed pegmatite mine quarter 62 of Monetnaya Dacha [7]. Based on this find, the mine was named Monatsitovaya.

The pegmatite mine reaches a length of 30–35 m with a thickness of 2–4 m, a strike azimuth of 65°, and a dip angle of 70–85°. Zoning from the salvages to the center: pegmatoid quartz-feldspar zone with annite and magnetite – graphic zone of quartz-feldspar composition with annite, muscovite and REE mineralization – block quartz-feldspar zone with muscovite and REE mineralization. In pegmatite, xenotime is yttrium and occurs in the graphic and block zones, where it associates with annite, muscovite, monazite-(Ce), ilmenite, ilmenorutile, magnetite, thorianite, fluorapatite and zircon. It forms large bipyramidal crystals, up to 1 cm in size, often with internal zoning from bluish-green in the center through reddish-brown in the middle to greenish-yellow at the edges [7, 11].

## Research methodology

A quantitative analysis of the chemical composition of xenotime was performed on a CAMECA SX 100 electron probe microanalyzer (IGG Ural Branch RAS, Yekaterinburg). A polished section was made from a xenotime crystal, up to 1 cm in size, then the specimen was sprayed with a thin layer of carbon. Measurement conditions: accelerating voltage 15 kV, current 250 nA, electron beam diameter 2 μm. The pressure in the sample chamber is $2 \times 10^{-4}$ Pa. Before performing a quantitative analysis, the intensity distribution maps of the characteristic X-ray radiation in the rays of the analytical lines were recorded. Standard samples of synthetic REE phosphates, Th and U oxides, pyrope, and $Pb_2P_2O_7$ were used as standards. To measure the intensity, the following analytical lines were selected: Y *Lα*, Si *Kα*, (TAP analyzer crystal), U *Mβ,* Pb *Mα*, Ca *Kα*, Th *Mα*, P *Kα* (PET), Yb *Lα,* Dy *Lα*, Er *Lα*, Gd *Lα*, Lu *Lα*, Sm *Lβ* (LiF). The overlap of peaks of spectral lines was taken into account, which is extremely important in the quantitative determination of lead content (the Y $L\gamma_{2,3}$ и Th $M\zeta_{1,2}$ lines are superimposed on the analytical Pb *Mα* line). The time for collecting pulses at the peaks of analytical lines was twice as long as for the background and was 60 s for Th, 40 s for U and Pb, and 10 s for the other elements. When conducting research, linear experimental design was used to vary the time of measuring the intensities of the *Mβ* line of uranium, *Mα* lines of thorium and lead. The calculated detection limits are 345 ppm for U, 283 ppm for Th, 65 ppm for Pb, 205 ppm for Y. Oxygen content was determined assuming compositional stoichiometry. The theoretical and practical justification for the method of chemical dating using X-ray spectral microprobe analysis is given in numerous publications on this topic [6, 12], including the team of authors [2, 13]. The main condition of this method: during the process of evolution, the mineral did not lose radiogenic lead (i. e., the Th–U–Pb system was closed), all the lead in the mineral was formed due to the decay of thorium and uranium.

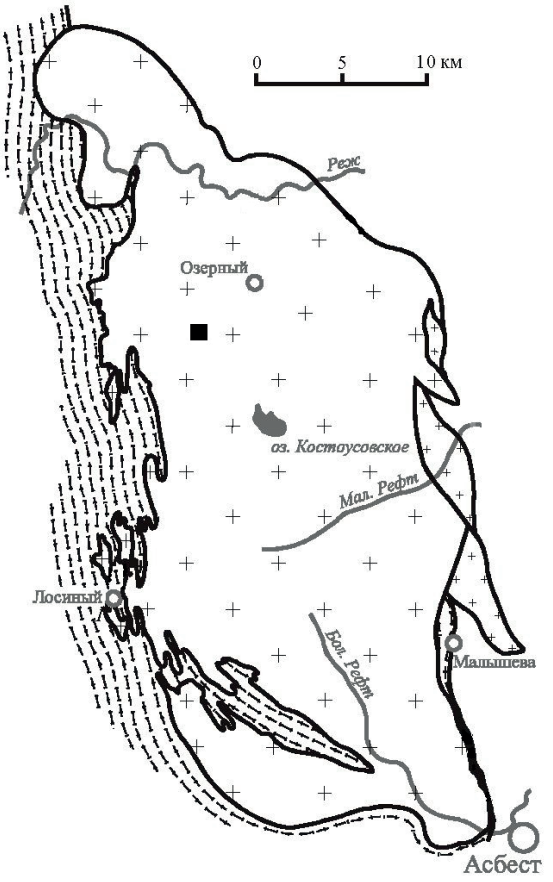


**Figure 1. Contours of the Aduisky granite massif with settlements and reservoirs (given according to [10] with our simplifications). The square shows the location of the Monatsitovaya mine**
**Рисунок 1. Контуры Адуйского гранитного массива с вынесенными населенными пунктами и водоемами (дано по [10] с нашими упрощениями). Квадратом показано расположение копи «Монацитовая»**

