A Rockfall and Debris Slide at Smugglers Notch

Mount Mansfield, Cambridge, Vermont

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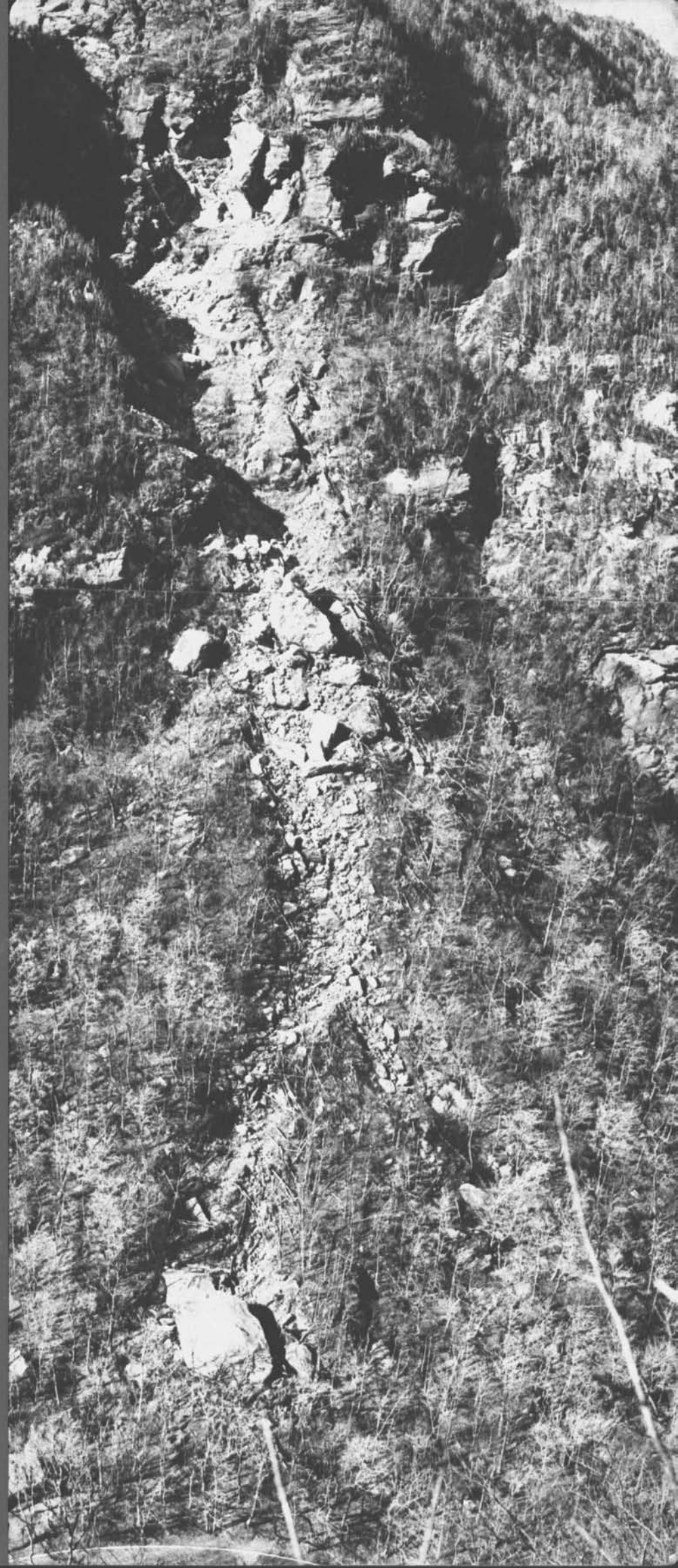

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COVER PHOTO:

Scar and debris of the July 13, 1983 rockfall and debris slide on the west wall (east facing) of Smugglers Notch. Note the road, VT. Rt. 108, at bottom of photo. The location of this feature is shown on Figure 1.

