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Applications of Electron Microscopy to Materials and Earth Sciences — Dislocations, Shape and Orientation Changes and Interdiffusion

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Interactions of solid materials with liquids, vapors or other solids are of concern in earth sciences, especially the diagenesis, weathering and metamorphic processes which involve the compositional, structural and morphological changes down to nanometers scale. The electron microscopy, SEM, TEM, HRTEM and AEM have been used to study some materials with emphasis on: (i) dislocations, (ii) shape and orientation changes and (iii) composition variation due to interdiffusion. The formation mechanism of the materials can then be inferred as outlined below.

TEM was used to characterize the defect microstructures of chromium spinel and pyrite in the serpentinized chromitite occurrence of the Kenting melange, southern Taiwan (Hwang et al. 1988). Dislocations arranged as dipoles, tangles and subgrains boundaries were found in chromium spinel and pyrite indicating that they were plastically deformed and polygonized later. The deformation episodes of the Hengchun chromitite were then inferred from the known creep behavior of analogue spinel materials and pyrite. In the other case, the disloca-tion outcrops revealed by optical microscope and SEM were found to be useful indicator of directional dissolution rate as demonstrated in the acidic dissolution of willemite, Zn_2SiO_4, an important phase for Zn source, crystalline glaze and phosphorous applications (Lin and Shen 1993a).

In the second category dealing with shape and orientation, the optical and SEM images of curved etch hillocks on the (0001) plane of willemite showed the role of screw axis on dissolution (Lin and Shen 1993b). Thus, lattice diffusion of minerals may be significant in some weathering processes under ambient temperature. Shape and orientation are also of concern in composite materials. For example, TEM indicated that the shape and orientation of the intragranular NiO particles have surprisingly aligned with those of the zirconia matrix when the NiO/ZrO_2 (alloyed with 10 mol.% Y_2O_3) composites were annealed for 300 h at 1600°C (Chen and Shen). Similar behavior is expected for the mineral assemblages in the interior of the earth. Surface features and the shape of a living organism can also be used as indicator of its behavior. For example, frictional bars and eroded areas of the coral-boring bivalve Lithophaga nigra were revealed by SEM, suggesting that this organism is a mechanical borer rather than a chemical borer, as previously believed (Fang and Shen 1988). However, the debris at the bottom of the burrow may dissolve chemically when metabolism reduces the pH. Near the carbonate compensation depth, the level at which the complete supply of carbonates is dissolved, the calcareous particles may become nanometers in size, and the size effect on dissolution (Lin and Shen 1994) may become important.

Finally, interdiffusion was known to cause disordering of atoms in some diffusion couples of metal alloys, and recently in aluminized coatings on Inconel 600, a Ni based alloy (Chen et al.). A drastic concentration gradient at interface may account for such changes. As for ceramic system, preliminary AEM study of the annealed yttriumiron garnet (YIG)/ZrO_2 composite showed that diffusion-induced amorphization (DIA) occurred within the lattice of YIG rather than at the YIG/ZrO_2 interface. These results have following implications: *(1)* previous determination of interdiffusion coefficient may have overlooked the fact that an intermediate phase exists at interface, *(2)* the diffusion path of a diffusion couple may be different from previous versions if phase and composition changes are considered at nanometers scale, and *(3)* DIA is expected in minerals assemblages such as in metamorphic rocks.

It is expected that future studies on surface changes of samples immersed in wet medium and spiked with poisons should improve the current knowledge of the diagenesis and weathering processes. Confocal microscopy should help to some extent in this regard. STM and AFM have been useful to reveal surface reconstruction and electronic structure of the atomic planes of some materials. However, the exact nature of an interphase interface remains to be explored theoretically and experimentally. Hopefully, the variation of the equation of state toward an interface can be considered in the future simulation of HRTEM images.

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