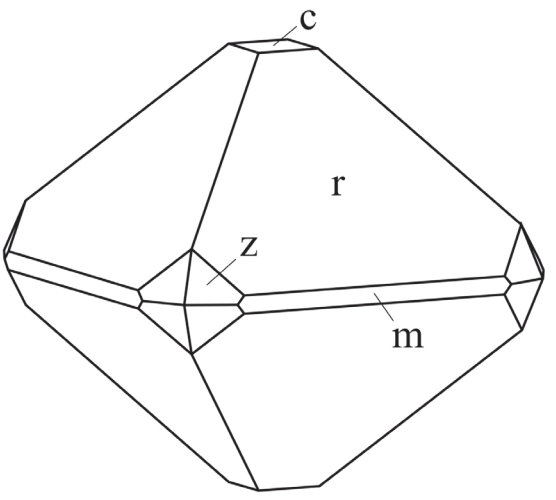


**Figure 2. Idealized xenotime crystal. Face indices are given in the text**
**Рисунок 2. Идеализированный кристалл ксенотима. Индексы граней даны в тексте**

## Results and discussion

For study and dating, we used a relatively large and opaque xenotime crystal from the block zone. It was kindly donated for

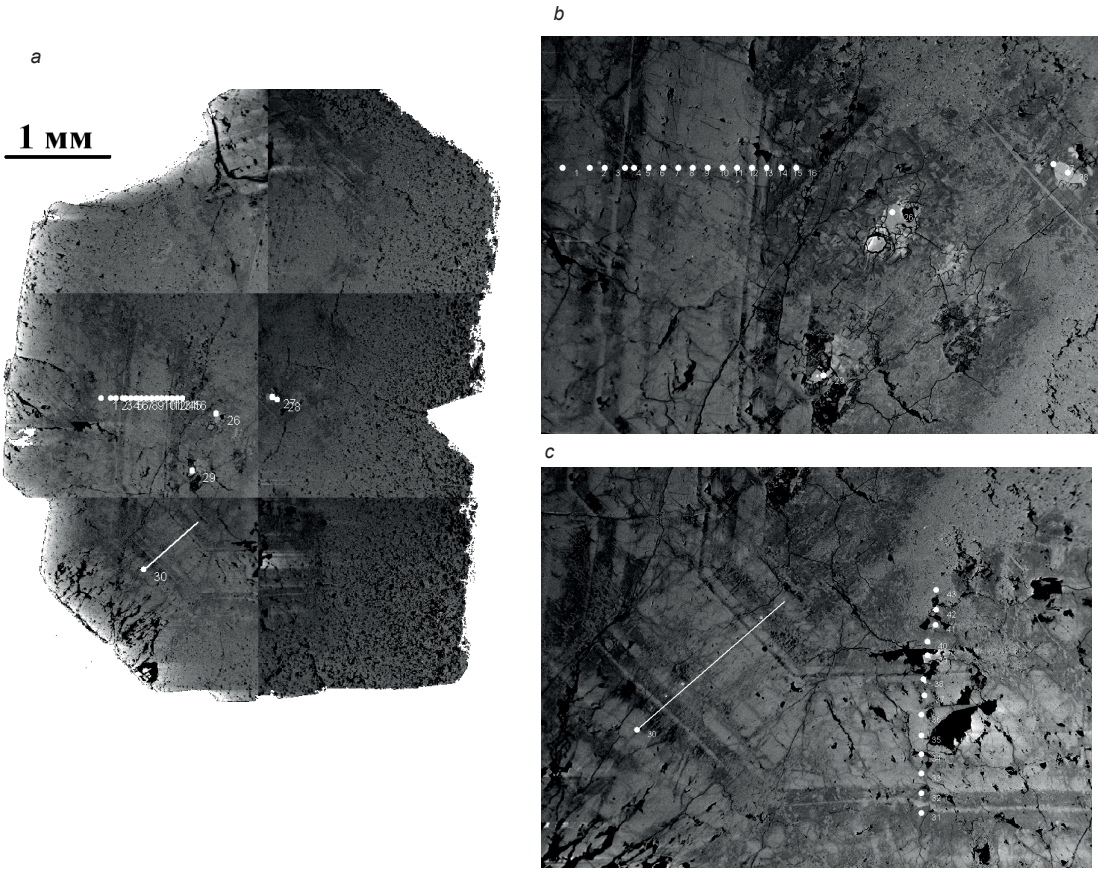


**Figure 3. Image of a xenotime crystal and its fragments from the Monatsitovaya mine:** *a* – general view of the cross section of the crystal, *b* – fragment of the central part of the crystal, *c* – fragment of the lower part of the crystal. BSE photo, CAMECA SX 100. A photo of an individual is made by gluing together smaller pictures. The dots and line show the analyzes and profile
**Рисунок 3. Изображение кристалла ксенотима и его