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Rock falls from Glacier Point above Camp Curry, Yosemite National Park, California

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(Cover photo: June 13, 1999 rock fall above Camp Curry taken by climber Lloyd DeForrest, used with permission)

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Abstract

A series of rock falls from the north face of Glacier Point above Camp Curry, Yosemite National Park, California, have caused reexamination of the rock-fall hazard because beginning in June, 1999 a system of cracks propagated through a nearby rock mass outlining a future potential rock fall. If the estimated volume of the potential rock fall fails as a single piece, there could be a risk from rock-fall impact and airborne rock debris to cabins in Camp Curry. The role of joint plane orientation and groundwater pressure in the fractured rock mass are discussed in light of the pattern of developing cracks and potential modes of failure.

Introduction

A series of rock falls (table 1) from an elevation of about 5500 ft on the north-facing wall of Glacier Point (fig. 1) have threatened employees and visitors to Camp Curry. No previous historic rock falls have been recorded from this release area (Wieczorek et al., 1992). The release area is slightly above the glacial trim line of Matthes (1930) for the Tioga glaciation and these rocks have been exposed to weathering for more than the last 1 million years. The arch-like rock mass involved in this rock-fall event was composed of granodioritic and tonalitic rocks from a unit included in the Sentinel Granodiorite by Calkins (in Matthes, 1930), later mapped as the granodiorite of Glacier Point by D.L. Peck (written commun., 1997). Below the release area this granodiorite overlies the Half Dome Granodiorite along a contact that dips steeply west.

Curry Village was established in 1899 and eventually extended upslope onto two major talus cones which are the result of prehistoric rock falls. Part of the charm of Curry Village is the presence of the cabins amongst huge boulders, the result of prehistoric rock falls. The currently-active release area is above the eastern part of a large composite talus cone behind Curry Village. The lower portion of this cone is an area referred to as the Terrace and contains tent cabins used for seasonal housing for employees.

Sequence of Events

The first rock fall in a sequence (table 1) from the location above Curry Village occurred on November 16, 1998 and had a volume of about 736 yd^3 (1738 tons). The location of some of the various releases from the cliff face are shown in figure 1B. Weights have been calculated using a density of 175 lbs/ft^3. Volume calculations were revised from earlier initial estimates on the basis of subsequent more detailed mapping and scaling using pre-existing photographs, photographs taken subsequent to the rock fall from helicopter, and photos of the release area taken from Stoneman Meadow with a 1000 mm lens (Jim Snyder, 1999). A tree growing along a prominent joint above the release area was used to scale the size of features near the release on the photographs. During several helicopter trips close to the release, we made several attempts to arrive at the tree's height, concluding that it was about 42 ft in height. Size and thickness of blocks in the talus known to have fallen in particular rock falls helped arrive at estimates of average thickness of the failed blocks, perhaps the most difficult and variable measurement.

The block(s) fell 100-150 ft down the the steep (75°) cliff face to a ledge, breaking up against the cliff. From there the rock fell another 950 ft, breaking up more before hitting the top of the talus (fig. 1A). The size and velocity of the rocks were sufficient to knock over and clear many large trees from the upper part of the talus. The rocks continued to bounce, roll, and slide down the talus, their paths determined in part by the distribution of larger boulders from prehistoric rock falls and large trees which either stopped or directed their paths. The rocks that travelled furthest, about 1600 ft from the top of the talus, took a northeasterly direction (fig. 2A). Large rocks reached within about 75 ft of the closest tent cabin (Tent 29), highest on the talus. A profile of the talus is shown on figure 3 with selected locales, such as Tent 29, identified for reference to the rock-fall events.

Smaller, mostly fist-sized pieces of fresh rock were found considerably beyond the limit of the larger rock blocks. The paths of the larger rock blocks could be traced through the forest by noting the trail of crushed vegetation, shattered boulders, and impact craters, whereas the smaller pieces were presumably airborne projectiles from points of impact along the cliff and high on the talus. Although large dust clouds were generated, no airblasts were observed from any of these rock falls, presumably because the rock blocks broke into moderate-sized pieces in impacts along the cliff by the time they reached the talus. The pattern of distribution of airborne splatter or fly-rock zone is shown in figure 2B.

A trigger for the November 16, 1998 rockfall cannot be precisely determined. Minimum daily temperatures fell below freezing for 11 of 12 days before failure. During that same period 2.14 in. of rain fell with 0.40 in. in the 24-h period preceding the rock fall. With the freezing temperatures and the availability of water, there is a strong possibility that the expansion of water in the joints during freezing and of the buildup of pore water pressures during thawing of the ice, weakened the rock mass and triggered the rock fall.

At 9:12 am on May 25, 1999, a much smaller (53 yd^3, 124 tons) rock fall occurred from the same general release area that reached the talus. The rock fall occurred in two parts. The impact from one generated the other, leaving behind a conchoidal-shaped fracture on the lower release. The pattern of distribution of rock onto the talus was similar to that of the November 16, 1998 event, but covering a smaller area (fig. 2A). Rock did not travel nearly as far, the farthest rocks traveling about 500 ft. Similarly the zone of airborne splatter was confined to a smaller area on the talus. No well-defined trigger for the May 25 event could be assigned, for there had been only a trace of rain several days before and no observed seismicity in the Yosemite Valley. Likewise ambient temperature change during the day is not a logical trigger for these rock falls since the timing of the events (table 1) does not fit a clearly defined pattern.

On June 13, 1999, an intermediate-sized rock fall of about 279 yd^3 (660 tons) occurred that killed one climber and injured two others who were climbing along a route beginning near the top of the eastern talus cone at Curry Village, immediately below the release area. The travel of rocks along the talus and airborne splatter of rock was again very similar to the previous observed distributions, extending to nearly the limits of the November 16, 1998 event (figs. 2A and B). Some of these airborne splatter pieces reached the tent cabins and, falling at steep angles, pierced the canvas tops, broke beams, and fell to the floor. Two of the larger projectiles, approximately the size of a football, pierced the canvas roofs of Tents 28 and 36.

Following the June 13 rock-fall event, the National Park Service (NPS) and U.S. Geological Survey (USGS) began monitoring the release area (fig. 4) by helicopter and on the ground using a telescope for development of cracks, new failures, patterns of seepage, and other changes possibly related to inherent instability. Comparing observations on the mornings of June 15 and June 16, a series of new extensional fractures and fine hairline cracks in fresh rock was noted indicating an area of potential instability (fig. 5) below the November 16 release. These new fractures accompanied a small rock fall (13 yd^3; 31 tons) from the November 16 release area that was heard about 10:13 pm (June 15) throughout the Yosemite Valley. The exposed thickness of exfoliation sheets at this site suggests that the thickness of the unstable mass could range from 3 to 6 ft thick. If the entire unstable mass failed as one single piece (at the same time), assuming a 3-ft thick section, then the resulting volume would be about 266 yd^3 (628 tons). The volume of a future potential rock fall of 266 yd^3 is roughly comparable to the estimated volume of the June 13, 1999 event (279 yd^3); hence, the area likely to be affected would be within the boundaries of the impact and flyrock zones of that event.

