Blackhawk landslide, southwestern San Bernardino County, California

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LOCATION AND ACCESSIBILITY

The Blackhawk landslide is located in southeastern Lucerne Valley at the southern edge of the Mojave Desert 85 mi (135 km) east of the Los Angeles, California, civic center. It lies across the eastern half of the line separating the Cougar Buttes and Big Bear City, California, U.S. Geological Survey 7½-minute Topographic Quadrangles. Its distal (lower) end is readily apparent on both the map and the ground near 34°25′N, 116°47′W.

The easiest way to reach the landslide is to take I-15 to Victorville, then California 18 east through Apple Valley, approximately 25 mi (40 km) to the center of the town of Lucerne Valley, and finally County Highway 247 (CH247, Fig. 1) east 8.7 mi (13.9 km) to its intersection with Santa Fe Road (SFR, Fig. 1). The steep, gray, 50-ft (15-m) scarp approximately 2,000 ft (600 m) to the southeast is the distal edge of the landslide. It can most conveniently be visited on foot either from the prospectors' road (moderate clearance or four-wheel drive advisable) that enters the highway at Santa Fe Road or from the highway itself about 0.6 mi (1.0 km) farther east. Features along the west side of the landslide can be reached along Blackhawk Canyon Road (BCR, Fig. 1; moderate clearance or four-wheel drive advisable), which crosses the highway 1.05 mi (1.7 km) west of the Santa Fe Road intersection. Features within the landslide lobe can be reached by taking Blackhawk Canyon Road south from the highway 1.05 mi (1.7 km) to the remains of a jeep trail that goes eastward, following it (four-wheel drive strongly advisable) to the dry wash nearest the landslide, and driving up the wash. Alternatively, these features can be visited on foot by hiking from the roads to the west and south. Features of the proximal (upper) part of the landslide can best be reached by taking County Highway 247 east from the Santa Fe Road intersection 3.25 mi (5.2 km) to a well-graded mine road marked by a large white marble boulder, then taking the mine road (low hill on right 4.4 mi (7.1 km) from highway is eastern lateral ridge of Silver Reef landslide) southwest 5.3 mi (8.5 km) to a prospectors' road (intersection about 1,400 ft (425 m) northeast of Round Mountain), next taking the prospectors' road (moderate clearance or four-wheel drive advisable) west approximately 0.25 mi (0.4 km) to where it crosses another similar road, and finally taking the other road northwest 1.6 mi (2.6 km) to the mouth of Blackhawk Canyon (BCM, Fig. 2). Features in the vicinity can be visited either on foot or, in most cases if road conditions permit, by vehicle (moderate to high clearance and low gear or four-wheel drive advisable). Good views of the landslide lobe on the alluvial slope and of its source area on Blackhawk Mountain can be obtained from the mine road (high clearance and low gear or four-wheel drive strongly advisable) that climbs the ridge just east of Blackhawk Canyon (VP, Fig. 2).

An ample supply of fuel and water should always be carried in the area, regardless of season. Only County Highway 247 and Santa Fe Road are regularly maintained. All other roads and trails are unpatrolled and are only sporadically maintained by the local ranchers, miners, and prospectors, so they can, and often do, change drastically in condition or even location.