фрагментов из жилы «Монацитовая»:** *a* – общий вид сечения кристалла, *b* – фрагмент центральной части кристалла, *c* – фрагмент нижней части кристалла. BSE-фото, CAMECA SX 100. Фото индивида сделано путем склеивания более мелких картинок. Точками и линией показаны анализы и профиль

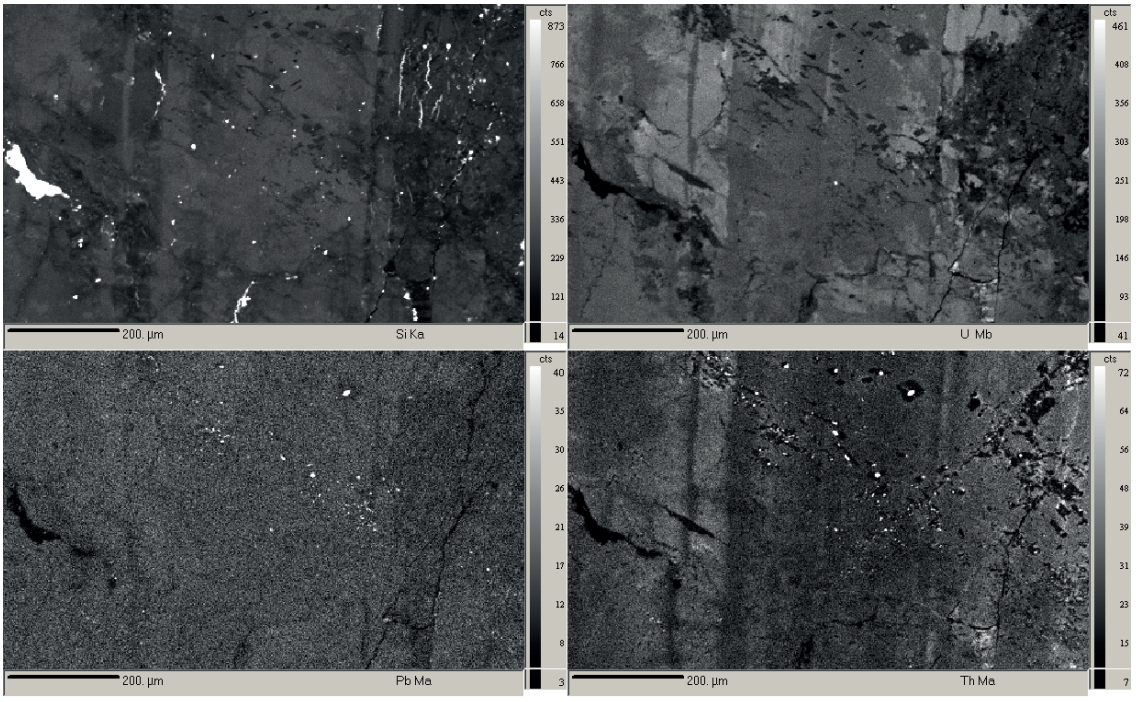


**Figure 4. BSE image of the central section of a xenotime crystal, 950 × 580 µm in size, in characteristic X-ray radiation of the Si *Ka*, U *Mb*, Pb *Ma* and Th *Ma* lines. The intensity reading step is 2 µm, the measurement time at a point is 50 ms**
**Рисунок 4. BSE-изображение центрального участка кристалла ксенотима размером 950 × 580 мкм в характеристическом рентгеновском излучении линий Si *Ka*, U *Mb*, Pb *Ma* и Th *Ma*. Шаг считывания интенсивности – 2 мкм, время измерения в точке – 50 мс**

