The following discussion briefly examines the physical process of projectile ricochet and compares the laboratory results with the impact record on the Moon and Mars. Such comparisons then provide a basis for considering the potential effects of a major oblique impact on the Earth.

**Ricochet process**

Although projectile fragments appear to skip off the surface at low impact angles, shock stresses exceeding dynamic strengths preclude viewing the process as simple elastic rebound; rather, the ricochet phenomenon must reflect the effects of projectile spalling. Hypervelocity impacts of aluminum spheres into aluminum plates provide evidence for this process (Fig. 13). In addition to an oblong crater created by first contact with the projectile, a downrange impact consistently develops. Photographs of the projectile in flight reveal that this double impact could not be the result of either a projectile fragmented at launch or other accompanying debris. Experiments were designed to isolate the downrange impactor by moving the target uprange such that the downrange impact missed the target completely and impacted a vertical witness plate. This procedure revealed that the downrange pits result from fragments along a trajectory only slightly displaced vertically from the primary impactor. Such a pattern is consistent with fragments spalled from the top of the projectile. At an angle of 15°, the spall fragments reimpact the surface; at lower impact angles, the vertical velocity component redirects the fragments off the surface. This interpretation implicitly requires that the shock wave travels across the diameter of the projectile before significant penetration into the target. Figure 14A shows that this condition is met for 15° impacts into solid aluminum or sand at velocities achieved in laboratory experiments. Figure 14B extends the calculations to velocities characteristic of planetary impacts. For vertical impacts with velocities greater than 12 km/s, the projectile completely penetrates the surface before the shock reaches the back side of the projectile. For oblique impacts, the projectile shock velocity will be bracketed by conditions related to the vertical component (vsinθ) and the actual impact