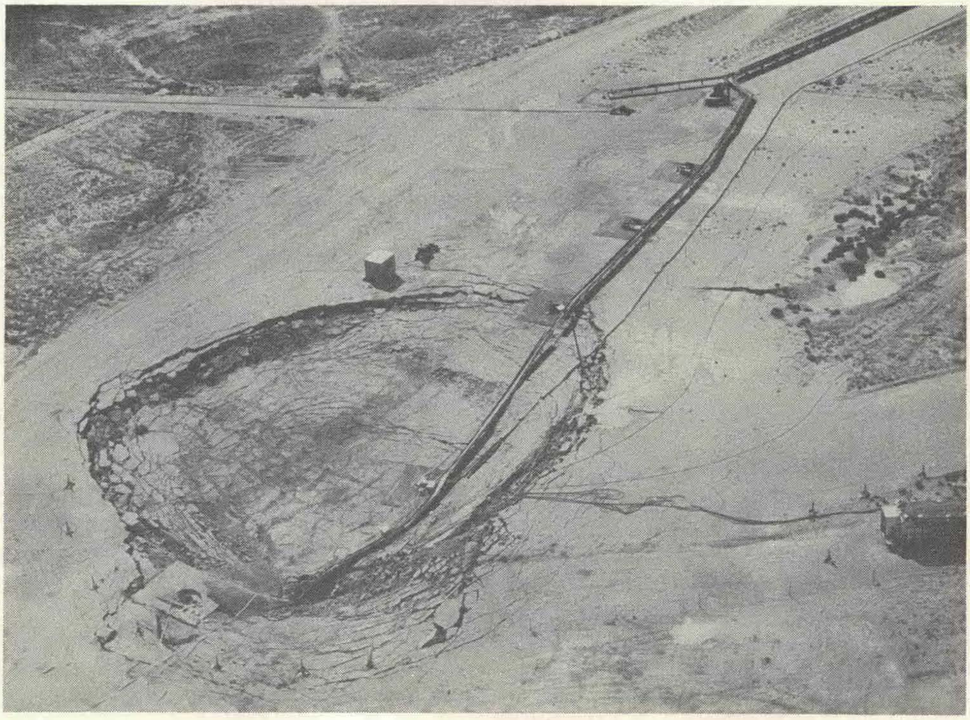

Fig. 9. Subsidence crater formed when the cavity collapsed. (View is to the southwest.) The square concrete block (left center of photo), now partly slumped into the crater, is the access-shaft pad. The shot point was directly below the north edge of the pad. The cable tray stretches from the pad along a path nine meters north of the tunnel. The crown block in the upper right corner lies directly above the end of the 122-meter tunnel. Along the cable tray are cable holes to the four instrument alcoves.

servation equations of continuum dynamics with respect to time, are based on the *von Neumann and Richtmyer* [1950] technique for the calculation of hydrodynamic shocks. The codes are discussed briefly below.

The Pufl conservation equations, which are shown in appendix A, are cast in 'pipe' geometry, where radial gradients are assumed to be negligible. Pufl zones are allowed to have mass sources or sinks; hence they are said to be 'almost Lagrangian.' To simulate the ablation process, auxiliary equations are used to calculate a heat sink and a mass source. In addition, an attempt is made to describe the radial turbulent diffusion of mass that enters from the walls of the pipe.

The Tensor equations are cast in the two-dimensional, cylindrically symmetric Lagrangian form. The equations consider the complete two-dimensional stress tensor composed of isotropic and deviatoric parts. Strain rates are calculated from the velocities, and stresses are obtained from the strains. General equations of state and other material properties such as the bulk and rigidity moduli may be used. Such effects as plastic yielding and fracture can also be considered. Tensor is used to simulate the alluvium off the axis of symmetry that surrounds the source region and the tunnel.

Tensor and Pufl are linked along their common boundary on each staggered time cycle in the CDC 6600 computer. They are run as two independent codes, with each supplying the other with the current boundary conditions. Pufl is entered and calculates pressures that it supplies to Tensor along the common boundary. Tensor is then entered and uses the pressures to calculate new radii, which are used by Pufl. Some details regarding this link are discussed by *Crowley and Barr* [1971].