Beginning with the June 13, 1999 rock-fall event and the development of cracks related to potential future instability, a large portion of the Terrace and some other adjacent parts of Curry Village were closed. In all 77 employee tent cabins and about 132 guest tents and cabins were evacuated within the closure area. The November 16, 1998, June 13, 1999, and June 18, 1999 closure lines in Curry Village are shown with respect to the locations of cabins and the flyrock zone by Snyder (1999).

On June 17 another small rock fall occurred which again was correlated with further extension of fissures and new hairline cracks observed subsequently. There were some crack extensions noted on June 18, but no accompanying rock fall. Observations from helicopter on June 19 confirmed that not only were new cracks appearing, but those that were noted on the previous days were judged to be enlarging. In the evening of June 19, sounds of popping, presumed to be the sound of rock cracking, were heard. Similar sounds were noted a day prior to a rock fall along the Upper Yosemite Falls trail in November of 1980 (Wieczorek and Jäger, 1996).

The process of crack formation and propagation began to show signs of slowing on June

24. Only very small and occasional rock falls and very limited additional cracking were reported between June 26 and July 8, when there was a slight increase in rock-fall activity between July 8 and July 14. Two small rock falls on July 14 followed an afternoon thunderstorm on July 13; this was the first rainfall in the valley since the June 13 rock-fall event, raising the possibility that the presence of water, and in particular, high pore water pressure developed in partially open joints may have played a triggering role.

Influence of Geologic Structure

Building upon the foundation of rock mechanics, the study of rock fracture mechanics has in the past several decades made significant progress in understanding and analyzing different modes of fracture and the propagation of cracks. However, the role of discontinuities and other details of geologic structure and their influence on crack propagation and slope stability remains a complex and poorly understood subject, not presently amenable to sophisticated analyses developed for more homogeneous rock masses. The following statement by Whittaker et al. (1992) summarizes the present state of understanding of rock fracture mechanics in discontinuous jointed rock masses:

> Rock excavating activities can alter the rock slope equilibrium sufficient to cause stress redistribution, stress and energy magnification, discontinuity dislocation and the generation of new fractures. Stable or unstable fracture propagation may occur, leading to the failure of excavated rock structures and slopes. *However, the fracture mechanism of a discontinuous jointed rock mass is generally not clearly understood.*

In addition to the plane of the steeply dipping exfoliation joints (J1) parallel to the cliff face, the site of the rock-fall releases and developing cracks is dissected by five other joint sets (J2-J6) shown in figures 4A, B. Characterization of the orientation of these joint sets (table 2) is approximate because of the inaccessibility of the site; estimates of the orientations of joint planes were made from stereo photographs made from helicopter, and from photographs taken from Stoneman Meadow with several cameras and telescopic lenses.

The sheet or exfoliation joint set J1 closely parallels the cliff face. Sheet structures typically form in environments of high differential stress, particularly upon vertical unloading of a rock mass that formed at depth under high triaxial compression and is now exposed at the surface due to uplift and erosion. Individual exfoliation sheets thicken perpendicular to the topographic surface of the rock mass and sheets tend to be thinner in fine-grained rocks than in coarse-grained rocks (Holzhausen, 1989). Gilbert (1904) noted that sheet structure in the domes of the Sierra Nevada tends to parallel all topographic surfaces and that the separation of sheets penetrated to depths between 50 and 100 ft perpendicular to the surface. At this rock-fall release the thickness of the most exfoliation sheets visible on the cliff surface, probably ranges only from 3 to 6 ft thick.

The most prominent joint set J2 is a pervasive ledge-forming discontinuity which dips steeply to the east and is oriented similar to the set of discontinuities forming the Staircase Falls, the abandoned "Ledge Trail" beginning behind Curry Village, and a prominent ledge from just above the release running towards Glacier Point (fig. 2). The prominent and continuous joint sets, J2, J5, and J6, can be followed for long distances on the face of Glacier Point (fig. 4A). Nearer the release, a few other discontinuous joint sets, J3 and J4, are also visible (fig. 4B). The "roof" of the November 16, 1998 release forms a crude arch with the intersection of J2, J5, and J6 (fig. 4B). This pattern of "roof" approximates a rough joint-defined arch which is repeated in many places on the face of Glacier Point, most closely about 150 ft to the west of the recent releases, although the dark-stained rock face indicates a collapse that did not occur recently (fig. 4A).

Inspection of the cliffs below Glacier Point in the vicinity of the release and stereoscopic analysis of the joint set orientations (table 2) using the ROCKPACK II software package (Watts, 1994) indicates that none of these joint planes or joint plane intersections form plane or wedge conditions favorable to sliding or toppling because the direction and inclination of the cliff face. The lack of plane or wedge conditions favorable to sliding on the north face of Glacier Point is due to the orientation of the joint sets (J2-J6) which dip either due east or west, with respect to the orientation of the cliff face which is roughly perpendicular to these joint sets (J2-J6) and dips due north. These conditions do not apply to the east face of Glacier Point, where abundant potential plane and wedge failures exist due to the direction of joint sets and their intersections along the east dipping slope face of Glacier Point (Gilliam, 1998). The orientation of joints and cliff face along the east side of Glacier Point led to a massive rock fall above Happy Isles in July of 1996 (Wieczorek et al., in press).

The joints and their intersections at the release points on the north face of Glacier Point define the top and lateral boundaries of the rock-fall releases of exfoliation sheets that split along these joints and their intersections. Thus joint sets (J2-J6) on the north face of Glacier Point do not form the surface(s) along which sliding occurs, but these joint sets do determine the size of exfoliation sheet segments that fail.

With exfoliation joint set J1 closely paralleling the very steep slope face, a slight variation in the degree of dip of either the exfoliation sheet or the slope face could affect the distribution of stresses and the local stability of the rock mass. If the exfoliation sheets dip less steeply than the cliff face, then the exfoliation sheet tends to "daylight" in the cliff face, a condition favoring sliding along exfoliation joints. If exfoliation joints dip more steeply than the cliff face, then toppling would be the favored mode of failure. If the exfoliation sheets parallel the face, then neither sliding nor toppling are favored, but a vertical load would tend to buckle, open and separate the exfoliation sheets. Extension of joints may also occur due to concentration of loads at the tip of joints. The relatively thin (3-6 ft-thick) sheets, make flexural bending and opening between sheets more likely as the height of exfoliation sheet segments increase. The maximum height of the exfoliation-sheet segment forming the November 16, 1998 collapse was about 50 ft, approximately a 10:1 height to thickness ratio. Generally it is not possible to tell the extent to which the sheets are attached and maintain connections along their backsides. The extent to which the sheets are open not only affects the strength of the sheets and local stability, but also influences the patterns of groundwater flow through the jointed and fractured system and the development of high pore water pressures in partly open joints.

