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Slope Stability of Proposed Ski Facilities at the Southeast Side of Snodgrass Mountain, Gunnison County, Colorado

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by

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ABSTRACT

Part of the proposed expansion of ski facilities at Crested Butte Mountain Resort, Gunnison County, Colorado, is in an area underlain by landslide deposits that are on the southeast side of Snodgrass Mountain. Except for localized movement, the landslides do not appear to be moving at present or to have moved in the past several decades. Shallow sliding and debris flows have occurred in similar materials nearby and are likely to occur in the landslide deposits during the 50-100 year life of the proposed facilities. Hazards related to debris flow, shallow slumping, and expansive soils in the deposits can be reduced by appropriate engineering and remedial measures but maintenance for the proposed facility may become costly. Snow making is likely to aggravate the hazards of shallow slumping, deep-seated sliding, and debris flow. Reactivation and deep-seated movement of a 1.6-million-m^3 slide at the east side of the deposits would damage or destroy a proposed gondola, ski lift N-3, and related facilities. Moving the gondola and lift off the slide and prohibiting snow making on the slide will protect the gondola and lift and reduce the chances of debris-flow damage to a proposed development near the toe of the slide. Insufficient data are available to assess the current or future stability of the landslides or to evaluate possible mitigation strategies; detailed stability analyses are needed before developing any facilities on the landslide deposits.

INTRODUCTION

Crested Butte Mountain Resort has proposed to expand and develop new ski facilities on Snodgrass Mountain, 6 km north of the town of Crested Butte, Gunnison County, Colorado. The proposal includes a gondola, ski lifts, ski runs, roads, utilities, and a village in the valley between Crested Butte (mountain) and Snodgrass Mountain (also called Crested Butte North in some documents related to the proposed development). Much of Snodgrass Mountain is within the Gunnison National Forest, but its proximity to the resort town of Mount Crested Butte has generated considerable public interest in the development and its potential environmental impact.

The National Environmental Policy Act requires an environmental impact assessment for the proposed development. As part of this assessment, two private contractors have prepared reports on geologic hazards in the area of the proposed development (Resource Consultants and Engineers (RCE), 1995; Irish, 1996). Both reports recognized and discussed hazards related to expansive soils, rock fall, soil creep, and shallow landslides. Both also recognized large landslide deposits on the southeast side of Snodgrass Mountain (Sec. 14, 15, and 23, T.13 S., R. 86 W.), but they differed in their interpretations of the extent, depth, age, probability of reactivation of the deposits, and the degree of hazard the deposits pose to the lifts, the gondola, and other facilities (figs. 1*A* and 1*B*).

As a result of the differing interpretations of RCE (1995) and Irish (1996), the U.S. Forest Service sought an independent opinion on the landslides from the U.S. Geological Survey. These large landslides and the hazards they pose are the subject of this report. The USGS was asked to review the previous reports and evaluate the stability of the southeast slope of Snodgrass Mountain. The evaluation was to consider the impact of water added to the slope as a result of snow-making operations, the effects of and hazard to ski-area development (lift towers, roads, utilities, etc.), the hazards to proposed commercial real estate development at the foot of the mountain, and the desire of the local community to preserve environmental values (view, etc.) that would be destroyed in the event of major slope movements.

I visited the southeast slope of Snodgrass Mountain, Gunnison County, Colorado, on August 20 and 21, 1996. Daryl Gusey, geologist, and Jeff Burch, planner, (both USFS) accompanied me in the field on the afternoon of August 20, and Mr. Burch accompanied me on August 21. The field investigation consisted of two traverses (fig. 2) through the site to examine geologic evidence for past or present slope movement. We also observed the landslide features from an elevated point on Crested Butte. I studied published geologic maps and several sets of aerial photographs, including color photographs by the USFS 1988, black-and-white photographs taken in 1958 and 1973, and false-color infrared photographs taken by NASA in 1975. This report briefly reviews previous work relevant to slope stability at the site, documents my own observations, and assesses the hazards in relation to the proposed development.

PREVIOUS WORK

The Colorado Geological Survey conducted reconnaissance mapping of geologic hazards in the Crested Butte area (Soule, 1976). The mapping identified a large area of landsliding on the southeast side of Snodgrass Mountain. A photograph in the report records evidence of recent landslide activity south of the study area (Soule, 1976, fig. 8). Gaskill and others (1991) mapped the same large landslide complex in considerable detail. Their map delineates the extent of the deposits, scarps and other landslide features, and slump blocks of Mancos Shale within the slide complex.

