MINERAL ASSEMBLAGES IN PLANETARY INTERIORS: PREDICTIONS BASED ON ESTIMATES OF PLANETARY COMPOSITION. Edward Stolper, Division of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125

Estimates of the bulk compositions of Mercury, Venus, Earth, Moon, Mars, and the parent body of eucritic meteorites are reviewed in (1). These estimates of planetary composition and the mineral compatibilities determined experimentally in the system $CaO-MgO-Al_2O_3-SiO_2$ (2,3) can be used to predict the mineral assemblages expected at different depths in the interiors of these planets. Despite the uncertainties in estimates of planetary composition, in the experimentally determined phase equilibria, and in the application of these equilibria to determining mineral assemblages in the complex, multicomponent systems relevant to real planets, systematic differences in a petrological sense between the planets emerge from this analysis. Predicted mineral assemblages are summarized schematically in Fig. 1.

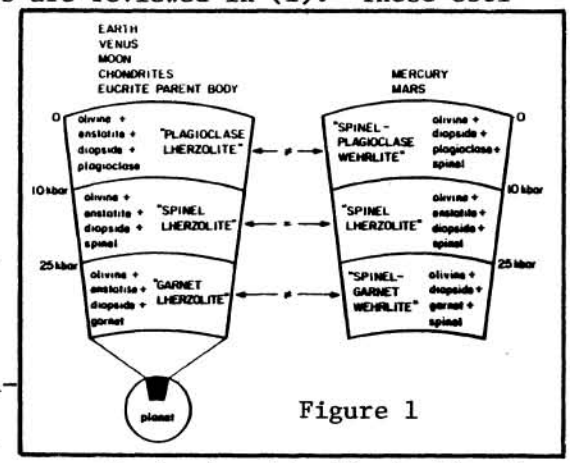

Figure 1

Mineral compatibilities in the system $CaO-MgO-Al_2O_3-SiO_2$ are shown graphically in three pressure ranges in Fig. 2 & 3. Fig. 2 shows olivine-saturated assemblages projected from olivine (Mg_2SiO_4) onto the plane $CaSiO_3-MgSiO_3-Al_2O_3$ (molar units). Fig. 3 shows diopside-saturated assemblages projected from diopside ($CaMgSi_2O_6$) onto the plane $MgO-SiO_2-CaAl_2O_4$ (molar units). Also shown in Fig. 2 & 3 are the average estimates of the compositions of several terrestrial planets (1). Averages were used to simplify the figures; individual estimates of planetary composition vary greatly for each planet (even for those planets which have been sampled), but in general, the trends apparent in Fig. 2 & 3 hold for most of the individual estimates as well as the averages. The recalculation procedure of (4) was used to recast the estimates of planetary composition, which contain oxides other than CaO, MgO, Al_2O_3, and SiO_2, into "equivalent" amounts of these four oxides.

The mineral assemblages predicted for each planetary composition can be determined from Fig. 2 & 3 by noting in which regions of these figures the planetary composition plots. The sequence of mineral assemblages expected with increasing pressure in the earth's upper mantle, which is well known, is successfully predicted by these figures: ol+en+di+plag ("plagioclase lherzolite") from 0-10 kbar; ol+en+di+sp ("spinel lherzolite") from 10-25 kbar; ol+en+di+ga ("garnet lherzolite") at higher than 25 kbar.

Several uncertainties are associated with the use of these diagrams to predict mineral assemblages in planetary mantles: (a) The diagrams ignore the effects of variations in Fe/(Fe+Mg) ratio and oxidation state between the planets and cannot fully account for the effects of the abundances of minor elements on these mineral assemblages. (b) The compositions of coexisting minerals vary continuously with P and T, and thus the mineral assemblages depend on the "geotherms" for each planet. The diagrams are drawn for specific, representative P-T conditions in each pressure range. (c) The pressure limits of these assemblages are only approximate because the transformations do not take place at a discrete pressure but over a pressure interval, depend on the geotherm, and have not been unambiguously located in P-T space even for simple systems, let alone for complex systems. (d) The estimates of planetary composition generally are for the mantle + crust, rather than the mantle. However, in planets such as the Earth where the ratio of crust to mantle is

small, the difference between the projected bulk planet and mantle composition is negligible.