Groundwater and Cleft Pressures

The presence of water issuing from the release areas following the June 13, 1999 rock fall suggests that groundwater flowing along joint surfaces and possibly backed up in any partially open joints could have increased pore water pressures (cleft pressures), further weakening the rock mass to trigger the rock failure. In general, the presence of water in rock causes chemical weathering which gradually reduces the strength of the rock (Robertson, 1986). The expansion caused by freezing of groundwater can also act to weaken rock masses by widening the opening of joints, propagating extension of tight joints, and reducing the cohesive strength of the rock mass.

Some of these seeps in the release area dried up in the days following rock-fall events, suggesting that the flow of water through the joints had been impeded and then released by the failure; once released the flow of water quickly decreased. Most of the water appeared to be emerging from the intersection of the exfoliation joint set J1 with joint set J2, the thoroughgoing main ledge-forming joint set that proceeds towards Glacier Point. The process of spring snowmelt can be slow and gradual, perhaps taking weeks or months, but the flow of water through open joints and coarse sandy grus, a byproduct of decomposition of the granodioritic mass, could be relatively rapid. According to field reconnaissance and inspection of the contours of the 1:24,000 Half Dome topographic map, no well defined catchment area near Glacier Point feeds this rock-fall release area. The peak of runoff of the Merced River in late May and early June suggests that the two rock falls of May 25, and June 13, 1999 were possibly related to the buildup of pressures in joints from infiltration and fracture flow from spring snowmelt, but it is not possible to better substantiate the timing nor the magnitude of the cleft pressures. The timing of the initial November 16, 1998 rock fall does not fit the pattern of influence from spring snowmelt; however, it does fit the freeze-thaw pattern of early winter storms with temperatures alternating above and below freezing in the days preceding the event.

An afternoon thunderstorm in Yosemite Valley on July 13 caused noticeable changes in the locations and amounts of water flowing from joints at the site in the subsequent days (July 14-15). Quite possibly two small rock falls on July 14 (9:57 am and 8:20 pm) and a short crack noted on July 14 are attributable to the rapid buildup of groundwater cleft pressures in joints caused by the infiltration and flow of water through the jointed rock mass from the thunderstorm. The triggering of a rock fall in Yosemite by an increase in cleft water pressure in a joint during an intense rainstorm has been previously documented (Wieczorek and Jäger, 1996, p. 23). In the rainless days following July 15 without additional rainfall, the rate of water issuing from the seeps notably decreased; however, internal seepage through the jointed rock mass never completely ceased.

Crack Development

The pattern and timing of cracks that developed below the rock-fall releases may indicate something about the present stability of the mass, and the mechanism of how it will eventually fail. The cracks appear to be of three apparent types: 1) shear, and 2) tension cracks exposed in the plane of the exfoliation sheet that are in the process of splitting the top exfoliation sheet, and 3) parting or opening cracks that indicate separation between successive exfoliation sheets in the plane perpendicular to the slope face. These cracks are concentrated in a roughly rectangular area of about 60 by 75 ft with a center section devoid of cracks. This center section is an exposure of an exfoliation plate extending behind the two sections to the east and west as an apparent "window" into the deeper exfoliation sheet (fig. 5).

Using the length of new shear and tension cracks detected since June 14, we compared the percentage length of new cracks formed during each 48-hr period. This rate of crack propagation fluctuated widely although some of the variation could be attributed to the selected time intervals and to observational difficulties. Initially, the rate of crack propagation rate was high during the June 13-14 period, but gradually decreased during the following week. The rate again increased dramatically during the period of June 20-22. Between June 22 and 26 the rate of new crack formation notably decreased. Subsequently, only a few very short additional cracks have been detected, although a spike of small rock-fall activity and a few short cracks occurred between July 8 and 14. The pattern of the propagation of cracks with time in shown in fig. 5B.

The questions of how the cracks formed and how to interpret the pattern and timing of cracking are difficult to answer due in part due to the inaccessibility of the site and the complexity of the jointed rock mass. Although the development and propagation of cracks associated with exfoliation sheets in Yosemite has been examined by Bahat et al. (1999), the present configuration of several types of cracks not developing along joint planes is distinctly different. One possibility to explain the initiation of cracking, suggested by small fragments of rock missing from the face, is that impacts from the June 13 and June 15 rock falls hit the area below the release and initiated cracking. Another possibility is that changes in the loading conditions at this site caused the initiation and propagation of cracking. The large previous rock falls, particularly the events of November 16, 1998 and June 13, 1999, changed the geometry and structure of the site, probably causing a redistribution and concentration of stresses. The primary load can be assumed to be principally vertical and the stresses in the rock mass chiefly compressional along a steep, nearly planar rock face near the releases. The distribution of vertical stress on the face would be concentrated at the points above and below the previous releases because of the changes in geometry of the cliff face with the removal of material by rock falls. Compressive forces acting on the relatively thin (3-6 ft) exfoliating slabs could initiate shear cracking and possibly failure. The orientation of many of the cracks at a steep angle of about 60-70 degrees to the horizontal, not aligned with any joint set, is indicative of a pattern of shear under high confining stress. High shearing stresses could induce small movements that could have generated small rock falls, by forcing small fragments from the face. Popping and other sounds similar to rock bursts have been noted from the site during the development and extension of cracks.

The future rate of cracking and connection of individual cracks leading to failure will depend upon the fracture toughness of the rock mass. The dilation brought about by movement along cracks in some materials causes a slight increase in friction angle, strengthening the material. Under the forces of gravity and other external triggers, movement and interconnection of the cracks may continue at the present very slow rate (creep) or resume at a more rapid rate. A more thorough analysis of fracture toughness and of the conditions necessary to cause failure is beyond present capability. Measuring the properties of this remote site and developing models to determine the relative stability of the rock face require direct contact with the near vertical face. Still the analytical techniques currently available to assess the stability of the site cannot yield reliable results reflecting the complexity of the geologic situation.

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Figure Captions

Figure 1- Photographs of rock-fall release areas below Glacier Point (A) north face of Glacier Point (top), area of recent releases (center), and talus above Curry Village, photograph taken in 1984 (NPS, Yosemite National Park, Search and Rescue neg. # 5444). (B) Solid colored lines indicate individual release areas: blue-11/16/98, brown-5/25/99, red- 6/13/99 and yellow-6/15/99 taken from helicopter on June 16, 1999. Dark shaded areas indicate water seeps from joints and cracks. Photograph slightly oblique to rock face with approximate scale as indicated.

