Reports of the Academy of Sciences of the USSR

A. M. PODURETS, R. F. TRUNIN

1970

SovietRxiv

Abstract

Full Text

Reports of the Academy of Sciences of the USSR
1970. Volume 195, No. 4

PHYSICS

A. M. PODURETS, R. F. TRUNIN

ON A PECULIARITY OF THE SHOCK COMPRESSIBILITY OF QUARTZITE

(Presented by Academician Yu. B. Khariton on 27 IV 1970)

Among the many interesting phenomena accompanying the propagation of shock waves in quartzite, the following attracts attention. When a shock wave passes through a specimen, over a certain rather broad interval of pressures at the front, from $p = 120$ kbar to $p = 330$ kbar, the wave velocity is constant and equal to 5.75 km/sec. Outside this pressure interval the shock-wave velocity D is a monotonic function of the pressure p. This phenomenon was first discovered experimentally by Wackerle (1) for single-crystal quartz, which differs only slightly in its properties from the polycrystalline quartzite considered here. In itself, the constancy of the shock-wave velocity is not surprising. An analogous picture occurs in those cases where, during passage of a shock wave, a substance undergoes phase transformations. If the uncompressed substance is in the form of one crystalline phase and, at high pressures at the shock-wave front, transforms into another, denser one, then in the pressure region where both phases coexist behind the front, the shock wave, losing stability, splits into two waves traveling one after the other, the first wave propagating with constant velocity and carrying a constant pressure. This typical situation occurs when both phases are in thermodynamic equilibrium with one another. In contrast to this, Wackerle found that in the case considered by us there is no such splitting, and that when the pressure in the shock wave is varied its velocity is close to constant. We have established the same thing for quartzite as well.

After the discovery by Stishov and Popova of a new, dense phase ($\rho_0 = 4.28$ g/cm^3) of silica—stishovite—it became clear (2) that the cause of the anomalous behavior of the shock adiabat of quartzite lies in the possibility of the phase transformation quartz—stishovite*, while the fact that no splitting into two waves occurs was interpreted as the absence of complete equilibrium between the two phases of silica.

Thus, after the first studies, which indicated the cause of the anomaly, there remained unresolved one question which, in our view, is important: the question of the constancy of the shock-wave velocity. In other words, if the light and dense

Figure 1

Figure 1: Figure 1

phases, quartz and stishovite, are not in thermodynamic equilibrium, where their concentrations would be established by the condition of equality of the Gibbs potentials, then what is the mechanism for selecting that single value of the concentration ratio at each pressure which is capable of ensuring $D =$ const? Below we shall show that such a mechanism exists; namely, under certain natural assumptions about the kinetics of the phase transformation, confirmed experimentally, the cause ensuring the constancy of the wave velocity is its stability.

Let us now turn to the question of the rate of phase transformations in silica. It is known that in static experiments the phase transformations quartz—coesite (^{3}) and coesite—stishovite (^{4}) proceed extremely slowly—

slowly. The characteristic times turn out to be on the order of tens of minutes. In other words, when the lattice is deformed uniformly and smoothly, the probability of forming a nucleus of a new phase is very small. The fact that in our case phase transformations nevertheless do occur points to the exceptional role of the shock-wave front as a generator of a new crystalline phase. The reason for this, in our view, is that the wave front is a source of a large number of dislocations during the initial uniaxial deformation, and it is known that in the presence of dislocations the growth rate of crystals increases by many orders of magnitude. Thus, we arrive at the following idea about the kinetics of the phase transformation: the transition from the light phase to the heavy one occurs at the shock-wave front, while behind the front, in the smooth wave, the phase composition remains practically fixed. From this assumption, as a consequence, the following follows: if a strong shock wave is split into several successively compressing waves of smaller amplitude (the limiting case being a smooth compression wave), then the content of the heavy phase decreases. As will be seen below, for us the decisive fact is that even under twofold compression the content of the heavy phase is less than under single compression at the same pressures. It is precisely this fact that we confirmed experimentally (see below).

Fig. 1. *a* —first equilibrium shock adiabat, *b* —first experimental shock adiabat, *c* —second experimental shock adiabat

Let us now turn to clarifying the specific features of the mechanism of wave stability, which ensures the linearity of the shock adiabat in the plane p —pressure, V —specific volume (or $D =$ const).

Figure 1 shows the shock adiabat of quartzite in the case of complete thermodynamic equilibrium and the shock adiabat determined experimentally. If the

* The transformation of quartz into coesite, an intermediate phase in density ($\rho_0 = 3.01$ g/cm^3), apparently does not occur in the experiments described.

wave front corresponds to a point on the shock adiabat lying above B, then the wave, as usual, is stable, and the material behind the front is, in the main, the equilibrium dense phase—stishovite. Now suppose that the pressure at the front drops; the representative point shifts to the position B_1 and falls below the wave ray OAB. Such a wave is unstable and breaks up into two. The material is compressed to the same pressures twice, and in this process the content of the heavy phase sharply decreases, while the second adiabat, beginning at point A, takes a position above the wave ray OAB.

The figure shows the experimentally obtained second adiabat. (The fact that the second adiabat lies above the first is also evidence that there is no complete thermodynamic equilibrium.) The velocity of the second wave AB_2 turns out to be greater than the velocity of the first OA; the waves overtake each other

merge with each other again into one. The content of the heavy phase increases again, and the representing point tends to move to the left. The only stable equilibrium position is points lying on the wave ray itself; therefore the concentration of the heavy phase on the first shock adiabat is automatically established as smaller than the maximum possible, such that the shock adiabat coincides with the straight line AB.

Let us note that the mechanism of stability described here has a large rigidity: small deviations from the equilibrium position give rise to a finite restoring force, for in passing through the wave ray a single compression changes discontinuously into a twofold one; there are no intermediate modes of transition—either one wave or two.

As was already said, two successive waves AO and AB_2 traveling in the same direction cannot separate; therefore, experimentally, the second adiabat was determined by us by the method of reflection of the first shock wave OA from various rigid barriers; in this case the motion of the successive waves proved to be opposite.

In conclusion, let us draw attention to the fact that the shock adiabats of many rocks are distinguished by the indicated peculiarity. It is possible that the general cause is the content of quartz in their composition.

Received
16 III 1970

REFERENCES

1. J. Wackerle, J. Appl. Phys., **33**, 922 (1962).
2. R. McQueen, F. Fritz, S. Marsh, J. Geophys. Res., **68**, 2319 (1963).
3. F. Boyd, J. England, J. Geophys. Res., **65**, 749 (1960).
4. S. Akimoto, Y. Syono, Techn. Rep. of ISSP, Ser. A, No. 327 (1968).