SIGNIFICANCE OF SITE

The Blackhawk is among the largest landslides known on Earth, although it is small compared to some on Mars. It is the type example for a class of relatively rare large landslides that Shreve (1966, p. 1642; 1968a, p. 37–38) proposed slid on a layer of trapped, compressed air, in order to explain not only their high speed, low friction, and long runout but also their special peculiarities of form and structure, which are nearly all outstandingly exemplified at this site. The mechanism is still controversial, and a variety of alternatives to air-layer lubrication have been proposed: simple unlubricated sliding (McSaveney, 1978, p. 232; Cruden, 1980, p. 299); sliding lubricated not by air but by water-saturated mud (Buss and Heim, 1881, p. 145; Voight and Pariseau, 1978, p. 31; Johnson, 1978, p. 502–503), by frictionally melted ice, snow, or rock (Lucchitta, 1978, p. 1607; Erismann, 1979, p. 34), by frictionally vaporized ice, snow, or ground water (Habib, 1975, p. 194; Goguel, 1977, p. 697–698), or by carbon dioxide from disassociated carbonate rock (Erismann, 1979, p. 34); and "thixotropic" fluidization of the debris by interstitial water, air, or dust (Heim, 1932; Kent, 1966, p. 82; Hsü, 1975, p. 135; Lucchitta, 1979, p. 8111), by intergranular impacts (mechanical fluidization, or inertial grain flow; Heim, 1882, p. 83; Hsü, 1978, 1975, p. 134; Davies, 1982, p. 14), or even by intense sound waves (acoustic fluidization; Melosh, 1983, 1979, p. 7513). The Blackhawk-type landslides and many of these mechanisms have also been invoked, in most cases equally controversially, in connection with large volcanic debris avalanches (Siebert, 1984, p. 180), pyroclastic flows (Sparks, 1976, p. 175), underwater debris flows (Foley and others, 1978, p. 115), Tertiary megabreccias (Brady, 1984, p. 145, 152; Kerr, 1984, p. 239), the cryptic Heart Mountain structure in northeastern Wyoming (Hsü, 1969, p. 945; Kehle, 1970, p. 1649), the Tsiolkovsky Crater ejecta lobe on the Moon (Guest, 1971, p. 99; Guest and Murray, 1969, p. 133), and the huge landslides (as much as 60 mi (100 km) of runout) and rampart craters of Mars (Lucchitta, 1978, 1979; Schultz and Gault, 1979, p. 7681).