Fig. 2. Maps of rock-fall release area below Glacier Point and affected areas in Camp Curry, Yosemite National Park. Maps does not include locations of all structures within Curry Village. (A) Recent rock-fall impact zone near Camp Curry in the Yosemite Valley. Outlines of 11/16/98 (blue), 5/25/99 (brown), and 6/13/99 (red) rock-fall impact zones. Location of profile line A-A' along eastern talus cone shown in Fig. 3. (B) Recent rock-fall fly rock zone near Camp Curry. Outlines of 11/16/98 (blue), 5/25/99 (brown), and 6/13/99 (red) rock-fall flyrock zones.

Fig. 3. Profile (A-A') of eastern talus cone at Camp Curry showing location of selected features on and above the Terrace. Location and representation of trees and boulders is approximate. Location of profile is indicated in fig. 2A.

Fig. 4. Jointing on the north face of Glacier Point. (A) Depiction of major through-going joint sets J2, J5, and J6 on middle of north face Glacier Point. Recent release area is in center of photograph. Photograph taken by Leroy Radanovich for the National Park Service. B) Joint sets J2-J5 (Table 2) identified in photo mosaic of release area below Glacier Point (only a few selective joints are identified) . Joint set J1 is the plane of the cliff face. Photographs taken June 16, 1999 by John Weller, Ansel Adams Gallery and used with permission of the National Park Service.

Fig. 5. Depiction of cracks and their propagation. (A) Photomosaic of releases and area of cracking below Glacier Point. Cracks are shown by red dashed lines. Some selected joints and other structural features are identified by solid red lines for reference. Window notation refers to area of inset exfoliation sheet. Note water seeps over surface of exfoliation sheet J1 issuing from joint set J2 (left). (B) Sketch showing progressive propagation of cracks with time in area below rock-fall releases.

Table 1. Series of reported rock falls near Camp Curry

DATE	TIME	COMMENTS
11/16/98	5:30 pm	A rock fall forced the evacuation of 500 employees and visitors at Curry Village. Minimal damage to some cabins was caused by impact of airborne pieces of rock. Temperatures had been dropping below freezing each night, so freeze and thaw may have played a role in triggering the release.
	10:50 pm	Another rock fall was heard in the same vicinity behind Curry Village. An additional four or five smaller rock falls occurred later that night.
5/25/99	9:12 am	A loud crack was heard and a ranger saw another small flake falling. There was a temporary evacuation of parts of Curry Village for several hours, it was reopened by about noon.
6/13/99	7:35 pm	Rock slide kills one rock climber, injures two others; flyrock reaches the Terrace, hitting Tents 28 and 36.
6/14/99	4:56 am	"Rock activity on Glacier Point Apron"--Yosemite Dispatch
6/15/99	5:30 am	"Small rock fall"--Incident Command Operations Chief
	10:13 pm	Rock fall audible across Yosemite Valley; flyrock damages Terrace Tent 29.
6/17/99	5:42 pm	Rock fall "seemed to be as big as Tuesday night (6/15)"; Terrace Tent 29 hit on downhill side by flyrock.
	5:46 pm	"Relatively small" rock fall with a small cloud of dust reported by perimeter guards.
6/19/99	1:30 am	A perimeter guard "may have heard a couple of rocks falling."
6/20/99	1:24 am	Popping noise from release point.
6/22/99	12:18 am	Perimeter guards "heard a boom like a shotgun blast" at Glacier Point apron.
	10:08 pm	Perimeter guards report "Terrace rock fall, small but consistent.

6/23/99	6:13 am	"Rocks falling last 5 minutes"--Yosemite dispatch
7/8/99	3:48 am	Upper Pines Campground campers report cracking and popping noises, and rock fall loud enough to wake them up.
7/12/99	11:46 am	Yosemite Curry Service Maintenance worker in Terrace reported "15 seconds of rock coming down above the Terrace." An NPS worker in Upper Pines Campground saw the dust.
7/14/99	9:57 am	A backpacker in the Wilderness Parking Lot observed a "large" rock falling from the release point, crashing down to the ledge, then down the ramp, shattering and creating a dust cloud by the time it was three quarters of the way down the ramp. This followed 0.18 inches of rain in an afternoon thunderstorm on 7/13. The rock came from the roof of the June 13, 1999 release. Rainfall from the Glacier Point Apron carried fresh rock fall sediments in a small channel along the cliff face to the Wilderness Parking Lot.
	8:20 pm	Report of 15-20 seconds of rock fall onto the Terrace.
7/20/99	10:50 pm	Report of 10 seconds of minor rock fall
7/21/99	9:53 pm	Rock fall reported

Table 2- Joint sets and their orientations from near the rock-fall release area. Estimates of dip direction and dip amount from stereo photos are approximate due to inaccessibility of site.

JOINT SET	DIP DIRECTION (Degrees)	DIP AMOUNT (Degrees)	COMMENTS
J1	0	70	Exfoliation sheet parallel to slope face
J2	90	45	Smooth, regular, closely spaced
J3	90	90	Infrequent, smooth
J4	90	25	Infrequent, smooth, filled with vegetation
J5	270	10	Regular, widely spaced
J6	270	45	Regular, frequent, smooth


