Review of Potential Rockfall Hazards at El Morro National Monument, New Mexico

By

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Administrative Report

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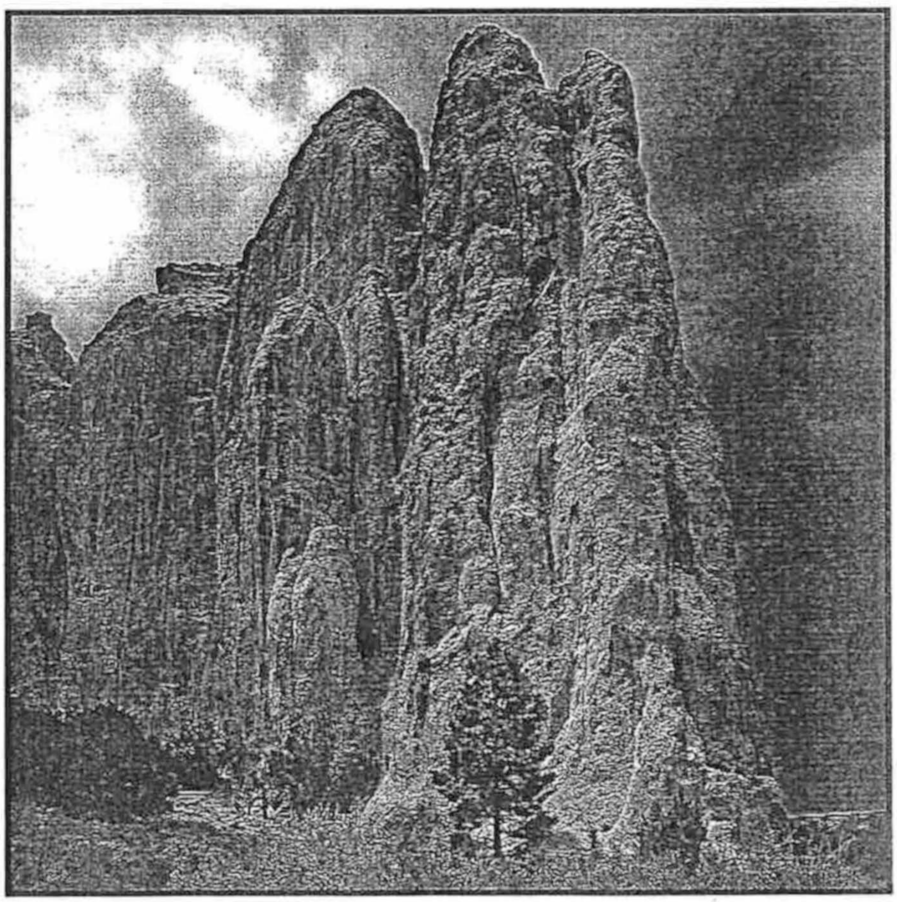

Inscription Rock, El Morro National Monument, New Mexico

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INTRODUCTION

In late March 2000, the NPS (National Park Service) at El Morro National Monument in New Mexico contacted the USGS Central Region Geologic Hazards Team with a request for technical assistance. Specifically, the NPS was requesting a review and updated assessment of rockfall hazards at the Monument, and was also seeking advice on the possible development of a monitoring system to detect rock movement at critical locations in the park. In response to that request, the author scheduled a visit to El Morro National Monument for the week of May 29, 2000. Two days were spent at El Morro examining potential rockfall hazard areas and reviewing previous rockfall hazard reports and memoranda on file in the Park headquarters. This report presents a summary of observations and recommendations concerning rockfall hazards at the Park and presents recommendations and cost estimates for monitoring potential rock movement in the Park.

El Morro National Monument is located in west-central New Mexico about 200 km west of Albuquerque. The site has a long history as a landmark, watering hole, and stopover for early Spanish explorers and later, American explorers and frontiersmen. Many of these early explorers and visitors left inscriptions carved into the sandstone cliffs, dating from 1603 through the late 1800's. It was in the interest of preserving these historic inscriptions and cultural treasures that El Morro National Monument was established in 1906. The Park also contains petroglyphs and Anasazi ruins. Figure 1 is a generalized trail map of the Park. About 80,000 people visit the El Morro annually, mostly between the months of April and November. The heaviest visitation is in the June to September time frame.

As is often case, the very features that attract the visiting public to the natural and cultural resources of our National Park system also expose them to some degree of risk from natural hazards. Such is the case at El Morro, where viewing of the historic inscriptions requires public access to the base of 50- to 65-m-high sandstone cliffs. Weathering and other natural processes gradually result in deterioration of the exposed rock surfaces, and ultimately lead to the downward gravitational movement of rock material. Such movement can range in scale from grain-size fragments to large rockfalls. There apparently have been few moderate to large historic rockfalls at El Morro, although at least three are mentioned in Park records. In 1942 a rockfall occurred from near the top of the cliff above the historic pool located at marker #2 on the Inscription Loop Trail (fig. 1). The rockfall filled the pool, which later had to be excavated by the Park Service. A small rockfall (less than 500 lbs of material) was reported by Wachter (1978, Addendum to Report A) to have occurred in the summer of 1978 near the Onate inscription at marker 10. Most recently, in June 1999 a large rock (originally estimated at 400 lbs., but more likely in excess of 2000 lbs) detached and fell from a height of around 3 m impacting within 1 m of the trail near marker #9 (fig. 2). Although no one has reportedly been injured by rockfall at El Morro, the Park Service recognizes that a rockfall hazard does exist and has commissioned previous work to evaluate and advise regarding such hazards. It is out of the Park Service's concern for public and employee safety that this updated assessment and review of rockfall hazards was requested.

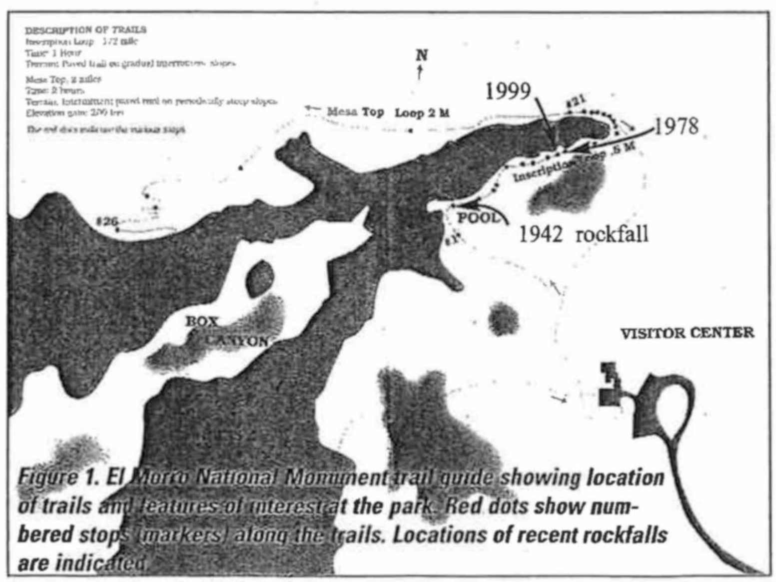


Figure 1. El Morro National Monument trail guide showing location of trails and features of interest at the park. Red dots show numbered stops (markers) along the trails. Locations of recent rockfalls are indicated.

