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DEC 3 1962

BNL 6451

"Ages" of the Sikhote Alin Meteorite*

Abstract. The potassium-argon age of the Sikhote Alin iron meteorite has been determined. The value is $1.7 \pm 0.2 \times 10^9$ years. Previous lead data suggest an age of 4.6×10^9 years. The date of solidification may be the sum of these two ages.

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Lead isotopic ratios showing an excess of the nuclides lead-206, -207, and -208 relative to lead-204 have been measured in several iron meteorites⁽¹⁾. As with such ratios reported for stone meteorites, these excesses may represent radiogenic contributions from the natural decay of uranium-235, uranium-238, and thorium-232, respectively. However, in one of these meteorites, Sikhote Alin, an upper limit was set to the abundance of uranium-235 such that the excess lead-207 could not be accounted for by uranium decay in a period less than 10^{10} years⁽²⁾. This represents two orders of magnitude too little uranium to agree with the calculated lead-lead age of 4.6×10^9 years⁽³⁾.

A possible explanation for this uranium deficiency would be a recent melting and chemical fractionation of the material that is now the Sikhote Alin meteorite. A suitable method of testing this hypothesis is by means of potassium-argon dating, since any process capable of removing uranium from the meteoritic mass would also remove the argon. Such an experiment is reported here, and leads to a potassium-argon "age" of about 1.7×10^9 years. This is significantly less than such ages previously measured for other iron meteorites⁽⁴⁾, and may indicate that a recent melting (or at least a severe heating) did occur. This is a necessary but not a sufficient condition for the removal of uranium from lead.

Three separate runs were made at the Brookhaven Reactor, in which samples 3-5 grams in size were irradiated for three hours at a flux of 5×10^{12} n/cm² sec., together with ~200 milligrams of potassium chloride as a flux monitor. The samples were prepared for the irradiation by an acid bath in which approximately twenty per cent of the mass was etched away. After irradiation this etching was repeated just as severely, to remove all possibility of surface contamination. The sample

*Research performed in part under the auspices of the U. S. Atomic Energy Commission.

was placed in an alumina crucible in a vacuum line, then boiled by induction heating for twenty minutes in the presence of argon carrier. The evolved gases were passed over hot titanium, which was then cooled to remove hydrogen. The gases were then pumped into a proportional counter with a background of about 10 counts per minute. The chemical yield was 100% in all cases. Initial counting rates in the three samples varied from 4000 to 300 counts per minute. The activity followed the argon-41 half-life down to about 15 cpm, then decayed with the argon-37 half-life of thirty-five days for over a month. The potassium was separated from the melted mass and from the material vaporized onto the walls of the furnace by repeated ion exchange and tetraphenyl boron precipitation cycles. Counting was done on beta-proportional counters with backgrounds of about 8 cpm. Initial counting rates varied from 7×10^5 to 2×10^4 cpm. The activity followed the potassium-42 half-life for many half-lives.

The argon-41 activity results from the $\text{Ar}^{40}(n, \nu)\text{Ar}^{41}$ reaction, and gives directly the argon-40 content. A correction for cosmic ray produced argon-40 can be made from the argon-37 activity, which results from the $\text{Ar}^{36}(n, \nu)\text{Ar}^{37}$ reaction. Argon-36 is produced in meteorites through direct nuclear production and through the decay of cosmic ray produced chlorine-36. The cross section ratio, from iron targets, of $(\text{Ar}^{36} + \text{Cl}^{36})/\text{Ar}^{40}$ is about 5⁽⁵⁾. The correction for cosmogenic argon-40 in this meteorite amounts to about ten per cent in that sample having the lowest argon-40 content, the correction being proportionally smaller for the other samples. No correction is made for possible primordial argon, since this would make the age even younger, and a meteorite younger than two billion years should not contain primordial gases. Further, the observed variation of argon-41 activity with the potassium activity (see Table 1) indicated the close association of argon with potassium in the meteorite. This potassium-argon togetherness also renders unlikely the possibility of argon diffusion loss: the three samples show a total variation of a factor of fifteen in potassium content, yet the potassium/argon ratio stays constant to within plus or minus twenty per cent. Diffusion loss is improbable also because: 1) there seems to be no such loss of cosmogenic helium, neon, or argon during Sikhote-Alin's cosmic ray age of about 150 million years,⁽⁶⁾ 2) no such loss of cosmogenic rare gases is observed in other iron meteorites over periods of perhaps up to 1.5×10^9 years, and 3) several other iron meteorites selected at random show no evidence of diffusion loss of radiogenic argon during their (potassium-argon) age of up to 13×10^9 years.

The potassium-42 activity results from the $K^{41}(n, \gamma)K^{42}$ reaction. Terrestrial isotopic abundance of potassium is assumed in order to calculate the potassium-40 content. This abundance ratio can be modified probably only by cosmic ray produced potassium, and this can be estimated from the work of Stauffer and Honda⁽⁷⁾. The correction for this meteorite is negligible.

The results are shown in Table 1. Stoenner and Zahringer have previously⁽⁴⁾ dated several iron meteorites by this method, and obtained ages ranging from six to thirteen $\times 10^9$ years. Preliminary results from experiments run concurrently with those reported here confirm these earlier results. These larger ages will not be discussed here, it is merely pointed out that the Ar^{40}/K^{40} ratios measured in Sikhote-Alin are two to three orders of magnitude smaller than those found in several other meteorites selected at random. This is taken to indicate a lower age for Sikhote-Alin, interpreted as a melting event about two billion years ago. Such a melting event could have included a silicate-iron chemical fractionation, resulting in a depletion of uranium relative to lead in what remained as the iron mass.

A provisional acceptance of this event necessitates a reinterpretation of the lead-lead "age". If one assumes that the lead in Sikhote Alin contains a radiogenic portion, and if one makes the usual⁽⁸⁾ assumptions concerning the primordial lead ratios, an age of 4.6×10^9 years can be calculated from the data of Starik et al⁽¹⁾. But there has been no contribution to the lead isotopes from uranium decay within at least the past 1.7 billion years. A lower limit to the original time of solidification is then $4.6 \pm 0.2 \times 10^9$ years (the lead-lead age) plus $1.7 \pm 0.2 \times 10^9$ years (the potassium-argon age), or $6.3 \pm 0.5 \times 10^9$ years. This result contradicts the common assumption that stone and iron meteorites are cogenetic (the stones being well dated at $4.5 \pm 0.2 \times 10^9$ years), but is not in disagreement with earlier potassium-argon ages of iron meteorites⁽⁹⁾.

David E. Fisher
Cornell University, Ithaca, New York, and
Brookhaven National Laboratory, Upton, New York

Table 1

Sample	Weight grams	Ar ⁴⁰ radiogenic x 10 ¹² atoms/gm	Ar ⁴⁰ /K ⁴⁰	"Age" x 10 ⁹ years
1	3	14.0	0.18	1.7
2	3	1.0	0.20	1.8
3	4.25	5.4	0.15	1.5

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9. The author is grateful to Dr. R. Dodson, chairman of the Department of Chemistry of Brookhaven National Laboratory, and especially to Dr. R. Davis, Jr. of that department for their cordiality and hospitality and to Dr. Davis for many valuable suggestions. The author also expresses his gratitude to Academician E. L. Krinov of the Committee on Meteorites of the Academy of Sciences of the USSR, for supplying a generous sample of Sikhote Alin, and to the United States Atomic Energy Commission for their financial support.

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