Initial Conditions

The initial conditions used in Tensor-Pufl for the numerical simulation of Marvel are shown in Figure 10. Each Pufl zone extends between the axis of the tunnel and the inner wall of the tunnel. Initially, the Pufl zones are all 0.5 meter in radius. Axially, many Pufl zones are placed in each of the four material regions. Region 1 consists of alluvium and extends from −180 meters (minus infinity) to −0.75 meter. Region 2 is the source region that represents the homogeneous energy-source canister and consists of high-energy gas between −0.75 and +0.75 meter. Region 3 is the atmospheric air in the tunnel that extends from the end of the canister (zero point) to the end of the tunnel, +122 meters. Region 4 is again alluvium, from +122 to +300 meters (plus infinity). Tensor extends from −180 to +300 meters in the axial direction and from 0.5 to 180 meters (the surface) in the radial direction. All the two-dimensional array of cylindrical Tensor zones is alluvium.

The same material description for alluvium, which is based on an initial, average, in situ density (ρ_0) of approximately 1.7 g/cm^3, is used in Pufl and Tensor. During the early preshot operations, sound speeds were obtained in the alluvium between approximately 1000 and 1200 m/sec. Samples of the alluvium indicated a water content of approximately 5 wt %.

The pressure versus μ ($\mu = (\rho/\rho_0) - 1 =$ compression $- 1$) curves up to 40 kb shown in Figure 11*a* are provided by D. R. Stephens (private communication, 1969). Stephens obtained the curves by estimates based on his previously acquired data for alluvium [*Stephens et al.*, 1970].

Shock Hugoniot data for various initial density alluviums exist in the literature. We considered the P–μ data of *McQueen and Marsh* [1961], *Bass* [1966], *Shipman et al.* [1969], *Petersen et al.* [1969], and *Bass et al.* [1963]. When the compressions given in these reports are all adjusted for an initial density of 1.75 g/cm^3, the array of data shown in Figure 11*a* results. It is not clear whether this type of initial density adjustment is the best way to handle the data from different densities. However, it was felt that no one set of the data at one density was sufficient. Between 40 kb and 1 mb, we chose the smooth P–μ curve through the data points shown in Figure 11*a*.

To obtain higher pressure values, the P–μ curve was extrapolated. This extrapolation was

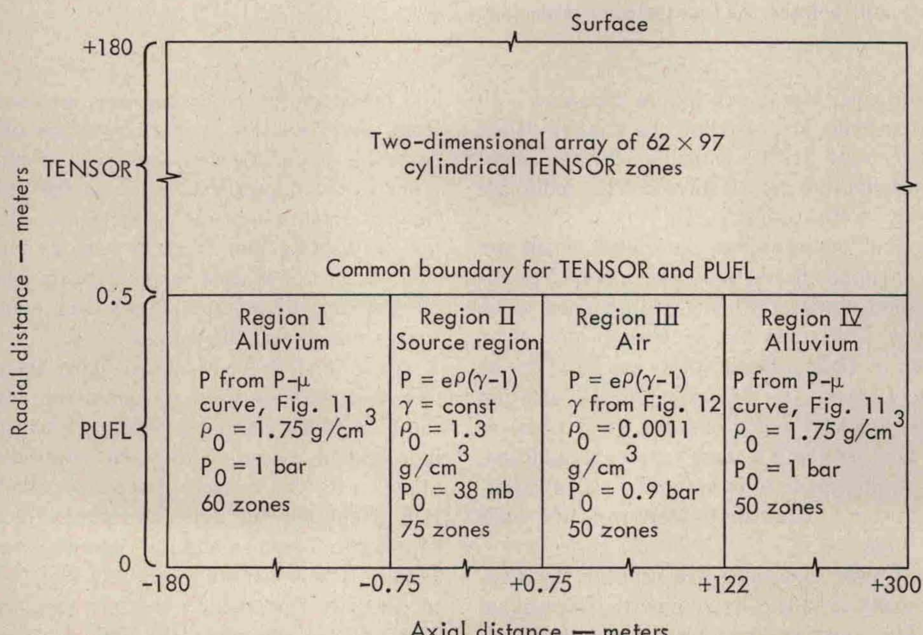

Fig. 10. Initial conditions used in Tensor-Pufl code for the numerical simulation of Marvel.