ITINERARY

On Tuesday, May 30, I traveled from my headquarters in Golden, Colorado, to El Morro National Monument, arriving at the Park approximately 6:30 pm. On the morning of Wednesday, May 31, I met with Park Superintendent Ms. Peri Eringen and Ranger Brian Quigley, who then accompanied me on a tour of the Inscription Loop and Mesa Top Loop Trails (fig. 1). Parts of these Trails traverse along the base of the 50-m-high cliffs that form Inscription Rock. During this initial examination of the rock faces, Ms. Eringen and Mr. Quigley pointed out the locations of previous rockfall events and areas identified in previous assessments to be of special concern for potential rockfall. In the afternoon of May 31 I reviewed the Park file containing reports and memoranda concerning previous rockfall assessments and monitoring efforts at the Park. In the late afternoon/early evening I made a second trail hike to examine the cliff exposure along the Inscription Loop Trail.

On Thursday morning, June 1, I made a more detailed examination of the cliff exposures along the Inscription Loop and Mesa Top Loop Trails, and also examined the source area of the 1942 rockfall above the pool. In the afternoon I again met with Park Superintendent Eringen to review my initial findings and recommendations. We also walked along the Inscription Loop Trail where I pointed out specific areas of concern and discussed ideas for monitoring.

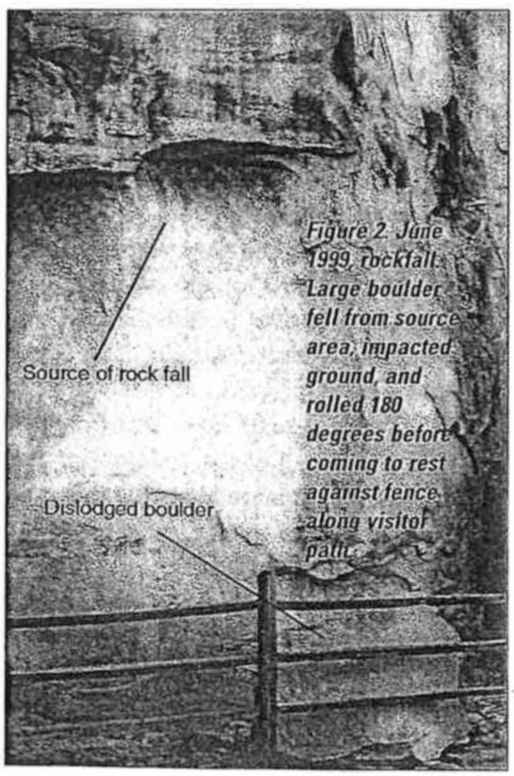


Figure 2. June 1999, rockfall. Large boulder fell from source area, impacted ground, and rolled 180 degrees before coming to rest against fence along visitor path.

GEOLOGY OF THE AREA[1]

The small mesa that forms the cliffs of El Morro is a cuesta, or gently dipping headland. At El Morro the headland slopes downward to the west, and the eastward and northward facing cliff of Inscription Rock is an erosional escarpment, or cuesta face (fig. 2). The mesa and cliffs at El Morro are comprised of sandstone of the Zuni Formation, formed from desert dune and fluvial sand deposits of Jurassic age. The Zuni Sandstone is overlain by the Dakota Sandstone of Cretaceous age, which is derived primarily from fluvial and near-shore marine beach deposits. Remnants of the Dakota Sandstone are present on the mesa top just above the "bleached zone" at the top of the Zuni formation. The lowlands around El Morro are made up of 1.5-million-year-old lava flows from a volcanic vent east of El Morro.

At El Morro, the Zuni Formation exhibits a very well defined and prominent northeast-trending vertical joint system (fig. 3). It is these predominant northeast-trending joints that form many of the cliff exposures at El Morro. Smooth remnants of the old joint surfaces, composed of joint infilling material up to several centimeters thick, are exposed at several locations on the cliff face. Another well-defined but less prominent vertical joint system trends perpendicular to the main set. A third, very poorly defined and inconsistent set of near-horizontal joints and planes of weakness, probably related to depositional sequences in the sandstone, is sometimes visible. Such near-horizontal weakness planes can sometimes be the locus of failure of large, overhanging rock slabs, such for the June 1999, rockfall (fig. 2). Because the weakness planes are often hidden, it is difficult to identify specific areas of potential failure or to predict when and where failure might occur.

[1] Geologic names and ages were taken from National Park Service information display.

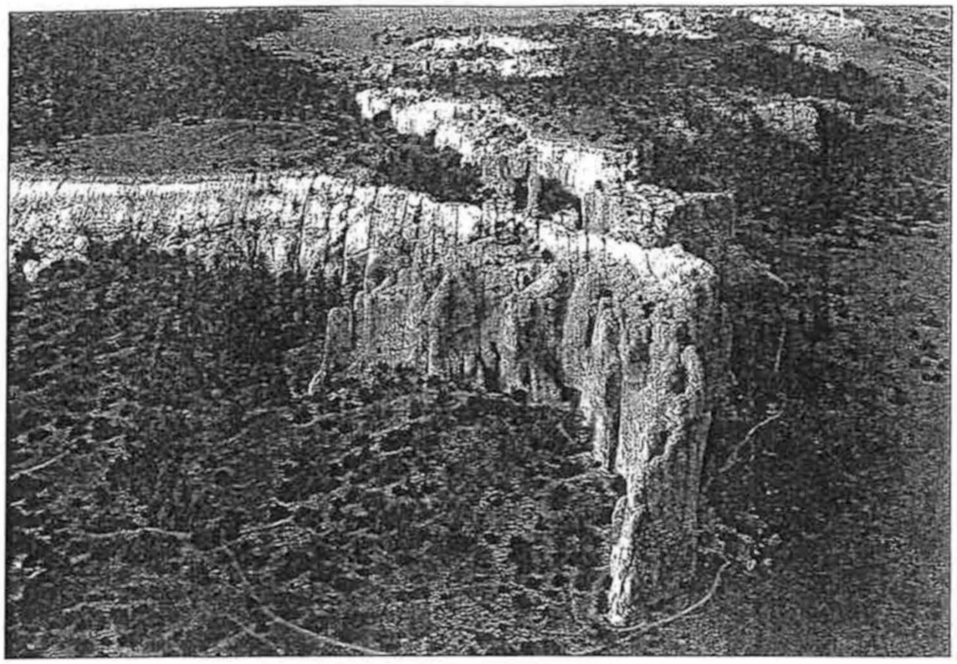


Figure 3. Cuesta that forms Inscription Rock at El Morro National Monument. Inscription Rock is in right center to foreground with visitor trail visible around base. View is to southwest. Note prominent northeast-southwest-oriented vertical joint set. The pool is visible at the curve in the base of the cliff just below and to the right of the center of photograph. [Photograph by Douglas E. Enry]

Near the base of the exposed Zuni Formation is a layer of weaker and lighter colored sandstone, that in places, has eroded faster than the overlying, more-competent sandstone cliff. This undercutting has resulted in potential instability of the overlying rock in some locations.

PREVIOUS INVESTIGATIONS

Park records indicate that Bruce G. Wachter conducted the first formal assessment of the rockfall hazard at El Morro National Monument in 1978. Wachter's work at was part of a broader examination of rock movement at several National Monuments and Parks in the southwestern U.S. In his report "Geologic Analysis of Rock Deterioration at Selected National Park Service Archeological Sites", Wachter noted several potential rockfall hazards at El Morro, but focused primarily on a large, split column of rock along the southeast-facing cliff and Woodpecker Rock. Both the split column and Woodpecker Rock are discussed later in this report. Wachter recommended monitoring of the large, split rock column.