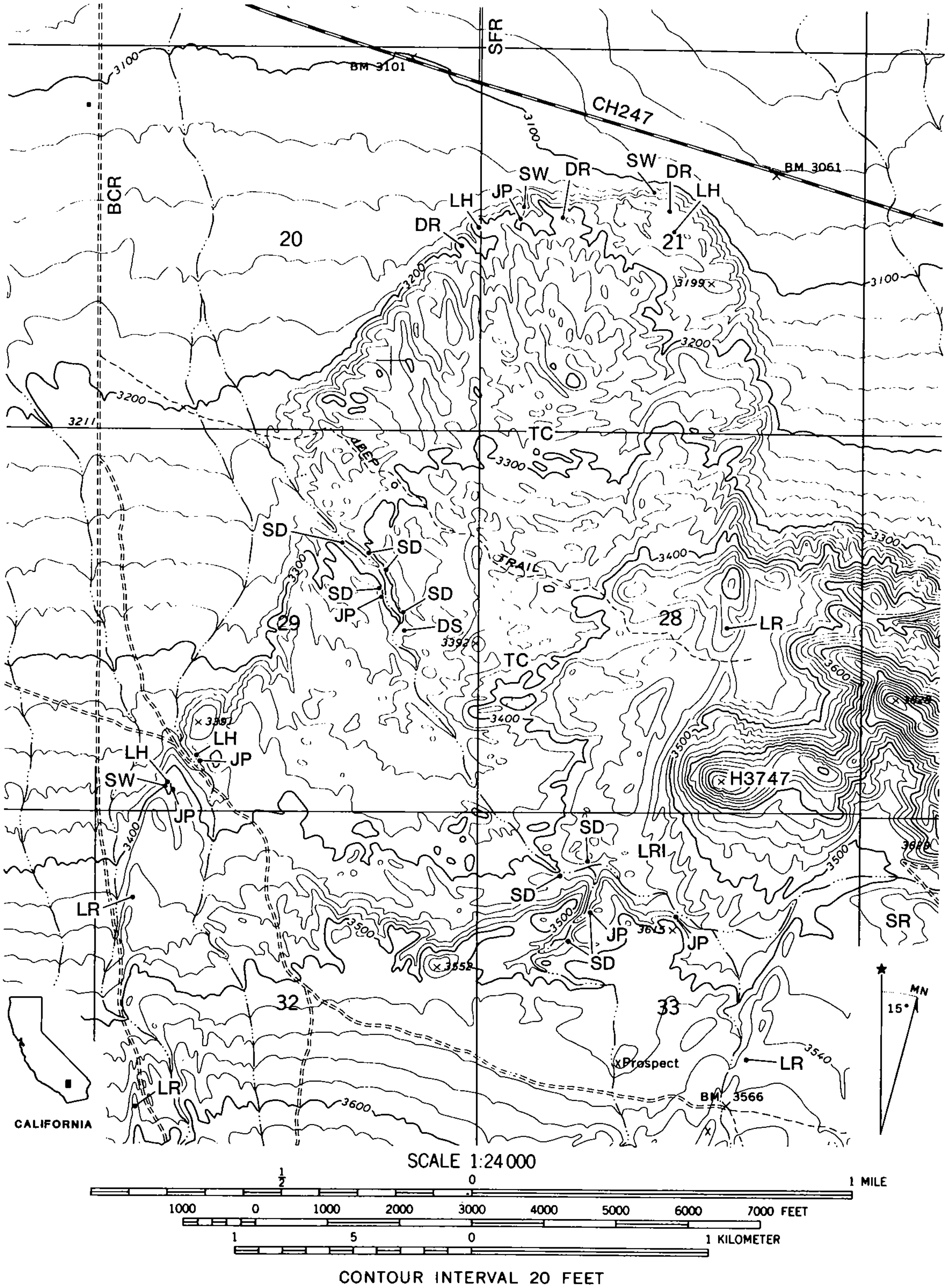

Figure 1. Distal part of Blackhawk landslide. DR, distal rim; DS, dated shells; JP, three-dimensional jigsaw-puzzle structure; LH, local homogeneity of debris; LR, lateral ridge; LRI, interior lateral ridge; SD, crushed-sandstone dike; SW, crushed-sandstone wedge; TC, transverse corrugations. JP, LH, LR, and TC are also present at many unlabelled localities. BCR, Blackhawk Canyon Road; CH247, County Highway 247; H3747, Hill 3747; SFR, Santa Fe Road; SR, Silver Reef landslide. Base map from U.S. Geological Survey Cougar Buttes, California, 7½-minute Topographic Quadrangle, 1971. Contour interval 20 ft (6.1 m).

SITE INFORMATION

The Blackhawk landslide was first recognized by Woodford and Harriss (1928), who described many of its peculiarities of form and structure and suggested that it was a debris outrush like the landslide of 1881 at Elm, Switzerland (Buss and Heim, 1881; Heim, 1882). It was studied in detail by Shreve (1968a), who likened it not only to the Elm landslide but also to the landslide of 1903 from Turtle Mountain at Frank, Alberta, Canada (McConnell and Brock, 1904; Daly and others, 1912), to the landslide of 1964 on the Sherman Glacier near Cordova, Alaska (Shreve, 1966; McSaveney, 1978), and to an adjacent older landslide, the Silver Reef (SR, Figs. 1 and 2; Shreve, 1968a, p. 16, 30, and Plate 2, facing p. 28). It was briefly restudied by Johnson (1978), who confirmed the previous observations and discovered sandstone dikes intruded upward into the distal parts of the landslide lobe, and by Stout (1977, p. 102–103), who obtained a radiocarbon age of 17,400 ±550 yr from fresh-water gastropod and pelecypod shells found in calcareous-mudstone pond deposits on the landslide surface (DS, Fig. 1).

The landslide originated as a huge rockfall from the summit of Blackhawk Mountain, which consists of resistant marble thrust northward over uncemented sandstone and weathered gneiss. It fell 2,000 ft (600 m) vertically and 7,000 ft (2,000 m) northward to the mouth of Blackhawk Canyon (BCM, Fig. 2), where it debouched onto the alluvial slope to form a narrow, symmetrical lobe of nearly monolithologic marble breccia 30 to 100 ft (10 to 30 m) thick (estimated), 1 to 2 mi (2 to 3 km) wide, and 5 mi (8 km) long. Its volume is 1×10^{10} ft^3 (3×10^8 m^3).