Release
Area
Talus Cone

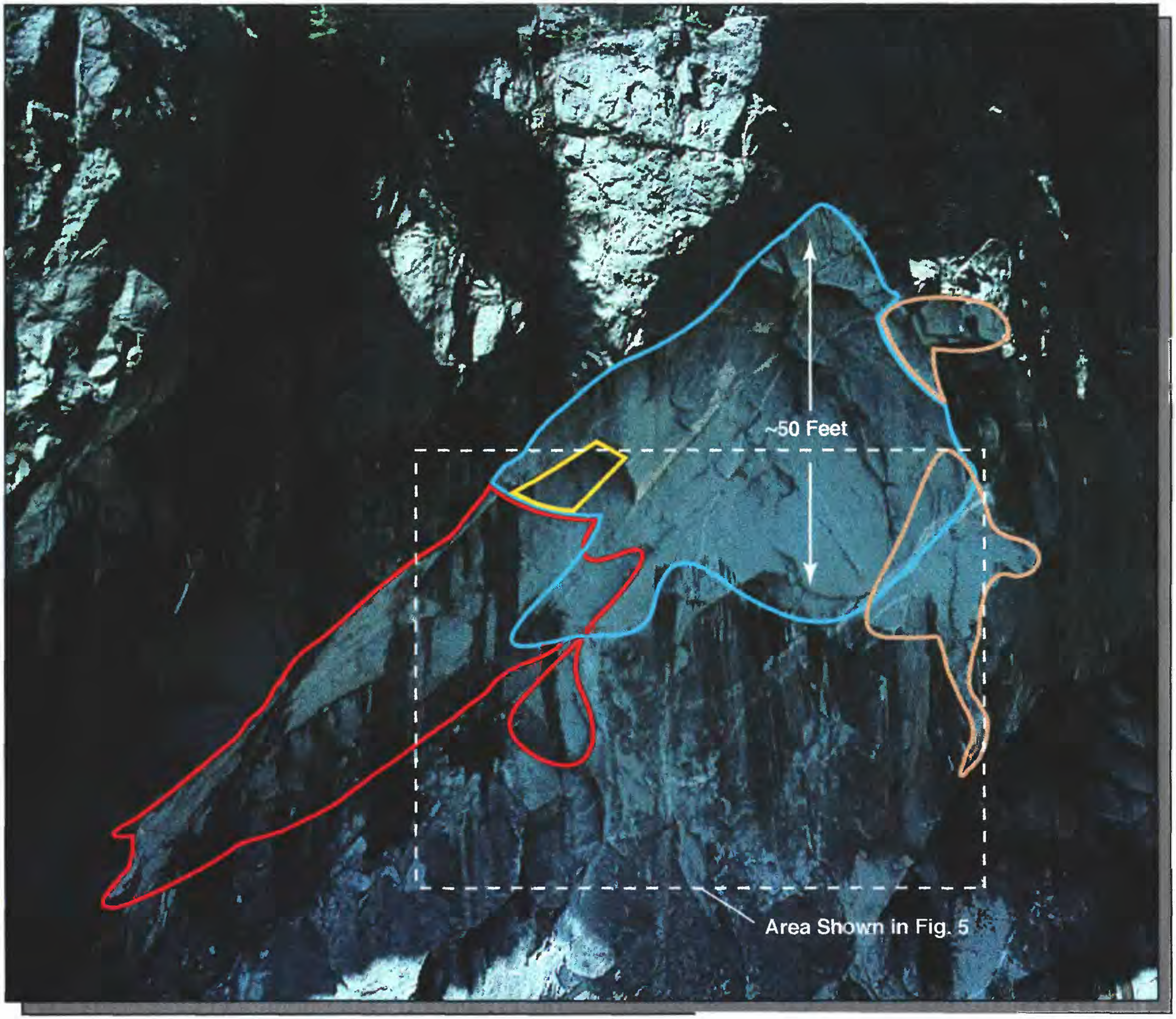


Fig. 1B

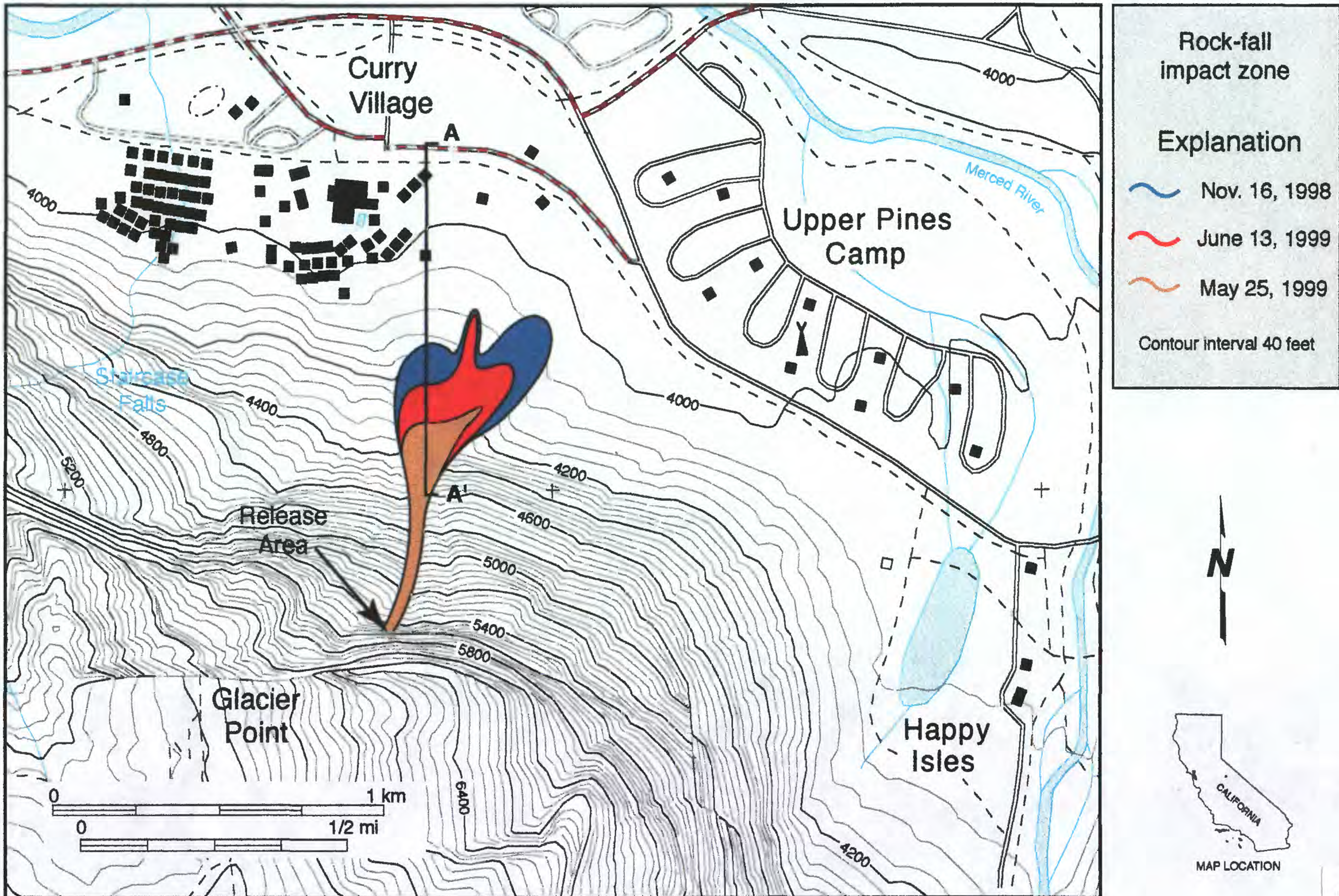

Rock-fall impact zone
Explanation
Nov. 16, 1998
June 13, 1999
May 25, 1999
Contour interval 40 feet
Curry Village
Upper Pines Camp
Merced River
Staircase Falls
Release Area
Glacier Point
Happy Isles
A
A'
4000
4200
4400
4600
4800
5000
5200
5400
5800
6400
0
1 km
0
1/2 mi
N
CALIFORNIA
MAP LOCATION