Following Wachter's report, there is additional Park service correspondence addressing rockfall hazards at El Morro. In a 1979 memorandum to the Chief, Division of Adobe/Stone Conservation of the NPS, Mr. Todd Rutenbeck, a structural engineer in the same Division, discussed Wachter's report and recommended monitoring the crack width in the large, cracked monolith. He also discussed results of survey work in 1972 to determine the width of the crack, but the overall accuracy of this work was questioned. In a January 1980 memorandum to the Park Superintendent, the General Superintendent, Navajo Lands Group, pointed out that rockfall hazards at El Morro appear to be no worse than at many other NPS areas, and that heroic or expensive methods of reducing the hazard could not be justified. He also made specific recommendations, including one that Park staff maintain a log of the times, locations, and weather conditions when rockfalls are noted in order to identify locations and conditions where rockfall was most likely to occur.

In May of 1983, a detailed reconnaissance of rock hazards at El Morro was conducted by Mr. Roger Siglin, the Chief of the Division of Protection and Visitor Use Management. Mr. Siglin's work resulted in recommendations to the Park Superintendent from the Regional Director, southwest Region in a memorandum dated June 2, 1993. Included in those recommendations was one for monitoring the large, split monolith.

In 1984, rock-movement monitoring instrumentation was installed to monitor movement across the crack in the split monolith and between the monolith and the cliff face. No details regarding the instruments could be found in the Park records. However, some of the instruments apparently failed soon after installation, and the remainder operated for a limited time. The small amount of data collected while the gauges were operational were determined to be inconclusive by NPS staff. In a 1989 memorandum to the Park Superintendent, the Chief, Division of Conservation, SWR, offered recommendations regarding re-initiation and operation of the monitoring system. Apparently, no further work relating to rockfall hazards at El Morro was conducted or documented in Park files until the initiation of this request to USGS for assistance with evaluation of rockfall hazards at the Park.

ROCKFALL HAZARD

As noted previously, by their very nature cliff exposures that form Inscription Rock are subject to rockfall hazards. The processes of weathering and erosion that formed the cliffs will continue to work to loosen and detach rock fragments and slabs that will ultimately fall. Fortunately, such processes are slow and rockfalls are infrequent, such that the risk of exposure to rockfall to any individual visitor located on the marked trail is small. However, recognition of those areas most susceptible to rockfall allows for actions to be taken to lessen the potential risks. In this report, several areas of special concern for potential rockfall along the Inscription and Mesa Top Loop Trails are identified. For discussion purposes the areas are grouped into two types: (1) locations that appear particularly susceptible to rockfall over a relatively large area, but for which no specific block or feature is identified as potentially unstable; and (2) specific rockfall hazards in which individual blocks or wedges are readily identifiable as potentially unstable.

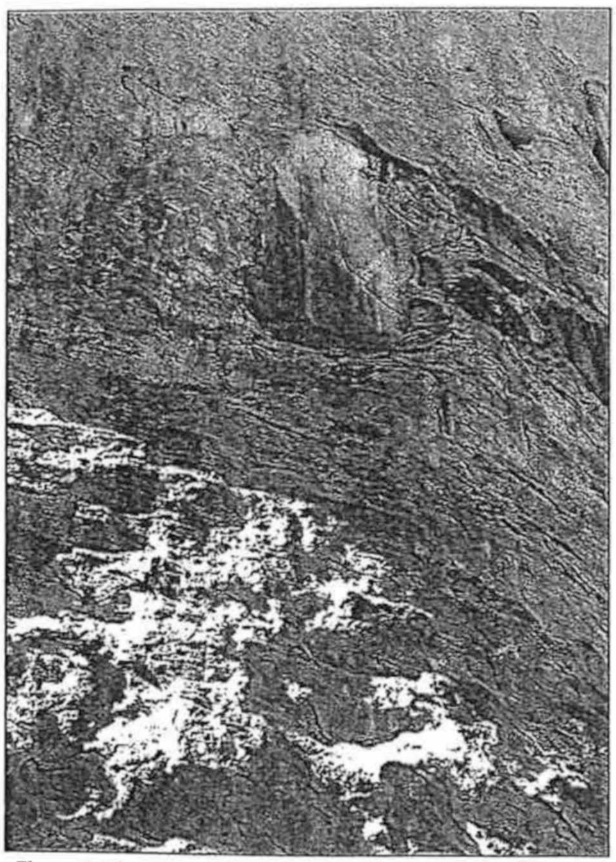


Figure 4. View of portion of cliff face between pool and marker 4, showing thin slabbing and flaking of rock surface. Also shown in top part of photo are remnants of old joint surface and joint infilling material (dark patches) typical of several locations on the southeast-facing cliff.

There is no reliable means to predict precisely when any particular rockfall might occur. Many of the rock features identified here as potentially unstable have likely been present for tens and perhaps hundreds of years or longer. However, as evidenced by the June 1999 rockfall, failure can occur at any time. In most cases, instrument monitoring of potential rockfalls would be of little practical value, as failure will likely be sudden and without sufficient warning for protective actions to be taken. At one site, instrument monitoring can be of value in establishing if long-term movement is occurring and for identifying any changes in movement rate that could be indicative of impending failure.

Areal Rockfall Hazards

In addition to specific locations where individual, large unstable blocks or slabs can be identified, there are also areas at El Morro that appear susceptible to more dispersed and smaller rockfalls. From the pool northward to about trail marker 4, the southeast-facing cliff is characterized by widespread thin flaking of much of the cliff surface (fig. 4). Most of the slabs are 1-2 cm thick and less than 0.25 m^2 in size. Detachment of such small slabs from moderate heights of 10-15 m likely poses little hazard, as the fragments are small and would slide down the cliff, impacting near the cliff base. The visitor trail in this area is located a short distance from the cliff, and rocks falling from a moderate height would not likely impact the trail. Rocks falling from higher on the cliff, however, might bounce off of the lower cliff and thus would be more likely to reach the trail. Little can be done to mitigate the potential hazard in this area, as scaling is not practical due to the widespread nature of the rock flaking and the fact that scaling would have to be repeated frequently. The trail location and apparent infrequency of rockfall in this area, however, would seem to indicate that the risk from rockfall is small.

At several locations along the southeast-facing cliff are patches of dark, smooth, remnants of joint surfaces (fig. 4). These patches are up to several centimeters thick and several square meters in area, and occur high on the cliff. Although the stability of these remnant joint surfaces/infilling patches is difficult to assess, they represent potential slab detachment. Periodic inspection and scaling of these old remnant joint surfaces could be done to identify and remove any loosened material.

The north-facing cliff of Inscription Rock, between markers 14 and 21, is also an area of active rockfall, as indicated by the accumulated deposit of sandstone blocks and slabs ranging from a few centimeters to several meters in thickness. Numerous overhanging slabs can also be seen on the cliff above the trail where it passes very near the base of the cliff. The spalling and slabbing that is occurring here may be enhanced by more pronounced freezing and thawing action on the north-facing exposure. The area is also the location of a large rockfall that can be seen in the right foreground of figure 3 and in the center of figure 5. Inscriptions along the cliff above the old rockfall debris date to the early 1600's, indicating that the rockfall is older than 400 years.

