PETROLOGIC STUDIES BEARING ON THE ORIGIN OF THE LODRAN METEORITE.
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Tschermak (1) first described the Lodran meteorite in a very detailed manner, and Bild and Wasson (2) produced the first modern study, except for the rare gas results of Zhmhringer (3). It is a one-of-a-kind meteorite containing roughly one-quarter metal (and some troilite) and three-quarters ol and ppy (in roughly equal amounts), plus minor phases. Bild and Wasson (2) concluded that the metallic and silicate portions probably formed during nebular condensation and were later equilibrated at the time of recrystallization in a parent-body setting. At that time it lost appreciable amounts of alkalis and Ca as a result of a small degree of partial melting. They also concluded that metal probably cooled rapidly (700°C/my) at high temperatures and slower (30°C/my) at lower temps. They found it had similarities to ureilites, except it would be a metal-rich (rather than carbonaceous) ureilite; however, it has higher Fe/(Fe+Mg) and may have originated on another parent body. They also noted a K-rich phase which they suggest may be a new mineral. Stolper (4), on the other hand, suggested that the phases in Lodran are similar to a residual assemblage after partial melting of a proposed source rock which gave rise first to eucritic melts and later magnesian pyroxenes found in diogenites, howardites, and mesosiderites. However, Stolper concluded the presence of Cr-diopside and the K-rich phase negated this idea. Nevertheless, the origin of Lodran either as a condensate which underwent some partial melting, partial melt residue, or cumulate with later intrusion of metal remain hypotheses which require further testing. The purpose of this project is to study new sections of this meteorite, acquire further petrologic data on unresolved problems, restudy the cooling rate, integrate these data with new major and trace element data of Fukuoka et al. (5), and reexamine the hypotheses.

MODE, TEXTURE, MINERALOGY. Modal analysis was carried out by automated electron microprobe techniques using 9 spectrometers. Preliminary results, based on only 195 points on one fragment, give: Kamacite, 24%; Taenite, 1%; Olivine, 37%; Opx with minor exsolved cpx, 36%; Chromite, 1%; trace amounts of schreibersite and K-rich phase. Megascopically, Lodran is highly friable and disaggregated. Microscopically, ol is euhedral to subhedral (0.5-1.0mm) and has small rounded inclusions of opx; it usually contains dark vein-like or patch-like areas, distinct from cracks, which contain unresolvable SiO2-rich, and perhaps Fe-rich material. Opx has similar grain size, is more anhedral, and contains small rounded inclusions of ol. Cpx is rarely seen as exsolution lamellae or blebs in opx, whereas Bild and Wasson (2), reported finding only one grain. Both silicates are fresh and free of any metal. Metal appears to surround silicates, including euhedral ol, and may indicate later emplacement or readjustment in the solid state. Troilite is often associated with metal, and also appears to be later than silicates. Schreibersite is included in metal. Chromite is generally small, rounded to euhedral, and most commonly included in ol. The new K-rich phase of Bild and Wasson (2) is "granitic" melt inclusion. One inclusion contains 3 crystals of apatite in a groundmass of "granitic" composition. Melt inclusions are always associated with minute grains of metal and/or troilite, which may have been immis-
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cible in the melt. Although they are compositionally puzzling, similar occurrences were reported in enstatite achondrites by Fuch (6) and Olsen et al. (7) and in some chondrules and veins in chondrites as reviewed by Olsen et al. (7).