Fig. 2A

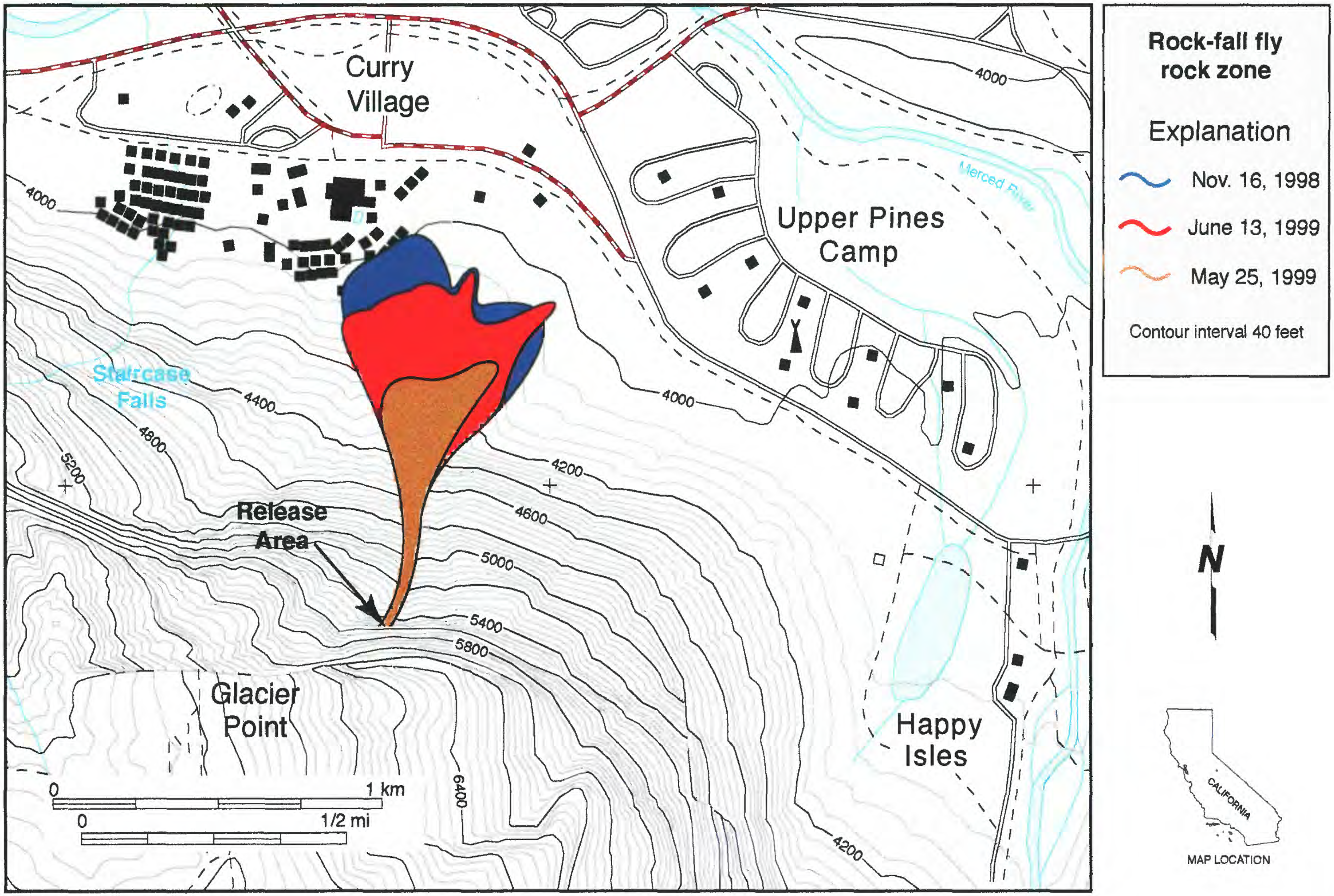

Rock-fall fly rock zone
Explanation
Nov. 16, 1998
June 13, 1999
May 25, 1999
Contour interval 40 feet
Curry Village
Upper Pines Camp
Merced River
Staircase Falls
Release Area
Glacier Point
Happy Isles
4000
4200
4400
4600
4800
5000
5200
5400
5800
6400
0
1 km
1/2 mi
N
CALIFORNIA
MAP LOCATION

