

GUIDEBOOK *for Field Trips in the*  
NORTHEAST KINGDOM *of* VERMONT  
*and Adjacent Regions*

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## POST-GLACIAL MASS WASTING IN FRANCONIA NOTCH, WHITE MOUNTAINS, NEW HAMPSHIRE

by

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### INTRODUCTION

This trip visits the northern end of Franconia Notch (Fig. 1) for examination of post-glacial mass wasting deposits and landforms, including talus slopes, rock falls, debris flows (landslides), and Profile Lake, which archives historic and pre-historic debris flow sediments.

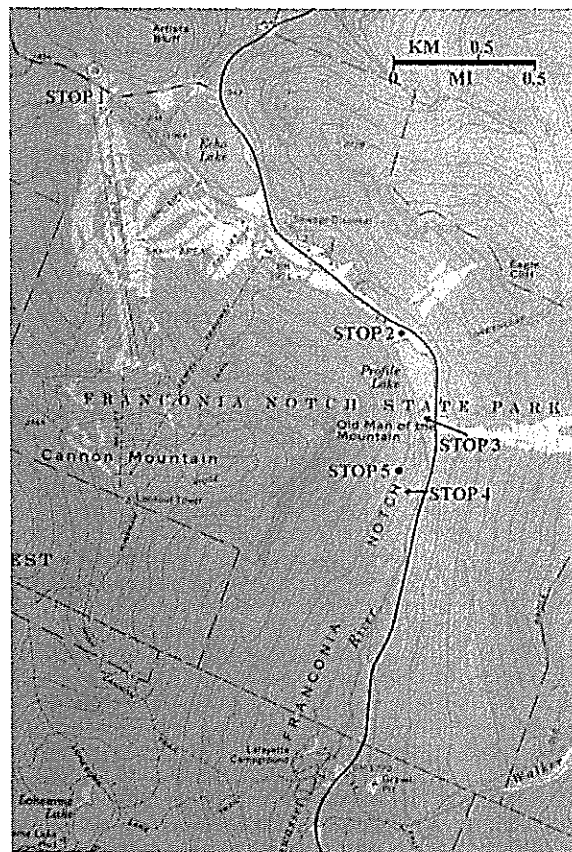


Figure 1. Part of Franconia, N.H., 7.5' U.S.G.S. topographic map showing locations of stops at the northern end of Franconia Notch. Note: this is the 1967 edition of the map, which better shows landslide features, so Rt. I-93 is not shown, although essentially is the same as Rt. 3 through the notch.

At the northern end of Cannon cliff in Franconia Notch (Fig. 1), the rock formation known as the 'Old Man of the Mountain' (Fig. 2) collapsed on 3 May 2003. While this event attracted national media attention, few are aware that on 19 June 1997, a much larger rockfall occurred at Cannon cliff. We will examine debris from both the Old Man rock fall event and earlier events that comprise the talus slope below the cliff. Large debris flows from Mount Lafayette (opposite Cannon cliff) covered old U.S. Rt. 3 with several meters of debris on 23 July 1947, 24 June 1948, and 24 October 1959. These historic slides left diagnostic signatures punctuating Profile Lake's sediment column, which reveal a nearly complete post-glacial record of both historic and prehistoric landslides from Walker ridge and Eagle cliff on Mount Lafayette.

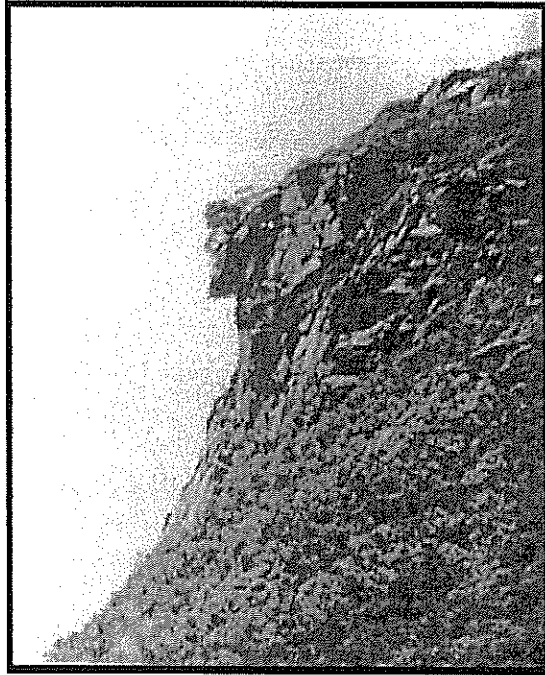


Figure 2. Historic photograph of the 'Old Man of the Mountain' taken from the northern end of Profile Lake on Rt. 3 / Rt. I-93 (R.I.P., 3 May 2003).