Summary of RCE report--Resource Consultants and Engineers (RCE, 1995) was awarded the investigation of geologic hazards (including identification, assessment, and mitigation) for the proposed expansion of Crested Butte Resort. Their investigation consisted of field mapping, interpretation of aerial photographs, and five borings in landslide deposits and their supposed source area on the southeast side of Snodgrass Mountain (fig 1*A*). RCE (1995) identified two large historic[1] landslides on the south side of Snodgrass Mountain (fig. 1*A*). The East Slide (fig. 1*A*) was considered the oldest and initiation of the West Slide was attributed to drag by the East Slide. The supposed source area of the East Slide, which extended downslope from the secondary summit of Snodgrass Mountain to about boring 2, was considered relatively stable (fig. 1*A*). Lifts N-3, N-5, N-6, and the gondola cross the landslide deposits or supposed source areas. RCE (1995) also mentioned a recent landslide, south of the permit area, that is in the same materials as the two large slides in the permit area.

The subsurface investigation showed the presence of medium-dense sands in the supposed source area of the East Slide (fig. 1*A*) and stiff clays in the slide deposits (RCE, 1995). The borings were made with 15-cm-diameter, hollow-stem augers and each boring was drilled to refusal (table 1). The standard penetration test was performed at approximately 1.5 m intervals and samples were collected but no index properties or strength measurements were reported. Borings 1 and 2 (fig. 1*A*) passed through clayey sands with gravel- and cobble-sized fragments of shale and granitic rock (quartz monzonite porphyry). Both borings terminated on granitic rock assumed to be in place, 7.2-8.7 m below the ground surface (table 1). Blow counts generally were consistent with a medium density for the clayey sand.

Borings 3, 4, and 5 passed through low-plasticity sandy clay of stiff to very stiff consistency and weathered shale (fig. 1*A*). All three terminated in hard shale that appears to be in place (table 1). In boring 3, fragments of granitic rock were present in the clay to a depth of at least 14.2 m and shale fragments were present in the clay below a depth of about 6.1 m. Boring 4 passed through low plasticity clay with

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[1]The use of historic in the RCE (1995) report is confusing; the report indicates that the East Slide moved initially after Pleistocene glaciers receded and that failure is still occurring locally. However, the USGS is unaware of any historic accounts of movements of these slides.

fragments of weathered shale of 18.7 m (granitic rock fragments were also present to a depth of 15.7 m). Weathered shale was present below 18.7 m to the bottom of the boring. Boring 5 passed through sandy clay containing weathered shale fragments to a depth of 16.7 m , where a buried soil containing organic matter and charred wood fragments was present. Sandy clay containing fragments of granitic rock was present below the buried soil. Weathered shale was present from 20 m to the bottom of the boring.

Ground water was present in the slide deposits (table 1, borings 3, 4, and 5), but not in the supposed source area (table 1, borings 1 and 2). Piezometers were installed in borings 3, 4, and 5 to monitor ground water in the slide (fig. 1A). The borings, which were drilled in October of 1994, showed evidence for a high water table in the slide deposits that persists into autumn (table 1). RCE (1995) noted many wetlands on the slides and that several surface drainage channels head at the base of scarps. The wetlands and heads of the channels are consistent with a high (possibly perched) water table in the slide deposits.

Table 1. Summary of bore-hole data for the East Slide of Figure 1*A* (RCE, 1995)

[Approximate boring locations shown in figure 1*A*.]

Boring	Depth	Depth of Water Table	Depth of Piezo-meter	Comments
	Meters	*Meters*	*Meters*	
1 - - - -	7.2	none	none	- - - -
2A - - -	7.6	none	none	- - - -
2B- - - -	7.2	none	none	1.5 m east of 2A
2C - - -	8.7	none	none	2.4 m west of 2A
3 - - - -	19.4	12.8	19.4	- - - -
4 - - - -	30.6	3.5	30.5	- - - -
5 - - - -	24.5	9.4	24.4	Buried soil with charred wood fragments at 16.8 m

