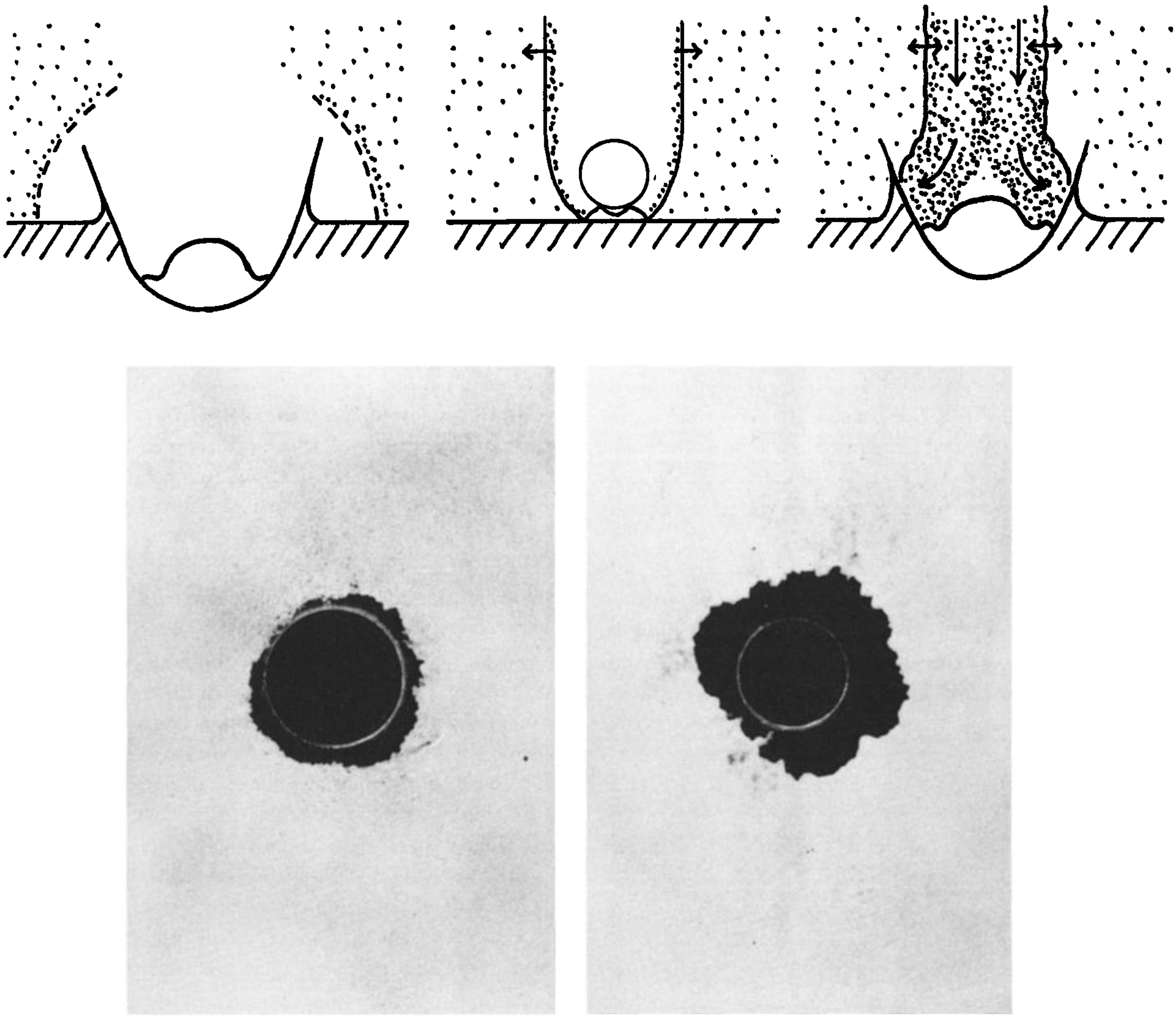

Fig. 12. (*a*) Three possible interactions between impactor and atmosphere that could modify cratering efficiency. The sketch at left depicts a zone of reduced atmospheric density/pressure possibly produced behind a rapidly expanding air shock. This early time reduction in atmospheric pressure may be expressed in a second-order effect on cratering efficiency at late times. The center sketch summarizes early time projectile-atmosphere-target interactions suggested by *Gault and Sonett* [1982]. At the moment of contact, interacting air shocks create an overpressure in front of the projectile shock. Consequently, early time energy partitioning could be significantly modified. The sketch at right shows the possible effect of the disturbed atmosphere trailing the projectile. High frame rate photography reveals that this trailing wake fills the early time transient cavity, thereby creating a backpressure that might partly offset the effect of the ambient atmosphere. At low Mach numbers ($M < 6$), this disturbed zone creates a trailing wind largely decoupled from the overall transfer of energy from projectile to target. Consequently, this "wake wind" should modify scaling relations established by the direct transfer of energy from projectile to target. At higher Mach numbers but lower densities, the trailing wake resembles a jet of compressible gas filling the transient cavity and creating wake blast. This process is still decoupled from the direct transfer of energy/momentum from impactor to target. At high Mach numbers and high atmospheric densities, the colliding wake represents a nontrivial fraction of the impactor energy and directly modifies the early-time transfer of energy from impactor to target. Such modification includes an increase in both the effective diameter and length of the impactor. (b) Evidence for the potential effect of the trailing wake on the cratering process from "craterless" impacts. The projectile was allowed to pass through a 5.1-cm-diameter hole in an aluminum plate. Sand (no. 24) was sprinkled on the plate in order to document any effect of the colliding wake at large distances from the projectile. Figure 12*b* shows the well-defined zone of sand removal resulting from passage of a 0.635-cm impactor through a 1-bar atmosphere of air at 1.7 km/s (left) and a 0.895-bar CO_2 atmosphere at 5.1 km/s (right).

The role of the projectile wake can be inferred from observations of experiments using high frame rate photography (8000-35,000 frames per second). At hypersonic velocities, the ionized luminous wake gases trailing the projectile are observed to fill and feed the early time transient cavity. In order to document the potential significance of this process, an aluminum plate with a 1-cm diameter hole (~ $3r_p$) permitted the projectile to pass without impacting, while arresting the movement of the trailing ionized wake. A thin (single grain) layer of sand (no. 140-200) and styrofoam tracers placed on the top of the plate documented the effects of the colliding wake. Paint was scoured away out to $10r_p$; sand tracers swept away out to $50r_p$; and the styrafoam tracers, out to $200r_p$. Figure 12*b* illustrates