**Table 1. Chemical composition of xenotime from pegmatites of the Monatsitovaya mine, wt. %**
**Таблица 1. Химический состав ксенотима из пегматитов жилы «Монацитовая», мас. %**

| Oxides | Analysis number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| $P_2O_5$ | 29,12 | 29,46 | 30,16 | 29,00 | 29,02 | 29,81 | 29,77 | 29,36 | 29,02 | 27,67 | 29,58 |
| $ThO_2$ | 3,17 | 3,18 | 3,02 | 4,28 | 3,30 | 3,18 | 3,07 | 3,53 | 3,90 | 3,60 | 4,39 |
| $UO_2$ | 6,22 | 6,32 | 6,34 | 7,97 | 7,85 | 6,22 | 6,31 | 6,47 | 6,54 | 8,81 | 3,75 |
| $SiO_2$ | 1,99 | 1,81 | 1,97 | 1,46 | 1,90 | 2,14 | 2,22 | 1,83 | 1,87 | 1,78 | 1,35 |
| $Y_2O_3$ | 37,07 | 36,37 | 36,80 | 33,57 | 35,66 | 37,45 | 37,60 | 36,12 | 35,82 | 34,31 | 35,96 |
| $Lu_2O_3$ | 0,58 | 0,64 | 0,61 | 0,69 | 0,48 | 0,42 | 0,51 | 0,45 | 0,35 | 0,42 | 0,61 |
| $Yb_2O_3$ | 4,59 | 4,39 | 4,68 | 4,61 | 4,51 | 4,41 | 4,52 | 4,51 | 4,62 | 4,26 | 4,36 |
| $Tm_2O_3$ | 0,73 | 0,70 | 0,72 | 0,74 | 0,66 | 0,74 | 0,66 | 0,59 | 0,71 | 0,64 | 0,64 |
| $Er_2O_3$ | 3,95 | 3,96 | 3,98 | 3,86 | 3,85 | 3,90 | 3,93 | 3,91 | 3,97 | 3,67 | 3,77 |
| $Ho_2O_3$ | 0,88 | 0,98 | 0,79 | 0,83 | 0,87 | 0,85 | 0,86 | 0,85 | 0,73 | 0,73 | 0,89 |
| $Dy_2O_3$ | 4,18 | 4,13 | 4,24 | 4,10 | 4,09 | 4,29 | 4,32 | 4,24 | 4,27 | 3,98 | 4,06 |
| $Gd_2O_3$ | 1,71 | 1,68 | 1,64 | 1,64 | 1,63 | 1,75 | 1,73 | 1,75 | 1,70 | 1,66 | 1,65 |
| $Sm_2O_3$ | 0,46 | 0,43 | 0,45 | 0,47 | 0,47 | 0,43 | 0,46 | 0,30 | 0,36 | 0,40 | 0,50 |
| $Nd_2O_3$ | 0,37 | 0,36 | 0,40 | 0,37 | 0,29 | 0,44 | 0,39 | 0,45 | 0,36 | 0,35 | 0,37 |
| PbO | 0,30 | 0,27 | 0,26 | 0,25 | 0,37 | 0,26 | 0,30 | 0,29 | 0,25 | 0,35 | 0,18 |
| CaO | 0,38 | 0,50 | 0,26 | 1,21 | 0,66 | 0,06 | 0,05 | 0,59 | 0,60 | 1,06 | 1,07 |
| *Total* | 95,71 | 95,17 | 96,32 | 95,04 | 95,61 | 96,36 | 96,71 | 95,23 | 95,05 | 93,69 | 93,15 |