The edges of the proximal 3 mi (5 km) of the lobe (that is, the part nearest the source) are bounded by straight, narrow lateral ridges (LR, Figs. 1 and 2), like levees, that rise 50 to 100 ft (15 to 30 m) above the surrounding terrain. In places, the major ridge is accompanied, usually on its interior side, by parallel subsidiary lateral ridges (LRS, Fig. 2). The edge of the distal 2 mi (3 km) of the lobe is bounded by a somewhat sinuous scarp about 50 ft (15 m) high, whose crest generally rises a few feet (2–3 m) above the nearby landslide surface to form a definite distal rim (DR, Fig. 1). The surface of the lobe, where it is not buried by later alluvial fan gravels, is covered with low rounded hills and small closed basins with about 10 to 30 ft (3 to 10 m) of local relief. In the distal 2 mi (3 km) of the lobe these hills and valleys are elongate and form a strong pattern of transverse corrugations (TC, Fig. 1). The higher hills on the landslide lobe probably reflect underlying gneiss knobs that projected above the former alluvial surface. The most prominent of these is Hill 3747 (H3747, Fig. 1) near the eastern edge of the lobe about 2 mi (3 km) from its distal end, which blocked the progress of the landslide across a zone 1,500 ft (500 m) wide. The subparallel ridges on the western and southwestern slopes of the hill doubtless are interior lateral ridges (LRI, Fig. 1) that were successively formed and abandoned as the unimpeded middle region of the landslide adjusted to the arrested motion of the debris ascending the hill.

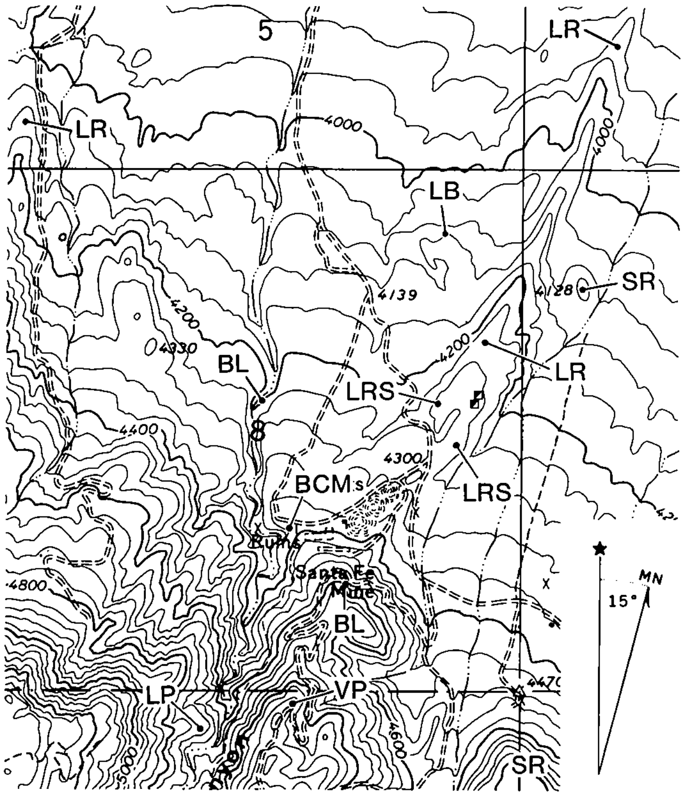

Figure 2. Proximal part of Blackhawk landslide. BL, base of landslide debris; LB, largest block on landslide; LP, launch point; LR, lateral ridge; LRS, subsidiary lateral ridge. BCM, mouth of Blackhawk Canyon; SR, Silver Reef landslide; VP, view point. Base map from U.S. Geological Survey Big Bear City, California, 7½-minute Topographic Quadrangle, 1971, photorevised 1979. Map scale same as in Figure 1; contour interval 40 ft (12.2 m).

The landslide lobe consists almost exclusively of crushed marble. The individual fragments are roughly equant, and range in size from powder to about 10 in (250 mm), the most common (that is, the modal) diameter being approximately 1 in (25 mm). A few exceptionally large blocks of a well-cemented older breccia range up to 35 ft (11 m) in maximum dimension (LB, Fig. 2). Neither the size distribution nor the lithologic characteristics of the fragments varies systematically with position on the landslide lobe. Locally, however, the debris tends to consist predominantly of a certain size of fragment or variety of rock; that is, it displays local homogeneity (LH, Fig. 1). In many places the fragments in roughly lenticular zones up to 20 ft (6 m) across are all pieces of a single source block that are loosely fitted together, giving a distinctive three-dimensional jigsaw-puzzle structure (JP, Fig. 1), in which color bands, for example, continue from fragment to fragment without significant offset.

