Astronomy

Corresponding Member of the USSR Academy of Sciences I. E. STARIK, M. M. SHATS, and E. V. SOBOTOVICH

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Abstract

Full Text

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ON THE AGE OF METEORITES

Data on the content of uranium and lead and on the isotopic composition of lead in meteorites make it possible to approach the solution of a number of cosmogonic problems, including the determination of the age of meteoritic bodies and of the Earth. Until now, the age of meteorites has been determined chiefly by the helium ([1]) and argon methods ([2,3]). Patterson ([4]), on the basis of data on the abundance of Pb^{207} and Pb^{206} in meteorites, obtained for their age a value of 4.5 billion years, which at present is regarded as the most reliable.

Of considerable interest is the determination of the age of meteorites from other lead-uranium isotope ratios.

Our first ([5]) studies on the determination of uranium showed that its concentration in stony meteorites and in the olivine of pallasite is approximately $2 \cdot 10^{-7}$ g/g, and for iron meteorites $1 \cdot 10^{-8}$ g/g. According to the data of Hamaguchi, Turkevich, and Reed ([6]), as well as Wänke et al. ([7,8]), the abundance of uranium in stony meteorites ranges from $1.3 \cdot 10^{-7}$ (for the achondrite Nuevo Laredo) to $1 \cdot 10^{-8}$ g/g (for chondrites), and for iron meteorites ([9]) from $n \cdot 10^{-9}$ to $n \cdot 10^{-12}$ g/g. In connection with the discrepancy between the data obtained by us and by other authors, we carried out a number of special investigations on the determination of uranium in meteorites. The method of work was described earlier ([5]).

Table 1

Sample	Content, 10^{-7} g/g: uranium, luminescent	Content, 10^{-7} g/g: lead	Sample	Content, 10^{-7} g/g: uranium, luminescent	Content, 10^{-7} g/g: lead
Stony meteorites			**Pallasite**		
Staroye Pesyanoye (achondrite)	1.7 ± 0.1* 1.8 ± 0.1**	3.6 ± 0.4	Pallasovo iron (olivine)	1.8 ± 0.1* 2.0 ± 0.1**	

Sample	Content, 10^{-7} g/g: uranium, luminescent	Content, 10^{-7} g/g: lead	Sample	Content, 10^{-7} g/g: uranium, luminescent	Content, 10^{-7} g/g: lead
Norton County (achondrite)	1.1 ± 0.1 1.0 ± 0.1	5.7 ± 0.5	**Iron meteorites**		
Elenovka (chondrite)	1.1 ± 0.1* 2.4 ± 0.1**	4.8 ± 0.5	Sikhote-Alin	< 0.01	200 ± 20
Saratov (chondrite)	0.9 ± 0.1* 2.5 ± 0.1**	4.0 ± 0.5	Chinge	< 0.01	70 ± 10
Kunashak (chondrite)	1.0 ± 0.2* 2.1 ± 0.2**	5.3 ± 0.8	Schreibersite from Sikhote-Alin	0.10.07	
			Troilite from Sikhote-Alin	0.20.1	
			Silicate from Copiapo	2.0	

* Data of 1956. ** Data of 1958.

As follows from Table 1, the results of the experiments for stony meteorites and pallasite confirm the order of magnitude proposed by the authors in 1956 ([5]).

For determining the age of meteorites by the lead method, the study of the abundance of uranium in iron meteorites was of undoubted interest. The great difficulties associated with determining such small amounts of uranium, and the inhomogeneity of the composition of iron meteorites, lead to a large scatter in the results obtained by different authors. As our investigations have shown, the uranium content in the most widespread troilite, schreibersite, and silicate inclusions in iron meteorites exceeds its concentration in the main iron-nickel mass of the meteorite, which is in full agreement with the data of Deitch, Picciotto, and Goutermans [(10)] for troilite.

The uranium content in the main iron-nickel mass of the Sikhote-Alin and Chinge meteorites is of the order of $< n \cdot 10^{-9}$ g/g*.

The complex methodological problem of separating lead from stony meteorites in amounts sufficient for reliable mass-isotopic analysis was solved with the

Fig. 1

Figure 1: Fig. 1

aid of the pyrochemical method developed by us [11] for the separation and determination of lead from practically any natural formations.

As can be seen from Table 1, the lead content in all stony meteorites is approximately the same; in iron meteorites it is 1-2 orders of magnitude greater than in stony ones. Our data are in complete agreement with Patterson' s data [4].

