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The Nature of Electron Diffraction Patterns of Amphibole Asbestos and Their Use in Identification

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The reported insensitivity of electron diffraction patterns of single amphibole fibers to tilts of ±20° (Skikne *et al.*, 1971; Chisholm, 1973; Seshan, 1976) does not occur when the fibers are thin enough, and Seshan's explanation of it is incorrect. When sufficiently thin fibers are used the patterns can be readily indexed and very clearly differentiate between the different amphibole species.

In view of the importance that is now attributed to air- and water-borne asbestos fibers in connection with public health it is important that identification of the different fiber types should be unambiguous, especially as there is evidence that some types are more carcinogenic than others (Harington, *et al.*, 1971). Seshan (1977) has stated that the three clino-amphibole asbestos minerals (amosite, crocidolite, and tremolite) are difficult to distinguish by selected-area electron diffraction on the following grounds:

(i) The lattice spacings differ by less than 0.5%;
(ii) the diffraction patterns are complicated, and tilting often does not distinguish the different crystal orientations because the patterns are insensitive to tilts of ±20°.

These conclusions, and Seshan's difficulty in indexing his selected-area diffraction patterns, fail to take account of our earlier work (Hutchison *et al.*, 1975). We also showed such an unindexable diffraction pattern, but established that its complexity did not arise from extension of the reciprocal lattice points due to the thinness of the crystal as postulated by Seshan. On the contrary, it is excessively thick, and probably composite, fibers which give complex, unindexable patterns, and when thin fibers are chosen they give simple indexable patterns. Furthermore, these simple patterns change in a systematic way on tilting, and in exactly the manner predicted by considering the appropriate sections of the reciprocal lattice. In certain orientations it is true that there is some degree of insensitivity to small tilts but this is fully explained when the twinning is taken into account.

Although our paper did not deal explicitly with the problem of distinguishing between the different amphibole species from selected-area diffraction patterns, this is quite practicable in the case of amosite and crocidolite by making use of their different values of the monoclinic angle β, and of the fact that the fibers are highly twinned on (100). If a fiber is oriented with the y axis parallel to the electron beam one obtains a composite diffraction pattern consisting of the x^*z^* sections of the reciprocal lattices of both components of the twin, and a very clear distinction

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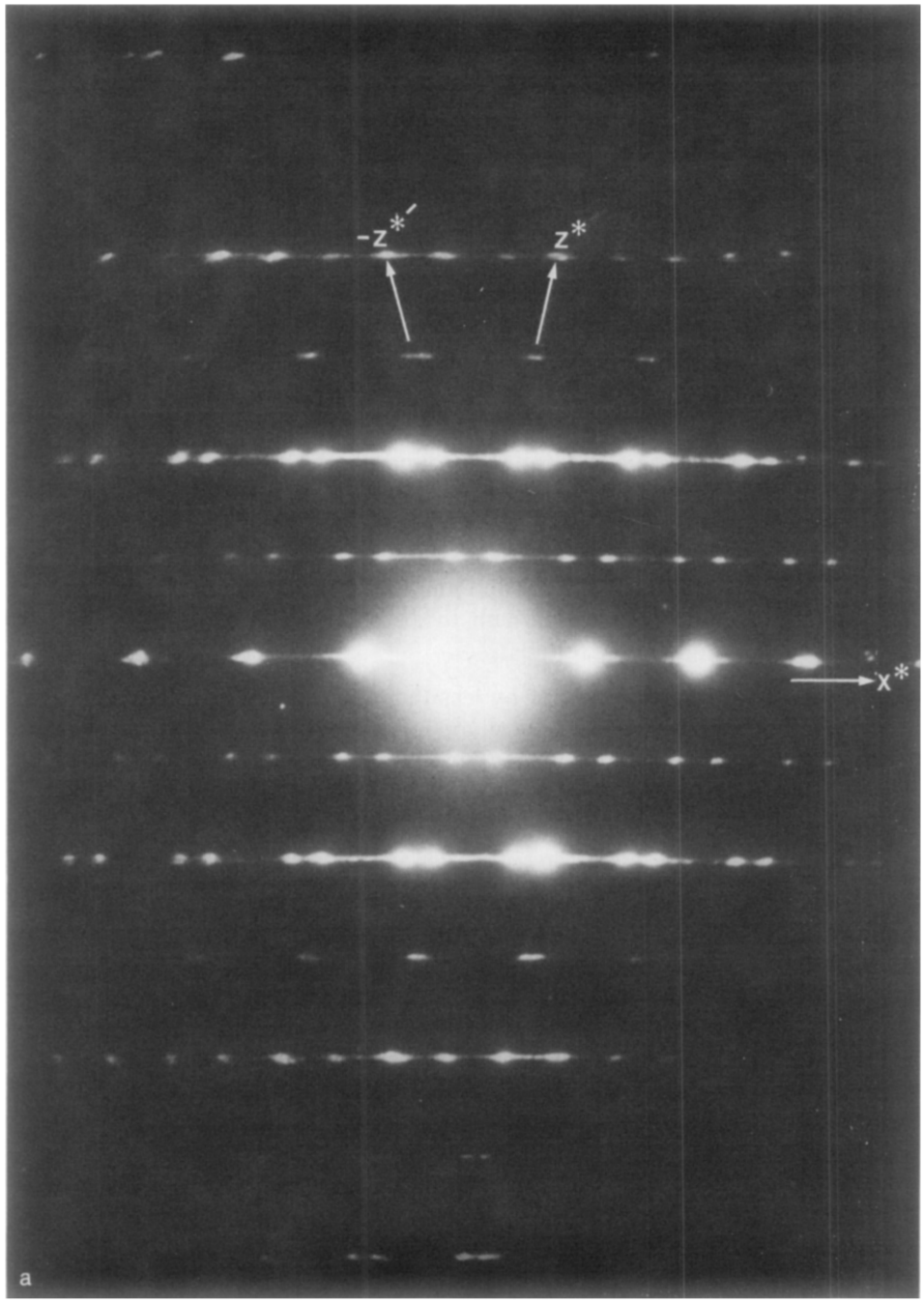

