

Ar-Ar and I-Xe Ages and the Thermal History of IAB Meteorites

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ABSTRACT

Studies of several samples of the large Caddo County IAB iron meteorite reveal andesitic material, enriched in Si, Na, Al and Ca, which is essentially unique among meteorites. This material is believed to have formed from a chondritic source by partial melting and to have further segregated by grain coarsening. Such an origin implies extended metamorphism of the IAB parent body. New ³⁹Ar-⁴⁰Ar ages for silicate from three different Caddo samples are consistent with a common age of 4.50-4.51 Gyr ago. Less well defined Ar-Ar degassing ages for inclusions from two other IABs, EET8333 and Udei Station, are ~4.32 Gyr, whereas the age for Campo del Cielo varies considerably over ~3.23-4.56 Gyr. New ¹²⁹I-¹²⁹Xe ages for Caddo County and EET8333 are 4561.9 ± 0.1 Myr and 4560-4563 Myr, respectively, relative to an age of 4566 Myr for Shallowater. Considering all reported Ar-Ar ages for IABs and related winonaites, the range is ~4.32-4.53 Gyr, but several IABs give similar Ar ages of 4.50-4.52 Gyr. We interpret these older ages to represent cooling after the time of last significant metamorphism on the parent body, and the younger ages to represent later ⁴⁰Ar diffusion loss. These older Ar-Ar ages are similar to Sm-Nd and Rb-Sr isochron ages reported in the literature for Caddo County. Considering the possibility that IAB parent body formation was followed by impact disruption, reassembly, and metamorphism (e.g., Benedix et al. 2000), the time of the post-assembly metamorphism may have been as late as ~4.53 Gyr ago. However, precise I-Xe ages reported for some IABs define a range of ages of ~4560 to ~4576 Myr. The older I-Xe ages exceed the oldest precise radiometric ages of meteorites, appear unrealistic, and suggest a bias in the calibration of all I-Xe ages. But even with such a bias, the I-Xe ages of IABs cannot easily be reconciled with the much younger Ar-Ar and Sm-Nd ages and with cooling rates deduced from Ni concentration profiles in IAB metal (Herpfer et al., 1994). An explanation for the difference in radiometric ages of IABs may reside in combinations of the following: a) I-Xe ages have very high closure temperatures and were not reset during metamorphism; b) a bias exists in the ⁴⁰K decay constants; c) the reported Sm-Nd and Rb-Sr ages for Caddo are in error by amounts equal to or exceeding their reported 2-sigma uncertainties; and 4) the IAB parent body may have experienced a mild metamorphism ~30 Myr after the initial heating that produced differentiation of Caddo silicate and mixing of silicate and metal.

INTRODUCTION

IAB irons are one of a few types of iron meteorites which contain silicate inclusions and whose higher abundance of siderophile elements suggests that the metal was not solely formed as part of a differentiation sequence (Mittlefehldt et al. 1998). Inclusions in IABs show a wide range of types, including sulfide-, graphite-, and phosphate-rich, non-chondritic silicate, and those with more primitive chondritic silicate composition (Benedix et al., 2000). Winonaites are non-chondritic silicate meteorites, with much smaller metal contents, that are thought to derive from the same parent body as IAB irons (Benedix et al. 1998; Mittlefehldt et al. 1998). The oxygen isotopic composition for IABs and winonaites, however, are unlike other chondrite groups (Clayton and Mayeda, 1996). Formation models that have been proposed for IABs include parent body partial melting and fractional crystallization (Kracher, 1985) or incomplete differentiation (Takeda et al. 2000) due to internal heat sources, and impact-induced melting and mixing (Choi et al., 1995; Wasson and Kallemeyn, 2002). A chondritic parent was favored by several of these studies. Benedix et al. (2000) prefer a hybrid model whereby a chondritic parent experienced metamorphism, partial melting, and incomplete differentiation that produced metallic, sulfide-rich, and silicate partial melts. These authors suggest that the parent body may have reached interior temperatures of 1200-1400°C and may have begun to differentiate. While the body was near its peak temperature, a large impact caused it to breakup. This was followed by reassembly, resulting in molten metal being mixed with near-surface silicate. Scott (2004) has suggested that such collisional breakup and reassembly of asteroidal bodies may have been common in the early solar system.

Coarse-grained gabbroic material rich in plagioclase and diopside (Di) occurs in the Caddo County IAB iron meteorite (Takeda et al., 2000) and represents a new type of chemically differentiated, extra-terrestrial silicate material. Because of the high abundance of Na-rich plagioclase (albite, Ab), the bulk composition (SiO_2 59 wt%) is within the field of andesites. Similar materials were found in silicate inclusions in many IIE irons (Takeda et al., 2003). The andesitic materials can be a general partial melt product of the chondritic source materials. Andesitic materials of this type previously studied are surrounded by orthopyroxene (Opx) and olivine, and it has been difficult to estimate their bulk compositions. A new Caddo sample described in this work contains a large inclusion of mainly Di and Ab surrounded by metal. This sample will provide us with further information on formation mechanisms by inhomogeneous segregation of partial melts from chondritic sources.

An understanding the thermal history of IAB meteorites requires precise determination of their radiometric ages, and several radiometric ages for IAB meteorites have been reported (and are summarized later). All reported ^{129}I - ^{129}Xe ages are >4.56 Gyr and a few are ≥ 4.567 Gyr. The oldest I-Xe ages are troubling because, whereas they are very precise, they equal or exceed the 4.567 Gyr Pb-Pb age of Ca, Al-rich inclusions in primitive meteorites, which are thought to be the earliest condensates in the solar system (Amelin et al., 2002). However, the absolute values of these I-Xe ages are based on the assumption that the times of isotopic closure for the Pb-Pb and I-Xe chronometers are the same in a meteorite dated by both techniques (Nichols et al., 1994), an assumption that may not be correct. In contrast to the I-Xe ages, several ^{39}Ar - ^{40}Ar ages of silicate from several IABs and the Sm-Nd age of one IAB meteorite appear significantly younger at ~ 4.53 - 4.43 Gyr. In addition, Herpfer et al. (1994) used Ni concentration profiles in metal to determine cooling rates of ~ 25 - 70 °C/Myr for eight IAB meteorites, suggesting that an extended cooling history of the IAB parent body might result in different expected ages for different chronometer systems. Because of the spread in apparent radiometric ages, the evidence for relatively slow cooling rates, and the complex history of the IAB body preferred by Benedix et al. (2000), we undertook a new Ar-Ar and I-Xe study of some IAB silicates.