Along the distal end and western edge of the landslide, the marble debris is nearly everywhere underlain by a wedge of crushed sandstone (SW, Fig. 1) and minor gneiss that was transported more than 4 mi (7 km) down the alluvial slope. The contact between the two generally dips toward the interior of the landslide, normally is marked by up to 6 in (150 mm) of clayey green gouge, and is quite sharp, although in places scattered angular fragments of marble are mixed with the crushed sandstone within about 1 to 2 ft (0.5 m) of the contact. At the distal end of the lobe, several mildly contorted layers of marble debris as much as several feet (a few meters) thick, alternating with thinner layers of crushed sandstone and gneiss in sheared contact, overlie the sandstone wedge and extend at least 150 ft (50 m) toward the interior of the landslide lobe. Crushed-sandstone dikes (SD, Fig. 1) intrude the marble debris in arroyo walls at several localities 1 to 2 mi (2 to 3 km) from the edges of the lobe (Johnson, 1978, p. 492–493), which suggests that the whole landslide may be underlain by a layer of crushed sandstone. Unfortunately, the base of the landslide debris is exposed in very few places (BL, Fig. 2).

No remnants of crushed sandstone are present anywhere on the upper surface of the landslide, however. This implies that, barring a remarkable coincidence, the landslide cannot have crossed the alluvial slope simply as an unusually large debris flow. In debris flows, material at the forward edge necessarily arrives there by way of the upper surface, because the surface material in any relatively wide flow moves faster than the forward edge, eventually overtakes it, and is rolled under. Thus, the presence of crushed sandstone at the distal edge of the Blackhawk landslide unaccompanied by similar material anywhere on its upper surface means that it could not have been a flow in the normal sense. Instead, it must have had essentially a sliding mode of movement.

The landslide overtopped Hill 3747 (H3747, Fig. 1), which would require a minimum speed of 75 mph (35 m/s or 120 km/hr) if accomplished solely by conversion of kinetic energy to potential energy. The actual minimum would of course differ to the extent that the debris ascending the hill was pushed from behind by that descending the alluvial slope (Johnson, 1978, p. 497), which is a process that cannot be treated quantitatively in general terms. Support for the approximate correctness of the conservation-of-energy estimate, however, comes from the Elm and Frank landslides, which are the two historical cases that most closely resemble the Blackhawk. Conservation of energy gives minimum speeds of 65 mph (30 m/s or 105 km/hr) and 110 mph (50 m/s or 175 km/hr) for the two, in reasonable agreement with the average speeds of 110 mph (50 m/s or 175 km/hr) and 90 mph (40 m/s or 145 km/hr) estimated from eyewitness accounts (Heim, 1932, p. 93; McConnell and Brock, 1904, p. 8). The same witnesses also reported that both landslides decelerated from high speeds to a complete halt with remarkable abruptness. Thus, the Blackhawk probably also traveled at a high speed and stopped abruptly.

The assemblage of characteristics just described defines a remarkable genre of landslides that Shreve (1966, p. 1639) termed Blackhawk type. These landslides are exemplified not only by the Blackhawk but also by the Silver Reef, Elm, Frank, and Sherman landslides, and doubtless others. Indeed, had the Elm not been entirely obliterated (Shreve, 1968a, p. 33) by subsequent agricultural rehabilitation, it would have been an even better type example, because it not only had all the same characteristics but also was seen in action; and, as Voight and Pariseau (1978, p. 28) noted, it has precedence.

Not all large, high-speed, long-runout landslides are Blackhawk type; a notable exception is the Huascarán, Peru, landslide of 1970 (Plafker and Ericksen, 1978). Nor does Blackhawk type imply air-layer lubrication, as Voight and Pariseau (1978, p. 32) mistakenly assumed. Rather, it implies an assemblage of characteristics that the air-layer lubrication hypothesis was put forward to explain.