A poetic account of a debris avalanche in Smugglers Notch:

But never in such fearful storm
Have I been caught. I'd stopped to take
A sketch beside the mountain lake,
When suddenly, and unaware,
A dense black vapor filled the air.
I seemed enveloped in a cloud,
Where lightnings leaped and thunder loud,
Were underneath, above, around
Filling my ears with stunning sound.
I sought the shelter of a rock,
When instantly I felt a shock.
The earth gave way beneath my feet,
When rocks and trees and shrubs complete,
Went sliding down the mountain side,
Leaving a chasm deep and wide
Behind, while everything before
Was crushed with most terrific roar.
As on I went, with bated breath,
Expecting every instant, death,
A ponderous rock upon one side
Caught on its way the moving slide,
And held it firmly in its course,
While breaking with resistless force
Went crashing o'er a precipice,
Into a seething wild abyss.
I stood upon the arrested part
Quite safe and with most thankful heart.

from ''A Legend of Smuggler's Notch'' by Samuel Slayton Luce, published by the Record Press, Waterbury, VT, 1936.

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A Rockfall and Debris Slide at Smugglers Notch

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INTRODUCTION

On July 13, 1983 at approximately 7 A.M. (E.D.T.), a block of schist estimated to have weighed 11,500 tons (10.4×10^6 kg) broke loose from an east-southeast facing cliff near the 3000 ft (914 m) elevation in a tributary valley to Smugglers Notch, Mount Mansfield, Cambridge, Vermont (Plate I C, Location C, in the centerfold). The block traveled diagonally across this narrow drainage valley, smashed into the opposite wall at a point some 50 feet (15 m) lower, and broke into many smaller blocks. Several large and small fragments travelled about 1300 ft (400 m) downslope to the road (VT. Rt. 108) level, 2180 ft (664 m), into Smugglers Notch proper (Cover Photo).

Smugglers Notch, in the town of Cambridge, Vt., is located within the Mount Mansfield State Forest. The Notch is a steep walled, V-shaped valley that forms a north-south trending mountain pass between the southwesternmost peak (Spruce Peak) of the Sterling Range and the northernmost ridge (The Chin, The Adam's Apple, and Bear Head Mtn.) of Mount Mansfield (Figure 1). A paved, two-lane, winding road through this pass connects the town of Stowe (to the south) and the village of Jeffersonville (to the north). This road (VT. Rt. 108) serves three major ski areas. Smugglers Notch is a popular attraction for tourists, rock climbers and hikers. The road is heavily traveled from May to November; the short section through the pass (i.e., the immediate area of the Notch) is closed during the months of December through April.

Average relief in this steep walled valley is 1800 ft (550 m). Several steep tributary drainage valleys empty into Smugglers Notch from its east and west sides. One of these tributary valleys is the site of this investigation (Plate I B, Locations B and C). The growth and location of these tributary valleys is controlled by prominent brittle fractures (joints, faults) that weather and erode more rapidly than immediately adjacent areas. Christman (1956, 1959) attributed the development of Smugglers Notch, the main (north-south) valley, to headward erosion by an ancient (glacial meltwater) river. The valley is currently being gradually modified by headward erosion in the headwaters area of the Brewster and West Branch Rivers. These rivers flow north and south, respectively, out of Smugglers Notch.

The failed block of schist originally had the form of a horizontally elongated, east-west oriented, prismatic mass, consisting of a basal inverted trapezoidal prism overlain by a rectangular prism (Figure 2). On its north side the block was separated from the main mountain mass by an open, weathered joint surface. The south and east faces were free. At its west end, the prism was attached (at least in the lower part) to the main mountain mass. The eastern end of the block was an overhang. The entire mass needed only a small disturbance to initiate failure.

The valley bottom through Smugglers Notch is littered with enormous blocks, indicating that rockfalls are a common type of slope failure on these steep slopes. Investigations of this rockfall and debris slide were made for the purpose of identifying the geologic characteristics of the area and the processes responsible for the rockfall. It was also thought desirable, if possible, to determine the triggering event that caused the rock mass to fail at that particular time. Knowledge of the conditions leading to this failure may help to better understand this and similar events, and thus lead to the ability to predict future potentially hazardous rockfalls.

REGIONAL AND SITE GEOLOGY

The bedrock of the western cliffs of the Smugglers Notch area is composed of a prominently foliated, Cambrian-age schist of the Underhill Formation (Camels Hump Group). The rocks range in composition from mica-albite-quartz schist, with some graphitic phyllite, to chlorite-quartz-mica schist (Christman, 1959). Weathered surfaces of these rocks are a rusty brown color, whereas fresh fracture surfaces are silver gray to greenish gray.

