Ca,Al-rich inclusions (1,2) are widely thought to represent some of the earliest material condensed from the solar nebula (3) and they have provided much information about the chemical and isotopic composition of the environment in which they formed. Although isotopic distinctions have been preserved (4), alteration products within the inclusions and the existence of mineralogically-distinct rims (5) indicate that the inclusions were not isolated from reactions with the hot nebula after formation, but were altered, probably under conditions of solid state diffusion (6).

Mineral separates and sections of whole inclusions have been examined by transmission electron microscopy (TEM), in anticipation that their microstructures might provide additional information about the conditions of formation and alteration. Mineral separates were prepared by crushing selected inclusions and by separation with heavy liquids, followed by hand picking. They were then classified and analysed by SEM/EDS, prior to preparation for TEM. Whole inclusions were removed for sectioning with a dental drill. All materials were ion-thinned for TEM work, the separates being mounted individually on single hole Cu-grids having hole diameters of 30-400 μm, as appropriate. TEM was carried out at 100 and 200 kV, HVTEM at 1 MV.

The separates consisted of four main types; (i) spinels (ii) Ti-clino-pyroxenes (iii) melilites (iv) plagioclases. In addition, wollastonite needles taken from a void in a type B inclusion and one 'fluffy' type A melilite assemblage have been studies.

Results: The main observations and conclusions are as follows:

(i) Spinel. This group were genetically the most varied and included Fe-rich and 'normal' type B spinels, and type A spinels with perovskite overgrowths. Differences in their chemistry and luminescence were not reflected by apparent differences in dislocation content or other microstructure. Dislocation densities were low and, to date, technical problems have not enabled the spinel-perovskite interfaces to be studied. The spotty black contrast often seen in spinel-structured minerals (7,8) appears common to all the separates. Its occurrence is a barrier to recognition of possible variations in trapped gas content in spinels, at least at present, even though the effect appears particularly strong in some spinels within gas-rich residues which have also been studied. The nature of the spotty contrast in spinels is being further studied by HRTEM. The current conclusion is that the Allende spinels formed under near equilibrium conditions, yielding euhedral habits and low dislocation contents. Variations in coloration mainly reflect differences in trace element concentration and they are not matched by microstructural differences; internal alteration effects are absent.

(ii) Clinopyroxenes. These separates contained numerous polygonal voids which appear to be either growth features or to have formed along healed cracks. Where dislocations occurred, they were mainly linked to the voids and appeared to be either generated by stresses around them, or pinned by them. Dislocations also occur in the proximity of alteration zones, amongst which grossular and chromite were easily identified. These alteration zones appeared to lie along cracks in the grains.

(iii) Melilites. Although, in general, these are internally featureless, the melilites show the greatest evidence of alteration invading from exterior surfaces. The alteration has caused high dislocation densities to occur.
adjacently, which would have effectively increased local reactivity. The contact boundary between melilite and the alteration is corrugated, suggestive of a highly reactive and mobile agent of attack.

(iv) Plagioclases. These separates have yielded more information than (ii) and (iii). There are dislocations associated with void strings, as in the pyroxenes. Pericline twins also occur but the dislocation density is low. A striking feature is ubiquitous fine scale lenticular exsolution, the presence of which would not be anticipated from bulk electron microprobe analyses. TEM/EDS microanalysis with a \( \approx 10 \) nm probe has shown that where a lower density of coarser precipitates occurs these, at least, are Mg, Ti, Fe-bearing pyroxene, with minor Cr, Ni. An interesting comparison can be drawn with the lunar anorthite from sample 15415,25 reported by Lally et al. (9) to contain fine scale pyroxene exsolution, with heterogeneous nucleation on twin boundaries. The Allende anorthite lacks the deformation features seen in the lunar sample, but is apparently otherwise similar. However, the anorthite in the lunar anorthosite 15415 was thought by James (10) and Lally et al. to result from recrystallization of deformed parent rock.

The types of antiphase domains occurring in plagioclases depend on thermal history and An content (11,12). The presence of particular types can be used to deduce which lattice transformations have occurred, while domain size and domain boundary curvature indicates the rate of cooling. C-type domains, imaged with b and c reflections, occur in plagioclase separates and have smoothly curved boundaries, indicating fairly rapid geological cooling rates.

Preliminary conclusions point to the formation of the minerals examined under conditions close to thermal equilibrium, followed by an alteration stage during which the mineral surfaces were exposed to a highly penetrating mobile, probably gaseous medium. There is evidence that the melilites may have suffered attack from a secondary, lower-melting-point fluid alteration product. The spinels have had an environment which has largely protected them from alteration. None of the minerals show evidence for significant deformation, minor shock, etc., since achieving temperature at which diffusion would obviate dislocation climb and other recovery effects.