ABSOLUTE AGE OF THE ARAL SEA FROM NONEQUILIBRIUM URANIUM

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Abstract

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ABSOLUTE AGE OF THE ARAL SEA FROM NONEQUILIBRIUM URANIUM

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Many works have been devoted to the question of the time of formation of the Aral Sea and of the ancient courses of the rivers flowing into it.

L. S. Berg ([1]) did not exclude the possibility that the Aral belongs to relict lakes, and considered that it formed in historical time. I. P. Gerasimov and K. K. Markov ([2]) believe that the Aral Sea formed as a result of the restructuring of the ancient hydrographic network in the second half (or middle) of the Quaternary period. In the works of A. S. Kes' ([3,4]), the formation of the Aral Sea is assigned to the beginning of the Upper Quaternary time.

The rivers flowing into the modern Aral, according to geological data, changed the direction of their flow during the Quaternary period. In accordance with the works of B. A. Fedorovich ([5]), the Syr Darya, which arose at the threshold of the Quaternary period, repeatedly changed its channel in ancient Quaternary time and began to flow into the Aral at the beginning of Upper Quaternary time. At that time it flowed toward the southeastern corner of the Aral and only later laid down its modern channel, moving ever farther north. No less complex is the history of the Amu Darya ([4–6]), which also more than once changed the direction of its flow. Its turn into the Aral, in accordance with recent studies ([4,6]), occurred after the formation of the Prisarykamysh delta, in the very latest time. An estimate of the time required for the formation of deposits in the Aral-region delta of the Amu Darya gives a figure of 10–15 thousand years, and for the entire delta 50–60 thousand years ([7]).

There are no data in the literature on the absolute age of the Aral Sea. In connection with this, we have undertaken an attempt to determine the age of this body of water from the isotope ratio U^{234}/U^{238} in the waters of the basin and in bottom sediments.

Taking into account the constancy of the isotope ratios U^{234}/U^{238} in natural waters ([8]), it can be shown that, for practically all real cases, the change in the number N_1 of atoms of U^{238} and the number N_2 of atoms of U^{234} per unit time in the object whose age is determined by nonequilibrium uranium is, with sufficient approximation, described by the equations

$$dN_1/dt = ae^{-nt} - \lambda_1 N_1,$$

$$dN_2/dt = be^{-nt} - \lambda_2 N_2 + \lambda_1 N_1, \quad (1)$$

where ae^{-nt} and be^{-nt} are, respectively, the rates of input of atoms of U^{238} and U^{234} into the object under study; λ_1 and λ_2 are the decay constants of these isotopes; a and b are constant quantities; n determines the decrease in the rates of input of uranium isotopes into the object. The solution of these equations, if the decay of U^{238} is neglected, gives, in general form, the formula for determining the age of objects from nonequilibrium uranium

$$\gamma_t = \frac{(\gamma_0 n - \lambda_2)(e^{-nt} - e^{-\lambda_2 t})}{(\lambda_2 - n)(1 - e^{-nt})} + \frac{1 - e^{-\lambda_2 t}}{1 - e^{-nt}}. \quad (2)$$

where γ_0 is the ratio of the isotopes U^{234}/U^{238} (in activity units) entering the object; γ_t is their ratio in the object at time t. In limiting cases: if $n \to 0$,

$$\frac{\gamma_t - 1}{\gamma_0 - 1} = \frac{1 - e^{-\lambda_2 t}}{\lambda_2 t}; \quad (3)$$

if $n \gg \lambda_2$,

$$\frac{\gamma_t - 1}{\gamma_0 - 1} = e^{-\lambda_2 t}, \quad (4)$$

and we obtain solutions (9), which, with sufficient approximation, may be used for practical calculations.

To determine the absolute age of the Aral Sea, we collected uranium samples from the surface and deep waters of the sea, the Syr Darya and Amu Darya rivers, and also bottom sediments in the western deep-water part of the sea. Expeditionary sampling work was carried out aboard the vessel *Lomonosov* of the Aral Observatory of the Hydrometeorological Service Administration of the Uzbek SSR. Determination of the U^{234}/U^{238} ratios in waters and bottom sediments, after preliminary chemical treatment of the samples ([8,10]), was carried out by physical measurements on an ionization α-spectrometer ([11]).

The following summary results were obtained for determination of the isotope ratios U^{234}/U^{238} (in activity units) in the waters of the Aral Sea basin.

