with undulatory extinction nor extinction bands. They occur parallel to planes of low shear stress, usually normal but occasionally parallel to the direction of maximum compressive stress. According to CARTER, CHRISTIE and GRIGGS (1964) they are open extension fractures produced during unloading of the samples.

*(3) Undulatory extinction:* A continuous gradation between deformation bands and undulatory extinction exists, both involving reorientation of the quartz structure by bending. If bending has taken place with a radius of curvature comparable with or larger than the half-width of the reoriented zone, the feature is designated undulatory extinction. Undulatory extinction in the experimentally deformed quartz samples most commonly occurs in zones subparallel to c, as it is known from undulatory extinction in naturally deformed quartz. Therefore, undulatory extinction is connected with bending of basal planes. The maximum observed difference in the orientation of adjacent c-axes is 12°, a value which corresponds to undulatory extinction known from naturally deformed quartz.

*(4) Deformation bands*: are generally less than 0.05 mm wide. They may occur as single individuals, however parallel sets are more common. Few grains may contain two sets of bands. The angles between c-axes of band and host grain vary between 3 to 25°, the average being about 10°. Generally the poles of band boundaries define two maxima at about 45° to the direction of maximum compressive stress, indicating that the bands formed in planes of high shear stress. The angles between poles of the band boundaries and the c-axes in the host grain may vary considerably, but most frequent the bands are parallel or subparallel to the c-axis: two thirds of the bands are inclined less than 20°, one half less than 10° to the c-axis. For bands subparallel to the c-axis the pole of the band, the c-axis in the host grain and the c-axis in the band commonly lie in a plane parallel to the direction of maximum compressive stress. The direction of rotation of the c-axis from the host to the band is most commonly towards this direction. Deformation lamellae that are approximately parallel to the base are present in all bands subparallel to the c-axis.

Deformation bands are interpreted by CHRISTIE, GRIGGS and CARTER (1964) to be kink bands originating by slip on the basal plane along the a-axes. Undulatory extinction in zones subparallel to the c-axis is similar to the kink bands and probably results from bending and gliding along the basal slip planes.

### *4.3. Planar Structures Produced in Experiments under Dynamic High Pressure Conditions*

Within the last years several investigators successfully reproduced planar deformation structures by shock loading quartz bearing rocks, polycrystalline quartz or single quartz crystals (MILTON et al., 1961; SHORT, 1966a, b, c; FRYER, 1966; MÜLLER and HORNEMANN, 1967). SHORT (1966a) observed planar structures parallel to $\{10\bar{1}3\}$ in quartz of a granodiorite from an underground nuclear explosion. A range of 50 to 75 kbar was estimated as the lower limit of shock wave peak pressure necessary for the formation of these planar deformation structures. Using explosives SHORT (1966c) obtained planar structures parallel to $\{10\bar{1}3\}$ at estimated peak pressures between 75 and 175 kbar and between 300 and 400 kbar.

Recently controlled shock wave experiments with exactly known pressures in the range of 50 to 600 kbar have been performed by MÜLLER and DEFOURNEAUX (1968), MÜLLER and HORNEMANN (1968) and HÖRZ (1968). These investigations resulted in the following information about shock induced deformation features in quartz:

*~50 — ~100 kbar*: characteristic for the lower pressure range are planar fractures parallel to $\{0001\}$, $\{10\bar{1}1\}$ and $\{10\bar{1}0\}$. They form in planes of high resolved shear stress: in experiments with single crystals, shock waves propagating perpendicular to $\{0001\}$ and $\{10\bar{1}0\}$ generate primarily planar fractures parallel to $\{10\bar{1}1\}$ whereas impacts parallel to $\{10\bar{1}1\}$ produce fractures parallel to $\{0001\}$ and $\{10\bar{1}0\}$. These fractures appear under the microscope as comparatively broad features, 2—10 μ thick and mostly 20 μ or more apart from each other.

*~100 — ~380 kbar*: besides the before mentioned structures, planar elements of the non-decorated type are formed which appear as planar optical discontinuities arranged in closely spaced (2—5 μ apart) multiple sets of crystallographic orientation. The shocked grains have a tendency to break along these elements. They are not resolved, even with highest magnification. HÖRZ (1968) observed very few (~ 1%) features of the type named "deformation lamellae" by CHRISTIE, GRIGGS and CARTER (1964). In general, no asymmetry was found in bright field and in phase contrast illumination. Some planar elements appear to be lamellae of a finite width of about 1—2 μ. The first planar elements to appear at pressures above about 120 kbar are parallel to $\{10\bar{1}3\}$. At pressures between 160 and 200 kbar planar elements parallel to $\{10\bar{1}2\}$ appear. They become more frequent than those parallel to $\{10\bar{1}3\}$ at pressures exceeding about 280 kbar. The spacing of $\{10\bar{1}2\}$ elements is closer than that of $\{10\bar{1}3\}$ elements. Less prominent are planar elements parallel to the following crystallographic planes: $\{0001\}$, $\{10\bar{1}1\}$, $\{11\bar{2}2\}$, $\{21\bar{3}1\}$, $\{51\bar{6}1\}$, $\{11\bar{2}1\}$ (HÖRZ), $\{10\bar{1}0\}$ (HÖRZ), $\{22\bar{4}1\}$ (MÜLLER and DEFOURNEAUX).

At pressures of 260—280 kbar MÜLLER and DEFOURNEAUX (1968) observed in single crystals of quartz the formation of deformation bands with diffuse boundaries inclined at 45—60° against the c-axis of the host. The angle between the c-axes of band and host was about 10°. The bands contain planar structures perpendicular and parallel to the band boundaries and are sometimes markedly bent.

Optical properties and density of the deformed quartz remain nearly unchanged below shock wave pressures of about 200 kbar. At higher pressures refractive indices, birefringence and density are markedly lowered, the decrease becoming most prominent at pressures of 280—300 kbar. In this range mean refractive index declines below 1.50, birefringence below 0.004 and density to 2.27 g/cm³.

At pressures of about 300kbar the first small patches of isotropic diaplectic quartz glass start to form. Larger amounts of diaplectic glass ($n = 1.460$) have been observed in experiments at about 380 kbar.

Peak pressures of 500 to 600 kbar produced normal fused quartz glass with $n =$ 1.459 (MÜLLER and HORNEMANN, 1968).

In experiments with untwinned single crystals MÜLLER and HORNEMANN (1968) have found that shock waves propagating in the directions [11.0], [21.0] and [10.0] produced planar structures exclusively parallel to $\{10\bar{1}3\}$ and $\{01\bar{1}2\}$, but not parallel to $\{01\bar{1}3\}$ and $\{10\bar{1}2\}$.