Fig. 2B

Fig. 3

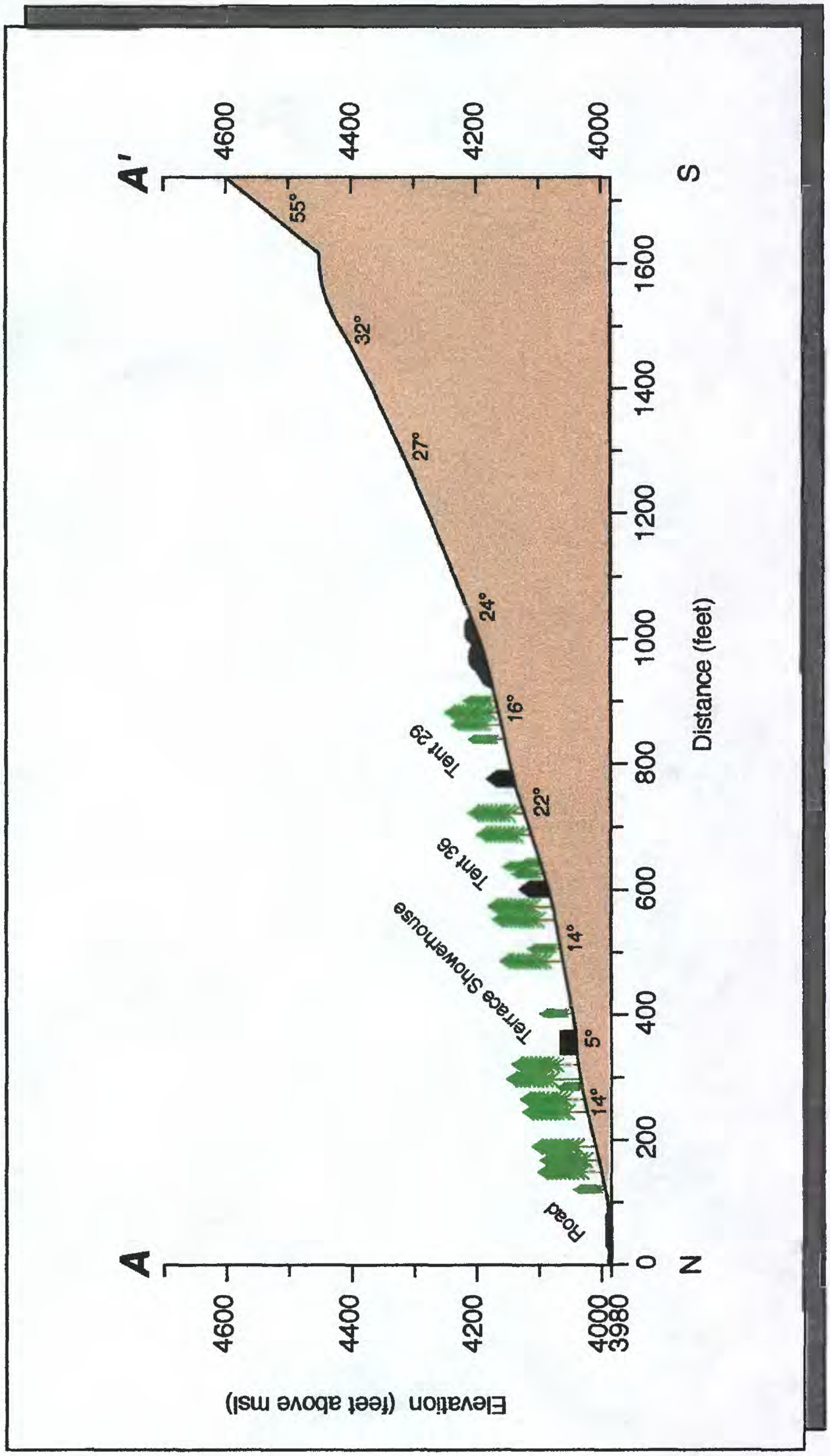
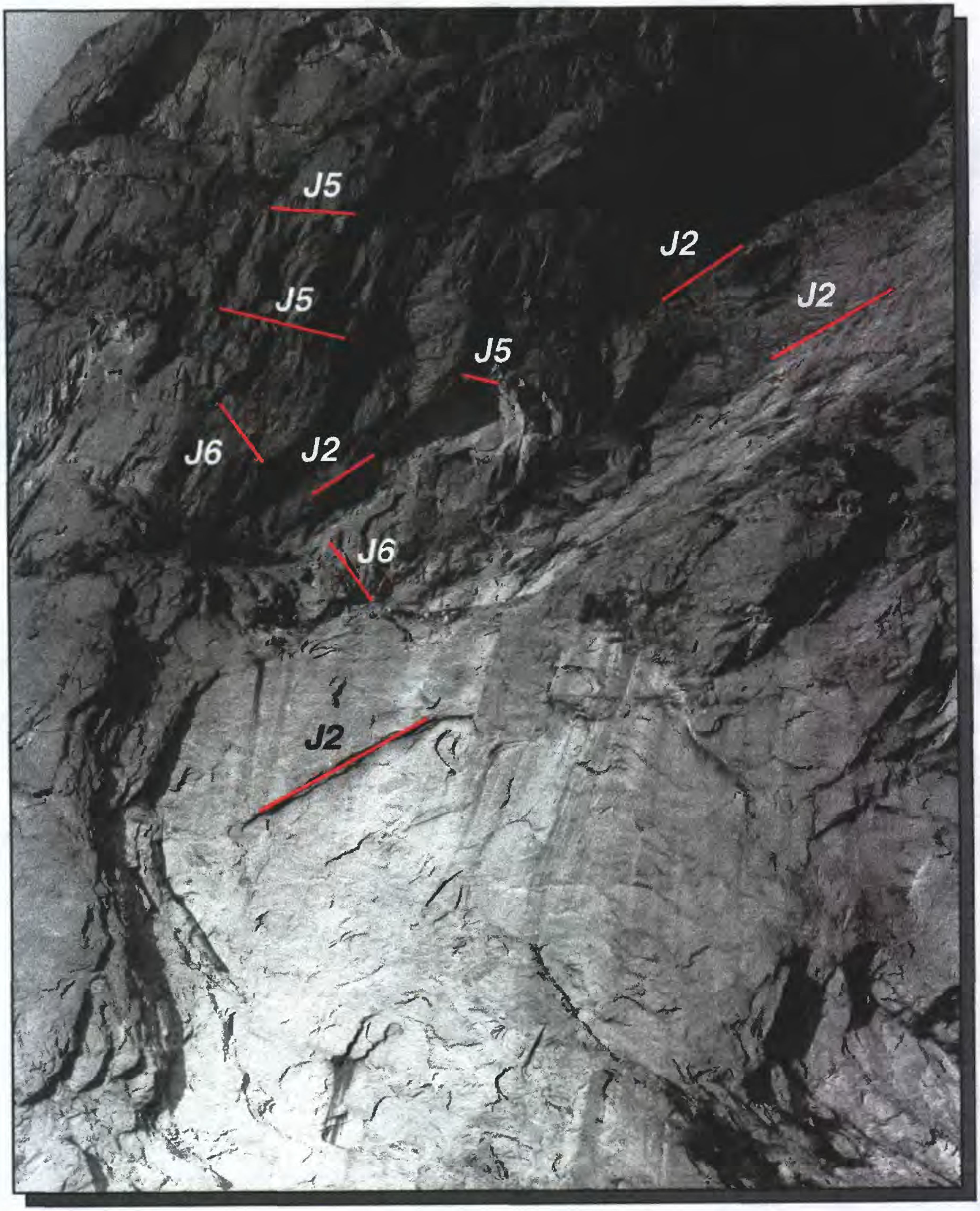
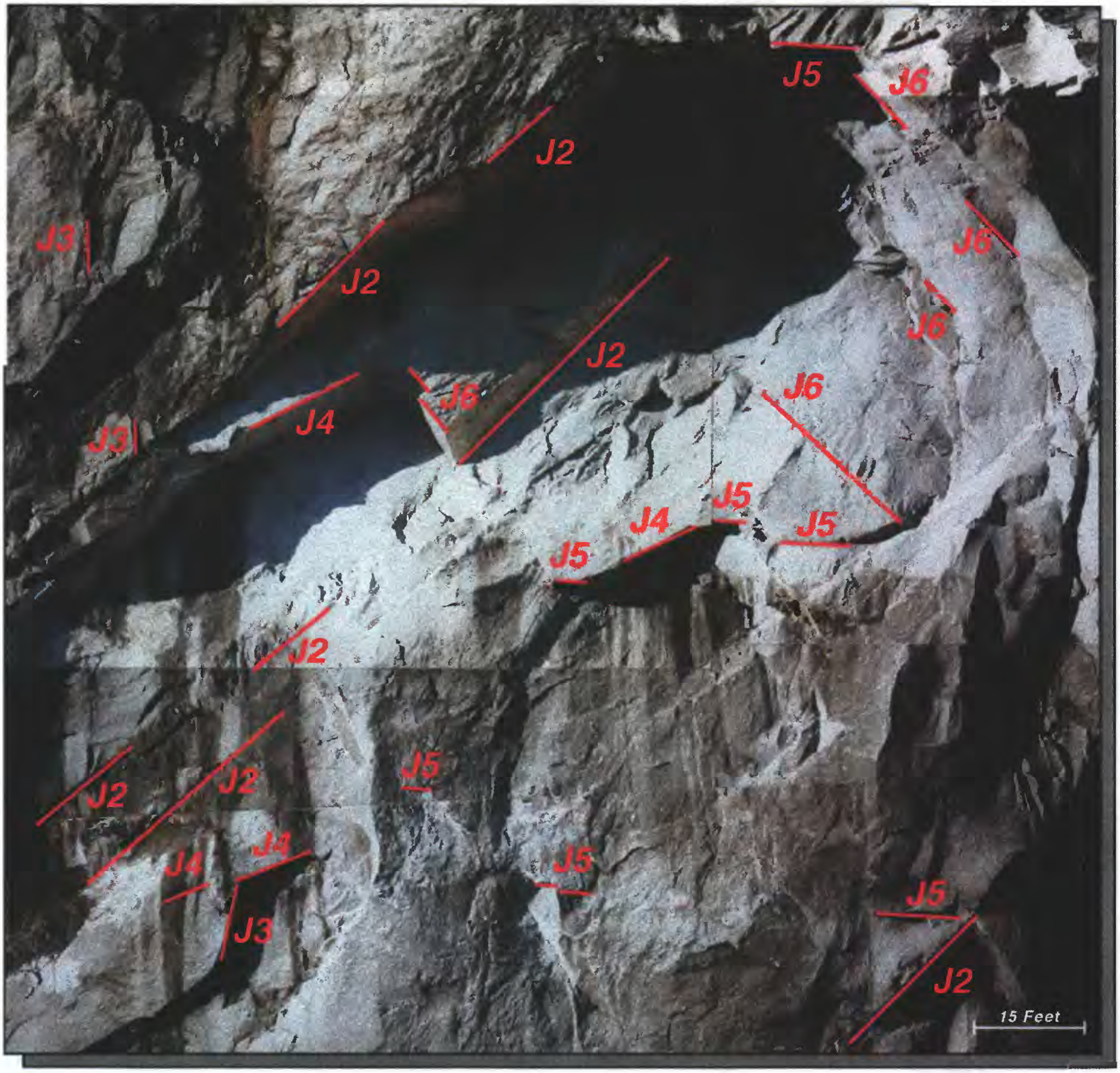