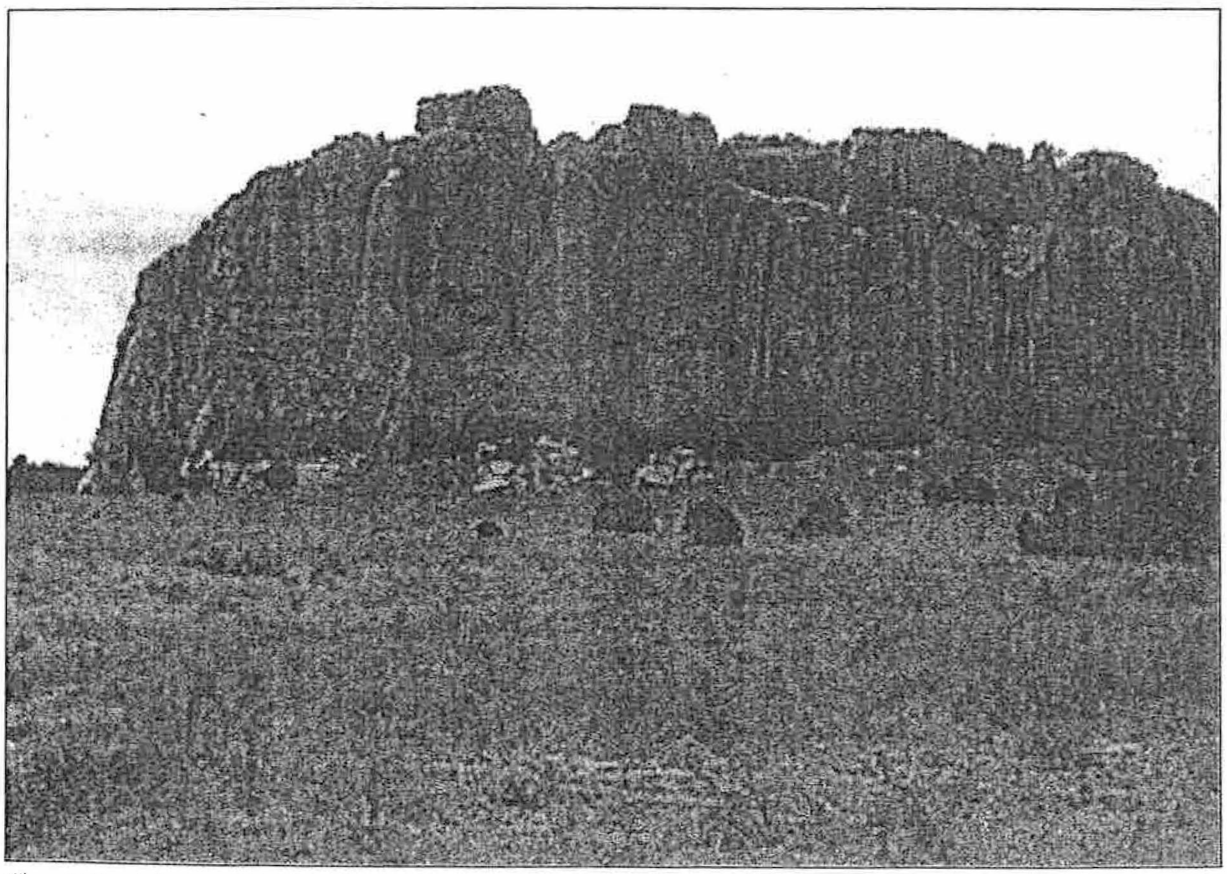


Figure 5. North-facing cliff of Inscription Rock. Note abundant dark staining caused by flow and seepage of water on older cliff exposure. Rockfall debris can be seen in center of photo below where dark staining is absent.

The recommendations of previous investigators that this portion of the trail be closed during periods of freeze and thaw are probably the best approach to reducing risk to visitors in this area. According to Park officials, this part of the trail is usually closed until late spring owing to the presence of ice on the trail surface. Careful inspection of the cliff face should be done each spring prior to opening of the trail to look for the presence of slabs that may have been loosened over the winter and early spring months.

Another broad source of potential rockfall is from the mesa top. The mesa top above the cliffs is quite clean, however, and very little loose debris or rock fragments were observed. Detached rock fragments that were observed tended to be quite small. It is possible that during periods of heavy rain or high wind such small rock fragments could be dislodged and fall from the cliff top. Even small rock fragments could be hazardous when falling from the high cliffs. As recommended in previous assessments, Park management may wish to restrict access to the trails during periods of heavy rain in order to reduce risk to Park visitors.

Specific Rockfall Hazards

Several possible rockfall locations were observed that warrant special consideration, some of which have been identified in previous rockfall assessments. These are locations in which specific features could be identified as posing a relatively significant rockfall hazard because of their size, indications of possible instability, and location near or above the visitor trail. There is no reliable way to predict that a rockfall from any of these features is imminent, and it is possible that the features have existed in their present state for many years. Nonetheless, because of indications of potential instability such as fractures, overhangs and the possible consequences of failure of any of the features, it is important that they be identified and documented. In many cases the only way to completely avoid the potential hazard would be to relocate the visitor trail. These specific rockfall hazard locations are referenced by proximity to the nearest trail guide marker.

Trail Marker #1

A large, partially detached block sits about midway up the bluff above marker #1 (fig. 6). Although the block appears to be stable, its mass is supported by a small base that could be susceptible to shear failure. The block should be examined periodically by Park staff for any signs of developing instability, such as new fractures or deterioration in the base area of the block. Because the visitor trail is located several meters from the cliff at this location, the risk from possible failure of the block is primarily limited by how far the block might travel after impacting the ground surface. A detailed analysis of the possible roll-out distance would be required to assess the risk, but because the trail is removed from the likely impact area the risk is considered to be low.

Trail Marker #4

Above trail marker #4, near the top of the cliff, there is a large overhanging slab with no support from below (fig. 7). Some fracturing is

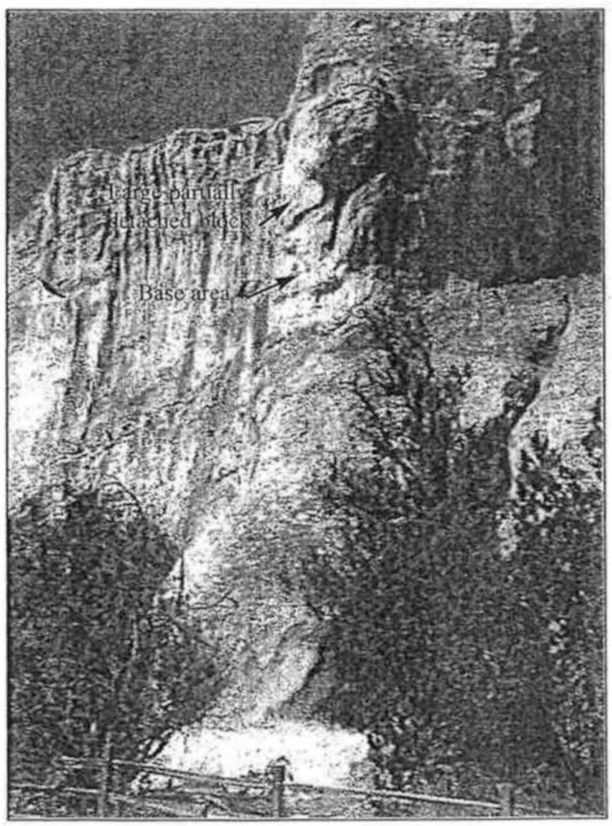


Figure 6. Large, partially detached block on bluff near trail marker #1.