#### BACKGROUND ON GLACIATION OF THE AREA

Looking northwest of the White Mountain highland area, it is clear that continental glacial ice had few topographic obstacles interfering with its movement southeastward until it got to the steep northwesterly slopes of the White Mountains. Because continental ice sought the path of least resistance through the mountains, it converged first into the deeper pre-existing passes through the mountains, and continued to flow through them for the entire duration of each glacial episode. As continental ice thickened during each glacial episode, it began to move through the higher-elevation passes and eventually covered all the peaks at least once (Goldthwait, 1970; Waitt and Davis, 1988; Davis et al., 1993, 1996; Davis, 1999; Bierman and Davis, 2000). We know that all of the peaks here were over-ridden at least once by continental ice because lodgment till has been found near the summit of Mt. Washington at an elevation of 1,900 m (6288 ft). Most workers agree that the last pulse of continental ice that affected this area (the late Wisconsinan Laurentide Ice Sheet) arrived here about 25,000 years ago, reached its peak about 18,000 years ago, and had fully retreated from lowlands in the area by about 12,000 years ago. Thompson et al. (1996, 1999, 2009) provide detailed reviews of the evolving deglaciation chronology for the region north and northwest of the notches, based in part on varve and  $^{14}\text{C}$  chronologies for glacial Lake Hitchcock sediments (Ridge, 2004) and  $^{10}\text{Be}$  exposure ages on moraine boulders (Balco et al., 1999).

Franconia, Crawford, and Pinkham Notches, from west to east, are the largest examples of glacial troughs in the White Mountains, and all three are accessible from highways. Other smaller but no less spectacular notches in

the White Mountains include, from west to east, Kinsman, Zealand, Carrigain, Carter, Mahoosuc, and Grafton Notches, some of which are only accessible by hiking trails. Each of these notches was a lower-elevation mountain pass prior to the start of the multiple episodes of continental glaciation during the Pleistocene Epoch. The three larger notches are substantially deeper than other higher elevation notches in the White Mountains because glacial ice moved through them for a longer period of time and/or was more erosive during each glacial episode (Allen et al., 2001).

### THE 'OLD MAN OF THE MOUNTAIN'

The 'Old Man of the Mountain' (also known as the Profile), was New Hampshire's most famous landmark and remains the emblem on its State Seal, license plates, and the recently minted millennial quarter. The 'Old Man' (Fig. 2) consisted of seven large blocks of Conway Granite bedrock juxtaposed in such a way as to provide the profile seen from Profile Lake (Fowler, 1982, 2005, 2009). The Profile was a delicately cantilevered, 7,200-ton rock mass formed naturally by the combination of two active and persistent weathering processes: 1) intense kaolinization of the joint systems in its Jurassic Conway Granite, and 2) mechanical excision of loosened blocks by freeze-thaw wedging. There are three systems of joints in the Conway Granite on Cannon cliff that are exploited by these processes: 1) subvertical and 2) deeply positioned subhorizontal joints formed in the rock mass during the cooling of the pluton (Fig. 3), and 3) a combination of more closely-spaced, near-surface subhorizontal and subvertical joints formed as the weight of late Wisconsinan glacial ice was removed and the surface dilated around 12,000 years ago (Thompson, et al., 1999).

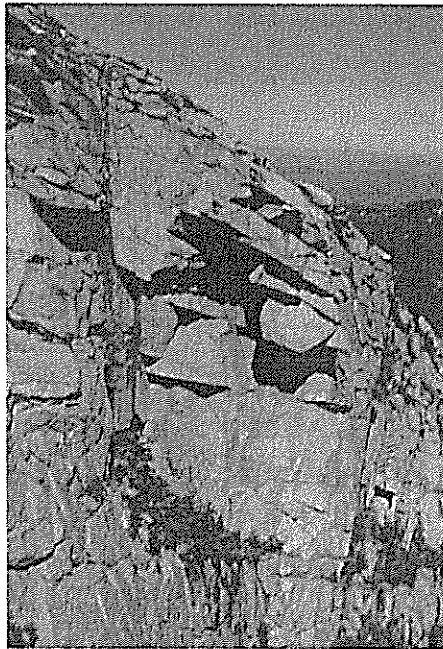


Figure 3. Aerial view looking north at joint distribution and bounding joints in the pre-collapse rock mass. Chin block (lost in 2003) creates lowest dark shadow.

