of which are lower than the principal indices of normal quartz.

Using samples from the Ries basin containing planar elements, we measured, on individual quartz grains, both refractive indices and density. We found refractive indices between 1.474 and 1.541, and corresponding densities between 2.263 and 2.648. Data for the shocked quartz of the Ries (Fig. 9) covers an appreciable part of the refractive index and density range between normal quartz ($\epsilon=1.544$; $\omega=1.553$; $d=2.65$) and fused quartz glass ($n=1.458$; $d=2.20$).

It appears that the refractive index and/or density of shocked quartz may be used as a

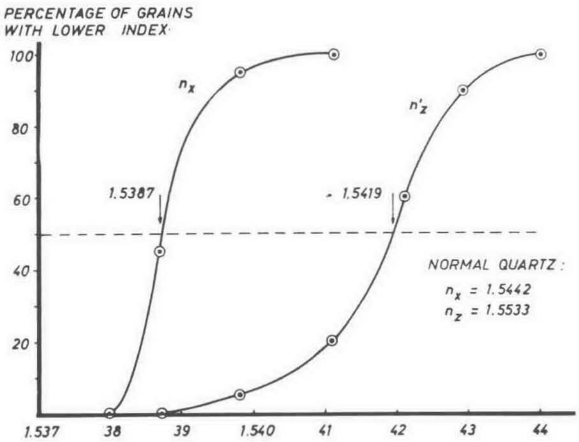

Fig. 5. Frequency distribution of refractive indices of quartz grains containing planar elements. Granite, West Clearwater Lake, Quebec.

rough indicator of shock wave intensity. In the Ries samples we found the lowest refractive indices and densities in rocks which show the highest degree of shock deformation of associated plagioclase (isotropization).

THE NATURE OF PLANAR ELEMENTS IN SHOCKED QUARTZ

The nature of planar elements in quartz is still under investigation, using optical methods, electron microscopy, and x-ray techniques. We can give here only some preliminary results and conclusions.

Two main types of planar elements can be distinguished:

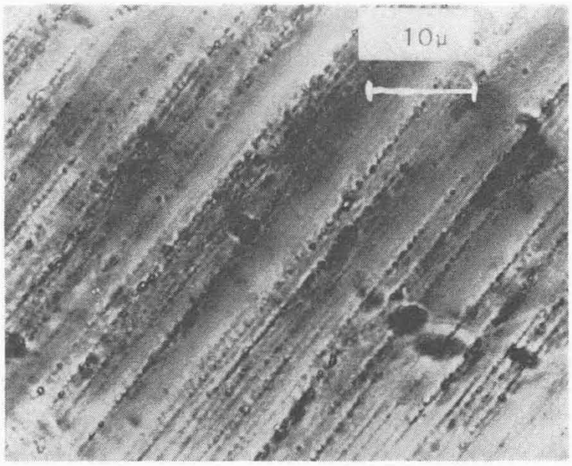

Fig. 6. Decorated planar elements in quartz. Granite inclusion, Zipplingen, Ries.

Decorated planar elements. These planar elements can be resolved under high magnification (oil immersion lens) into planar arrangements of very small inclusions, which appear to be either empty voids or cavities filled with gas or a liquid. The planar elements in quartz from the granite of Zipplingen (Table 2) belong to this type (Fig. 6).

Non-decorated planar elements. Planar elements of this type, if viewed in a direction parallel to

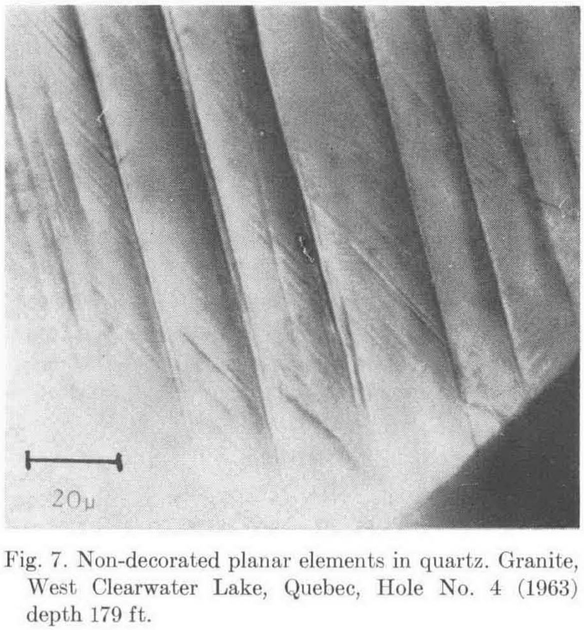

Fig. 7. Non-decorated planar elements in quartz. Granite, West Clearwater Lake, Quebec, Hole No. 4 (1963) depth 179 ft.