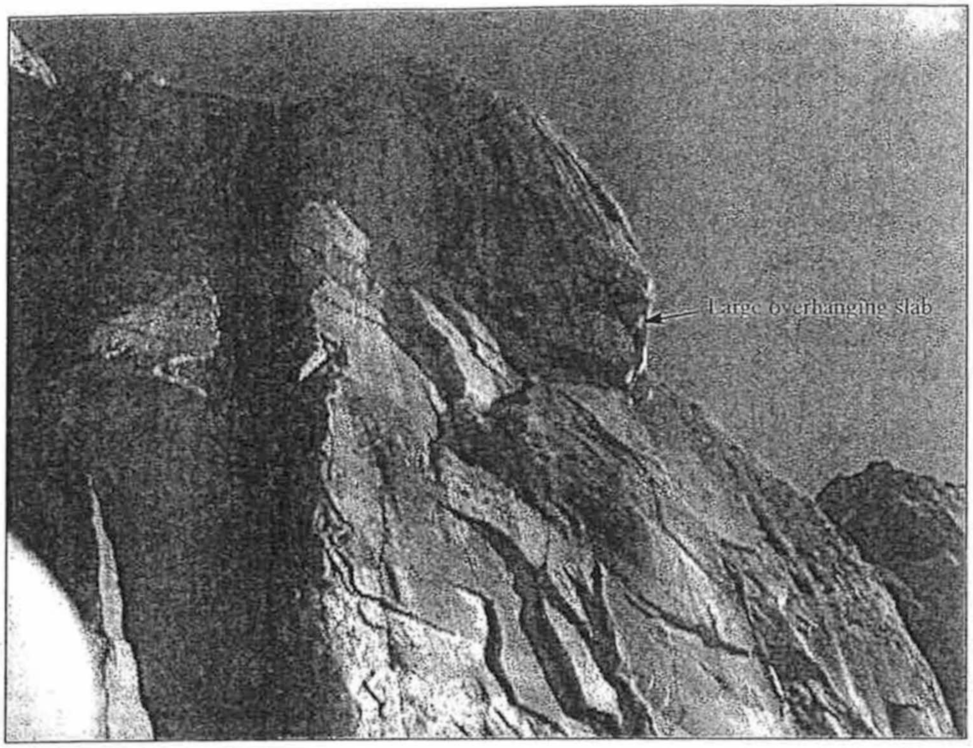


Figure 7. Large overhanging slab near top of cliff above trail marker #4. Numerous thin slabs are also present in this area.

apparent within the slab, but the presence of mud from swallow nests below the slab make it difficult to determine by visual inspection from the trail if fracturing occurs behind the slab. Several thinner slabs also are present on the cliff face in this area, but appear to be well attached to the cliff. The critical concern for the overhanging slab is its location above the trail. Separation of any part of the slab would impact the trail directly with little or no warning. No inscriptions are present in the area directly beneath the overhanging slab, so this is one area where the trail could be re-routed away from the cliff to reduce the risk. Careful inspection by a climber rappelling from above to determine if the slabs are firmly attached to the cliff may be warranted. Tapping along the outer surface of the slab with a hammer or pry bar is a method often used by experienced rock scalers to detect the presence of open fractures behind rock faces. Scaling could be done to remove unstable parts of the slab(s).

Trail Marker #11

A potential rockfall exists above trail marker #11, where a relatively large wedge-shaped slab is unsupported from below (fig. 8). A fracture can be seen behind the slab indicating that it is partially detached from the cliff face. Relocation of the trail is not practical in this area. Inspection by a climber rappelling from above could determine if the slab is firmly attached to the cliff or is partially detached and thus represents a threat. If determined not to be solidly attached, scaling by a climber to remove the slab is recommended.

Trail Marker # 12

Near trail markers #12 and #13 is one of the most dramatic features with respect to potential rockfall hazards in the Park. This feature is a very large, approximately 50-m-high column of rock that is split by a vertical fracture (fig. 9). The fracture appears to be 10-15 cm wide near the top of the column, and disappears into hairline fractures near the base. The geometry of the fracture indicates that the outer part of the column has rotated outward relative to the inner part, and that the motion is hinged near the base of the column. The sharp, angular edges of the fracture indicated that it is much younger than the separation between the main column and the cliff. The defor-

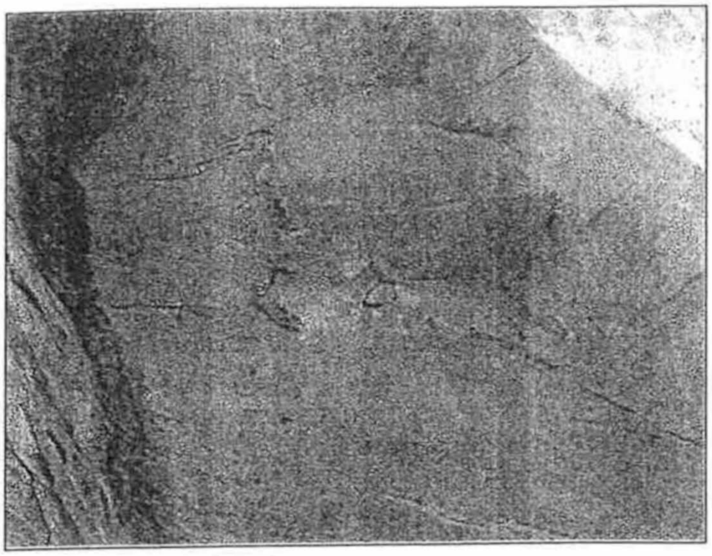
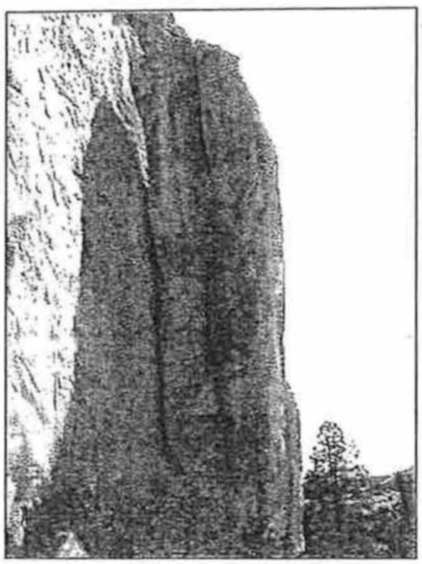


Figure 8. Telephoto view of relatively large, wedge-shaped slab above trail marker #11. Note fracture between bottom of slab and cliff face.



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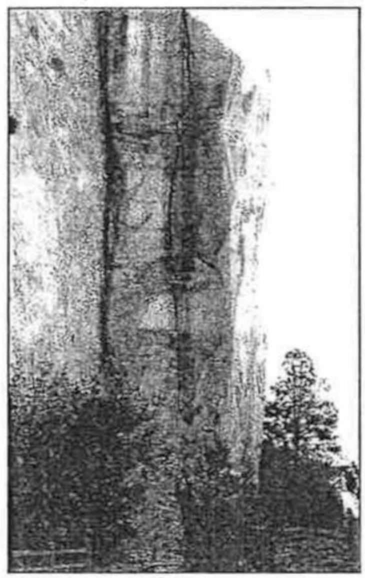

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Figure 9A and 9B. Two views of large split column of rock located between trail markers #12 and #13. Visitor trail, visible in view B, passes next to the base of the column.

