MINERALOGY AND Ar-Ar AGE OF THE TARAHUMARA IIE IRON, WITH REFERENCE TO THE ORIGIN OF ALKALI-RICH MATERIALS.

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Introduction:

Silicate inclusions in nine known IIE irons show diversity in mineralogy (e.g.,[1,2]), and Colomera, Kodaikanal, Elga and Miles contain alkali-rich silicate inclusions. Bogard et al. [3] showed evidence of a complex parent body evolution for IIE irons based on ^{39}Ar-^{40}Ar ages. Colomera contained a sanidine-rich surface inclusion [4] and the K-enrichment trends in the Na-rich inclusions are different from those of other IIEs [5]. To elucidate the origin of K-rich materials, we studied the mineralogy and Ar-Ar age of silicate inclusions from the Tarahumara IIE iron meteorite.

Samples and Experimental Techniques:

A small silicate inclusion was extracted from a larger, sawn metal slab of Tarahumara [6], which was obtained from the Planetary Materials Database collections. Twenty grains of silicate were used to prepare a polished grain mount (PGM) and 5.3 mg were neutron irradiated to determine the ^{39}Ar-^{40}Ar age. The blank and reactor corrections were negligible. The irradiation constant (J-value) for Tarahumara is 0.02670 ±0.00025 and contributes most of the uncertainty to the age.

One slice (PD), approximately 1.7 by 1.9 cm across, different from the Ar-Ar sample, was embedded in a plastic disc and one side was polished. Elemental distribution maps of the PD and the PGM were obtained with a JEOL 8900 electron probe microanalyzer (EPMA) at Ocean Research Inst. (ORI) of Univ. of Tokyo. Chemical compositions of minerals were measured with a JEOL JCXA-733 EPMA at ORI.

Results:

The 20 grains studied in the PGM can be divided into three types: 1) Na-plagioclase inclusions (17); 2) Composite inclusions consisting of Cr diopside, Na plagioclase, orthopyroxene, chromite, and Ca phosphate (2); and 3) An opaque inclusion rich in Ti minerals (1). One big silicate inclusion found in the PD has a shape of two combined dumb-bell with a V shape (Fig. 1). In the center of the large one (11.4 × 6.1 mm), a core of Mg-rich orthopyroxene ($Ca_{3.1}Mg_{80.1}Fe_{16.8}$) is zoned toward the rims ($Ca_{3.5}Mg_{74.5}Fe_{22.0}$), where aggregates of Cr-diopside ($Ca_{38.9}Mg_{49.1}Fe_{12.0}$ - $Ca_{43.0}Mg_{46.9}Fe_{10.1}$), orthopyroxene and chromite grew partly with skeletal shapes in Na plagioclase ($An_{3.2}Ab_{85.4}Or_{11.4}$). Platy crystals of Ca-phosphates are distributed along the curved metal-silicate boundary. A rectangular Na plagioclase fills the small dumbbell (7.1 × 3.6 mm), and K-Si-rich glassy materials fill the rounded spherical spaces left between the plagioclase and the metal. The glassy materials are mostly mixtures of K-rich feldspar ($An_{1.0}Ab_{69.9}Or_{29.1}$) and silica and The K and Si concentrations are the highest at the margins.

Sodium-plagioclase grains in the PGM are twinned and the chemical compositions are fairly uniform. The composite inclusion, 1.0 X 0.82 mm in size is mostly twinned Na plagioclase and includes irregular veins of Ca phosphate and Cr-diopside. Some K-rich regions (bulk comp. $An_2Ab_{85}Or_{14}$) are present at some parts of the rims of the Na plagioclase, where antiperthite textures with lamellae of K-rich feldspar ($An_4Ab_{56}Or_{40}$) 1-2 μm thick with 4-6 μm intervals in the host ($An_2Ab_{93}Or_5$). The opaque inclusion, 0.69 X 0.39 mm in size has orthopyroxene at one edge and the region rich in opaque minerals consist of chromite, rutile, Mg-rich ilmenite and a pyroxene-like phase with Ti in the tetrahedral site.

A plot of Ar-Ar ages and K/Ca ratios for the stepwise temperature releases is shown in Fig. 2. During the extraction, Ar was released in distinct peaks and the K/Ca ratio decreased by a factor of 18, then increased by a factor of ~4. From these observations, we conclude that Ar was released from Na plagioclase and from K-rich glassy materials found around the plagioclase. The first several extractions releasing ~9% of the total ^{39}Ar give variable ages, show slightly lower K/Ca, and suggest the presence of terrestrial Ar incorporated into weathered grain surfaces.

Over ~9-98% of the ^{39}Ar release, 20 extractions give a nearly constant age with an average value of 4,469 ±26 Myr. We will omit from this average two extractions releasing ~9-19% of the ^{39}Ar, which may have recently lost some ^{40}Ar, one extraction showing a low age at ~68% ^{39}Ar release, and one extraction showing a slightly low age and releasing ~84-98% of the ^{39}Ar. With these omissions, 16 extractions releasing 63% of the total ^{39}Ar define an Ar-Ar age of 4,476 ±18 Myr, which is the ^{39}Ar-^{40}Ar age we assign to Tarahumara.