Sample	U^{234}/U^{238} ratio (activity units)
Syr Darya River (relative weight 0.5)*	1.311 ± 0.004

Sample	U^{234}/U^{238} ratio (activity units)
Amu Darya River (relative weight 0.5)	1.118 ± 0.003
Weighted mean entering the water body	1.214 ± 0.004
Surface waters (from determinations at 8 different points)	1.213 ± 0.002
Deep waters (from determinations at 2 points, depths 50-60 m)	1.207 ± 0.002

These results show that, within the limits of measurement errors, the weighted mean isotopic mixture entering the water body is equal to the mean activity ratio of uranium isotopes in the surface and deep waters of the Aral. Such a picture may be associated either with an insignificant age of the water body or with the constant renewal of uranium in the sea waters as a result of its rapid transition into bottom sediments.

Table 1

Results of analyses of bottom sediments of the Aral Sea (from the deep-water part) for uranium content and isotopic composition

Horizon Nos.	Horizons, cm	Uranium content, rel. units	Activity ratio $\gamma = U^{234}/U^{238}$	Horizon Nos.	Horizons, cm	Uranium content, rel. units	Activity ratio $\gamma = U^{234}/U^{238}$
1	0-10	1.00	1.189 ± 0.018	6	50-60	0.35	1.147 ± 0.009
2	10-20	0.85	1.156 ± 0.010	7	60-70	0.28	1.123 ± 0.008
3	20-30	0.57	1.140 ± 0.008	8	70-80	0.40	1.142 ± 0.024
4	30-40	0.55	1.208 ± 0.010	9	80-90	2.00	1.290 ± 0.008
5	40-50	0.43	1.144 ± 0.011	10	90-95	2.56	1.203 ± 0.009

To clarify this question, columns of bottom sediments were analyzed that had been collected in the deepest part of the sea (western coast), where depths reach 50-60 m. When the silt columns were taken in this part of the sea, the entire layer of bottom sediments down to the salt deposits was penetrated. The results of analyses of one of the columns (coordinates of the point $\varphi = 45°20'$, $\lambda = 50°40'$, depth 51 m) for uranium content and isotopic composition are given in Table 1.

* The weights of the rivers are determined by the amount of uranium introduced into the water body per unit time.

These analyses show that authigenic uranium is indeed contained in the bottom sediments (since $\gamma > 1$) and that the isotopic ratio U^{234}/U^{238} in the bottom sediments, as depth initially increases, first decreases and then sharply increases with a subsequent decline. Analyses of the bottom sediments for uranium content give the same regularity down to horizon 9.

Similar changes in the isotopic composition and uranium content with the depth of occurrence of the bottom sediments are also observed in analyses of other cores, but they are less distinct because of the weaker differentiation of the sediments (the cores are shorter).

The regularities indicated above in the changes of γ and of uranium content with the depth of occurrence of the bottom sediments cannot be explained merely by the decay of U^{234} and, apparently, are due to the subsequent regime of the water body.

The lowermost layers of bottom sediments (horizons 10 and 9) were formed during a period of the existence of the water body associated only with the activity of the Syr Darya, in whose waters the uranium content is 3 times greater and the U^{234}/U^{238} ratio higher than in the waters of the Amu Darya. In the subsequent period—horizons 8-1—as a result of the strong influence of the waters of the Amu Darya, rapid sediment accumulation occurred, with a sharp decrease in the uranium content and in γ in the sediments of these horizons. The influence of the Amu Darya then decreased to the present-day ratio of the weights between the rivers of the basin. Thus, the radiological data presented in Table 1 make it possible to outline two stages in the history of the Aral: the first associated with the activity only of the Syr Darya, and the second with the activity of both rivers.

Calculation of the absolute age of the lower layers of the bottom sediments (horizons 9 and 10) from nonequilibrium uranium (formula (4)) makes it possible to identify the following principal stages in the history of the Aral in absolute chronology. The Aral Sea, most probably as a water body insignificant in area compared with the modern one, was formed 150 ± 30 thousand years ago. Not earlier than 40 thousand years ago (25 ± 15), the Amu Darya begins to flow into the Aral, and the water body apparently assumes its modern dimensions. In some works ([4,5]) there are indications that the Amu Darya may have partly flowed into the Aral during the initial period of its existence. If this actually occurred, then the value we have obtained (150 ± 30 thousand years) should be regarded as the upper limit of the absolute age of the Aral Sea.

Using nonequilibrium isotope ratios (U^{234}, U^{238}) in migration uranium, we carried out an absolute geochronology of three drainless water bodies. The results obtained (for Lake Issyk-Kul, 110 ± 40 thousand years; for Lake Chatyr-Kul, 320 ± 50 thousand years*; for the Aral, 150 ± 30 thousand years) agree with ideas concerning the relative age of these water bodies, and, in the case of Lake Issyk-Kul, also with hydrochemical determinations of the absolute age of the water body.

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* The age of Lake Chatyr-Kul in work ([8]) is overestimated, since the authors made an error.

Note: Figure translations are in progress. See original paper for figures.