Fig. 3 shows that all of the estimates of planetary composition would be rich in olivine (55-80 weight percent).

The venusian mantle and the lunar bulk composition would have the same sequence of mineral assemblages as the Earth with increasing pressure. The parent bodies of chondritic (not shown) and eucritic meteorites would show the same sequence, but assuming asteroidal parent bodies, only the low pressure assemblage would ever be realized.

The mercurian and martian bulk compositions behave differently from the Earth's composition with increasing pressure. At pressures less than 10 kbar, these bulk compositions would consist of ol+di+sp+plag ("spinel-plagioclase wehrlite"). From 10-25 kbar, they would be spinel lherzolites, like the terrestrial, venusian, and lunar bulk compositions. Above 25 kbar, however, the martian and mercurian bulk compositions would again differ from the other terrestrial planets, having an ol+di+sp+ga assemblage ("spinel-garnet wehrlite"). According to (2), the garnet composition coexisting with olivine, diopside, and spinel becomes more calcic with increasing pressure; as a result, either spinel or diopside will ultimately disappear from these mantle assemblages with increasing pressure. McGetchin and Smyth (5) first predicted that that the martian mantle might be different in a mineralogical sense from the terrestrial mantle, but their conclusion about the details of the assemblage is different. The martian and mercurian compositions are quite different from each other, although their mineral assemblages are predicted to be similar. The martian composition is rich in FeO and volatiles relative to the mercurian composition, which is expected to be poor in oxidized iron and volatiles. Nevertheless, the large component of "high-temperature condensate" expected in Mercury and the high FeO content of Mars both consume excess enstatite and thus have the same effect on the normative mineralogy.

Thus, the compositions of terrestrial planets fall into two distinct categories in a petrological sense (Fig. 1): Earth, Venus, and the Moon are expected to show the following sequence of assemblages with increasing pressure: plagioclase lherzolite, spinel lherzolite, and garnet lherzolite. Mars and Mercury are predicted to have a different sequence: spinel-plagioclase wehrlite, spinel lherzolite, spinel-garnet wehrlite.

The compositions of liquids produced on melting of planetary mantles are functions of the mantle mineralogy, the pressure of melting, the volatile content (e.g., H_2O, CO_2), and the degree of partial melting. Despite the large number of variables involved in melt generation, the predicted mineral assemblages of planetary mantles and an understanding of the characteristics of liquids produced by melting of these assemblages can be combined to predict in general terms the types of liquids expected to be erupted and involved in planetary differentiation on each of these planets. For example, if the mineral assemblages in two planetary mantles are similar, it is likely that the compositions of the liquids produced by melting will also be similar in some respects. Thus, if the melts are generated at pressures between 10 and 25 kbar, the source materials are spinel lherzolites in all of the planets and the liquid compositions can therefore be expected to be controlled by similar phase equilibria in all of the planets. There are, of course, differences in source region composition which will be reflected in the melt compositions even in this pressure range. For example, liquids on Mercury would be poor in iron and alkalis while those on Mars will be rich in these components. At higher pressures, dry melts on Earth and Venus will be saturated with a garnet lherzolite assemblage, and will probably be olivine-rich tholeiites. In the same pressure range on Mars and Mercury, however, the melts will be saturated

with a spinel-garnet wehrlite assemblage. At present, little information is available on the characteristics of liquids produced by melting of such an assemblage. At lower pressures, the characteristics of melts produced on Mars and Mercury will again differ from those on Earth and Venus. Melts on Mars and Mercury produced by melting of spinel-plagioclase wehrlites are expected to be more aluminous and more undersaturated than the tholeiitic melts produced by melting of the terrestrial and venusian plagioclase lherzolites.

REFERENCES: (1) BVSP, Chap. 4, 1980. (2) MacGregor (1965) Carnegie Inst. Yearb., 64, 126. (3) Biggar (1969) Progress in Exp. Petrol., NERC Rpt., p. 97. (4) O'Hara (1968) Earth Sci. Rev., 4, 69. (5) McGetchin & Smyth (1978) Icarus, 34, 512.