Following deglaciation, dilation opened easy paths for the deep penetration of rain, snow and ice melt, and wind-driven cloud water into the rock mass. This deep penetration of water in turn encouraged the rapid progress of kaolinization along the joints and a simultaneous increase in porosity and cleft water pressure within the weathered fillings of the intersecting joint systems (Fig. 4). Then this ample supply of cleft water made it relatively easy for the very active diurnal and seasonal freeze-thaw cycling on the cliff to mechanically remove joint-bounded blocks destabilized by the weathering process. Thus, the actual formation of the Profile was a serendipitous consequence of just which of these destabilized blocks was excised by these combined processes

and in just what order so that the delicate cantilevering needed to perch the rock mass on the cliff was created and temporarily (from a geologic point of view) preserved (Fig. 5).



Figure 4. Close-up view of intersecting weathered joints in the pre-collapse rock mass. Chin block on right behind vertically hanging rope.

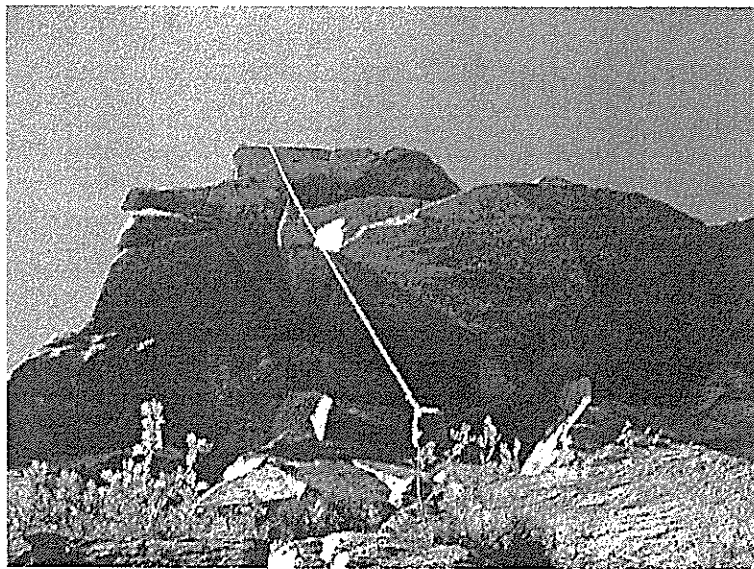


Figure 5. View looking up at delicately cantilevered pre-collapse rock mass. Triangular chin block to right of vertically hanging rope.

In the early morning hours on 3 May 2003, under the cover of darkness and cloud, the frontal portion of the rock mass that included the Profile's blocks toppled forward and off the cliff. This event created significant public mourning and a huge economic loss in tourism for the State. In response to these losses, numerous proposals have been put forward since to physically replace the Profile on the cliff using various combinations of rock and lighter-weight artificial materials anchored to the residual rock mass. Such proposals all rely on the assumption that this residual rock mass is in sound structural condition (Fig. 6), which would be critical to the successful anchorage and foundation of any replacement structure. However, based on studies of the residual mass since the collapse, this assumption is not accurate.



Figure 6. Post-collapse residual rock mass after the Profile toppled forward (left). Note broken steel turnbuckles on residual Forehead (topmost) slab and remnants of concrete water diversion trough at back.

Geoengineering studies demonstrate that the bulk structural integrity of the residual mass has been seriously compromised by the same intense processes that formed and destroyed the Profile (Fowler, 2009). These studies show that deep penetrative weathering, the build up of cleft water pressures, and intense freeze-thaw excision continue unabated on Cannon cliff and in the residual rock mass left behind after the Old Man's demise, continuing the reduction of intact or bulk strength of the rock mass. Of particular concern are probable steep reductions in the coefficient of internal friction between the deep surfaces of deteriorated joints, along with associated large increases in porosity and cleft water pressure. These latter two conditions reduce the direct physical contact between the block components in the rock mass and reduce resistance to sliding or other modes of displacement from the cliff.

Continuing observations show that these deteriorated conditions exist deep into the residual mass. From the cliff face inward, significant deterioration is observed to depths of at least 6 m, and similar observations on the mountainside behind and above the residual mass suggest deterioration extends to depths of 15 m or more, especially in the vicinity of the compound and most deeply weathered bounding joints at the margins of the residual rock mass (Fig. 3). All these joint surfaces continue to deteriorate and cleft water pressures continue to increase, processes that progressively compromise the capability of the bulk rock mass to provide a secure foundation.