Fig. 1

In the plot of Pb^{207}/Pb^{204} versus Pb^{206}/Pb^{204}, all meteoritic leads (with the exception of Norton County) fall on one straight line (isochron), whose slope corresponds to an age of 4.45 ± 0.05 billion years (Fig. 1). The position of Norton County lead on the plot is somewhat isolated: it does not fit the straight line sufficiently well. However, its isotopic composition is nevertheless closer to the chondrites studied by us than to the anomalous isotopic composition obtained by Patterson for the achondrite Nuevo Laredo.

It should be noted that, according to our data, the abundance of uranium and lead (Table 1) in the Norton County achondrite corresponds to the content of the elements in all the other stony meteorites studied by us. On the other hand, these data correspond to the abundance of uranium in the Nuevo Laredo achondrite. Therefore it seems to us that the data on the abundance of uranium in the Nuevo Laredo achondrite are characteristic of all stony meteorites, while the data obtained by Turkevich et al. [6] for other stony meteorites are too low.

The question of the anomalous isotopic composition of the lead of Nuevo Laredo requires additional investigation.

Table 2 gives the age values of stony meteorites calculated from the ratios Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206}.

The correction for the isotopic composition of primordial lead was introduced on the basis of data on the isotopic composition of lead in iron meteorites, where the lead-to-uranium ratio is extremely large and the addition of radiogenic lead may be neglected.

As an illustration we give the age values of the Nuevo Laredo, Forest City, and Modoc meteorites, calculated by us from Patterson' s data—

* The high values we previously obtained for the abundance of uranium in iron meteorites are apparently explained both by contaminations contained in the material supplied to us and, possibly, by the presence of troilite, schreibersite, and silicate inclusions in the analyzed sample.

son ([4]) and Turkevich, Hamaguchi, and Reed ([6]). The age of the Forest City and Modoc chondrites, calculated from the ratios Pb^{206}/U^{238} and Pb^{207}/U^{235}, is anomalously high (> 20 million years), which, apparently, can be explained only by the fact that too low a value was adopted for the uranium content in these chondrites,

Table 2

Meteorite	Pb^{206}/Pb^{204}	Pb^{207}/Pb^{204}	Pb^{208}/Pb^{204}	Age in billion years, by Pb^{206}/U^{238}	Age in billion years, by Pb^{207}/U^{235}	Age in billion years, by Pb^{207}/Pb^{206}
Nuevo Laredo	50.28	34.86	67.97	6.3*	5.1*	4.4
Forest City	19.27	15.95	39.05	> 10*	6.2*	4.3
Modoc	19.48	15.76	38.21	> 20*	7.0*	4.3
Saratov	19.53	16.70	40.25	3.2	4.1	4.5
Kunashak	19.64	16.24	40.04	3.8	4.3	4.4
Elenovka	21.54	16.94	39.86	3.7	4.2	4.5
Norton County **	22.75	15.87	37.70	4.5	4.2	3.9
Iron mete-orites ***	9.5	10.4	29.5	–	–	–

* Age calculated by us on the basis of the data of Patterson, Hamaguchi, Turkevich, and Reed.
** The isotopic composition of the lead of Norton County cannot be considered definitively established because of the small amount of material made available to us.
*** According to data from ([6]).

a value of $1 \cdot 10^{-8}$ g/g. For the achondrite Nuevo Laredo, a higher age was also obtained than could have been expected. Similar discrepancies in ages are explained by Hamaguchi, Turkevich, and Reed by the fact that uranium and lead were determined from different parts of one and the same meteorite.

In our experiments, the content of these elements and the mass-isotopic analysis of lead were determined on the same samples. If the age of meteorites obtained on the basis of the construction of an isochron is accepted, then a certain underestimation of the age calculated from the ratios Pb^{207}/U^{235} and especially Pb^{206}/U^{238} lies within the error of determination of U and Pb ($±$30%), and may also be explained by loss of lead or addition of uranium during the lifetime of the meteorites.

Thus, as a result of the work carried out, it may be concluded that the isotopic composition of lead in the meteorites studied does not reveal any significant anomalies; the uranium and lead content in them is also approximately constant. The age of stony meteorites calculated from our experimental data is in agreement with current ideas about their age, which confirms the correctness of the data we obtained on the abundance of uranium.

In conclusion, the authors take this opportunity to express their gratitude to the Committee on Meteorites for providing the samples, and also to B. B. Piotrovskii and S. I. Rudenko for their assistance in carrying out the work in the laboratory of archaeological technology of the Leningrad Branch of the Institute for the History of Material Culture of the Academy of Sciences of the USSR.

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