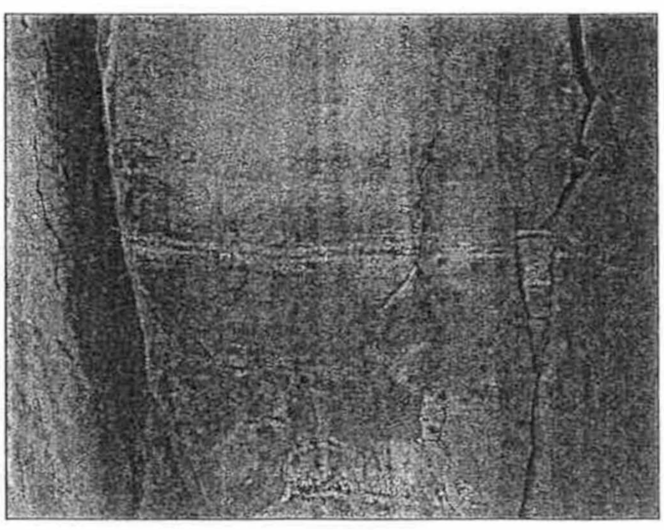

Figure 10. Small wedge of rock that has separated and downdropped along the central fracture of the large rock column of figure 9. The wedge is not present in the 1978 photo of the rock column.

mation that produced the fracture could therefore be relatively recent and perhaps ongoing. The rock column and fracture are very prominent and often prompt concern and questions from Park visitors about the column's stability and possible danger.

The fracture appears in 1929 photos and again in a 1978 photograph taken by Wachter (1978). Although it is difficult to determine, the fracture appears to be wider in the 1978 photo, suggesting that there has been recent outward rotation of the outer portion of the split column. Such rotation could be a gradual, ongoing process. Inspection of the fracture for this review indicates a small, wedge of rock about mid-way up the column has separated and fallen downward a few centimeters within the fracture since the 1978 photograph was taken (fig. 10). While the separation and downward movement of this small wedge does not necessarily mean the fracture has widened since 1978, it does indicate that geologic processes are actively at work along the fracture surface.

As noted previously, an unsuccessful attempt to instrument this fracture for movement was made in 1984. Four gages were installed approximately mid-way up the column to monitor for

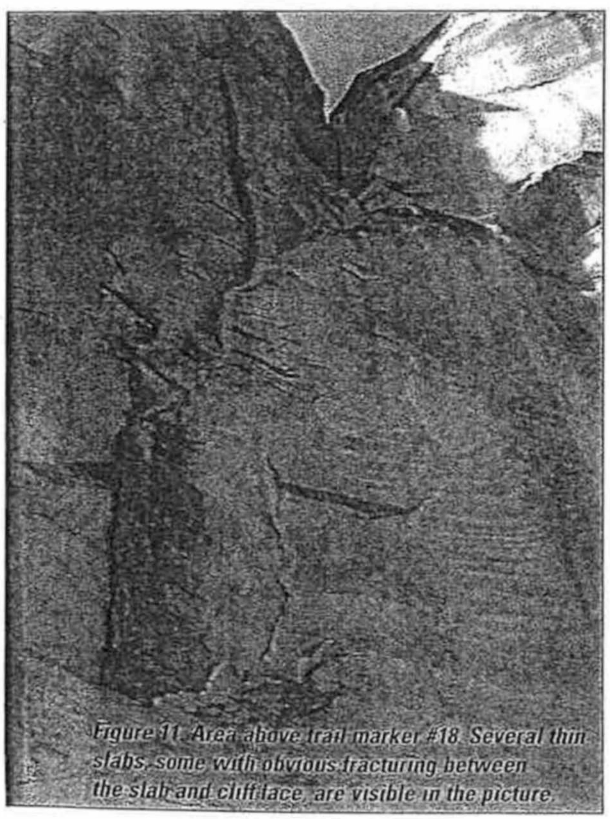

Figure 11. Area above trail marker #18. Several thin slabs, some with obvious fracturing between the slab and cliff face, are visible in the picture.

separation of the fracture. No details regarding the type and operation of the gages could be found in the records. One of the gages fell soon after installation, and a second fell a few years later. Apparently, none of the gages were in operation by 1989, and Park records indicate that no useful data were obtained in the monitoring effort.

Although there is no reason to expect that failure of this rock column is imminent, it's size, location, and indication of possible ongoing movement make it advisable to re-initiate a monitoring effort to determine if movement or further separation of the fracture is occurring. Because any further movement or fracture separation leading up to potential failure is likely to be gradual, instrumental monitoring is a viable and potentially valuable alternative at this site. Obtaining long-term baseline data is critical to assessing current or future hazard potential from this feature. Details of the recommended instrumental monitoring are discussed later under *Suggested Actions.*

Marker # 18

Above trail marker #18 is an area of several thin to moderately thick slabs, many with little or no support from below and with obvious fracturing between the slab and cliff face (fig. 11). This is within the area previously described in *Areal Rockfall Hazards* and is shown in figure 5 above the rockfall debris along the north-facing part of Inscription Rock. Figure 12 shows a close-up of another relatively large slab near the top of the cliff and just to the right of the area shown in figure 11. Here the trail passes very near the base of the cliff, which increases the hazard posed by these potentially unstable slabs. This is another area where close inspection by a climber rappelling from the top of the cliff could determine if any of the slabs are unstable. Scaling of any loose, unstable slabs would reduce the potential hazards in this area.

Markers #20 and #21

Directly above the trail between markers #20 and #21 is a large, approximately 1-m-thick slab

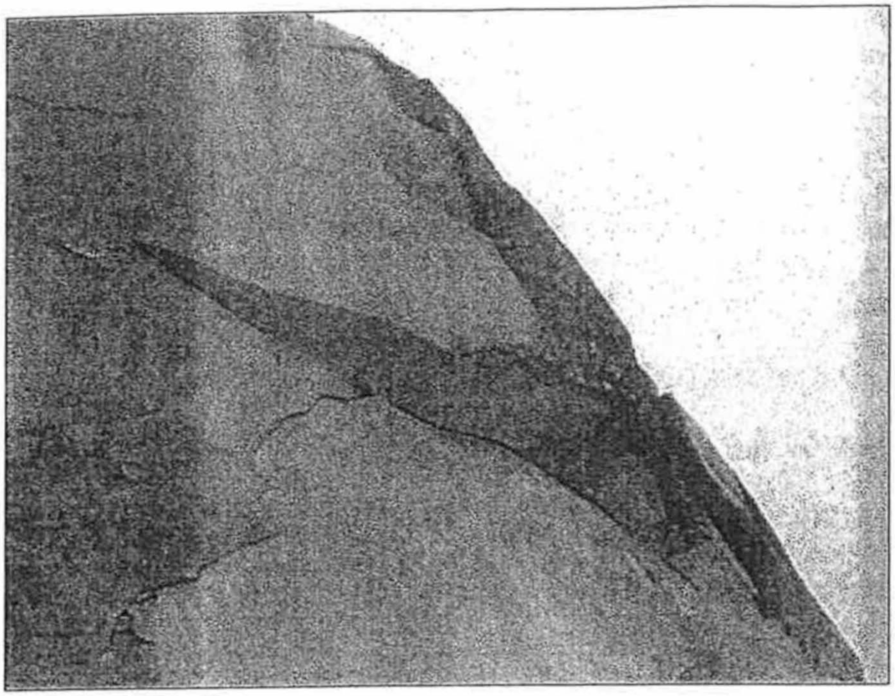

Figure 12. Close-up photo of large slab near top of cliff above trail markers #18 and #19. Note fracturing behind slab.

