

LODRAN: THE RESIDUE OF LIMITED PARTIAL MELTING OF MATTER LIKE A HYBRID BETWEEN H AND E CHONDRITES. T. Fukuoka, M.-S. Ma, H. Wakita* and R.A. Schmitt. Department of Chemistry and the Radiation Center, Oregon State University, Corvallis, OR 97331.

In a continuing study of chemical differentiations observed in achondritic meteorites and in an effort to understand and to test hypotheses (e.g., 1, 2) directed to the fractionation events which were responsible for the genesis of unique meteorites from primordial and fractionated nebular matter we have analyzed the unique meteorite Lodran via INAA and RNAA methods. From a detailed summary of previous work and their work, Bild and Wasson (3) have concluded that Lodran, consisting of roughly equal amounts of Fe-Ni metal, orthopyroxene and olivine had been equilibrated during recrystallization in a parent-body setting and had lost appreciable fractions of alkalis and Ca during a mild degree of partial melting. Reducing materials were incorporated and mild reheating reduced FeO to Fe⁰ and produced zoning in olivine. Prinz (4) has reported petrographic results on new sections of Lodran.

Two Lodran fragments were analyzed via INAA for bulk and few trace elements, and in one fragment (Lodran-A), the elements K, Sr, Ba, Cd, In and the REE were analyzed by standard RNAA methods. Table 1 lists the data and Fig. 1, the chondritic normalized data. Abundances of TiO₂, MgO, MnO, Cr₂O₃, Sc, V and the heavy REE, Dy-Lu, are similar within error to the ordinary chondrites. The avg. MgO of this work coupled to the observed MgO in opx and ol (3), yields 63% opx and 37% ol in the silicate fraction. Our calculated avg. MgO in the silicates of 37% compares to 39% by (3). The avg. CaO of 1.2 ± 0.4% in Lodran silicates overlaps within 2σ the 0.62% CaO reported by (3). Assuming that all Na, K and Al are confined to the new phase (K_{0.63}Na_{0.37})Al Si₅O₁₂, the avg. Al₂O₃ and Na₂O in Lodran-A and -B and the K₂O in Lodran-A yield a consistent new phase content of 1.6 ± 0.1%. From the total Fe of this work, the assumed avg. FeO of 10% in Lodran silicates (opx and ol) (3), ~0.3 vol.% chromite (3), and 2.7 vol.% troilite (3) we calculate 25.9% and 31.4% Fe⁰ in Lodran-A and -B, respectively. The 31.2% Fe_{tot} in Lodran-A and the 36.1% in Lodran-B are higher than the 27.6% Fe_{tot} in H chondrites and bracket the Fe_{tot} of 33% in E1 chondrites (5). Of 35 selected H chondritic analyses (6), all are below 30.8%, i.e., considerably below our weighted avg. of 32.4% Fe_{tot} in 0.93g of Lodran. (Fe/Ni)⁰ ratios of 14.4 in Lodran-A and 11.6 in Lodran-B are above the (Fe/Ni)⁰ ratio of 10.3 in H chondrites but less than the ratios of 18.2 and 16.6 in E1 and E2 chondrites. Ni/Co ratios of 18.4 were observed in both Lodran-A and -B, and Ni/Au ratios of 50,000 and 61,000 were observed in Lodran-A and -B, resp. To account for the siderophile data for Lodran-A, we assume no addition of outside metal, reduction of FeO from an assumed 9.0% FeO in the total starting matter to achieve a final avg. of ~6.8% in the final residue and to yield 2.3% Fe⁰ and no reduction of troilite. For such a model, the (Fe/Ni)⁰ ratio was ~13.2 in the initial metal before reduction with 23.6% Fe⁰ in the "primary" matter. For Lodran-B, if we assume 23.6% of initial Fe⁰ and similar reducing

*Permanent address: Dept. of Chemistry, University of Tokyo, Tokyo, Japan

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conditions, then $\sim 5.4\%$ of Fe° must be added to the primary matter. To yield a $(\text{Fe}/\text{Ni})^\circ$ ratio of 11.6 in the final Lodran-B fragment, it is necessary that the $(\text{Fe}/\text{Ni})^\circ$ ratio be ~ 6 in the added metal, which corresponds to compositions (5) similar to either ataxites or very finest octahedrites. Ratios of Ni/Co and Ni/Au are not inconsistent with the addition of these two types of metallic iron.

Cd and In, highly and very highly depleted, resp., in ordinary chondrites relative to C1 chondrites were analyzed in Lodran-A. The Cd abundance falls at the high end of the H chondritic range and low end of the C3 range and In, in the middle of the H chondritic range (5). Both Cd and In are close to the avg. E2 chondritic abundances. Assuming no loss of these chalcophile elements during the partial melting - mild reheating - recrystallization events, either H or E2 starting material is favored.