| Oxides | Analysis number | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| $P_2O_5$ | 28,30 | 28,23 | 28,41 | 29,25 | 29,00 | 27,93 | 28,37 | 29,76 | 26,50 | 30,00 | 29,39 |
| $ThO_2$ | 4,29 | 4,39 | 4,37 | 3,06 | 3,26 | 4,18 | 4,52 | 3,08 | 6,06 | 3,00 | 2,86 |
| $UO_2$ | 8,02 | 8,32 | 8,27 | 5,80 | 6,47 | 7,39 | 7,44 | 5,98 | 6,97 | 6,06 | 5,87 |
| $SiO_2$ | 2,93 | 2,97 | 2,96 | 1,89 | 1,86 | 1,62 | 1,62 | 1,93 | 1,07 | 1,93 | 2,05 |
| $Y_2O_3$ | 35,73 | 35,83 | 35,65 | 36,51 | 36,27 | 33,80 | 33,23 | 37,02 | 34,06 | 36,61 | 37,67 |
| $Lu_2O_3$ | 0,51 | 0,56 | 0,55 | 0,68 | 0,60 | 0,63 | 0,68 | 0,60 | 0,61 | 0,61 | 0,62 |
| $Yb_2O_3$ | 4,13 | 4,28 | 4,25 | 4,61 | 4,45 | 4,37 | 4,50 | 4,59 | 4,69 | 4,58 | 4,61 |
| $Tm_2O_3$ | 0,70 | 0,69 | 0,60 | 0,63 | 0,71 | 0,70 | 0,67 | 0,73 | 0,88 | 0,75 | 0,67 |
| $Er_2O_3$ | 3,76 | 3,76 | 3,79 | 3,93 | 3,92 | 3,91 | 3,82 | 3,87 | 4,75 | 3,96 | 4,04 |
| $Ho_2O_3$ | 0,81 | 0,71 | 0,73 | 0,74 | 0,76 | 0,75 | 0,81 | 0,84 | 1,09 | 0,96 | 0,90 |
| $Dy_2O_3$ | 3,95 | 4,11 | 4,06 | 4,07 | 4,10 | 4,03 | 3,94 | 4,22 | 4,07 | 4,20 | 4,14 |
| $Gd_2O_3$ | 1,62 | 1,68 | 1,65 | 1,65 | 1,63 | 1,61 | 1,65 | 1,65 | 1,96 | 1,70 | 1,67 |
| $Sm_2O_3$ | 0,41 | 0,38 | 0,39 | 0,31 | 0,39 | 0,43 | 0,40 | 0,45 | 0,62 | 0,40 | 0,36 |
| $Nd_2O_3$ | 0,41 | 0,38 | 0,42 | 0,28 | 0,33 | 0,39 | 0,36 | 0,36 | 0,30 | 0,27 | 0,31 |
| PbO | 0,36 | 0,35 | 0,38 | 0,25 | 0,29 | 0,26 | 0,20 | 0,28 | 0,25 | 0,26 | 0,27 |
| CaO | 0,05 | 0,05 | 0,05 | 0,57 | 0,55 | 1,28 | 1,42 | 0,52 | 1,12 | 0,23 | 0,14 |
| *Total* | 96,01 | 96,68 | 96,54 | 94,24 | 94,59 | 93,29 | 93,63 | 95,86 | 95,01 | 95,52 | 95,56 |

| Oxides | Analysis number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| $P_2O_5$ | 30,64 | 30,06 | 28,76 | 29,04 | 29,86 | 28,91 | 30,04 | 29,53 | 29,77 | 27,97 |
| $ThO_2$ | 3,68 | 2,66 | 3,58 | 3,45 | 3,10 | 3,39 | 3,31 | 3,16 | 3,12 | 4,02 |
| $UO_2$ | 6,16 | 5,64 | 8,07 | 7,36 | 6,33 | 6,84 | 7,78 | 6,50 | 6,62 | 6,80 |
| $SiO_2$ | 1,60 | 2,03 | 1,68 | 1,81 | 2,02 | 1,81 | 1,87 | 2,09 | 2,20 | 1,64 |
| $Y_2O_3$ | 36,07 | 37,92 | 34,84 | 35,46 | 36,48 | 35,77 | 34,43 | 36,70 | 36,72 | 35,02 |
| $Lu_2O_3$ | 0,56 | 0,57 | 0,65 | 0,61 | 0,63 | 0,62 | 0,61 | 0,64 | 0,58 | 0,55 |
| $Yb_2O_3$ | 4,62 | 4,57 | 4,46 | 4,39 | 4,46 | 4,42 | 4,36 | 4,46 | 4,35 | 4,51 |
| $Tm_2O_3$ | 0,69 | 0,67 | 0,71 | 0,63 | 0,69 | 0,68 | 0,73 | 0,65 | 0,80 | 0,72 |
| $Er_2O_3$ | 3,90 | 3,96 | 3,88 | 3,81 | 3,92 | 3,93 | 3,77 | 3,86 | 3,85 | 3,97 |
| $Ho_2O_3$ | 0,90 | 0,80 | 0,84 | 0,92 | 0,88 | 0,92 | 0,78 | 0,86 | 0,83 | 0,86 |
| $Dy_2O_3$ | 4,26 | 4,20 | 4,05 | 4,16 | 4,16 | 4,12 | 4,02 | 4,21 | 4,17 | 4,19 |
| $Gd_2O_3$ | 1,66 | 1,66 | 1,73 | 1,64 | 1,71 | 1,68 | 1,67 | 1,74 | 1,68 | 1,77 |
| $Sm_2O_3$ | 0,45 | 0,40 | 0,42 | 0,31 | 0,39 | 0,41 | 0,44 | 0,39 | 0,39 | 0,47 |
| $Nd_2O_3$ | 0,37 | 0,34 | 0,39 | 0,28 | 0,40 | 0,37 | 0,38 | 0,35 | 0,32 | 0,48 |
| PbO | 0,30 | 0,27 | 0,31 | 0,32 | 0,29 | 0,36 | 0,30 | 0,31 | 0,33 | 0,29 |
| CaO | 0,82 | 0,06 | 0,92 | 0,65 | 0,22 | 0,69 | 0,58 | 0,22 | 0,13 | 0,78 |
| *Total* | 96,69 | 95,83 | 95,29 | 94,84 | 95,55 | 94,91 | 95,05 | 95,66 | 95,85 | 94,05 |