The axis of Smugglers Notch coincides approximately with the axis of a synform. This synform is located at a position where the northeast striking axis of the Green Mountain anticlinorium is offset, as

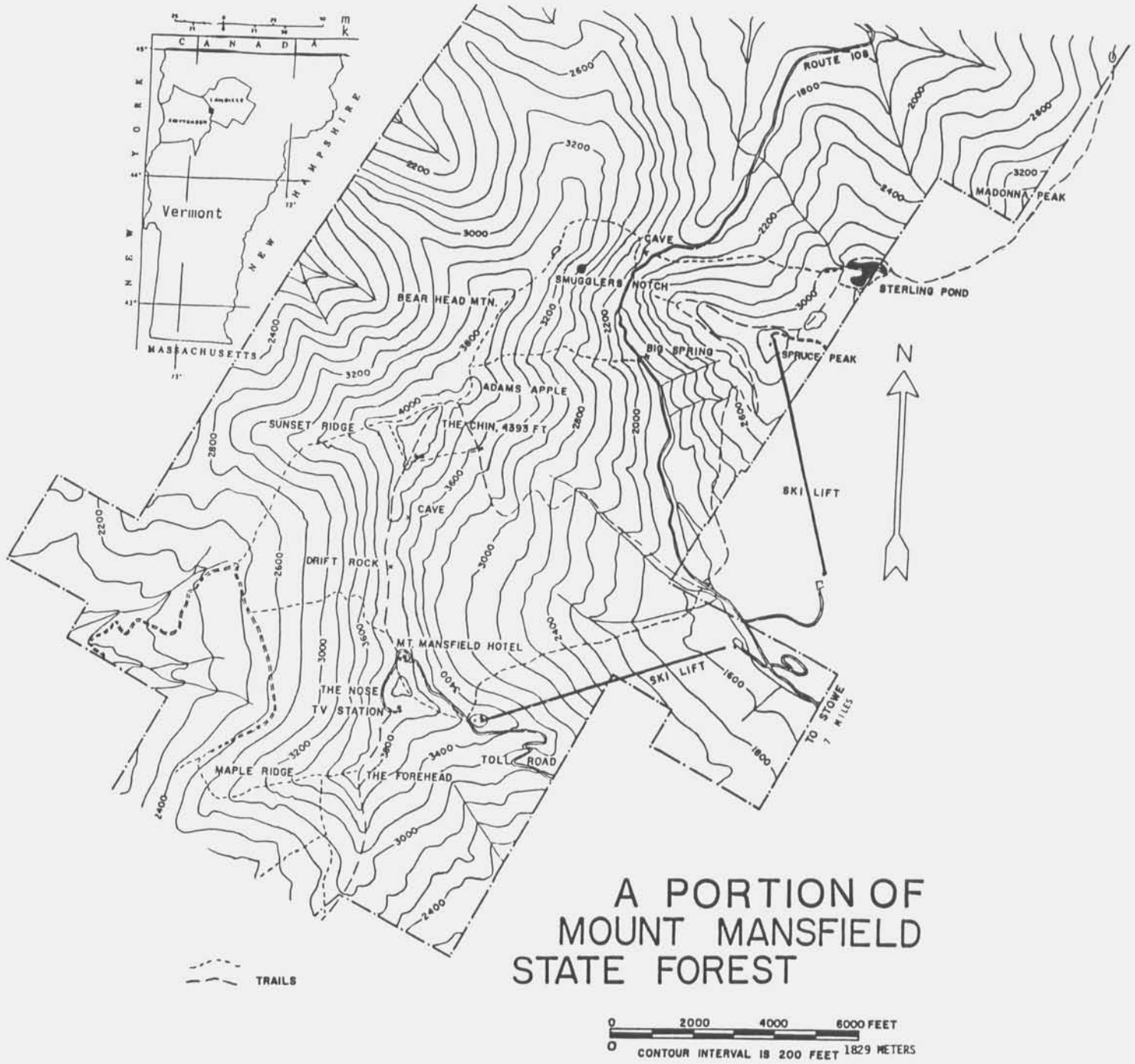


FIGURE 1

Location map of the Smugglers Notch area in the Mount Mansfield State Forest, Vermont. The small black square on the boundary between Lamoille and Chittenden Counties on the inset map is the location of the Mount Mansfield 7.5-minute quadrangle in which the Mount Mansfield State Forest is located. The approximate location of the rockfall and debris slide is shown by the black dot identifying the point of origin.

