STAGES OF SHOCK METAMORPHISM IN CRYSTALLINE ROCKS OF THE RIES BASIN, GERMANY

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The suevite of the Ries basin, Germany, is a breccia which occurs in small outcrops around the basin and also underlies the Tertiary lake sediments within the central depression. It contains few sedimentary rock fragments and many fragments of the crystalline basement. The latter show a continuous gradation of metamorphism by shock waves. Four main stages of shock metamorphism have been established. They are defined by critical alterations of rock-forming minerals (mainly quartz and feldspar), by the formation of high-pressure phases, and by shock-induced textures of the rock.

INTRODUCTION

Around the central basin, the fall-out breccia of the Ries impact event, called suevite, occurs in several outcrops which are the remnants of a formerly more extensive blanket. Suevite was also found in two drill holes below the Tertiary lake sediments in the central depression. The suevite contains, in a fine-grained matrix, fragments of all rocks involved in the impact event, in different stages of alteration by pressure and heat.

The amount of sedimentary rock fragments (limestone, shale, clay, and some sandstone, which form, in the Ries area, a sequence about 1500 feet thick) is variable, but it is always less than 10 percent of all rock fragments. We found that clay, shales, and sandstones are unaltered, and that limestones are only moderately altered by heat (Baranyi, 1966). The clay content of Upper Jurassic limestone was changed from a kaolinite-illite mixture to a dioctahedral chlorite with some amorphous material. Some limestone fragments have an outer rim (a few millimeters thick), which is different in color from the interior and which consists of fine-grained calcite. This rim was apparently produced by calcination of the limestone and later carbonation of the lime. We conclude from these observations that the sedimentary fragments in the suevite endured, for a short time (some minutes), temperatures between 400° and 600°C.

By contrast, fragments of the crystalline basement rocks occur in all stages of alteration ranging from fresh rock to molten material (glasses). The rock types include (1) granites, granodiorites and diorites, containing biotite and amphibole; (2) diorites and gabbros; (3) gneisses of the amphibolite facies with biotite and amphibole, some of them with garnet and sillimanite; and (4) plagioclase amphibolites. It was in these fragments of altered crystalline rocks that the high-pressure phases coesite and stishovite were found (Shoemaker and Chao, 1961; Chao and Littler, 1963), establishing the first mineralogical evidence for the impact origin of the Ries basin.

By means of microscopic studies of the basement rock fragments, a series of stages of increasing alteration can be established (Stöffler, 1965, 1966; Chao, 1967). We found that, in general, each crystalline rock fragment in the breccia can be classified into one of four main stages (Table 1) which are characterized by certain critical alterations of the rock-forming minerals (quartz, feldspar, biotite, and amphibole).

TABLE 1

A simplified, preliminary diagram, showing stages of progressive shock metamorphism of granitic crystalline rocks in the Ries basin, Germany. The stages are separated on the basis of distinctive petrographic effects in the rocks. The pressure and temperature values are estimated from experimental Hugoniot data for quartz, feldspar, and granite (Wackerle, 1962; Milton and DeCarli, 1963; David, 1966; Müller, 1967; Ahrens and Rosenberg, this vol., p. 59); their application to the petrographic data is only approximate.

Pressure (kbars)	Stage of shock metamorphism	Characteristic deformations and phase transitions	Residual temp. (°C)
ca. 100			ca. 100
	Stage I	Fracturing Plastic deformation (diaplectic quartz and feldspar)	
250–300			200–300
	Stage II	Phase transitions (diaplectic glasses of quartz and feldspar, high-pressure phases of SiO_2)	
500–550			1200–1500
	Stage III	Selective melting (normal glasses of quartz and feldspar, high-pressure phases of SiO_2)	
600–650			2000–3000
	Stage IV	Melting of all main rock forming minerals (inhomogeneous rock melts, Fladen)	
ca. 1000			ca. 5000
		Volatilization	

Such features may also be found in other impact structures. As in normal metamorphism, each shock stage corresponds to a particular range of physical conditions. However, in contrast to normal metamorphism, the assemblage of phases constituting a particular shock stage does not represent an equilibrium system, owing to the short duration of the impact.

The range of shock pressures and temperatures for these different stages of shock metamorphism cannot yet be given exactly. Shock wave experiments on quartz (Wackerle, 1962; Short, 1966; Müller, 1967) and plagioclase (Milton and DeCarli, 1963; Ahrens and Rosenberg, this vol., p. 59; Müller, 1967) establish pressure and temperature values for the most typical shock deformations and phase transitions in these minerals. The pressure data in Table 1 are based on these values, whereas the temperature data shown with them refer to the residual temperature in quartz found after pressure release, as calculated by Wackerle (1962). Table 1 gives only preliminary and approximate pressure and temperature values for natural shock metamorphism; these must be fixed more precisely by further experimental investigations.

Below, we describe the four main shock stages (see also Stöffler, 1965, 1966).

STAGE I

This stage is characterized by strong fracturing of minerals, and most typically by special plastic deformation phenomena in quartz, feldspar, and biotite, which are apparently generated in the pressure range from about 100 to 300 kilobars.

Quartz contains unique planar elements and exhibits lowered density and refractive index values, as described elsewhere in this symposium (Engelhardt *et al.*, *this vol.*, p. 475, Fig. 9).

Plagioclase displays such plastic deformations as bending of crystals, deformation bands, and multiple sets of planar features. The latter appear under the microscope as lamellae of lowered refractive index, in which birefringence is reduced or completely absent. These lamellae often pass gradually into completely isotropic areas of the same crystal or into areas with normal birefringence (Figs. 1 and 2).