Note: IGG Ural Branch of RAS, microanalyzer CAMECA SX 100, analyst V. V. Khiller.

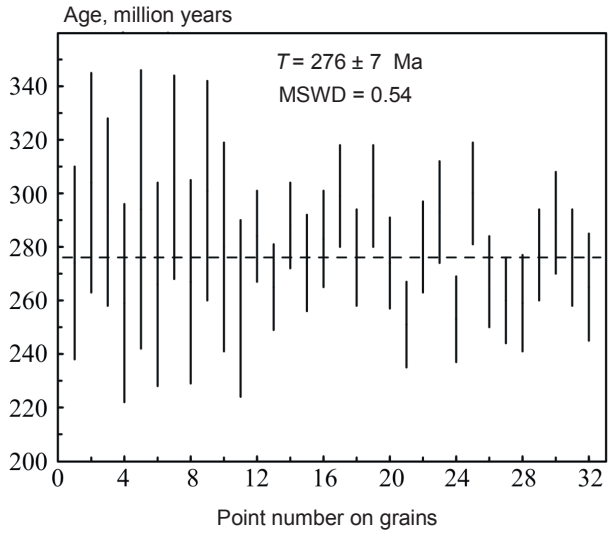


**Figure 5. Average weighted Th–U–Pb age of xenotime according to microprobe analyzes (a total of 32 determinations were made)**
**Рисунок 5. Средневзвешенный Th–U–Pb-возраст ксенотима по данным микрозондовых анализов (всего сделано 32 определения)**

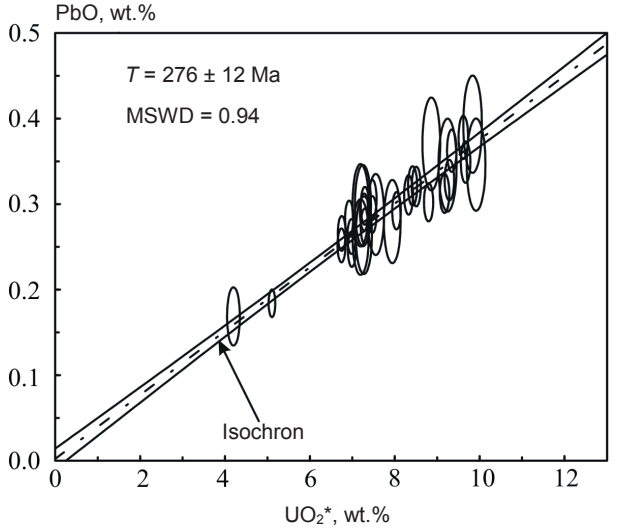


**Figure 6. $UO_2$*–PbO data for xenotime from the Monatsitovaya mine. The ellipses correspond to the error values 1 s, the dashed line is a regression line with two symmetrical hyperbolas that fix the errors**
**Рисунок 6. $UO_2$*–PbO-данные для ксенотима из жилы «Монацитовая». Эллипсы соответствуют значениям погрешности 1 s, штрихпунктир – линия регрессии с двумя симметричными гиперболами, фиксирующими погрешности**

research by V. A. Gubin. Xenotime is characterized by a dark brown color and has small epitaxial growths of zircon at the tops of the crystal. An individual xenotime is bipyramidal in appearance (Fig. 2), up to 1 cm in diameter, slightly flattened along the c[001] axis. The main shape in the cut of the crystal is a dipyramid – r{111}, narrow prism edges are marked on its edges – m{110}, and the vertices are cut by a basopinacoid – c {001} and a ditetragonal dipyramid – z{311}. The surface of the edges is matte, uneven in places.