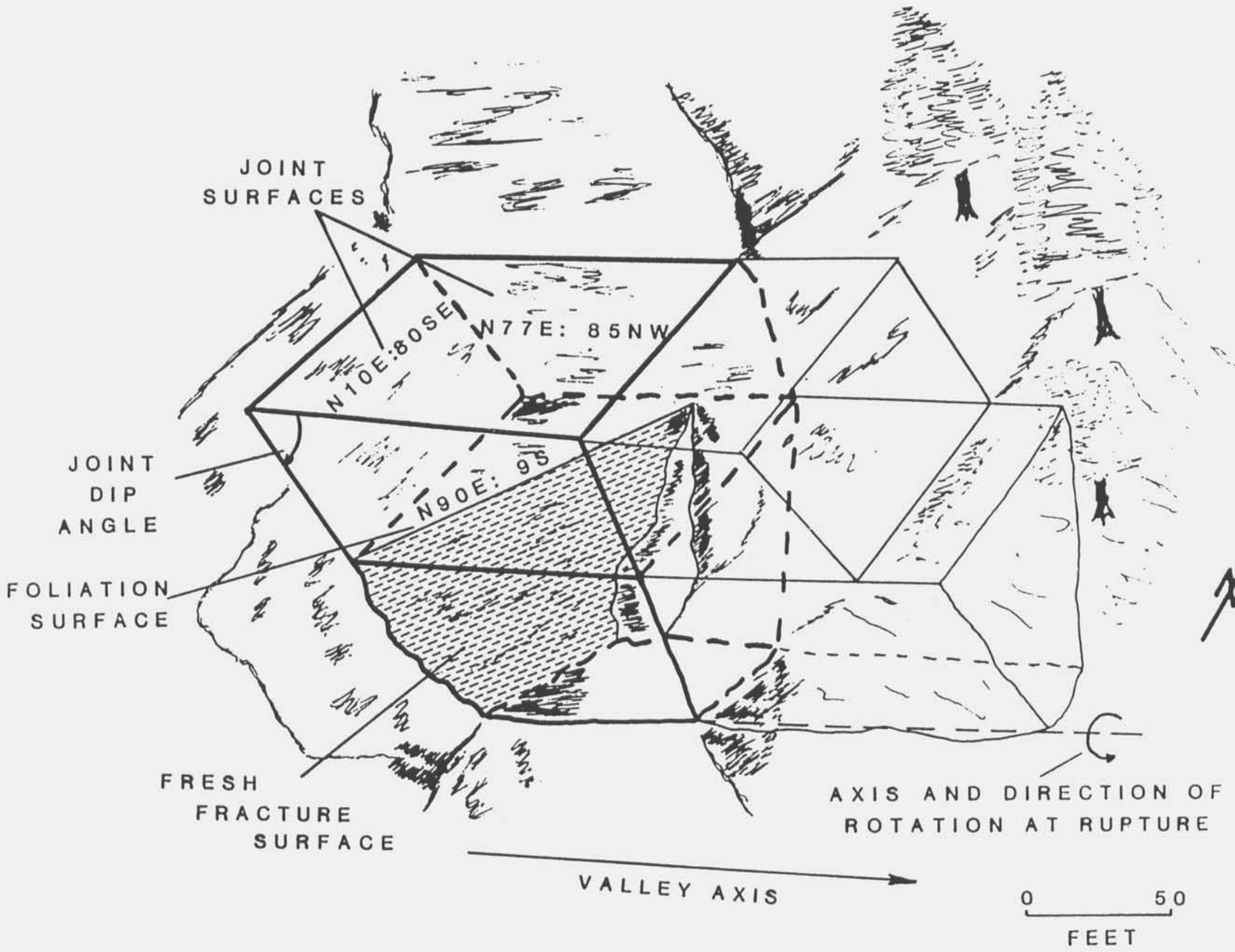


FIGURE 2

Schematic reconstruction of the composite block of schist at Smugglers Notch involved in the rockfall. The original block broke into several fragments on impact. Heavy lines indicate the outline of that portion of the reconstructed block as determined from measurement of the newly exposed joint faces and fresh fracture surface in the remnant scar area. The area encompassed by the scar alone cannot account for the large number and size of the fragments found in the slide area. Light lines show the reconstructed portion of the block that extended to the east as a cantilevered mass. In addition, some of the large blocks have deeply weathered faces suggesting that a large portion of the original block was free and exposed to weathering for a considerable length of time.