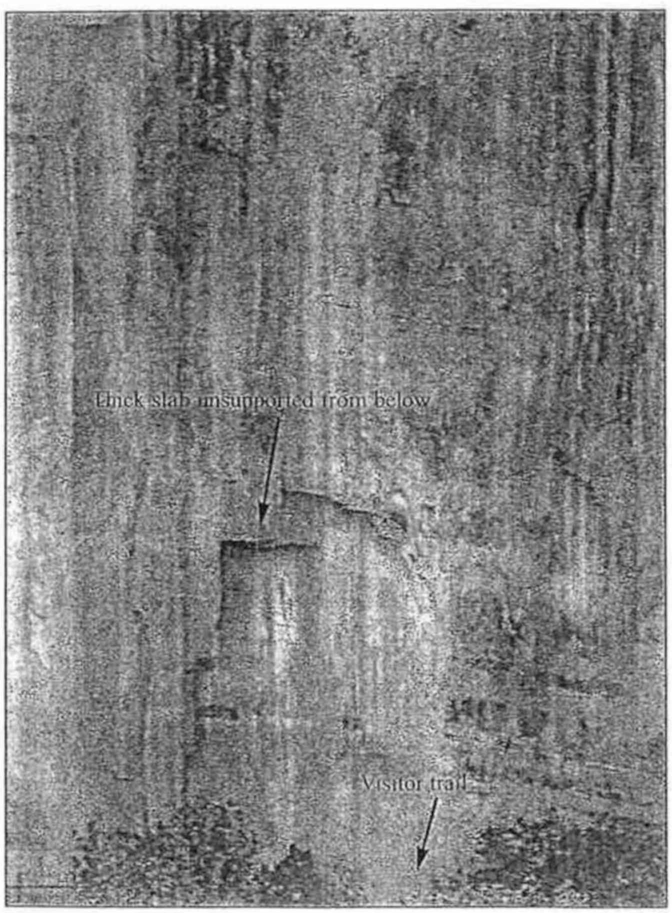

Figure 13. Large, overhanging slab directly above visitor trail between trail markers #20 and #21.

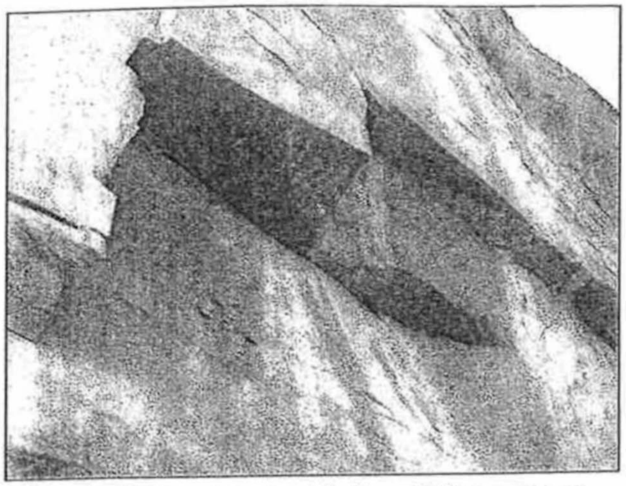

Figure 14. Close-up view of slab in figure 13. Note presence of fracturing behind and on left side of slab. A horizontal weakness plane, exposed by previous slab failure, can be seen above and to right of slab. This weakness plane probably extends into the inplace slab.

unsupported from below (figs. 13 and 14). This slab is perhaps the most ominous threat to visitors on the trail below. The slab overhangs directly above the trail, and any failure would be sudden and without warning. The consequences would most certainly be deadly for anyone located beneath the slab.

Other than removal, there is little that can be done to eliminate the hazard posed by this slab. Removal of the slab would likely just expose yet another section of the overhanging rock to potential slab failure. Rock bolting of the slab and the surrounding area would stabilize the potential failures, but is considered dangerous and impractical.

Fortunately, this potential hazard is in an area where trail relocation can mitigate the risk to visitors. The trail in this area contains steps as it traverses up and over the boulders and debris left from the old rockfall discussed previously and visible in Figures 3 and 5. Apparently, this section of the trail is under consideration by Park management for re-routing in order to improve accessibility for disabled visitors. Relocation of the existing trail in this area would therefore serve dual purposes; provide handicapped accessibility to marker #21 and a greater length of the Mesa Top Loop Trail, and also eliminate visitor traffic directly below the potential rockfall hazard. A portion of the existing trail to marker #20 could remain open as a dead-end spur of the trail, with the new section of trail traversing around the old rockfall debris. Another dead-end spur could then extend to marker #21. The area directly under the overhanging slab, where no inscriptions are present, would then be closed to public access. Because of the potential seriousness of a rock failure at this location it is recommended that trail rerouting be implemented as soon as possible

Woodpecker Rock

Woodpecker Rock (fig. 15) is located along the Mesa Top Loop Trail about mid-way between trail markers #22 and #23. The rock is a spectacular feature in that it is a large, approximately 30- to 40-m-tall fragment of the mesa front that is completely detached except for a very narrow intact base. The rock appears to be very precariously balanced on the small base. As noted by Wachter (1978), the rock does not show any signs of recent movement, but that the narrow base appears to be weathering and contains some diagonal fracturing. The feature appears in a historic 1929 photo from nearly the same camera location as in figure 15. No noticeable changes in the geometry or configuration of the rock are detectable between the two photos. I agree with Wachter's observation that failure would most likely be sudden, and that instrumental monitoring for motion would therefore be of little or no value.

Toppling of Woodpecker Rock is not considered likely, as the center of gravity of the rock mass is toward the cliff face. The most likely mode of failure for the rock would be shearing across the narrow pedestal base. Motion resulting from such shearing would be a downward sliding of the entire rock mass, which would likely be arrested by the ledge located below the rock. Sideways toppling of the rock might then occur.

Because the trail is somewhat removed from the base of the cliff at this location, the potential hazard imposed by Woodpecker Rock is not considered as severe as for some of the other locations described in this report. It would, however, be a relatively simple matter to relocate the trail further from the mesa in this area in order to bypass possible impact areas should the rock fail

