Re-Os Isotope Dating of Meteorites and Early Solar System Chronology: A Review F. Sedaghatpour[1] and D. W. G. Sears[2], [1, 2]Arkansas Center for Space and Planetary Sciences, and [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701, USA

Introduction: The Re-Os isotopic system is the most recent of a series of long-lived radiogenic isotope systems used for the study of early solar system materials and several proerties of the system make it particularly valuable [1, 2]. The half life of ^{187}Re is comparable to the age of the solar system, making it suitable for dating soilar system events. The siderophilic nature of the Re and Os causes them to concentrate in metal phases, so the system is useful to address the chronology of of core formation [3], the crystallization path and ages of asteroidal cores [4, 5], and the age of different types of metal-rich meteorites and, consequently, the chronology and early history of the solar system [1, 6]. Since Os is highly compatible element and enriched in the residual solid, while Re is moderately incompatible and enriched in the melt, the system is suitable for studying igneous processes, and thus Re/Os is a factor of ~100 higher in basalts than in the mantle. Finally, the system contains nucleosynthetic information since ^{187}Re is an r-process nuclide, ^{186}Os is an s-process nuclide, and ^{187}Os contains radiogenic and s-process components.

On the other hand, precise and accurate determination of the Re decay constant has been a challenge (the value 1.64×10^{-11} y^{-1} with a 3% uncertainty is most widely used [8, 9]), and measurement of ^{187}Re and ^{187}Os in meteorites is difficult because of very low concentrations (3-0.3 ppm). However, within the past twenty years the Re-Os system has achieved a degree of success in geology and cosmochemistry, particularly with reghard to chronology. Our present objective is to review the Re-Os isotopic dating of different groups of meteorites, especially iron and chondritic meteorites.

Iron Meteorite: Measurements of iron meteorite ages in the 1960s using the Re-Os method reported ages of ~4000 My [10, 11]. In 1980 Luck et al. [1] determined the ^{187}Re/^{186}Os and ^{187}Os/^{186}Os ratios of five iron meteorites. Using $1.52 \pm 0.04 \times 10^{-11}$ y^{-1} for λ^{187}Re, Luck et al [6] obtained the age of 4250 ± 50 My as the first precise age of this type of meteorite which is consistent with the value reported from Rb-Sr measurements on silicate fraction (4350 ± 100) [12]. Pernica's and Wasson's [13] investigation of the Re/Os fractionations in the iron meteorites showed no significant change in Re/Os ratio with Ni content in nonmagmatic groups. However, the Re/Os ratio increases by a factor 3 from low-Ni to high-Ni members of the magmatic groups IIA and IIIAB. Therefore, the Re/Os ratio change is large enough to allow Re-Os age determination for each of those groups. Horan et al. [14] showed that the Re-Os isotopic systematics of group IIA closed near the age of solar system (between 4444 - 4560 My), and their initial ^{187}Os/^{186}Os ratio was the same as that of carbonaceous chondrites. Data for IA, IIB and IIIA irons all plotted above the IIA isochron in this study (Fig.1).

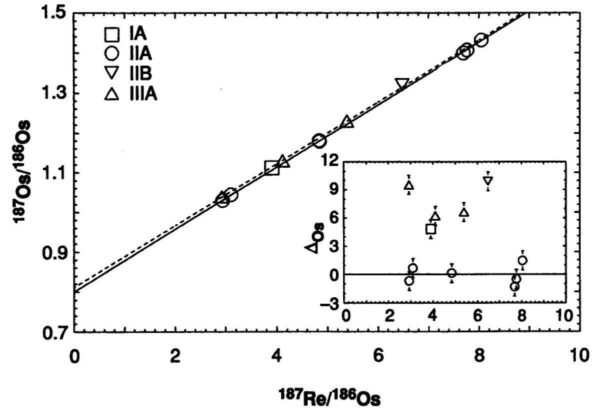

Fig.1 Plot of ^{187}Os/^{186}Os versus ^{187}Re/^{186}Os for iron meteorites in different groups. Isochron are regressed trough the IIA data (solid line) and IIIA data (dashed line). The inset shows the per mil deviation in ^{187}Os/^{186}Os from the IIA isochron, ΔOs, versus ^{187}Re/^{186}Os [14].

The data implied that the parent body of the IIIA iron meteorite melted and cooled 100 My after the oldest portions of chondrites. The other interpretation is that, if all those irons closed to Re and Os at the same time, their parent bodies would either form with different Os isotopic composition or change to different Os isotopic composition before core formation.

Morgan et al. [15] reported the age of 4584 ± 43 My for five meteorites of group IIA and eight meteorites of IIB, which is well within error of the canonical age of solar system. Most IIB irons are plotted on or within error of the IIA isochron, and their data gave an age of 4577 ± 37 My for this group. The younger age of 4430 ± 0.05 My for group IIB than group IIA was reported by Smoliar et al. [16], which is consistent with previous work. Their results are consistent with rapid core segregation, differentiation and crystallization in the IIAB parent. Using improved analytical techniques, Chen et al. [17] reported Re-Os data for low Re and PGE pallasites and IIIAB irons, which shows an age of 4560 ± 0.01 My for IIIAB and an age of 60 My younger for pallasites.