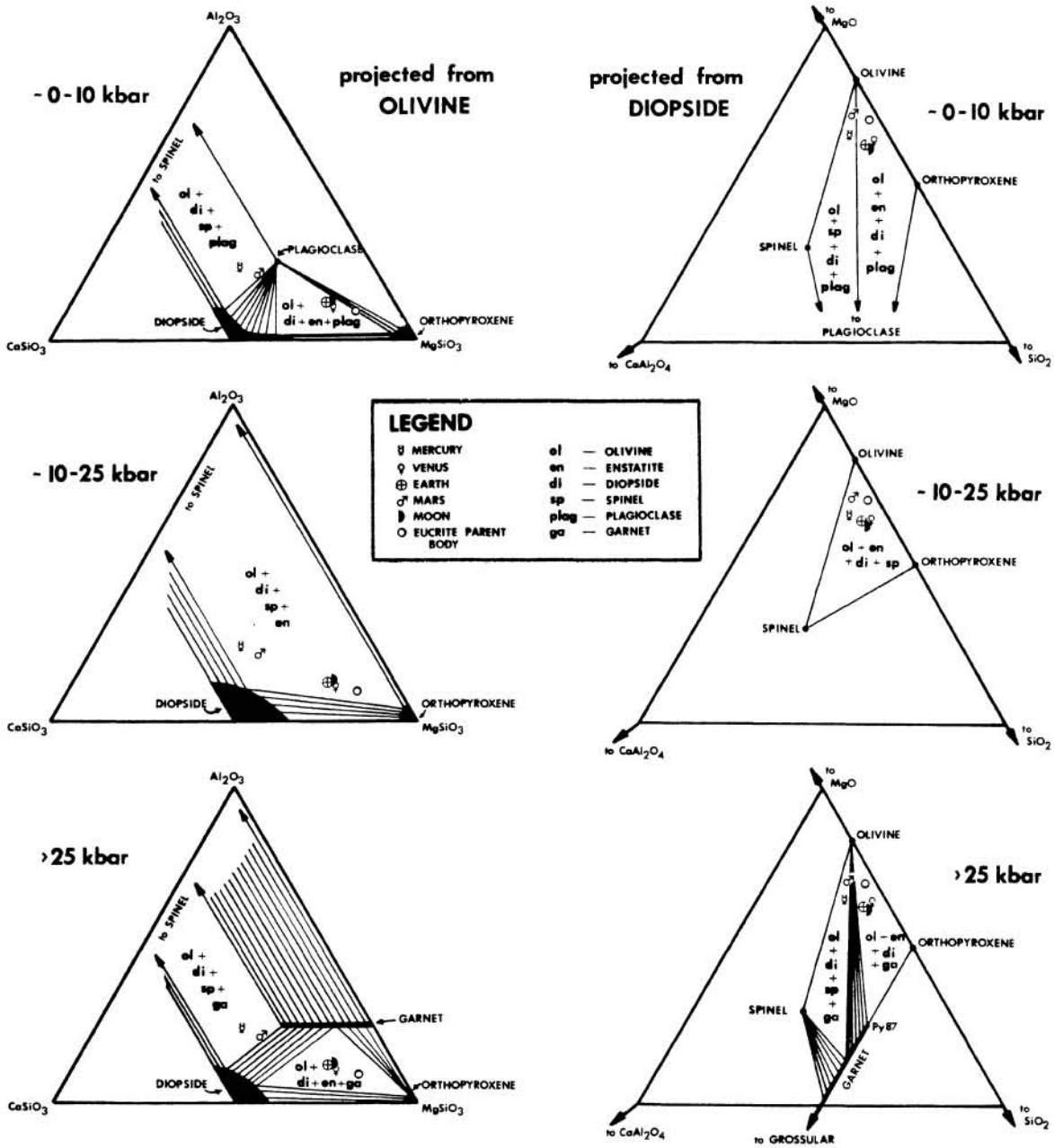

Figure 2

Figure 3