MINERAL CHEMISTRY. OL is variable (Fo98-94) with Fe decreasing towards grain boundaries and towards the dark vein-like areas within ol crystals. Mg increases as Fe decreases, but Mn does not follow Fe and remains constant. This indicates a reduction process rather than igneous fractionation, as also shown by Bild and Wasson (2). This effect is not present in opx (WoEn Fs) and exsolved cpx (WoEn Fs) which are homogeneous and in equilibrium with the unreduced ol or ol inclusions in pyx. Bild and Wasson (2) suggested that C may have been present as a reducing agent, but none was found. Our study has not revealed any to date. The reduction of the fayalite component of ol may have been either: (1) FeSiO4 + FeO + O2, or (2) FeSiO4 + 2Fe0 + O2 + SiO2, or both. Metallic iron was not observed in ol near grain boundaries, as was the case for the Kenna ureilite (8). Perhaps O2 diffused into surrounding metal, but Ni-free Fe near olivine grains has not yet been detected. There is some evidence for SiO2-enrichment near grain boundaries and within dark patches in ol, but it is difficult to resolve. There is also less evidence for Fe-enrichment in dark patches, but this is also difficult to resolve.

COOLING RATE. A new cooling rate was estimated from the size and composition of schreibersite lamellae. Ten lamellae with widths of 5-10 microns were analyzed. Lamellae centers contain 44-48% Ni and lamellae interfaces contain at least 1% more Ni than centers. Kamacite at interfaces contains 6.4% Ni and 0.03% P. The estimated bulk composition of the grains containing schreibersite is 7.3% Ni and 0.2% P. This is lower in Ni than the bulk metal composition (8% Ni) given by Prior (9) because these grains consist of kamacite and schreibersite with little or no taenite. With the estimated 7.3% bulk Ni, kamacite is the only phase present at equilibrium at 550°C and at lower temperatures schreibersite exsolves (10). The growth of schreibersite from kamacite can be modelled with computer techniques (11, 12). Using a bulk composition of either 7.3% Ni or 8.0% Ni computer simulation indicates schreibersite grew during cooling at about 10°C/m.y. This is compatible with the cooling rate of 10-30°C/m.y determined for kamacite-taenite by Bild and Wasson (2) using a calculation based on interface Ni concentrations. However, Bild and Wasson also reported a second estimate of cooling rate as 700°C/m.y, considering size as well as composition of taenite. This is considered erroneous because it is unlikely that evidence of two stages of thermal history can be preserved during diffusion-controlled growth at such low cooling rates. It is likely that the higher estimate was erroneous because of irregularities in taenite geometry. A higher cooling rate of about 10°C/m.y, supported by the new phosphide data, is similar to that of many other meteorites.

MAJOR AND TRACE ELEMENTS. Fukuoka et al. (5) determined major elements (except for SiO2) for Lodran and their results for silicate bulk chemistry are similar to ours as well as those of Bild and Wasson (2). Basically the silicates represent an ol-opx rock (harzburgite) surrounded by metal. Fukuoka et al. (5) show that selected trace elements indicate that the primary material of Lodran, prior to the reduction process, seems to be a hybrid between H and E chondrites. But Na, K, Sr, Ba, and Ca, as well as REE, show complex...
depletion and fractionation patterns which appear to be related to a partial melting event.

CONCLUSIONS:
(1) The Lodran silicates indicate an igneous cumulate texture (e.g. euhedral olivines, mineral inclusions in ol and opx) with some subsolidus recrystallization. Metal and troilite appear to be later.
(2) The melt associated with these cumulates recorded an earlier loss of a feldspar phase as indicated by a negative Eu anomaly. However, this could possibly have occurred in an earlier partial melting event.
(3) "Granitic" melt inclusions in ol are puzzling and may represent small degrees of partial melt or immiscible melt, that became associated with growing ol crystals.
(4) The complex alkali depletion and REE patterns may indicate that, although Lodran may have been ultimately derived from chondritic material, there may have been so much planetary processing that it is highly speculative to relate it closely to condensation processes.
(5) The origin and significance of the reduction process requires further study.
(6) The meteorite appears to be cumulate harzburgite which was surrounded by metal and which experienced reduction; it was derived at an earlier stage from "primitive" materials.
(7) Lodran ol differs greatly from ureilite ol in having low Ca and Cr and, along with other arguments, indicates that although there are some similarities, these two meteorite groups probably formed in different parent bodies.

REFERENCES.