RCE (1995) concluded that the proposed development could destabilize the slide deposits (roughly the downhill half of the East Slide and the downhill two-thirds of the West Slide, fig. 1*A*) and that planned snow-making could contribute to failure by raising the water table. The potential hazards related to failure of the deposits included shallow creep, debris flow, small secondary slides, settlements, and slow, deep-seated movements. RCE (1995) proposed mitigating the hazards by moving the gondola and related structures off the slide to the stable ridge to the east. Alternatively, if moving the gondola were not practical, then RCE (1995) recommended providing subsurface horizontal drains and monitoring ground water, surface monuments, and inclinometers. Surface monuments have been installed and are being monitored (Jeff Burch, USFS, oral commun., 1996)

Summary of Irish report.--Mr. R.J. Irish visited the site June 3 and 4, 1996 and conducted studies of existing reports and aerial photographs of the south end of Snodgrass Mountain (Irish, 1996). The objectives of his study were to describe geologic conditions, with particular reference to geologic hazards, assess the risk related to any perceived hazards, and suggest mitigative measures for the hazards.

Irish (1996) recognized two ancient or pre-historic landslide complexes on the southeast side of Snodgrass Mountain (fig. 1*B*); however, he interpreted their extent and depth differently than RCE (1995). Irish (1996) recognized a West Slide (fig. 1*B*) that he classified as a block-slide complex. He asserted that a Base Hill of in-place Mancos Shale buttresses the West Slide (fig. 1*B*). His East Slide (fig. 1*B*) is a thin (2.7 m) mud flow and single rotational block in the alignment of the gondola and lift N3. On the basis of the following observations and ideas, Irish (1996) concluded that the probability of catastrophic reactivation of either slide complex was low: (1) No open cracks or fresh scarps were observed and the landslide features, particularly of the West Slide (fig. 1*B*), have been rounded by erosion. (2) The Base Hill buttresses the West Slide (fig. 1*B*). (3) The East Slide (mud-flow complex), appears to be thin[2]. (4) The conditions thought to trigger the slides (glacial erosion and high precipitation) have changed or ceased. (5) Work by others (Kirkham and Rogers, 1981; Algermissen, 1983) indicates low probability of significant earthquake acceleration during the expected life of the project. Irish (1996) assigned low probability to small failures also, although he noted the presence of many small slumps and flows in the West Slide complex and uphill from the East Slide (fig. 1*B*). He concluded that more small slides can occur, especially if poor construction practices are followed.

Irish (1996) recommended that the hazards could be mitigated by sensible construction practices, including minimizing cut-and-fill construction, providing drainage to prevent ponding of water, revegetation of slopes after construction, and maintaining forests as much as possible. Although he did not expect the towers to affect the stability of the slides, Irish (1996) noted that the gondola and lift N-3 could be relocated to the east or west to avoid any potential problems related to putting them on the East Slide (fig. 1*B*). He did not expect problems for lift N-5 unless poor construction practices changed conditions. Irish (1996) stated that no houses or other major buildings should be placed on the slides and that he did not expect snow-making to affect stability of the slides.

SITE GEOLOGY

Gaskill and others (1991) have documented the geology of Snodgrass Mountain. It is capped by a 300-m-thick laccolith of quartz monzonite or granodiorite that intruded the Upper Cretaceous Mancos Shale. Mancos Shale underlies the lower slopes of the mountain. Glacial activity has modified the slopes and left deposits of moraine on the sides of the mountain.

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[2]Irish (1996) reinterpreted the boring logs of RCE (1995) and concluded that the East Slide was only about 2.7 m thick at boring 4 and underlain by in-place shale. This reinterpretation is inconsistent with the presence of the fragments of granitic rock as deep as 15.7 m in boring 4 and the buried soil, wood fragments, and organic matter found at 16.8 m in boring 5.

Colluvial deposits cover much of the east and west sides of the mountain. Extensive landslide deposits occupy a crudely semicircular basin at the southeast side and blanket slopes on the south side of the mountain (fig. 2). The topography of landslide deposits within the basin is stepped. Scarps on the sides of Snodgrass Mountain indicate shallow slumping in the colluvial, glacial, and landslide deposits (Gaskill and others, 1991).

DESCRIPTION OF THE LANDSLIDES

Based on examination in the field and on aerial photographs, the slide deposits in the basin at the southeast end of Snodgrass Mountain can be divided into three main units, the Slump Block, the West Slide and the East Slide (fig. 2). Movement of all three units was toward the southeast.