The increasing cleft water pressures are particularly problematic for rock stability for two reasons: 1) the lateral cleft water pressure exerted on the walls of the joints combines with the even more intense wedging force of freeze-thaw activity, which reduces the capacity of the residual mass to resist partial or even complete collapse from the cliff, and 2) there is no effective way to reduce or eliminate these pressures by sealing or draining the rock mass, as shown by numerous attempts to do so on and above the original Profile over many years (Hancock, 1980).

Fig. 3 clearly shows both the southern and northern bounding joint combinations of the residual rock mass. It is easy to see that joint surfaces have been extensively weathered and thus have deteriorated over the years. When the overhanging (cantilevered) blocks that comprised the Profile collapsed, most of the rearward bulk portion of the deteriorated rock mass did not fall simultaneously because of the toppling rather than sliding mode of failure. This process permitted the residual mass to remain perched, although no longer cantilevered, on the cliff side when the more fragile portions in front fell away. However, partial or even complete collapse of the residual rock mass easily occurred along these deteriorated and weakened boundary joint surfaces in response to the active

weathering and excision processes on the cliff. The intensity and effectiveness of these processes is clearly shown by the extent and thickness of the talus slope accumulated down slope from the cliff. The combined weathering processes on Cannon cliff are so effective that the talus slope is the largest in the White Mountains, if not all the eastern United States.

During past decades, efforts to secure the Profile with tie-rods and turnbuckles on the top of the Forehead and with epoxy seals to keep water out of its structure were perhaps psychologically reassuring, but largely ineffective in improving the fundamental security of the Old Man. But, there was no lack of interest or effort in these attempts, and a summary of these remarkable activities over the last two centuries is presented in Hancock (1980) and Fowler (2005).

From the foregoing discussion, several conclusions can be drawn. From an engineering geologic point of view, the successful reinforcement of this heavily deteriorated rock mass is very unlikely because precise locations of the most deteriorated portions of its bounding joint systems and internal mass are impossible to establish with any certainty. Thus, there is no reliable active (ex. tensioned rock bolts) or passive (ex. grouted tendons) way to knit the block components of the residual rock mass together so they are effectively again intact and capable of acting as a bulk foundation unit. This condition seriously mitigates against confident installation of tensional foundations within the rock mass, and leads most qualified observers to conclude that public and/or private investment in any project to restore the Profile in the residual rock mass would be both fiscally and structurally imprudent; the structural and investment security of any constructed outcome likely would be both tenuous and ultimately impermanent.

#### LARGE ROCKFAL FROM CANNON CLIFF ON 19 JUNE 1997

Cannon Mountain has one of the highest relief cliffs in northeastern United States (~300 meters). At about 10 a.m. on 19 June 1997, a large rockfall originated from near the top of the cliff's north end (Fig. 7). The release involved a large section of steeply inclined exfoliation slabs of Conway Granite, which became airborne over the lower half of the cliff. The rockfall was apparently not triggered by seismic, sonic, or meteorological events, as observers did not note an earthquake, sonic boom, or quarry blast, and the previous four days were precipitation-free. Both the cliff scar and the impact swath on the talus slope below the cliff remain clearly visible from the valley floor (Davis and Fowler, 1998).

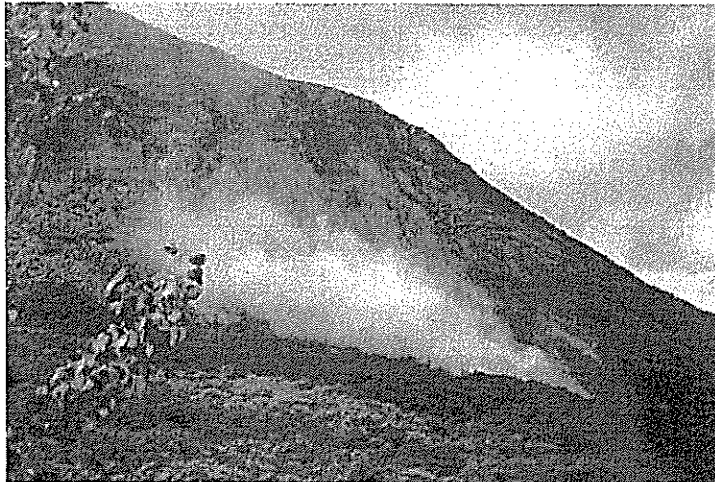


Figure 7. Last of a five-photo sequence taken by Richard Baker of massive rockfall from Cannon cliff about 10 a.m. on 19 June 1997 challenges Lyell's theory of Uniformitarianism.