The chondritic normalized pattern (Fig. 1) for Na, K, Sr, Ba, and the REE presents an intriguing distribution. We interpret this overall pattern as due to limited partial melting of chondritic like matter with the generation of a silicate rich liquid by the melting of plagioclase and the reduction of some FeO with the release of SiO_2 into the liquid phase. The presence of such a silicate rich liquid would favor the increased concentration of divalent Sr and Ba in the liquid. If the REE were in equilibrium with the primary minerals *opx* and *ol* and the liquid, the ratio of normalized Lu/La would be expected to be ~ 10 instead of ~ 3 ; therefore, only limited equilibrium was achieved as suggested by (3) on other grounds. The marked Sr depletion relative to Eu suggests that only ~ 0.3 of Eu was divalent if the primary matter were $\sim 1 - 1.5x$ in all lithophile elements. It is very difficult to fractionate both Sr and Ba to the same degree and deplete both Sr and Ba by a factor of ~ 10 relative to La by equilibrium fractionation of the customary minerals *ol*, *opx* or *plag* separately or in any combination. Moreover, the Ca depletion by only a factor of ~ 2 compared to the Na depletion by a factor of ~ 20 supports the claim by (3) that there was a loss of only the low melting fraction; i.e., loss of the albitic fraction would be favored over loss of the anorthitic fraction. Additionally, the greater K depletion relative to Na suggests that the primary matter was depleted in K by at least a factor of ~ 4 relative to known chondrites.

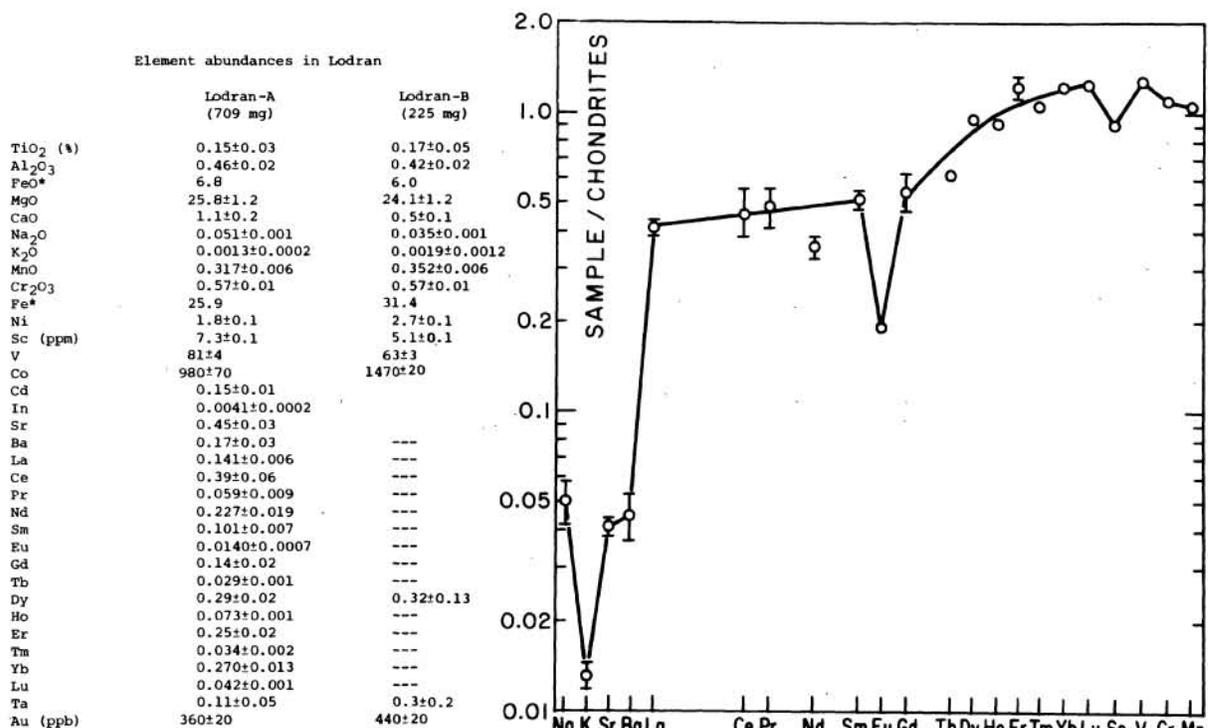
Bild and Wasson (3) have noted many similarities between the Lodran and ureilites in their rare gas contents, exposure ages and mineral phase compositions. They noted that differences in their metal and troilite contents and $\text{Fe}/\text{Fe}+\text{Mg}$ ratios suggested different parent bodies for the genesis of ureilites and Lodran. Assuming the validity of limited partial melting for loss of the light REE, we suggest that a lower $\text{Fe}/\text{Fe}+\text{Mg}$ ratio in Lodran relative to ureilites should result in a higher depletion of the heavy REE in Lodran relative to ureilites. From a comparison of ureilite data by Boynton et al., (7) we note that Lu abundances in ureilites are depleted to $\sim 0.2x$, quite contrary to the expected depletion based on $\text{Fe}/\text{Fe}+\text{Mg}$ data. The recent $^{16}\text{O}/^{17}\text{O}/^{18}\text{O}$ ratios reported by Clayton and Mayeda (8) fall far below the H chondrites and the ureilite groups, and strongly indicate that Lodran was not in either of the two parent bodies for H chondrites or ureilites. Also Lodran (8) may be in a different parent body than the AMP group.

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In conclusion, the chemical data support the Bild-Wasson mechanism for limited partial melting, perhaps a non-equilibrium event. The new phase $(K,Na)AlSi_5O_{12}$ probably represents relicts of the partial melt most of which was withdrawn from the system. Our evidence also supports different parent bodies for Lodran and the ureilites. The primary matter of Lodran before limited reduction apparently is unique in composition and seems to be more like a hybrid between H chondrites for the silicate phases and E chondrites for the metallic phase.

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*Total iron contents were 31.2% and 36.1% in Lodran-A and -B, resp.
Fe and FeO were calculated by assuming 10% avg. FeO in silicate phases (Bild and Wasson, 1976).