A low, rounded hill at the base of the complex constitutes the Slump Block. This hill is not in-place bedrock as asserted by Irish (1996), but rather a displaced mass that slid into its present position from a source area (evidenced by an eroded scarp) directly upslope. The surface of the hill is hummocky, and in aerial photographs the hill has a dark, slightly mottled tone that matches the tone of surrounding landslide debris and is different from the light, strongly mottled tone of nearby shale hills to the south and east. A 70-m-high, relatively steep scarp slope surrounds the Slump Block and marks its source area (fig. 2). Field examination confirmed a landslide origin for the Slump Block. The surface of the Slump Block, particularly south of the summit, consists of rounded hummocks, and the drainage is somewhat irregular. This contrasts sharply with the smooth slopes and dendritic drainage of the hills to the south and east. Weathered shale crops out locally on these hills, which have a thin, spotty cover of till (Gaskill and others, 1991).

A slide complex upslope (to the west and north) from the Slump Block constitutes the West Slide (fig. 2). The head of the West Slide is at the base of an arcuate scarp at the south end of the Snodgrass laccolith. Trees obscure much of the scarp and upper part of the deposits on the West Slide, however, parts of small benches and scarps are visible through the trees. The ground on the West Slide is hummocky, and drainage is irregular; intermittent ponds occur in closed depressions (fig. 2).

A slump-earth-flow complex at the east edge of the basin constitutes the East Slide (fig. 2). Two high, arcuate scarps (related to slumping) are at the top of the complex, and the surface of the earth flow, downhill from the scarps, is stepped and hummocky. The East Slide is draped over the Slump Block and 70-m-high scarp (fig. 2).

<u>Dimensions.</u>--The Slump Block has gentle (<10 percent) reversed (west-northwest) slopes between its west boundary and summit; slopes range from 25 to 40 percent on the downhill (east and south) faces. The Slump Block measures 580 m from head (at base of the 70-m high scarp) to toe and 700 m from north flank to south flank (including the area beneath the East Slide). The West Slide (fig. 2) has an average slope of 28 percent; slopes range from 25 to 40 percent on the 70-m-high scarp, 13 to 20 percent on the gently sloping ground above the scarp, and 25 to 60 percent near the head. The West Slide is 700 m wide from northwest flank to southeast flank and 900 m long from head to toe (at west edge of the Slump Block). The East Slide (fig. 2) slopes 22 percent; slopes locally range from 100 percent near the head to 11 percent in a gently sloping area near the toe. The slide has a volume of 1.6-million m^3 based on a length of 800 m, width of 200 m, and minimum average thickness of 10 m. The minimum average thickness is estimated from the difference in elevation between the East Slide and ground at either side (fig. 2). Boring 5 (fig. 1*A*) (RCE, 1995), in the toe of the East Slide (fig. 2), turned up charred wood at a depth of 16.8 m and "granitic sandy gravel," which is not native to the underlying Mancos Shale, as deep as 20 m. Thus the East Slide or a combination of the East Slide and underlying Slump Block may be as much as 20 m thick; no data are available to determine the thickness of the West Slide (fig. 2). A recent slide on the south end of Snodgrass Mountain slopes 39 percent, and is about 600 m long, 200 m wide, and probably a few meters thick (fig. 2).

Ages.--Absolute ages of the three units are unknown, but the East Slide is younger than the Slump Block and West Slide (fig. 2). The East Slide overlaps the Slump Block. The West Slide and Slump Block are more deeply eroded and have more rounded features than the East Slide.

The Slump Block, East Slide, and West Slide (fig. 2) have not moved significantly in historic times. No signs of recent changes in the slide deposits are evident between photographs spanning 30 years. The vegetation is undisturbed, and the same areas that are bare on the old slide deposits and scarps in the 1958 photographs are bare in the 1988 photographs. We found no field evidence of recent activity such as fresh scarps or open cracks; however, despite the lack of evidence for significant movement, the slides can still be marginally active because small (sub-centimeter) annual movements are known to occur in some slides without cracks or other visible evidence of movement being preserved (Fleming and Johnson, 1994).

The recent slide on the south slope (fig. 2) appears to have been active in the past 40 years. Boundaries of the recent slide appear to be sharp and barren, as if it were active, in the 1958 photographs. The same boundaries in the 1988 photographs appear subdued and partly overgrown. Also, a scar in the lower part of the slide has distinct head and flank scarps and exposes fresh landslide debris. The area occupied by the scar appeared to be unvegetated in the 1988 photographs, but no scarps were apparent.

