the shock wave which is more or less horizontal at the target surface, the affected material is ejected into divergent, oblique ballistic trajectories. The ejection velocity decreases strongly as the shock wave proceeds into the target. Thereby the crater grows as long as the energy of the shock wave is sufficient to accelerate the surface material. At this point where the crater rim is formed, the target rocks are broken into large blocks which are only slightly displaced or tangentially shifted. The continuous ejection of rocks during crater growth produces a continuous ejecta blanket in which the pre-impact stratigraphy is inversed and the proportion of rocks from deeper levels of the crater decreases with radial distance. The strongly shock compressed central and deepest part of the target near to the vaporized projectile is affected by a more vertical or even convergent upward motion due to the expansion of the compressed material. This motion is directed radially toward the center of the crater. Obviously the interaction of this motion of liquid and solid rock material with the expanding rock vapor leads to the ejection of a "suspended load" of molten, highly shocked, and shock comminuted material which forms the suevite breccia. It is deposited as a discontinuous, hot thin layer on top of the continuous bulk ejecta blanket called Bunte Breccia. A short period of time elapses between the deposition of both types of ejecta units. The different excavation mechanics for both units explain their marked compositional and shock metamorphic differences and the sharp discontinuity between them (ENGELHARDT et al., 1969; HÜTTNER, 1969; SCHNEIDER, 1971).

Progressive shock metamorphism of rocks

As discussed above the peak pressure and temperature of the propagating shock wave are steeply decreasing with radial distance from the point of impact. This pressure attenuation is mainly caused by the hemispherical geometry of the shock wave propagation which transfers the internal energy of the compressed matter into a steadily increasing volume of rock material. The radial decrease of pressure is approximately proportional $r^{-3/2}$ ($r =$ radial distance from the point of impact; GAULT & HEITOWIT, 1963). According to this pressure decay hemispherical zones of constant pressure and temperature decreasing with radial distance exist during the passage of the shock wave. The shock zoning is shown schematically in Fig. 4 for the dimensions of the Ries event. Within these zones of progressive shock metamorphism which predominantly affect the crystalline basement rocks, the most abundant rock-forming minerals such as quartz, feldspar, hornblende, pyroxene and biotite undergo very characteristic shock effects which are irreversible upon pressure release. Based on laboratory shock experiments with these minerals and their parent rocks it was possible to correlate the various "post-shock" effects with a pressure-temperature scale so that the observed deformation and transformation phenomena can now be used as natural pressure and temperature indicators (Fig. 5, for details see review in STÖFFLER, 1972, 1974). Quartz and feldspar show the greatest variety of different shock effects in the 100 to 500 kbar range and hence are most useful as petrographic pressure indicators.

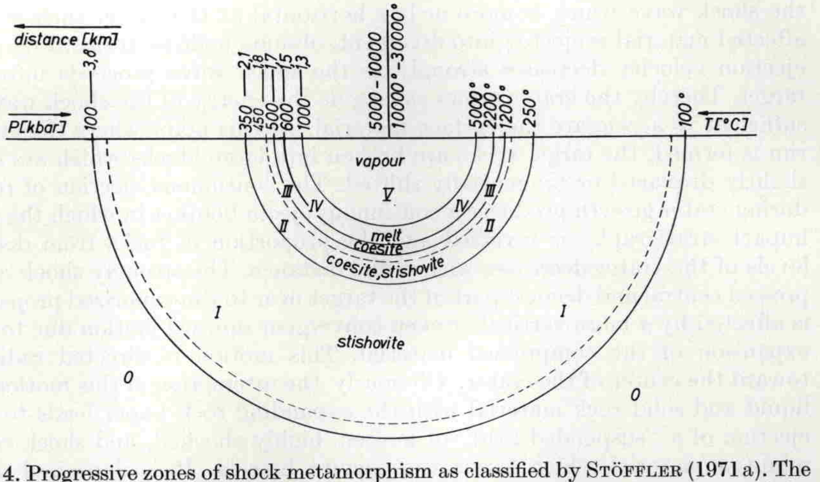

Fig. 4. Progressive zones of shock metamorphism as classified by Stöffler (1971 a). The shock zones present in the bedrocks of an impact crater during the passage of the shock wave may deviate from the hemispherical model, which is schematically adapted to the dimensional parameters of the Ries event as given by David (1969). From Stöffler (1971 b).

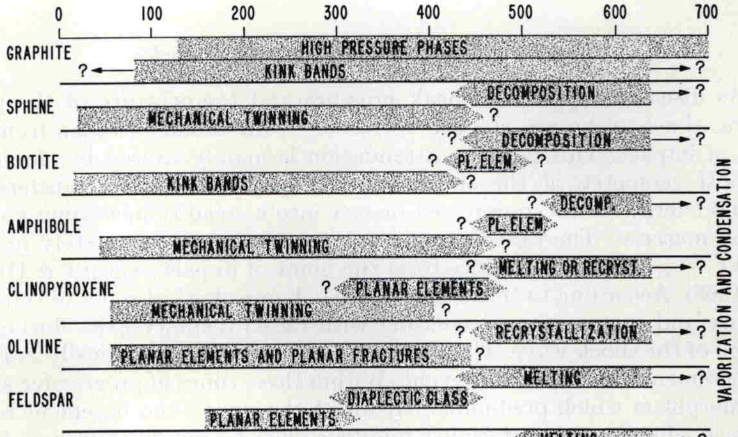

Fig. 5. Schematic representation of the pressure ranges in which various types of residual shock effects are produced in the most frequent rock-forming minerals. Question marks indicate uncertain pressure limits. The diagram is based on experimental data and natural observations referenced in Stöffler (1972).