Discussion:

A range of models has been proposed for their origin of IIE irons. One of the authors (H. T.) proposed a model, in which partly molten metal and

crystal mush were mixed by impact on the IIE parent body. Many models involve impact melting of the chondritic source material followed by growth of diopside and plagioclase [1,2]. Information on cooling rates for a sample with known Ar-Ar age may help in understanding this problem.

Radiometric ages of IIE meteorites tend to fall into one of two groups (Bogard et al. [3]). Three IIEs, Watson, Kodaikanal, and Netschaëvo, give K-Ar, Rb-Sr, and/or Pb-Pb ages of about 3.68 Gyr. Four other IIEs, Colomera, Weekeroo Station, Miles, and Techado, give older ages of 4.41-4.51 Gyr, as determined by Ar-Ar and Rb-Sr. (Model Sm-Nd ages of a few IIEs gave much younger ages that are inconsistent with these other ages.) These ages do not seem to correlate with the degree of differentiation of the silicate, as both primitive and highly differentiated silicate occur in both age groups. The Ar-Ar age of 4.476 ±0.018 Gyr reported here for Tarahumara is the first age reported for this meteorite. It agrees with Ar-Ar ages of 4.470 ±0.010 for Colomera, 4.49 ±0.03 Gyr for Weekeroo Station, and 4.489 ±0.013 Gyr for Techado (see [3]). Rb-Sr ages are similar for Colomera (4.51 ±0.04 Gyr) and Weekeroo Station (4.39 ±0.07 Gyr).

The ^{36}Ar isotopic data for Tarahumara can also be used to estimate its space (cosmic-ray) exposure age. The total concentration of ^{36}Ar released above 500°C from Tarahumara is 2.35 x10^{-8} cm^{3}STP/g, which we assume is entirely cosmogenic in origin. The production rate of cosmogenic ^{36}Ar depends on sample composition and shielding. The latter is unknown and the former can only be estimated (see discussion in [3]). Major element compositional data for the PGM may be essentially Na plagioclase with additional minor MgO and FeO, because 17 grains out of total 20 are Na plagioclase. Hohenberg et al. [7] estimated the ratio of the ^{36}Ar production rate from K to that from Ca to be 1.4-1.5 over a very wide range of shielding. If we use our measured K and Ca abundances in Tarahumara (1.8% each), ignore any contribution from iron-group elements, and the composition-dependant production rate equations of Eugster and Michel [8], we estimate a cosmogenic ^{36}Ar production rate of 5.7 x10^{-10} cm^3/g. When combined with our estimate of cosmogenic ^{36}Ar concentration, we estimate a space exposure age for Tarahumara of ~41 Myr. This age lies within the broad range of estimated exposure ages for other IIE silicates (~4-400 Myr; [3]).

Although the sanidine-rich material as in Colomera has not been found in Tarahumara, K-rich granitic materials with mixtures of antiperthite and tridymite as were reported for Miles [2] and Watson [9] were found as rims of a Na plagioclase. Segregation of K-rich materials in Colomera may be attributed to this difference. The presence of antiperthite at the rims of Na plagioclase implies slow cooling below ca 600°C and may be in line with slow cooling suggested by the relatively young Ar-Ar age.

References:
[1] Ruzicka A. et al. (1999) *GCA*, 63, 2123-2143.
[2] Ikeda Y. and Prinz M. (1996) *Proc. NIPR Symp. Antarct. Meteorit. Res.* 9, 143-173.
[3] Bogard D. D. et al. (2000) *GCA*, 64, 2133-2154.
[4] Wasserburg et al. (1968) *Science*, 161, 684-687.
[5] Takeda H. et al. (2003) *GCA*, 67, 2269-2288.
[6] Wasson J. and Choi B. (1996) *Met. Bull.* 80, A179. [7] Hohenberg et al. (1978) *Proc. 9th LPSC*, 2311-2344. [8] Eugster and Michel (1995) *GCA* 59, 177-200. [9] Olsen E. et al. (1994) *Meteorit.* 29, 200-213.
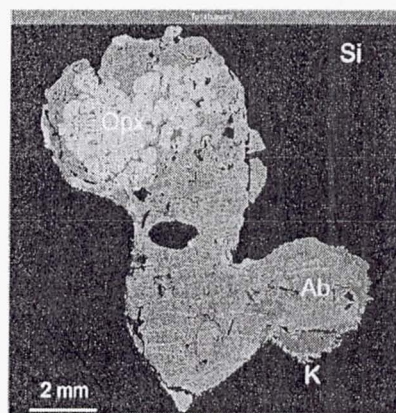

Fig. 1. Si distribution map of the Tarahumara PD. K: K-,Si-rich rims around Na plagioclase (Ab)
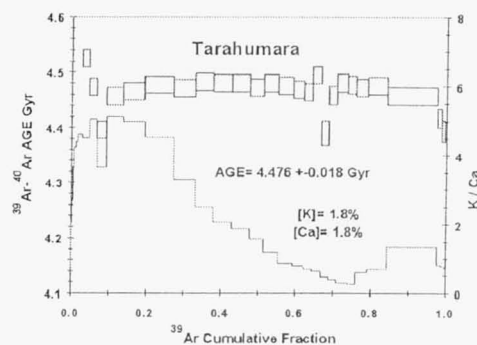

Fig. 2. A plot of Ar-Ar ages and K/Ca ratios for the stepwise temperature releases.