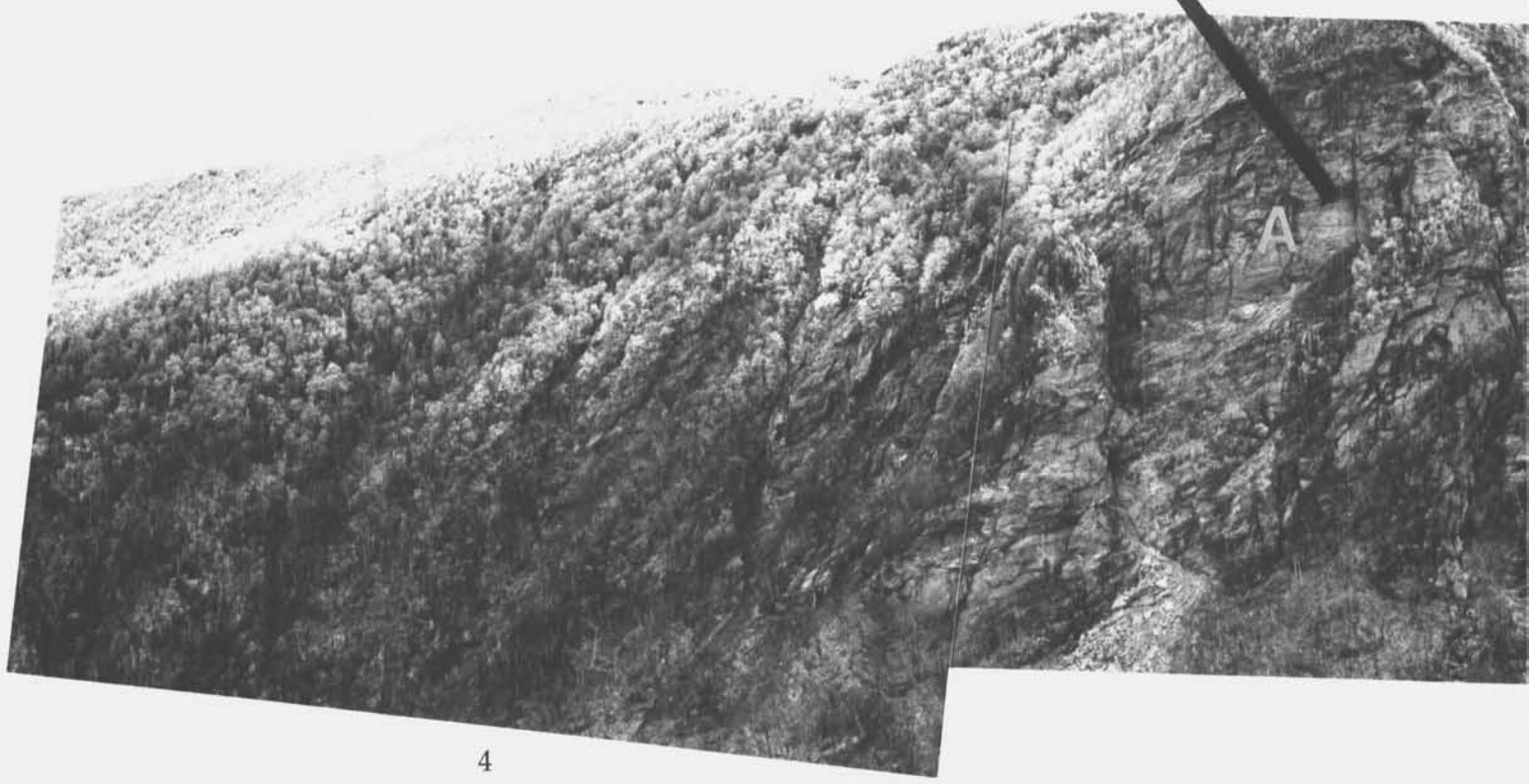
Plate I

Panorama of the west wall of Smugglers Notch, Mount Mansfield, Cambridge, Vermont. All views looking west. Photographs taken in October 1987.

A. Typical wedge shaped block formed by intersecting joints. The position of this block on the west wall of Smugglers Notch is shown at Location A on the panorama.