Other landslides of the Blackhawk type have additional characteristics either originally lacking or subsequently lost in the Blackhawk. In the Silver Reef, the Elm, and possibly the Sherman, but not the Blackhawk or Frank, for example, the preserved sequence of lithologic and other characteristics demonstrates that the lower part of the source block became the distal part of the landslide lobe (Heim, 1882, p. 102–103; Shreve, 1966, p. 1641, 1968a, p. 30, 36) and gives further support to the inference that the mode of movement was more akin to sliding than to flowing. A different mode of failure of the source block could explain the lack of this characteristic in the Blackhawk and Frank. The surfaces of the Elm, Frank, and Sherman were also dotted by scattered debris cones, which would long since have disappeared if originally present on the Blackhawk and Silver Reef. These cones consist of finer debris usually piled at the angle of repose atop single large blocks (Heim, 1882, p. 101, 104; McConnell and Brock, 1904, p. 9; Shreve, 1966, p. 1642). About a third of the cones on the Sherman are xenolithologic debris cones, in which both the cone and its underlying block have identical peculiarities not present in the surrounding surface debris, such as an uncommon rock type or distinctive quartz veining (Shreve, 1966, p. 1642).

A striking feature of the Sherman landslide, which sets it apart from the Blackhawk, Silver Reef, Elm, and Frank landslides, is the pattern of hundreds of parallel shallow V-shaped longitudinal grooves that covers almost its entire surface (Shreve, 1966, p. 1641). Although some of the more prominent grooves were formed by shear between substreams of the debris, the vast majority were not, and are probably the result of lateral spreading. Similar longitudinal grooves are present on many contemporaneous landslides in the vicinity, as well as on the Martian landslides (Lucchitta, 1978, p. 1602–1603; 1979, p. 8098), on the ejecta blankets of certain Martian rampart craters (Mouginis-Mark, 1979, p. 8013), and on the ejecta lobe associated with Tsiolkovsky Crater on the Moon (Guest, 1971, p. 99). All these grooved features seem to have formed in the presence of strong ground shaking. The cause was a magnitude-8.5 earthquake in the case of the Sherman and its contemporaries; possibly earthquake or impact in the Martian landslides, as indicated by widespread synchroneity (Lucchitta, 1979, p. 8106); and almost certainly impact in the case of the crater ejecta.

According to the hypothesis of air-layer lubrication proposed by Shreve (1966, p. 1642, 1968a, p. 37–38), landslides of the Blackhawk type start as huge rockfalls which acquire so much momentum in their fall that at a projecting rib of rock or abrupt steepening of slope they leave the ground, overriding and trapping a cushion of compressed air, upon which they slide with little friction. The Elm and Frank definitely left the ground and overrode substantial volumes of air (Buss and Heim, 1881, p. 145; McConnell and Brock, 1904, p. 8), as hypothesized; and the Blackhawk and Sherman (Shreve, 1966, p. 1642) almost certainly did so, the launch point for the Blackhawk being a projecting spur ridge about 2,000 ft (600 m) upstream of the mouth of Blackhawk Canyon (LP, Fig. 2; see Johnson, 1978, p. 501, for photograph taken from the source area).

The high speed, the long runout, the local homogeneity of the debris, the distal wedge of crushed sandstone bulldozed from sources near the proximal end of the landslide, and, where present, the preserved sequence of lithologic and other characteristics result because the air layer is so easily sheared. The dikes (also present in the Sherman landslide; Shreve, 1966, p. 1641) originate from a relatively thin basal layer of lower permeability crushed sandstone (or, in the other cases, mud or snow) that necessarily had to be present in order for the pressure drop in the leaking air to be sufficient to counterbalance the weight of the loose fragments at the underside of the debris sheet (Shreve, 1968b, p. 655–656). The lateral ridges form where leakage allows the sides of the sliding sheet to fall and stop, forming levees that stand higher than the thinner debris that arrives later. The subsidiary lateral ridges form where air escapes along the interior side of an existing lateral ridge or ridges; and the interior lateral ridges form where it escapes at shear zones between sublobes of debris. The original ridge in some cases may not be the main one, because it can be smaller than a later one, and hence be subsidiary (Fig. 2). The debris cones form where large blocks, carrying on their tops finer debris from within the landslide, emerge from the moving debris as it spreads and thins, so that its surface settles around them (Heim, 1882, p. 101). They are xenolithologic where the debris at depth is lithologically homogeneous and differs from that at the surface.