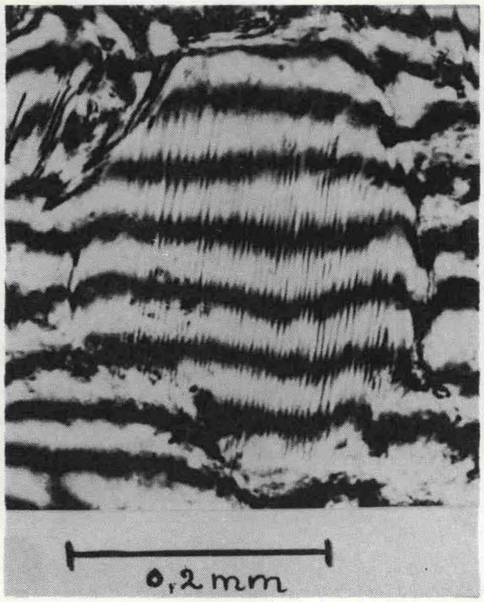

Fig. 8. Non-decorated planar elements in quartz. Two-ray-interference microscope (Leitz).

their planes, appear as unresolvable lines, even at the highest magnification. In some cases, they appear as very thin lamellae of lower refractive index and birefringence than the host quartz. The quartz from Clearwater Lake, described in this paper, contains planar elements of this type (Fig. 7).

Figure 8 shows a quartz grain with non-decorated planar elements as it appears under a Leitz two-ray interference microscope (green Hg line). The zig-zag course of the dark streaks is probably caused by discontinuous changes of the refractive index.

Separation along planar elements, observed in the Clearwater Lake sample and also in some quartz from the Ries basin, seems to occur only with the non-decorated type.

Quartz with decorated planar elements differs in density and refractive index from quartz with non-decorated planar elements. In samples from the Ries basin, we found the following ranges:

	$\tilde{n}$	d
Quartz with decorated planar elements	1.546–1.529	2.648–2.577
Quartz with non-decorated planar elements	1.480–1.478	2.280–2.263

There seems to exist no distinct relation between crystallographic orientation and the type of planar element. Planar elements of all crystallographic orientations occur as both the non-decorated and the decorated form. The non-decorated elements are generally more narrowly spaced than are the decorated planes.

Our observations in the Ries basin seem to indicate that decorated planar elements are produced by shock waves of lower peak pressure than are the non-decorated elements.[2]

ORIGIN OF PLANAR ELEMENTS

Regarding the origin of planar elements in quartz, the following hypothesis is suggested. Shock waves of at least 100 kb peak pressure can cause plastic deformation of quartz by forcing dislocation lines, which at lower stresses are locked and immobile, producing non-conservative movements along lattice planes. These movements produce cavities or holes of macroscopic or atomic dimensions, as well as narrow layers along the gliding planes in which the crystal lattice is more or less destroyed. The reduced densities and refractive indices indicate that shocked quartz is in a kind of "spongy" state.

Quartz with planar elements represents transitional stages of order between normal α-quartz and the x-ray-amorphous SiO_2-glasses which are formed, without melting, at still higher shock

[2] *Editor's note.* An alternative explanation, proposed by other investigators, is that decorated planar elements are produced from originally non-decorated planar elements during post-shock annealing and recrystallization of the quartz, during which the planes may act as preferential growth sites for small liquid inclusions, (see e.g., Carter, *this vol.*, p. 453; French, *this vol.*, p. 383; Robertson *et al.*, *this vol.*, p. 433). Such alteration might occur either immediately after impact, during cooling of the ejecta blanket, or much later, during unrelated metamorphism.

In this connection, it is worth noting that planar elements from older structures of Precambrian or Early Paleozoic age are dominantly of the decorated type. By contrast, the planar elements formed in quartz by shock waves generated experimentally in nuclear or chemical explosions have never been observed to be of the decorated type. (see, e.g., Short, *this vol.*, p. 185). These observations also suggest that the decoration process itself is not directly related to the shock itself, but must depend on the post-event environment.