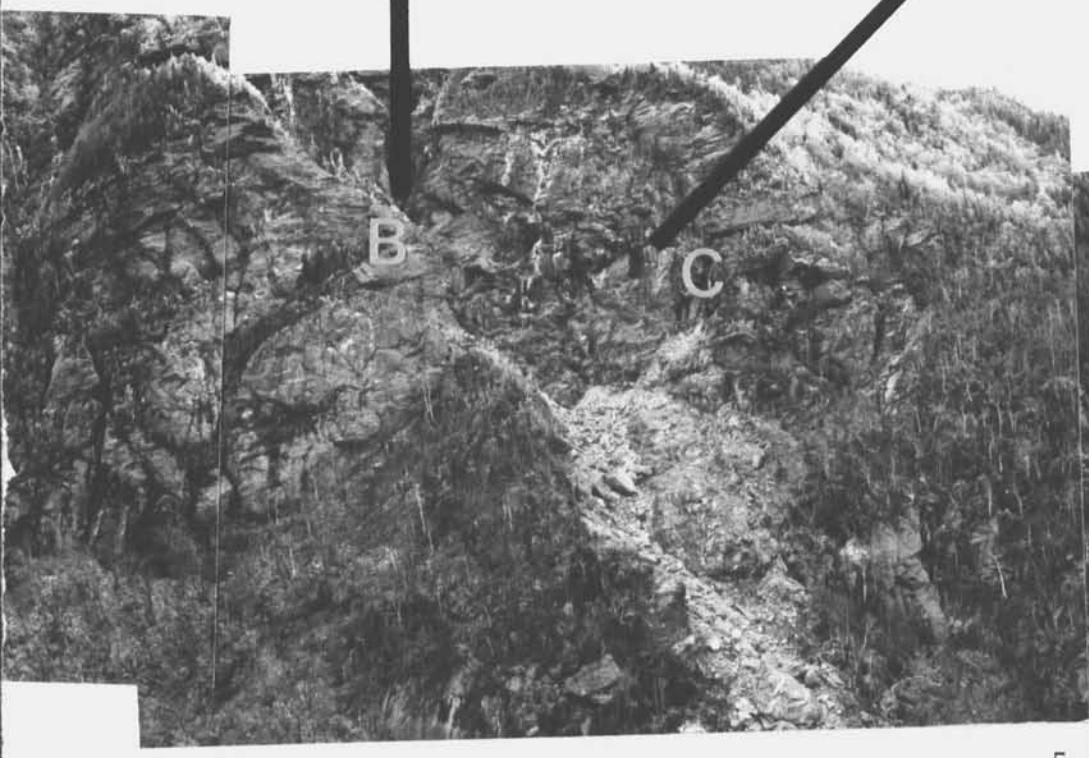
B. Cleft (fault) in the west wall of Smugglers Notch at the head of the tributary valley in which the rockfall/debris slide occurred. The position of this cleft is shown at Location B in the panorama.

C. Scar at the site where the failed block of the July 13, 1983 rockfall originated. The position of this site on the west wall of Smugglers Notch is shown at Location C.



B

C



shown on Christman's geologic map (1959) of the Mount Mansfield quadrangle. To the west of Smugglers Notch, the axis of the Green Mountain anticlinorium continues to the southwest; to the east of the Notch, the axis continues to the northeast. The axis of the synform traverses the Smugglers Notch-Mount Mansfield area at approximately N.10°E. for a distance of about 1.5 mi (2.4 km) between the north and south extensions of the Green Mountain anticlinorium (Christman, 1959, plates 1 and 2). This configuration places the west limb of the synform on the same side of Smugglers Notch as the failed block with the foliation dipping gently toward the axis of Smugglers Notch (axis of the synform). Foliation attitudes in the schist near the rockfall site are not constant; variations between a strike of N.90°E. dip 9°S., and strike N.60°E. dip 5°S.E., have been observed.

The failed block was defined by joints and foliation surfaces having attitudes that are common in Smugglers Notch (Plate I C and Figure 2). Strikes and dips of these joint sets and the foliation vary through a range of 5° to 10°. The joint and foliation attitudes of the failed block are shown on Figure 2. The joint system and foliation which define this block establish a prominent fracture pattern which also defines other similar blocks that take the form of crude rectangular prisms. In addition, other common intersecting joint sets combine with foliation surfaces to create wedge-like blocks that take the form of triangular prisms (Plate I A, Location A).