A
A′
Elevation (feet above msl)
4600
4400
4200
4000
3980
Distance (feet)
0
200
400
600
800
1000
1200
1400
1600
N
S
Road
Terrace Showerhouse
Tent 36
Tent 29
14°
5°
14°
22°
16°
24°
27°
32°
55°

Fig. 4A




J5
J6
J2
J3
J2
J6
J2
J6
J6
J4
J3
J5
J4
J5
J5
J2
J5
J2
J2
J4
J4
J5
J3
J5
J2
15 Feet


Joint
Lens
Pegmatite Dike
Roof
Window
15 Feet

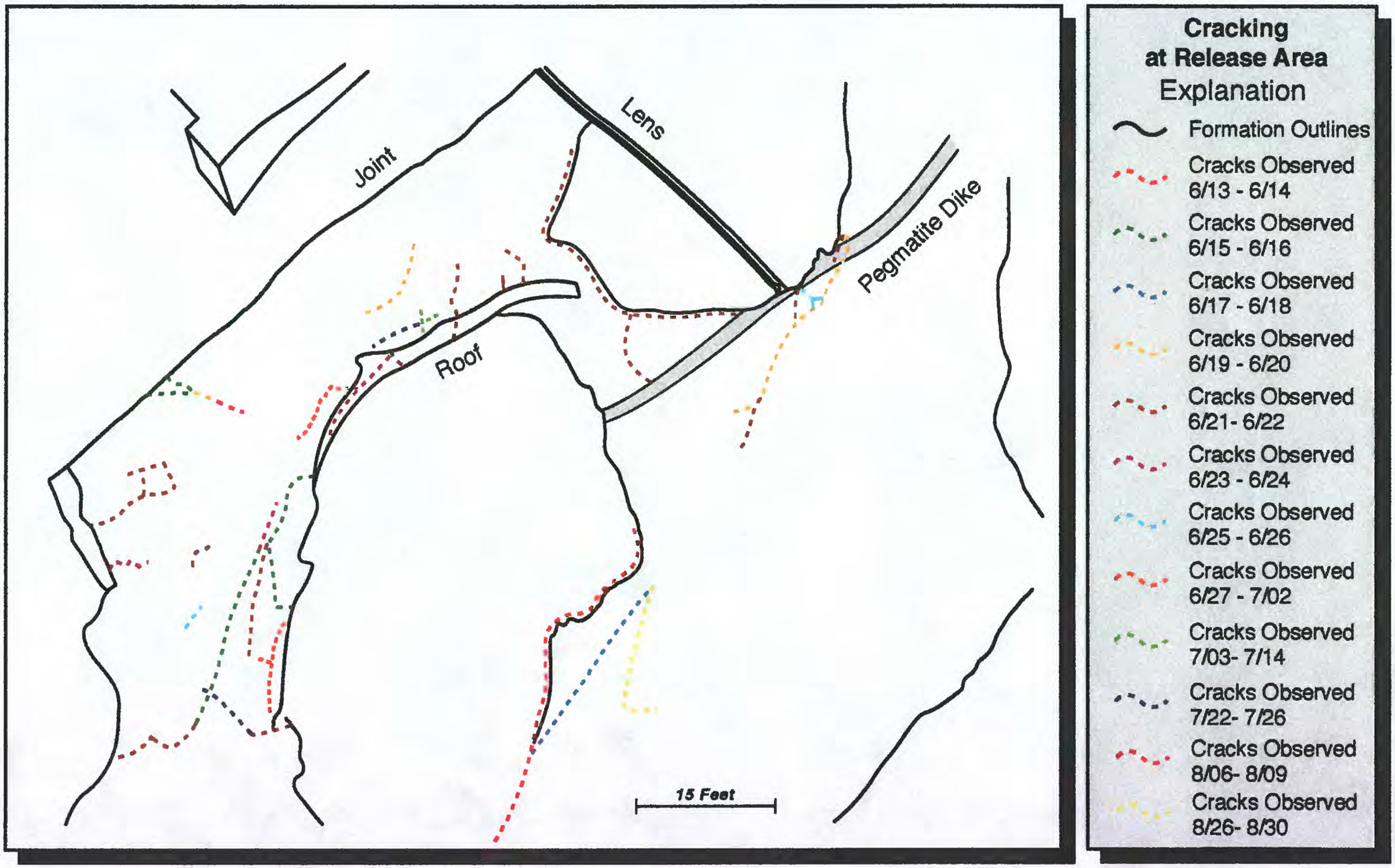

Joint
Lens
Pegmatite Dike
Roof
15 Feet
Cracking
at Release Area
Explanation
Formation Outlines
Cracks Observed 6/13 - 6/14
Cracks Observed 6/15 - 6/16
Cracks Observed 6/17 - 6/18
Cracks Observed 6/19 - 6/20
Cracks Observed 6/21- 6/22
Cracks Observed 6/23 - 6/24
Cracks Observed 6/25 - 6/26
Cracks Observed 6/27 - 7/02
Cracks Observed 7/03- 7/14
Cracks Observed 7/22- 7/26
Cracks Observed 8/06- 8/09
Cracks Observed 8/26- 8/30

Fig. 5B