The abrupt stop occurs and the distal rim and scarp form when the air layer becomes spread so thin that the leading edge of the sheet of debris hits the ground, slows rapidly, and causes the debris behind to pile up. The pattern of transverse corrugations reflects an imbricate internal structure that forms as the zone of impact propagates rearward up the landslide lobe, in the process destroying any lontigudinal grooves present. However, when the initial impact occurs toward the proximal end of the sheet of debris, the zone of impact propagates forward down the landslide lobe, in which case the stop, though still quick, is somewhat less abrupt, no distal rim or transverse corrugations form (unless the zone of impact meets a second one propagating rearward), and longitudinal grooves are preserved. The three-dimensional jigsaw-puzzle structure forms where the impact shatters large blocks into fragments that remain loosely fitted together because of the near lack of further movement.

The hypotheses advanced as alternatives to air-layer lubrication are motivated by doubts, predominantly intuitive, as to whether the initial speed of the Blackhawk was sufficient for the necessary launch (Johnson, 1978, p. 502; Voight and Pariseau, 1978, p. 31), whether sufficient air can be trapped (Johnson, 1978, p. 502; Voight and Pariseau, 1978, p. 30–31; McSaveney, 1978, p. 235; Erismann, 1979, p. 30, 31), whether it can be retained sufficiently long (Erismann, 1979, p. 31), and whether debris supported by a layer of compressed air is sufficiently stable (Bishop, 1973, p. 360–361), among other concerns. They are also motivated by purported long-runout landslides on the Moon (Hsü, 1975, p. 129, 132, 1978, p. 88, 91–92; Erismann, 1979, p. 32; Davies, 1982, p. 10, 11; Melosh, 1983, p. 158), which has almost certainly always lacked an atmosphere (and water), and by the Sherman-like landslides on Mars (Lucchitta, 1979, p. 8110; Davies, 1982, p. 11; Melosh, 1983, p. 158) which, except locally during impacts, probably always lacked sufficient atmosphere (Lucchitta, 1979, p. 8110), although not definitely (Schultz and Gault, 1979, p. 7681; Mouginis-Mark, 1979, p. 8020).

Actually, only two lunar candidates are known. One is the ejecta lobe at Tsiolkovsky Crater (Guest, 1971, p. 98–100), which formed at the same time as the crater (Guest and Murray, 1969, p. 133; Guest, 1971, p. 102), so that high energy (Lucchitta, 1978, p. 1605) and possibly released gas (Guest, 1971, p. 99; Sparks, 1976, p. 184) from the impact could have been involved. The other is the light-mantle deposit at the Apollo-17 site (Howard, 1973), which definitely is not Blackhawk type in form and probably is not even a landslide (Lucchitta, 1977). No landslide forms have been seen on Mercury (Lucchitta, 1979, p. 8097). Thus, the Martian examples are the only known apparently Blackhawk-type landslides from airless or nearly airless environments; and even they are open to debate.

Not surprisingly, inasmuch as they are intended to explain the same things, the alternative hypotheses have much in common with air-layer lubrication. They can be classified into three groups: unlubricated sliding, lubricated sliding, and "thixotropic" fluidization. Proponents of the first group believe that the apparent friction is not in fact unusually low or that it does not need to be. In order to account for the abrupt stop, they have to assume, with Heim (1882, p. 106), that friction increases considerably with decreased speed. Proponents of the second group, which includes air-layer lubrication, agree as to the necessity for a lubricant but differ as to its nature or source. Those of the third group insist, on the other hand, that the motion is flow, not sliding, but state (or imply) that the fluidized debris has special (as yet unconfirmed) rheologic properties such that a relatively thin basal layer shears much more rapidly than the rest, producing a result closely akin to sliding.

Virtually all the proposed processes are likely to occur in large landslides somewhere and sometime; and in many cases, if not most, some of them undoubtedly occur simultaneously. The question, therefore, is not whether they occur but what is their relative importance in specific classes of landslides, such as those of the Blackhawk type. Although eyewitness reports, as at Elm and Frank, have produced much essential information, direct observation—especially by trained observers—is severely limited by the rarity and unpredictability of all large landslides. Observation of experimentally induced landslides is possible, albeit not very practical for the Blackhawk type, because large size seems to be a prerequisite for long runout. More promising are experimental studies aimed at elucidating and quantifying the proposed processes, which would provide fundamental information on which to base theoretical calculations or computer simulations of the resultant landslides. Equally important are further field investigation and interpretation of the details of form and structure of existing Blackhawk-type landslides, including the Blackhawk itself as the premier example of the genre.

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