On the west wall of Smugglers Notch (Plate I) a wide range of orientations for the brittle fractures is well displayed. Certain fracture sets are dominant. Several prominent, near vertical, clefts that trend N.85°E. are visible. The cleft in the vicinity of the rockfall (Plate I B, Location B) contains a .5 to 1 in (1 to 2 cm) wide gouge zone and displays numerous, closely-spaced, parallel joints whose surfaces are strongly weathered (rusty oxidation). Also, foliation immediately adjacent to this zone is highly contorted for a width of 1 ft (30 cm). This cleft and others parallel to it are shear zones (faults) that control the development of the narrow, incipient valleys which are tributary to the main, Smugglers Notch valley. Scree deposits that head at the base of these narrow clefts indicate that the greatest rockfall activity occurs in and immediately adjacent to these zones. The presence of intersecting joints, faults and easily cleavable foliation surfaces produce a rock mass of naturally segmented blocks which are highly susceptible to chemical decomposition and mechanical disintegration. The east-southeast exposure and high elevation enhance the instability of this rock mass through increased precipitation and cyclic frost wedging.

DESCRIPTION OF THE ROCKFALL AND DEBRIS SLIDE

Eyewitness Account

Mr. Dan Rogers, a resident of Jeffersonville, was the only witness to the rockfall and debris slide on the morning of July 13, 1983 at Smugglers Notch. Rogers was jogging south from Jeffersonville and was about 100 ft (.30 m) north of the site (toe of the slide) on Vt. Route 108 when the event began. Rogers estimated that perhaps 60 s passed from the moment he first heard what sounded like a ''sonic boom'' until he could hear boulders crashing through the trees at the base of the slope ahead of him (oral communication, 1984). The first sound may have been the smashing of the original block against the valley wall (as discussed below). Mr. Rogers then saw boulders rolling across the road about 15 ft (5 m) from where he had been only moments before ([Morrisville, Vermont] News & Citizen, July 28, 1983).

Field Observations

Because of the cantilevered geometry, the area of the block connected to the rest of the mountain (i.e., along the lower triangular surface and a portion of the base) may have been under high tensile stress and close to the threshold of failure. The surface on which final failure took place did not appear to be a natural joint surface because the fracture was fresh and slightly irregular (Figure 2). The large block traveled diagonally (southeast) across the small tributary valley colliding with the opposite wall at an elevation about 50 ft (15 m) lower and broke into many smaller fragments ranging from 1 to 1100 yd^3 (1 to 850 m^3) in volume. Two large blocks remained in the slide channel near the point of impact of the original block with the wall, and other large blocks, one 1100 yd^3 (850 m^3) in volume and weighing about 2550 tons (23.1×10^5 kg), stopped a little more than one-third of the way down the slope (Figure 3 and Cover Photo).

As other large fragments tumbled down the 42 degree slope, they broke into smaller pieces and scoured the soil, trees, and other vegetation in their paths. At this stage, the moving mass acquired the characteristics and proportions of a debris slide (Varnes, 1978). The main mass of the debris slide lost momentum as it was slowed by a 20 to 50 ft (6 to 15 m) high thicket of yellow birch that formed a protective buffer upslope from Vt. Route 108 (Cover

FIGURE 3

Photograph of the 2550 ton (23.1×10^5 kg) block that stopped about 1/3 of the way down the slope of the tributary valley in which the failure occurred. This block is visible in the Cover Photo.

Photo). Two boulders, one about 5 tons (4500 kg), the other 26 tons (23,600 kg), plowed through the trees leaving two distributary tracks trending east and northeast and branching away from the main debris chute. These boulders came to rest in the yellow birch thicket. A small boulder slightly damaged the roof of the tourist information booth north of the slide channel. At least two other boulders knifed through the trees and bounced across Route 108 leaving several large holes in the pavement. They came to rest in the parking area on the east side of the road. Two additional large blocks created a major distributary channel oriented in a southeasterly direction and came to rest about 25 ft (8 m) from the west side of Vt. Route 108. These two blocks were estimated to weight 550 and 1200 tons (5 and 11 x 10^5 kg) with volumes of 240 and 510 yd^3 (190 and 390 m^3) respectively. The width of the slide chute at the 2300 ft (700 m) level measured 120 ft (37 m). The chute is somewhat wider above the 2600 ft (792 m) level and flares into two easily discernible distributaries below 2300 feet (700 m) (Cover Photo).

OTHER PHYSICAL CONDITIONS AT THE ROCKFALL SITE

We cannot at this time make a definitive judgement regarding the ultimate destabilizing event that caused the rockfall. Given the naturally highly unstable condition of the block, a slight disturbance such as expansion induced by diurnal heating could have caused the final break.