Due to the wide range of uranium, thorium and heavy REE contents, individual xenotime from the Monatsitovaya mine is characterized by clearly defined zoning in backscattered electron images (Fig. 3). The matrix contains small inclusions of uranium and thorium phases, uraninite and thorianite, no more than 50 microns in size (Fig. 4).

The chemical composition of the studied xenotime is quite heterogeneous (Table 1) and correlates well with previously obtained data [11], which, unfortunately, were few. Based on our results of all the above 32 analyses, we can say that phosphate in the block zone is represented by yttrium variety (since yttrium significantly predominates over heavy rare earths) with a fairly high content of uranium ($UO_2$ up to 8.8 wt. %) and thorium ($ThO_2$ up to 4.5 wt. %). Among other impurities, one can note the presence of significant concentrations of erbium ($Er_2O_3$ up to 5.5 wt. %), ytterbium ($Yb_2O_3$ up to 5.3 wt. %), calcium (CaO up to 4.0 wt. %) and silica ($SiO_2$ up to 2. 9 wt. %). The content of radiogenic components varies quite strongly, wt. %: $ThO_2$ – 2.57–6.06; $UO_2$ – 1.94–8.81; PbO – 0.08–0.41. The sums of the analyzes indicate that xenotime may contain water, although some elements may not have been measured.

For each point of the crystal at which the analysis was carried out (about 32 points in total), the age was calculated using the method of [6], the scatter of which is in the range from 251 to 306 million years. Their weighted average is 276 ± 7 Ma, MSWD = 0.54 (Fig. 5).

Thanks to the wide range of contents of uranium and lead oxides, we were able to construct an isochron from a set of analytical points using the CHIME method [5] in $UO_2$*–PbO coordinates, and from its slope angle ($m$ = 0.0373) we calculated the U*/Pb age, which was 276 ± 12 Ma (Fig. 6). Here $UO_2$* = ($UO_2$+$ThO_2^{eq}$), where $ThO_2^{eq}$ is the thorium content, converted into the equivalent uranium content, capable of producing the same amount of Pb during the lifetime of the system with equal U–Pb and Th–Pb age values. The content of non-radiogenic lead in the xenotime, calculated from the intersection of the U*–Pb isochron with the PbO axis, is less than 0.005 wt. %, which is comparable to the limit of its detection in the mineral and therefore did not affect the age calculation.

The age values obtained for xenotime from granite pegmatites of the Monatsitovaya mine are quite difficult to estimate, since, according to existing ideas, the time of formation of the Aduisky granite massif covers a wide time interval and is estimated from 291 ± 8 million years (based on zircon [14]) to 256 ± 0.6 million years (according to monazite [15]) and 255–241 million years (according to micas [10]). Moreover, the most ancient rocks are recorded in the western part of the massif, and the youngest ones – in the central and eastern parts of the body. The pegmatites of the Aduisky massif mainly record two age boundaries: 268–262 and 255 million years. Moreover, the latter vein bodies are most often found in this area. Thus, in granitic pegmatites near the village of Ozernoye (northern part of the massif), accessory zircon was studied by chemical dating, the age of which was calculated to be within 255 ± 7 million years [16]. In nearby mines, a completely reliable Th–U–Pb dating was obtained for accessory monazites – 254 ± 15 Ma [17], and in the western part of the massif for monazite from the Semeninskaya mine – 256 ± 21 Ma [18]. Similar datings within the range of 255–241 million years were shown by micas (K–Ar method) from various Aduisky pegmatites [10].

More ancient pegmatites are characteristic of the eastern contact of the Aduisky massif. Thus, the age of granite pegmatites of the Kvartalny tantalum-niobium deposit, according to the bimineral uraninite-monazite isochron, is calculated to be within 268 ± 2 million years [19]. Rare-metal pegmatites from the nearby deposit of the same type Lipovy Log give a close dating – 262 ± 7 million years (according to the Re–Os age of molybdenites [20]), and granite pegmatites of the Lipovsky vein field located at the junction of the Aduisky and Murzinsky granite massifs – 266 ± 3 million years (according to the three-mineral isochron with uraninite, coffinite and monazite [2]).

