NEW INSIGHTS INTO THE ORIGIN OF LOVINA, A MYSTERY METAL. R. D. Ash[1], R. J. Walker[1], A. Yamakawa[2], Q-Z Yin[2], [1]Dept. of Geology, University of Maryland, College Park, MD 20742 USA (rdash@geol.umd.edu), [2]Dept. of Earth and Planet. Sci., Univ. of California at Davis, Davis, CA 95616, USA.

Introduction: Lovina was found as an 8.2 kg metal mass on Lovina beach, Bali, in 1981 [1]. It has been classified as an ungrouped ataxite [1-2], and its chemical composition and texture has been considered within the context of melting and crystallization inside an asteroid [3]. However, very low abundances of cosmogenic nuclides have led some to question the extraterrestrial origin of Lovina [4].

In order to futher consider the origin of Lovina we have determined minor and trace element concentrations, including some highly siderophile elements (HSE: Re, Os, Ir, Ru, Pt, Pd), and measured ^{187}Re-^{187}Os and Cr isotopic compositions.

Sample: Previous studies have reported that the main mass of Lovina consists of weathered nickel-iron with cm-scale pyramids projecting from the surface as well as cm-sized vugs [1-2]. The dominant Fe-Ni phases are taenite and awaruite. Kamacite is absent. Troilite is a common additional phase. Flemming et al. [2] and Teplyakova [3] have noted chemical and textural similarities to some other types of iron, but neither study recognized a good match to Lovina.

Methods: Samples were prepared for trace element analysis by isotope dilution and laser ablation ICPMS. Trace element abundances were determined on a small polished slab at UMd by rapid rastering of a 25-100μm diameter laser beam (New Wave UP213) over a pre-cleaned sample surface. Ablated material was entrained in a stream of He for analysis by ICPMS (ThermoFinnigan Element 2). Data reduction was carried out using LAMTRACE [5]. HSE abundances and ^{187}Os/^{188}Os were measured for one bulk sample (270mg) at UMd using our standard dissolution, purification and mass spectrometric methods using a Thermo Triton and Nu Plasma [e.g., 6].

Two sample pieces (222 and 133 mg) of Lovina were analyzed for Cr isotopic composition at UC Davis using our standard methods [7]. In brief, samples were dissolved in 6N-HCl in Teflon vials. About 80 % of the sample aliquots were taken for Cr isotope measurements. Purification was achieved via a two step column chemistry. Since ^{54}Fe is an isobaric interference of ^{54}Cr, column steps were repeated several times to completely remove Fe.

Chromium isotopic composition was determined using a Thermo *Triton-Plus* TIMS at UC Davis. All sample runs were bracketed by Cr standard, SRM 979. Instrumental mass fractionation effects were corrected according to an exponential law, using a ^{50}Cr/^{52}Cr of 0.051859 [8]. Interferences on ^{50}Cr and ^{54}Cr from ^{50}V and ^{54}Fe, respectively, were corrected for by monitoring ^{51}V and ^{56}Fe.

Results: Figure 1 shows results for the laser ablation analysis of trace elements in bulk Lovina comapred with terrestrial material and the IIE iron Elga [15]. All data have been normalized to CI chondrites.

Absolute abundances of HSE range between 4.38 (Re) and 584 ng/g (Ru). The CI-normalized HSE pattern for bulk Lovina bears no resemblance to any magmatic or non-magmatic irons we have previously analyzed. In Fig. 2, typical patterns for high and low Ni IVA irons are shown for comparison. The ^{187}Os/^{188}Os ratio of the bulk piece of Lovina analyzed is 0.12664±0.00003, which is well within the range of bulk chondrites and many iron meteorites. It is also well within the range of the modern terrestrial mantle. The ^{187}Re/^{188}Os of 0.116, however, is more than a factor of 3 lower than for any known bulk chondrites or iron meteorites. The present day Os isotopic composition, coupled with the very low Re/Os, requires either major open-system loss of Re, to a level we have never previously observed in irons, or recent formation (i.e. terrestrial origin).

Chromium isotope results are presented in Table 1, together with data for a terrestrial sample (San Carlos Cpx). Compared to the Cr isotope data for the iron meteorite Carbo (IID) [9], Lovina has a very low, nearly terrestrial Cr isotopic composition, in constrast to Carbo, which is characterized by a high level of spallogenic ^{54}Cr, due to its long exposure age of 850 Ma [10]. The ε^{53}Cr data for duplicate analyses of Lovina are not resolved from terrestrial Cr, whereas one of the two pieces (L4) has slightly higher ε^{54}Cr (Fig. 3). The data for Henbury (IIIA) [9] highlight the challenges of obtaining high precision Cr isotope composition out of iron matrix.

Table 1. Chromium isotope results for Lovina.

Sample	ε^{53}Cr	2SE	ε^{54}Cr	2SE
Lovina L2	0.07	0.05	0.26	0.10
Lovina L4	0.01	0.04	0.12	0.09
San Carlos Cpx, from [7]	0.01	0.03	0.02	0.07

Discussion: If Lovina is an iron meteorite, the very low spallogenic ε^{54}Cr suggests an extremely short cosmic ray exposure history (*viz.* Carbo ε^{54}Cr is *ca.*+100ε units), or the specimen we analyzed came from the deep interior of a large body, prior to atmospheric entry. This result is consistent with [4].