FIG. 1. Electron diffraction patterns with the beam parallel to [010], and containing the *h0l* reflections: (a) amosite, (b) crocidolite. Both patterns show twinning on (100). On the third-layer line the spots form much closer pairs on (a) than on (b). (Reproduced from *Acta Crystallographica*.)

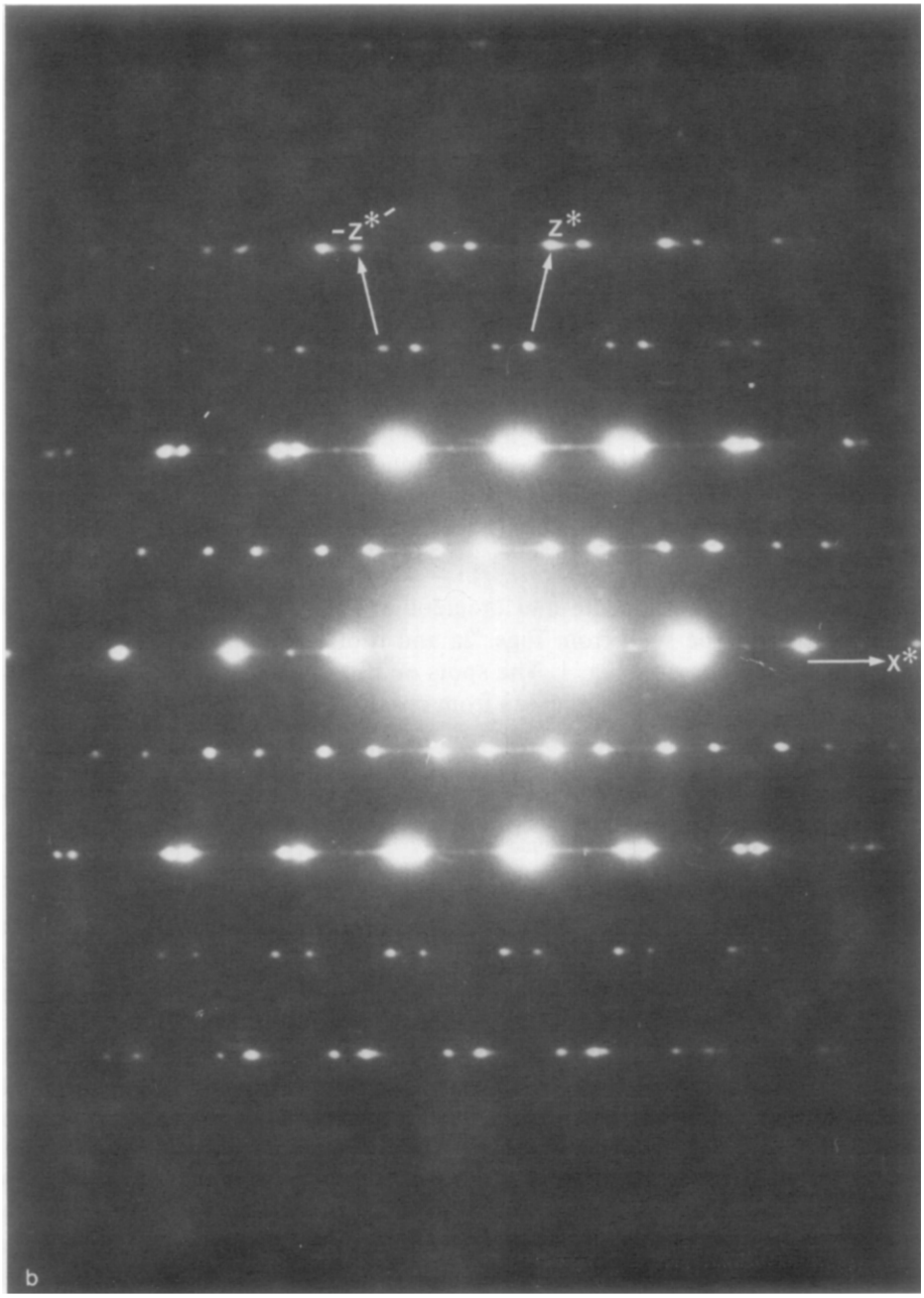

FIG. 1b

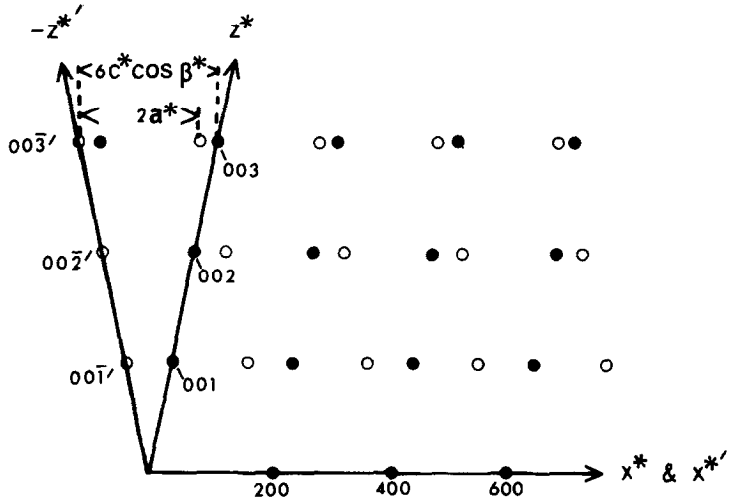

FIG. 2. One quadrant of the composite reciprocal lattice of the two components of a twinned amphibole approximating to amosite in cell parameters. Axes and indices of the second component of the twin (empty circles) are distinguished by primes from those of the first component (filled circles).

can be made between amosite and crocidolite from the third-layer line of this pattern. This may be seen from Figs. 2a and b of our paper (Hutchison *et al.*, 1975), reproduced here as Fig. 1. The spots on this layer line occur as very close pairs in the case of amosite, whereas from crocidolite the corresponding pairs of spots are much more widely separated.

The reason for the sensitivity of this method of distinguishing between the species is illustrated in Fig. 2. The distance between the $h03$ spot of one component of the twin and the $h + 2, 0, \bar{3}$ spot of the other component is given by

$$6c^* \cos \beta^* - 2a^*. \tag{1}$$

For amosite this quantity has a value of about 0.02 Å^{-1}, whereas for crocidolite it is about 0.05 Å^{-1}. Since these values are, respectively, $^1/_{10}$ and $^1/_4$ of the repeat distance in the pattern parallel to x^* (i.e., $2a^*$) they can be clearly distinguished qualitatively even without making any measurements.

In principle the same method would serve also to identify tremolite. In this case the distance between pairs of spots $h03$ and $h + 2, 0, \bar{3}$ from a twinned fiber would be 0.09 Å^{-1} (almost half the repeat distance) and these spots would not be markedly associated in pairs. On the second-layer line, however, $h02$ and $h + 2, 0, \bar{2}$ would be very closely associated into pairs separated by a distance of only 0.01 Å^{-1}. Unfortunately, in our experience it has not been possible to find a tremolite fiber lying in an orientation such that the y axis could be brought parallel to the beam, nor have we found tremolite fibers to be twinned. Thus if one were to succeed in orienting a fiber appropriately it would be necessary to superimpose on the pattern a mirror image of itself in order to obtain a qualitative identification in terms of spot pairing.

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