LANDSLIDE HAZARDS

Several geologic hazards, including expansive soil, debris flow, shallow sliding, and deep-seated failure must be considered in developing ski facilities on or near the landslide deposits. Expansive soils have caused damage to buildings at Crested Butte Mountain Resort (D.J. Varnes, USGS, oral commun., 1996) and have been discussed by RCE (1995) and Irish (1996).

Debris flows can be triggered during times of high rainfall or rapid melting of natural or artificial snow. A debris flow that occurred in the spring of 1996 on the north side of Crested Butte (J. Burch, oral commun., 1996) demonstrates that debris flows do occur on similar slopes under existing conditions. Debris flows originating in the slide deposits can damage access roads, utilities, or the proposed development in the valley between Crested Butte and Snodgrass Mountain. In particular, debris flows originating on or near the East Slide (fig. 2) can damage the proposed development at the foot of Snodgrass Mountain. Use of artificial snow on the East Slide (fig. 2) may increase the probability of debris flow there. The occurrence of debris flows is highly likely during the life of the facility, given the recent occurrence.

Shallow sliding or slumping can damage access roads, utilities, towers of the gondola, or towers of lifts N-3, N-5, and the south end of lift N-6. The recent activity of the shallow slide on the south side of Snodgrass Mountain demonstrates that such slides can and do occur under existing conditions. Slopes on the West Slide, Slump Block, and East Slide (fig. 2) are locally as steep as the recent slide (fig. 2). The lower 2/3 of lift N-5 is in the area of scarps mapped by Gaskill and others (1991).

Deep-seated failure and renewed movement of the entire landslide deposit (i.e. the East Slide, West Slide, and Slump Block, fig. 2) would threaten all the proposed facilities in the area (i.e. lifts N-3, N-5, N-6, the gondola ,and the proposed development). Such movement might occur if the Slump Block is disturbed by excavation or erosion. The Slump Block appears to buttress higher deposits of the West Slide (fig. 2) and secure them against massive failure. Excavation of the toe or top of the Slump Block will remove part of the buttress load and increase the chances of failure. Downward erosion of the stream channel at the toe of the Slump Block (related either to a basin-wide episode of incision or a local increase in discharge) will increase the height of the slope and tend to destabilize the Slump Block.

Deep-seated failure resulting in reactivation of the East Slide (fig. 2) can damage or destroy the gondola and lift N-3. Reactivation and deep-seated movement of the East Slide is more likely than reactivation of the entire landslide complex; the East Slide rests on top of the Slump Block (fig. 2). Slides that were similar in geometry and degree of erosion of surface features were reactivated by rapid melting of a heavy snowpack during 1983 in central Utah (Baum and Fleming, 1989). The 1.6-million-m^3 (or greater) East Slide (fig. 2) is too large to remove and any other methods of stabilizing it will be costly. Avoidance of any development or snow-making on the East Slide (fig. 2) may be the safest and least expensive option for reducing the potential losses. Site-specific studies are needed to evaluate other possible mitigation options.

The preceding paragraphs describe potential landslide and debris-flow events and related hazards to the proposed ski facilities for the southeast side of Snodgrass Mountain; however, the paragraphs contain little information on the probability of the events occurring. Estimating the probability of landslide occurrence is speculative, particularly when the estimate is based on qualitative data alone. Quantitative data needed to perform stability analysis of the landslide deposits and estimate the probability of their reactivation are lacking in the reports of RCE (1995) and Irish (1996). These data include, at a minimum, relevant shear-strength, geometric (topography and thickness), and pore-pressure measurements of the landslide deposits. Detailed site investigation and engineering analysis are needed to predict whether the slide deposits will remain stable during the life of the proposed facilities. Such investigation and analysis should be required before any facilities can be constructed on the landslide deposits.

CONCLUSIONS

The ski facilities proposed for the southeast side of Snodgrass Mountain (Crested Butte North) are subject to several geologic hazards inherent to development on large landslide deposits. Safe and economic development of facilities on the West Slide and Slump Block (fig. 2) will require detailed, site-specific studies and adequate engineering to reduce damage from expansive soils, debris flows, and shallow sliding or slumping. In addition to damage from these, facilities on and downslope from the East Slide (fig. 2) are also subject to possible damage or destruction by deep-seated sliding. Detailed field investigation and stability analysis are required to determine whether the East Slide is sufficiently stable to support the proposed facilities. Given the magnitude of the investment to develop the ski facilities and the potential losses due to deep-seated failure, detailed subsurface investigation and stability analysis should also be undertaken for the West Slide and Slump Block (fig. 2) before going ahead with development of any proposed facilities on or near the southeast side of Snodgrass Mountain.