The age values we obtained for xenotime can quite possibly be attributed to the last group of "ancient" pegmatites, because the existing error allows us to cover the entire interval of 268–262 million years. At the same time, the age of the xenotime is in good agreement with the dating of pegmatoid granites of the Krutikhinsky massif (272–271 million years, according to U–Pb data on accessory zircon [21]), which is located on the western contact of the Aduisky granite massif and, relatively close to the Monatsitovaya mine (4–5 km southwest). It is likely that some pegmatites in the western part of the Aduisky massif were formed as a result of the formation of the Krutikhinsky massif.

## Conclusions

Thus, we studied accessory xenotime from pegmatites of the Monatsitovaya mine, located in the western part of the Aduisky granite massif. According to microprobe analysis, xenotime belongs to the yttrium variety and is characterized by an increased content of uranium ($UO_2$ up to 8.8 wt. %) and thorium ($ThO_2$ up to 4.5 wt. %). An isochron age of 276 ± 12 Ma was calculated for it. The obtained age values for the xenotime are in good agreement with the dating of the pegmatoid granites of the Krutikhinsky massif, which is located on the western contact of the Aduisky granite massif and relatively close to the Monatsitovaya mine. It is quite possible that some pegmatites in the western part of the Aduisky massif were formed as a result of the formation of the Krutikhinsky massif.

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# Ксенотим-(Y) из гранитных пегматитов копи «Монацитовая», Адуйский массив, Средний Урал (химический состав и возраст)

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Аннотация

***Актуальность работы*** обусловлена необходимостью совершенствования метода химического датирования в применении к высокоурановым и высокоториевым акцессорным минералам, которые сложно изучать изотопными методами исследования.

***Цель работы*** – исследование химического состава акцессорного ксенотима из гранитных пегматитов копи «Монацитовая» (западная часть Адуйского массива) и определение его возраста.

***Методология исследования.*** Количественный анализ химического состава монацита выполнен на электронно-зондовом микроанализаторе CAMECA SX 100 (ИГГ УрО РАН, г. Екатеринбург). Условия измерения: ускоряющее напряжение 15 кВ, сила тока 250 нА, диаметр пучка электронов 2 мкм. Давление в камере образцов $2 \times 10^{-4}$ Па. Спектры получены на наклонных волновых спектрометрах, измерение интенсивности проводилось по аналитическим линиям: Y *Lα*, Si *Kα*, (кристалл-анализатор TAP), U *Mβ*, Pb *Mα*, Ca *Kα*, Th *Mα*, P *Kα* (PET), Yb *Lα*, Dy *Lα*, Er *Lα*, Gd *Lα*, Lu *Lα*, Sm *Lβ* (LiF). Проведен учет наложения пиков спектральных линий, что крайне важно при количественном определении содержания свинца (линии Y $L\gamma_{2,3}$ и Th $M\zeta_{1,2}$ накладывается на аналитическую линию Pb *Mα*). Время набора импульсов на пиках аналитических линий в два раза больше, чем для фона, и составляло 60 с для Th, 40 с для U и Pb и 10 с для остальных элементов. При проведении исследований применялось линейное планирование эксперимента по варьированию времени измерения интенсивностей *M*β-линии урана, *M*α-линий тория и свинца. Рассчитанные пределы обнаружения составляют 345 г/т для U, 283 г/т для Th, 65 г/т для Pb, 205 г/т для Y.

***Результаты.*** Установлено, что ксенотим относится к иттриевой разности и отличается повышенным содержанием урана ($UO_2$ до 8,8 мас. %) и тория ($ThO_2$ до 4,5 мас. %). По результатам химического датирования (по данным 32 анализов), ксенотим-(Y) показывает средневзвешенный возраст 276 ± 7 млн лет (СКВО = 0,54). При построении зависимости ($ThO_2 + UO_2^{экв}$)–PbO точки ложатся на одну изохрону. Расчет возраста по углу наклона изохроны дал датировку 276 ± 12 млн лет (СКВО = 0,94).

***Выводы.*** Полученные значения возраста для ксенотима хорошо согласуются с датировками пегматоидных гранитов Крутихинского массива, который находится на западном контакте Адуйского гранитного массива, и относительно недалеко от копи «Монацитовая». Вполне возможно, что некоторые пегматиты в западной части Адуйского массива формировались в результате становления Крутихинского массива.

***Ключевые слова***: ксенотим-(Y), химическое датирование, гранитные пегматиты, жила «Монацитовая», Адуйский массив, Средний Урал.

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