However, most of the evidence reported here suggests that Lovina is not an iron meteorite.

Although the $\varepsilon^{53}Cr$ data for duplicate analyses of Lovina are not resolved from terrestrial Cr, one piece (L4) has slightly higher $\varepsilon^{54}Cr$. We speculate that this is an analytical artifact, and that our Fe separation from Cr may not have been sufficiently effective with this sample, although the average $^{54}Fe/^{52}Cr$ was $(2.6\pm1.1)\times10^{-6}$ for L2 sample, compared to $(6.5\pm0.9)\times10^{-7}$ in L4, a factor of four times higher than L4, which has no measurable ^{54}Cr excess.

The HSE and Os data are also inconsistent with an origin as an iron meteorite. Such a large portion of unsupported radiogenic ^{187}Os has never been observed for irons, in which Re and Os are hosted by the same metal phases. Further, the HSE pattern of Lovina differs considerably from any known iron. The most similar pattern for a meteorite, of which we are aware, is for the unique carbonaceous chondrite NWA 5958 [11] (Fig. 2), however, this meteorite has much higher abundances of Re, Os and Ir compared with Lovina.

Trace element abundances are also unlike any other iron meteorites, including the IIE irons to which it has been likened [3]. Instead, it has some geochemical features in common with terrestrial native metals, such as enrichments in Mo, W and As, suggestive of formation by reduction.

Assuming Lovina is not an iron meteorite, it most likely formed under the highly reducing conditions associated with serpentinization of mantle peridotite. Terrestrial metals, such as those found associated with the Josephine Ophiolite, Oregon, and Disko Island, Greenland, are well known [12-13]. In such cases, it may be expected that, if the metal can efficiently extract HSE from the associated serpentinite, the metal should have a HSE pattern similar to that of the host peridotite. Indeed, the pattern for Lovina is remarkably similar to that of a harzburgite xenolith (FS-44) sampled from the Fansi locale of the North China Craton, albeit with ~100x lower HSE [14].

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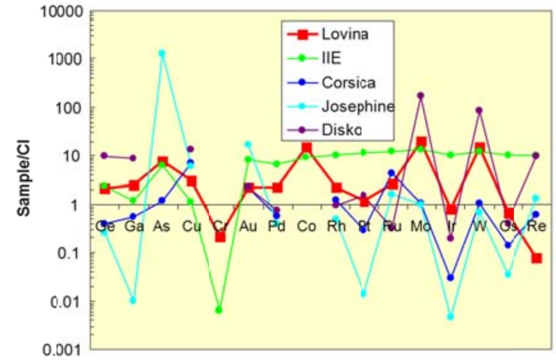

Figure 1. CI chondrite normalized plot for Lovina (red squares), compared to awaruite from Josephine County, Oregon and Cap Corse, Corsica, and with terrestrial metallic iron from Disko Island, Greenland and the IIE iron, Elga [15].

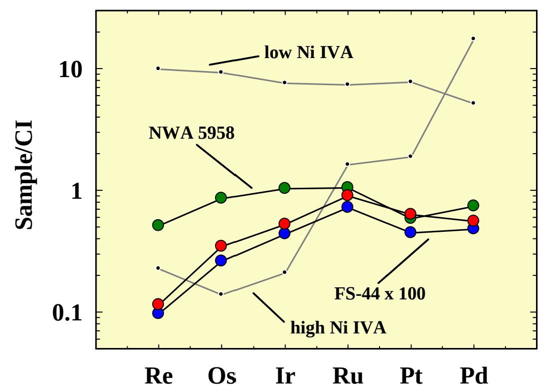

Figure 2. CI chondrite normalized plot for Lovina (red circles) and high and low Ni IVA iron meteorites from [6] for comparison. Also for comparison is the pattern for the unique carbonaceous chondrites NWA 5958 (from [11]). Also shown for comparison is the pattern for terrestrial harzburgite xenolith FS-44 from [14] (x 100).

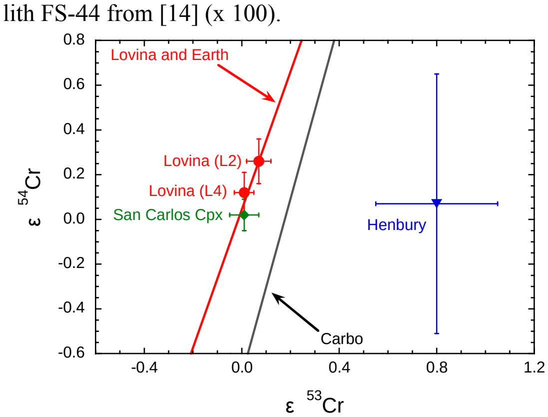

Fig. 3. Lovina Cr isotope compositions compared with the correlation line for Carbo (IID) and Henbury (IIIA) [9].