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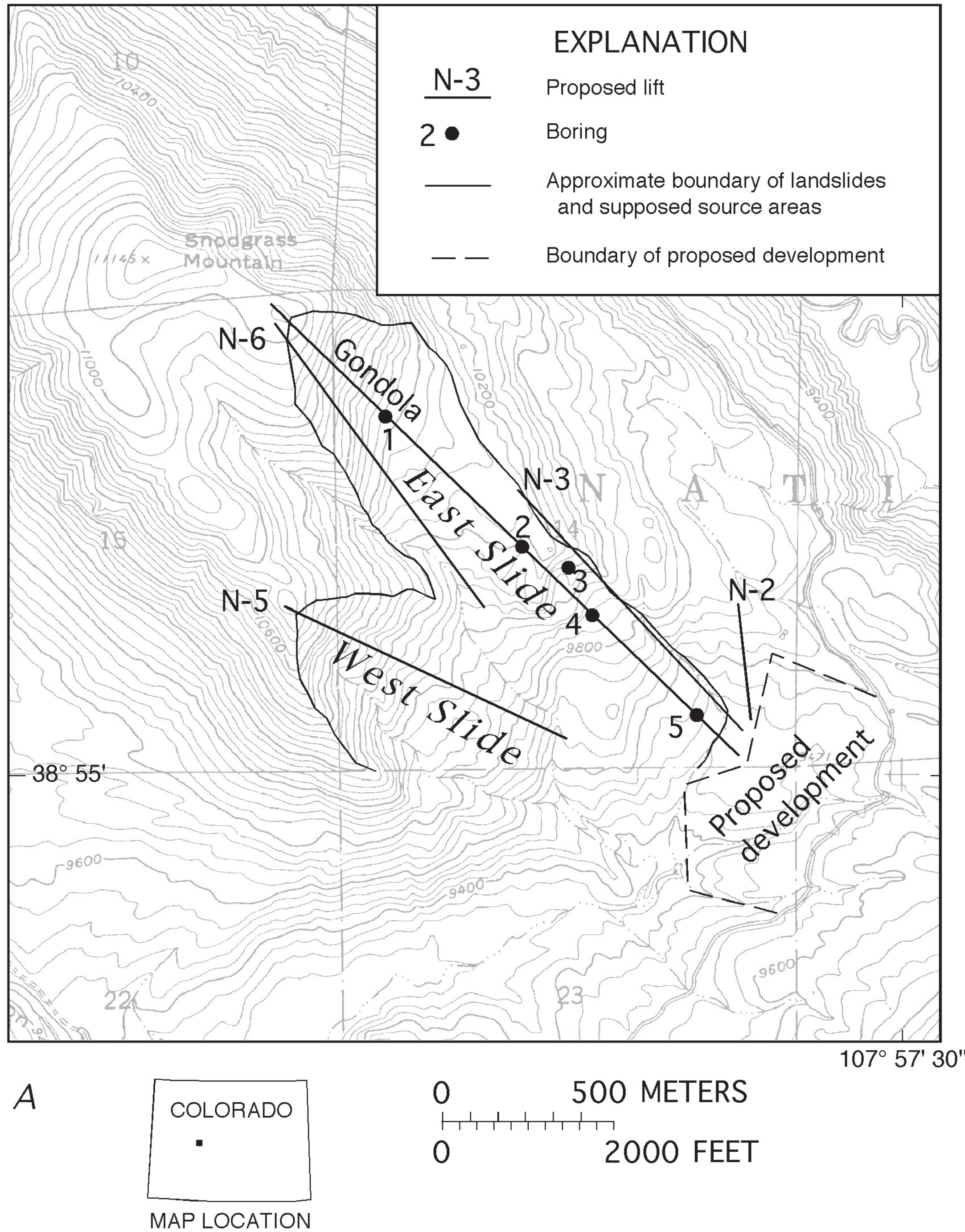
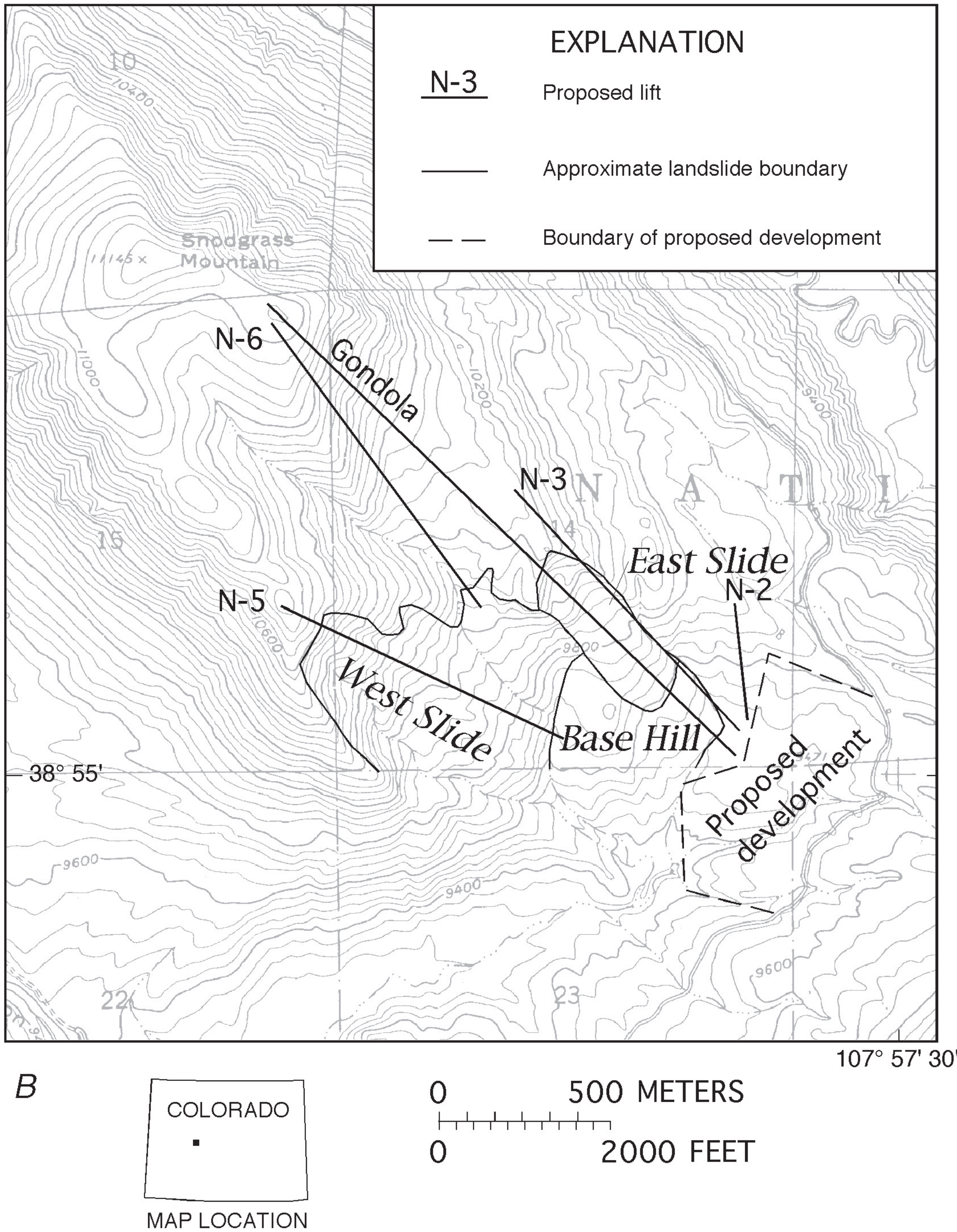