Frost wedging: The cliff on which the failure occurred faces east-southeast and is subject to diurnal temperature changes from above freezing to below freezing for nearly half the year. Annual freeze-thaw cycles are likely to be the greatest on southerly facing slopes at this altitude. Average daily temperatures were at or below freezing at the high altitudes of Smugglers Notch for at least 183 days between September 1982 and May 1983, the average maximum temperature for this period was 37° F (3° C), and the average minimum temperature was 23° F (-5° C) (National Oceanic and Atmospheric Administration, 1982a-d and 1983a-e). Temperatures were above freezing after this time, and were the highest during the month of July (NOAA, 1983f; Montpelier Flight Service Station weather records).

The north face of the failed block was bounded by an open joint, as indicated by its weathered surface. The west end of the block had a weathered upper surface, indicating that it had been open to receive water and was likely subjected to frost wedging. The lower west surface was an irregular fresh break that developed at the time of rupture (Figure 2). The freezing of water in the joints surrounding the block during the September-May period each year added stress throughout this joint system and, through time, had weakened the attachment of the lower west surface to the cliff face.

Hydrostatic pressure: At times during the period of this study, i.e., following rainstorms or during periods of melting snow and ice, water ran down the exposed joint faces where the failed block had rested. This phenomenon is apparently common (note the stained joint surface shown in Plate I C). Water in joints or tension cracks, when confined, exerts pressure that increases linearly with depth within the cracks (Hoek and Bray, 1977). The force is small when a small area of rock is examined, but the water force can be large when very large areas (many square yards or meters) are involved (Hoeck and Bray, 1977).

Mr. Edward Salvas of the WCAX-TV transmission and weather station on Mount Mansfield, approximately 2 mi (3 km) south-southwest of the rockfall site (Figure 1, TV Station), stated that rainfall of 3 in (8 cm) or more commonly triggers mud and rock slides of varying proportions on the mountain (personal written communication, 1984). Mr. Salvas reported no precipitation on July 13, 1983 over Mount Mansfield. Whether or not water was ever confined in the open fractures surrounding the failed block is not known. It is quite unlikely that such conditions (hydrostatic pressure in joints) prevailed during the first few days of July 1983, however, water draining from the open, weathered fracture system may have moved small amounts of supportive material.

Root wedging: Although there is no direct evidence that wedging action of root growth was a significant factor in loosening the block that failed at this site, trees and other vegetation are growing in the vicinity of the joint surfaces. Dapples (1959, p. 148) points out that ''Although some prying action [by root growth] . . . may occur the primary action appears to be one which permits water to permeate the joint''. Thus root growth in joints undoubtedly aids water entry by keeping fractures open. Root growth in joint openings associated with the rockfall may have had an important influence in joint propagation and weakening the attachments of the failed block with the cliff face.

RECOMMENDATIONS

Smugglers Notch is a scenic, tourist and recreation area. Slope failures of the type described in this

report are potentially life threatening. Prediction of future landslide events in this area requires detailed consideration of many variables (e.g. climate, joint configuration, weathering rates). Data are lacking to establish any sense of the frequency of occurrence of past slope movements in Smugglers Notch. Numerous overhanging, joint-bounded blocks appear to be perched and ready to break away from the cliff face. These blocks provide an opportunity to study the mechanics of rock-slope failures. Instrumentation such as extensometers and other types of strain gauges could be used to record the effects on these blocks of freeze-thaw action (frost wedging), hydrostatic pressure, and any seismic activity set up by wind and earthquakes. Microseismic instrumentation might be applied to detect ''rock noise'' to determine the nature (location, frequency, magnitude) of instability, i.e., if existing joints are opening or if new fractures are forming (Stateham and Merrill, 1979 and Goodman, 1980). Because of the inaccessibility of most of the steep, cliffy area, photogrammetry may be a successful technique for monitoring the frequency and location of rockfall activity. Methods of remote detection of block movement should be explored. Efforts should be made to maintain a close observation of the direct relationship between local weather conditions and slope failure.

ACKNOWLEDGEMENTS

This report is the result of work done as part of a project to study slope stability problems in Vermont. The project is jointly funded by the U.S. Department of Interior, Geological Survey, and the State of Vermont, Agency of Natural Resources, Office of the State Geologist.

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