Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 492

Experimental Studies of Sulphide Melt Textures in the Lower and Upper Mantle

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Introduction

Fe-rich sulphide melts are well known to concentrate Cu, Ni and the Pt group of elements (PGE) with respect to silicate melts and minerals, and their capacity for segregating these elements is greatly enhanced by the facts that: sulphide melting temperatures are distinctly lower than common silicates and Fe (Usselman, 1975), and the density of sulphide melts is much greater than that of silicates. As a consequence, the formation and segregation of sulphide melts is believed to have played a major role at opposite ends of the Earth's mantle: (1) in the formation of the Earth's outer core (where S concentrations of 9-12 wt% are postulated e.g. Ahrens, 1979), and (2) in the development of economic Ni and PGE ore deposits in the crust. In both cases the mobility of small volume sulphide melts in a silicate matrix (whether it be of mantle silicates or a cumulate pile of silicates crystallised from basic-ultrabasic melt) will be affected by how the Fe-(Ni-Cu)-S melt will distribute itself between silicate minerals. This will depend on the surface tension forces, or interfacial energies, operating between sulphide melt and silicate crystals; it will express itself in the values of dihedral angles for a sulphide melt pool between two grains of a given silicate (e.g. Hunter, 1987). Since sulphides rarely preserve high temperature textural relationships, we have endeavoured to determine sulphide-silicate-silicate dihedral angles experimentally

Methods

Experiments were performed using two bulk compositions made up from natural minerals as follows (in weight%): (1) orthopyroxene [$(Mg,Fe)SiO_3$] 80%; pyrrhotite [Fe_{1-xS}] 13.3%; pentlandite [$(Fe,Ni)_9S_8$] 4.4%; chalcopyrite ($CuFeS_2$) 2.3%. (2) olivine [$(Mg,Fe)_2SiO_4$] 75%; pyrrhotite [$Fe_{1-x}S$] 16.5%; pentlandite [$(FeNi)_9S_8$] 5.5%; chalcopyrite [$CuFeS_2$] 3%.

For lower mantle conditions, where $(Mg,Fe)SiO_3$-perovskite is the principal stable phase, experiments were conducted on the $(Mg,Fe)SiO_3$-rich composition at ca.1500 C and 24 GPa in multianvil apparatus. To simulate conditions in the upper part of the upper mantle and the crust, where orthopyroxene and olivine are the principal phases concerned, we carried out experiments at 2 GPa and 1200 C on both the $(Mg,Fe)SiO_3$-rich and $(Mg,Fe)_2SiO_4$-rich compositions in piston-cylinder apparatus.

Results

Coherent experimental charges showing the textural relations of the quenched sulphide melt and the silicate matrix were obtained at all run conditions. Optical microscope (oil immersion reflected light) and SEM study of the charges indicates that a single silicate phase is present in each case; whilst the sulphide melt has dominantly quenched to a mixture of pyrrhotite and pentlandite. The silicates occur as fine-grained aggregates showing granuloblastic (or polygonal-granoblastic) grain shapes, indicative of textural equilibrium. The overall shape of the sulphide mineral aggregates gives the shape of the quenched sulphide melt, and commonly shows sharply pointed projections at junctions with two silicate grains (see Fig. 1), with extensions along silicate grain boundaries where melt is more abundant.

Measurements of the dihedral angles have been made on graphic images collected both in high-powered oil immersion reflected light microscopy and by SEM. Corrections are made for 'cut effect' using histograms and cumulative frequency plots (Rieeger and van Flack, 1960). Measurements on the ultra-high-pressure (lower mantle) charges necessitate great care because of the very fine grain size (0.5 to 2 μm) of the $(Mg,Fe)SiO_3$ silicate matrix (see Fig. 1). Measurements to date show dihedral angles at or below 60 degrees for all the charges.

Conclusions

These preliminary results show that very small volumes of FeS-rich melt will be relatively mobile; and endorse the likelihood of sulphide melt sinking through the Earth's silicate Mantle and forming a significant component of the Outer Core, where it is expected to lower melting temperatures and may play an important part in magnetic properties. With respect to the formation of Ni and PGE deposits in igneous cumulate bodies in the crust or uppermost mantle, the results show that relatively low temperature, low-volume, sulphide melt would tend to percolate downwards through the silicate cumulate pile, rather than remaining located near the cumulate/magma interface. However, such a tendency for downward sulphide melt percolation may be countered by entrainment in silicate interstitial fluids rising upwards during compaction.

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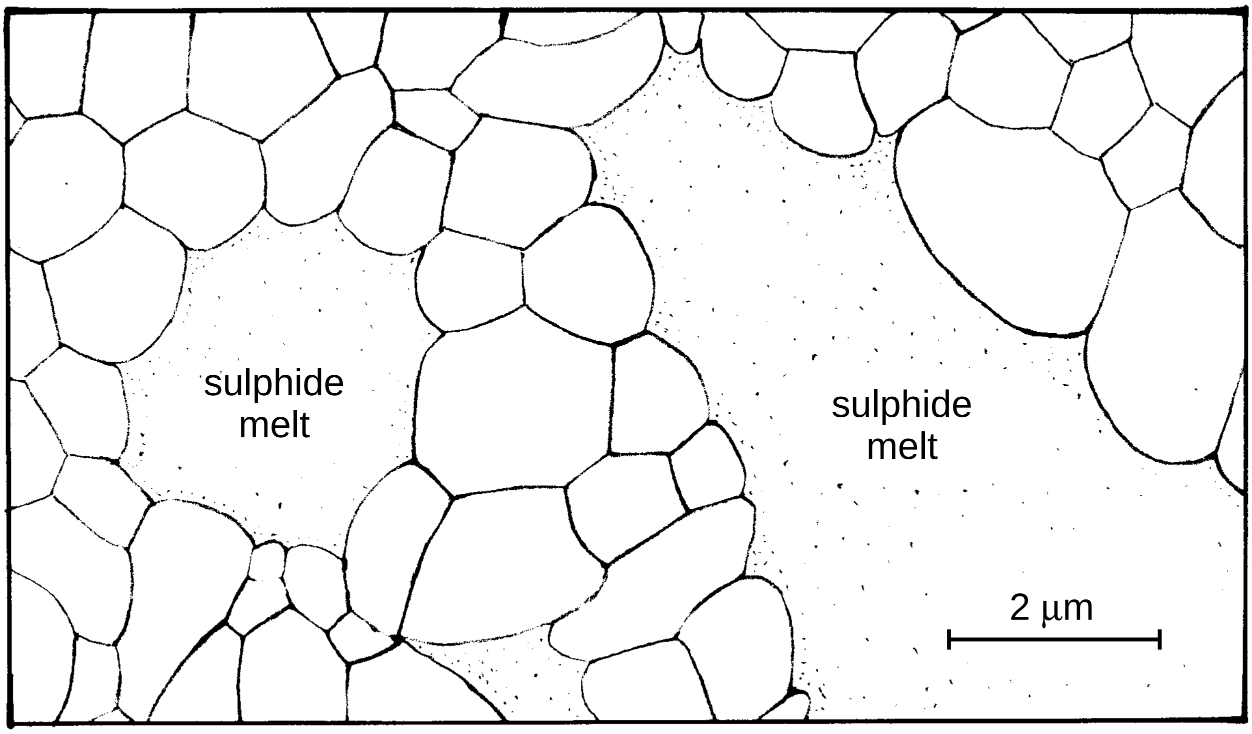

Figure 1: Texture of sulphide melt in $(Mg,Fe)SiO_3$ granuloblastic aggregate at Lower Mantle P-T conditions.

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