Figure 1. Approximate landslide boundaries as interpreted by previous investigators. Boundaries shown only within Gunnison National Forest, Section 23 is outside the Forest. Base from USGS Gothic 7-1/2 minute quadrangle, 1961. A. Landslides and borings of RCE (1995). B. (facing page) Landslides and Base Hill of Irish (1996).



EXPLANATION
N-3
Proposed lift
Approximate landslide boundary
Boundary of proposed development
Snodgrass Mountain
N-6
Gondola
N-3
East Slide
N-2
N-5
West Slide
Base Hill
Proposed development
38° 55'
107° 57' 30"
COLORADO
MAP LOCATION
0 500 METERS
0 2000 FEET

B

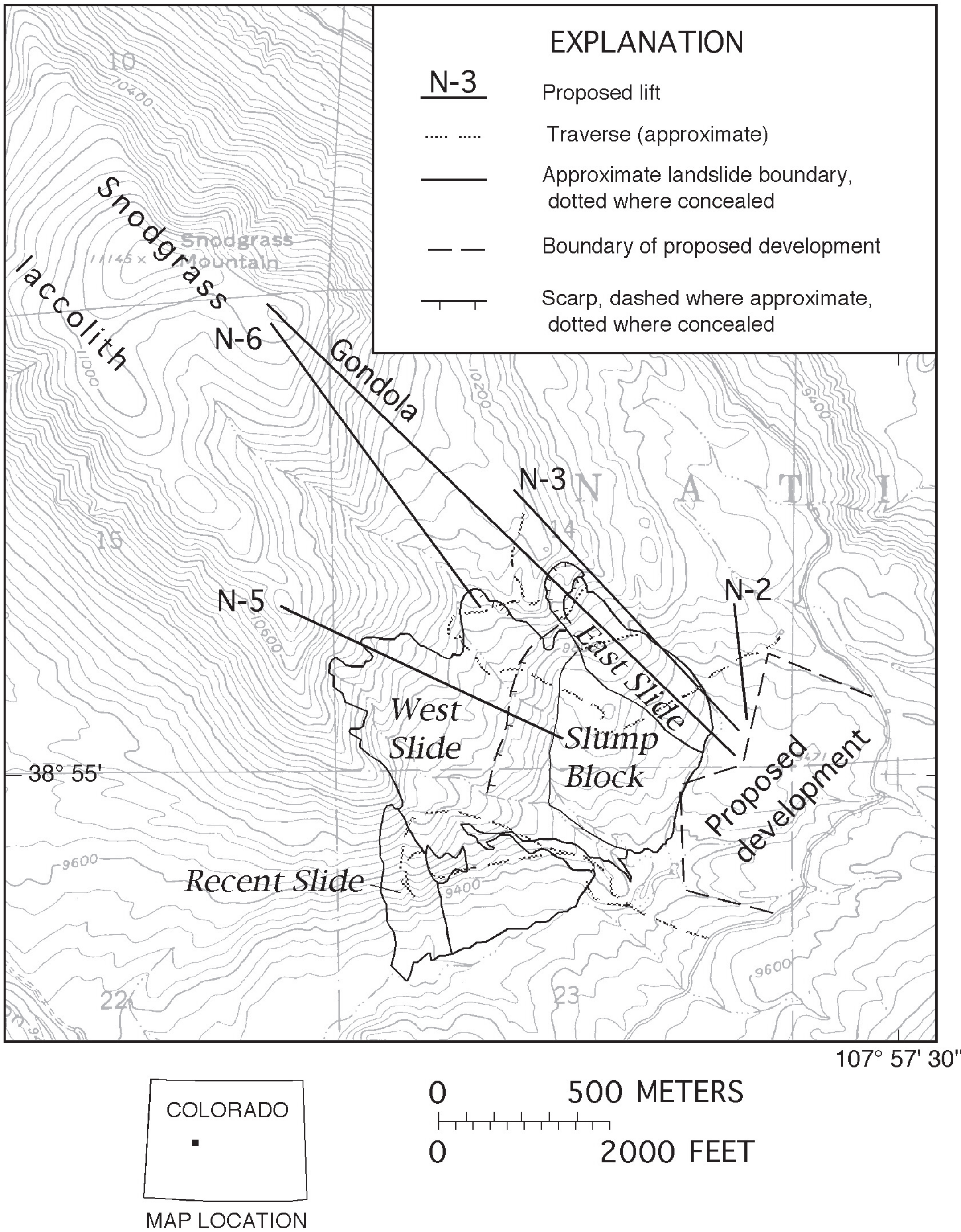


Figure 2. Landslide deposits and proposed development on southeast side of Snodgrass Mountain, Gunnison County, Colorado. Outer boundaries of landslide deposits from Gaskill and others (1991). Internal boundaries (approximate) based on field reconnaissance and interpretation of aerial photographs (this investigation). Base from USGS Gothic 7-1/2 minute quadrangle, 1961.