Chondrites: Chondrites probably represent one of the most primitive samples of the primordial solar nebula. They consist of materials agglomerated during the early solar system evolution. Therefore, chondrite meteorites provide the initial composition of Os in the early solar system. However, contrary to magmatic irons, chondrites show a relatively minimal spread in Re/Os ratios. Therefore, obtaining precise isochrons for chondrite groups is a challenge. Despite this, Re-Os isotopic studies of chondrites are of interest [2]. First, as pointed out by Walker et al. [18], "the precise determination of the initial $^{187}Os/^{188}Os$ ratio of the solar system may prove critical for ultimately utilizing the system to date refractory components in chondrites". Second, the characterization of the long-term evolution of ^{187}Os in different chondrite groups may provide constraints on the behavior of their highly siderophile elements during the early solar system [2], and also help to characterize the materials added to planetary mantle through the late accretion. Third, differences in the modern Re/Os and the time-integrated $^{187}Os/^{188}Os$ of whole-rock chondrites may reflect fractionations resulting from high-temperature nebular condensation processes in precursor materials. Therefore, this system can provide a robust method to compare the nebular histories of refractory phases within chondrite components.

Luck et al. [1, 6] reported the first Re-Os isotopic data for metal phases separated from ordinary chondrite. Re-Os isotopic reported for the whole rock samples of carbonaceous chondrites (group CI, CM, CV and CO) and an ordinary chondrite (Semarkona, LL3) [19] showed a significant difference between irons and chondrites. A younger age for iron meteorites was reported in this study. Most chondrites plotted 1 - 2% above the iron meteorites. They suggested that either irons have significantly younger Re-Os closure ages than chondrites or that chondrites were formed from precursor materials with different chemical histories from the precursors of irons. Being plotted 4 – 6% above the iron meteorite isochron, Semarkona (LL3) and Murray (C2M) may have lost Re by aqueous alteration. However, since there is an evidence for only slight aqueous alteration in Semarkona, the Re-Os isotopic composition can reflect the isotopically heterogeneous components in the primordial solar nebula.

Calcium-Aluminium-rich Inclusions: Calcium-Aluminium-rich Inclusions (CAIs) are inclusions in chondritres that are thought to be either the first minerals to condense in the solar nebula or the high temperature residues of flash heating. The Re-Os systematics of CAIs in chondrite clarify the Re-Os system's behavior in bulk chondrites and the timing of chemical fractionation in primitive chondrites [20]. Re-Os systematic of CAIs in carbonaceous meteorites has been investigated by Becker et al. [20]. It was shown that differences in Re/Os early established in solar system history are the major cause of the observed variability of $^{187}Os/^{188}Os$ in CAIs. No overlapping between the abundance of group II CAIs and the other groups was reported. This suggests that the group II CAIs have lost the bulk of their highly refractory elements in a previous condensation event. In this study, some bulk CAIs and CAI splits plotted on the IIIA iron meteorite isochron reference resulting in 4558 My age. Whereas, eight samples plotted off the isochron. This deviation could have reflected either chemical differentiation in the early solar system or primitive heterogeneities in $^{187}Os/^{188}Os$. However, there are neither evidences for such a fractionation nor resolvable anomalies in other Os isotopic ratios for thes CAIs to prove the primordial heterogeneities. The most likely explanation for this deviation is late-stage movement of Re or Os in CAI samples.

Conclusion: The Re-Os isotopic has allowed unique advances in the precise chronology of meteorites, this is despite experimental difficulties and uncertainty in Re decay constant. The Re-Os age dating has accomplished for the iron groups and their initial isotopic ratio determined. High- precision analysis of chondrites and refractory components has been achieved.

References: [1] Luck. J. M. et al (1980) *Nature* **283**, 17, 256. [2] Shirey S. B. et al (1998) *Anuu. Rev. Earth Planer. Sci.* **26**, 423. [3] Walker R. J. et al (1995) *Science* **169**, 819. [4] Shen. J. J. et al (1996) *Geochim. Cosmochim. Acta* **60**, 2887. [5] Smoliar M. I. et al (1996) *Science* **271**, 1099. [6] Luck J. M. et al (1983) *Nature* **302**, 130. [7] Clayton D. D. (1964) *Astrophys. J.* **139**, 637. [8] Selby D. et al. (2007) *Geochim. Cosmochim. Acta* **71**, 1999. [9] Linder M. et al. (1989) *Geochim. Cosmochim Acta* **53**, 1597. [10] Herr W. et al (1961) *Naturforschung* **16a**, 1053. [11] Hirt B. et al (1963) *Radioactive dating*, 35. [12] Murthy V. R., Coscio, M. R. and Sabelin T. (1997), *Geochim. Cosmochim. Acta* **8**, 177-186. [13] Pernica E. et al (1987) *Geochim. Cosmochim Acta* **51**, 1717. [14] Horan M. F. et al. (1992) *Science* **255**, 1118. [15] Morgan J. W. et al (1995) *Geochim. Cosmochim Acta* **59**, 11, 2331. [16] Smoliar M. I. et al *LPS XXVIII*, 1341. [17] Chen J. H. et al (2002) *Geochim. Cosmochim Acta* **66**, 21, 3793. [18] Walker R. J. et al. (2002) *Geochim. Cosmochim Acta* **66**, 23, 4187. [19] Walker R. J. and Morgan J. W. (1989) *Science* **243,** 519. [20] Becker H. et al. (2001) *Geochim. Cosmochim Acta* **65**, 19, 3379.