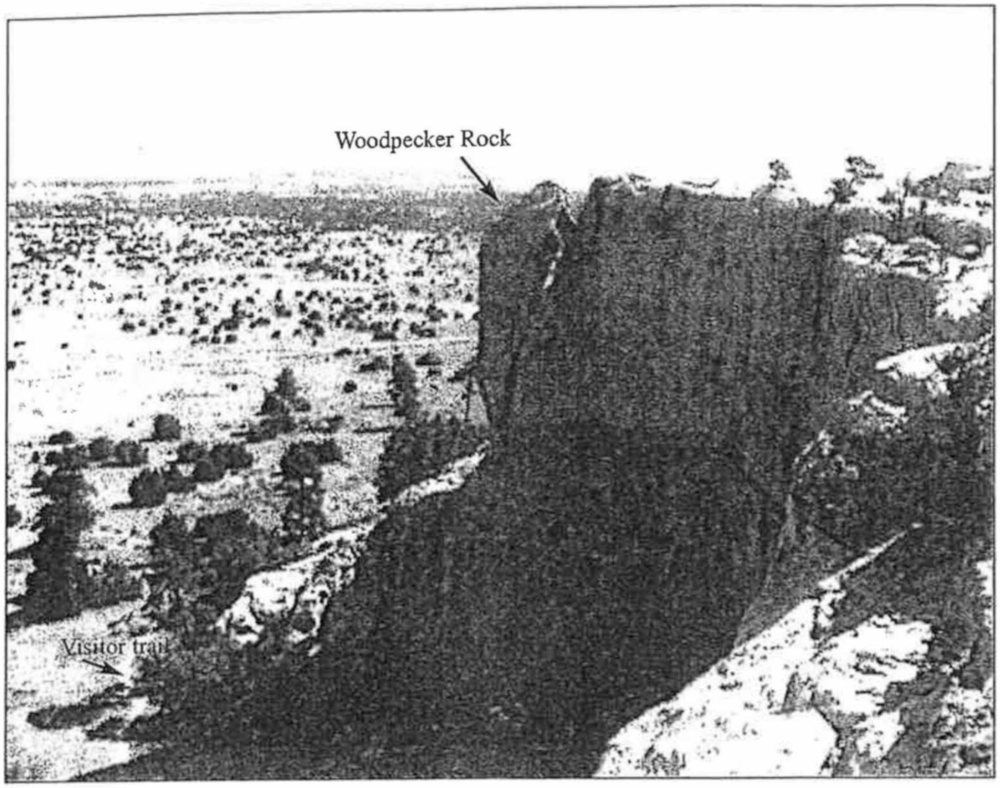

Figure 15. Woodpecker rock, looking northeast from upper section of Mesa Top Loop Trail. Rock is completely detached from the mesa except for the small base on which it rests. Note location of visitor trail in lower part of photo.

and topple sideways. Park staff should periodically inspect the base area of the rock from the trail to look for any signs of new fracturing or fresh spalling that might indicate further deterioration of the base.

Source Area of 1942 Rockfall Above Pool

The source area for the 1942 rockfall that filled the historic pool was examined to determine if any further instabilities were present or developing. The 1942 rockfall included or was later followed by the outward toppling of an approximately 1-m-thick tabular section of rock between two vertical joints near the top of the mesa (fig. 16). Toppling was probably promoted by weathering-induced undercutting in a thin weaker layer of sandstone.

Although a number of boulders and smaller rock fragments remain on the ledge just below the original failure, the rocks appear to be stable with further movement unlikely. No fresh jointing or separations were observed behind the existing intact rock exposures.

Large, overhanging sections of sandstone visible above the pool area were also examined for any evidence of impending instability. Although the overhanging rocks appear ominous from below, their center of gravity is located behind the cliff face (fig. 17). Although jointing is present behind the cliff, no open or fresh jointing that would indicate developing instabilities in the overhanging sections of sandstone were observed. In summary, nothing was evident on the mesa top above the pool area to prompt concern for potential rockfall hazards to the area below.

SUGGESTED ACTIONS

The combination of high cliffs, jointing, weathering, and climate make rockfall hazards an inherent feature at El Morro National Monument. As such, public safety cannot be totally assured, short of placing complete restrictions on public access to the base of the cliff. Because the purpose of the National Monument is to preserve and make available for public viewing the historic inscriptions, restriction of public access is not an acceptable option. Certain actions, however, can be taken to reduce risk to the visiting public. Previous rock-

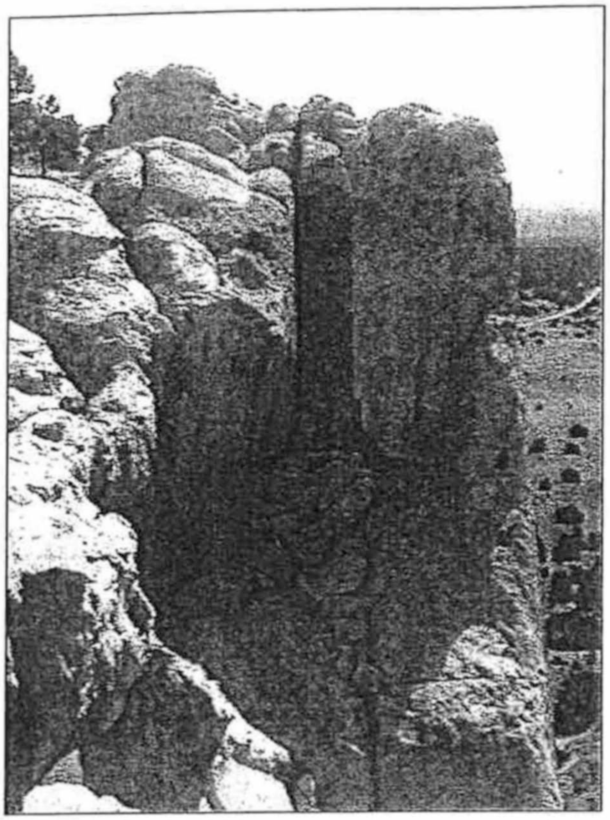

Figure 16. Source area of 1942 rockfall above pool. Failure and outward toppling of tabular section of rock bounded by vertical joints resulted in rockfall that filled historic pool below. Note remaining boulders and rock fragments from the original failure.

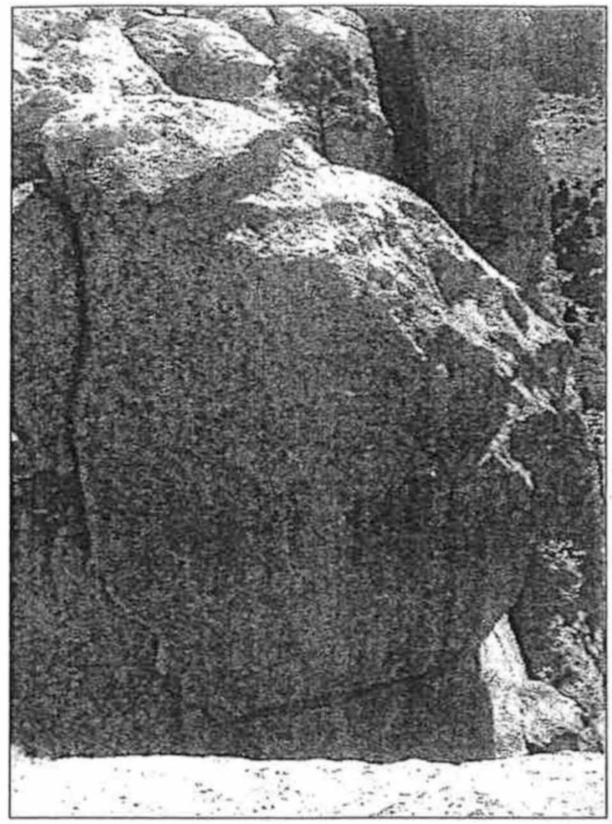

Figure 17. Section of overhanging mesa rim above pool area. Center of gravity of rock mass is well behind cliff face, indicating that topping failure is unlikely. Joint behind large section of rock shows no indication of recent movement.

fall assessments at the Park have all contained useful recommendations, many of which will be repeated in this report. Some recommendations may not be judged as viable by the NPS. The degree to which any or all of these recommendations may be implemented is ultimately a management decision based on NPS experience and determination of appropriate balance between cost, feasibility, and risk to the public.

1. Re-routing of the visitor trail near markers 20 and 21 is considered a high priority. The existing trail between markers 20 and 21 should be closed, thus eliminating public exposure to the overhanging slab directly above the trail. As noted earlier, re-routing of the trail would also provide handicapped accessibility to marker 21 and further reaches of the trail. As no inscriptions are present between markers 20 and 21, the only inconvience to the public is a small amount of additional walking to gain access to the inscriptions at marker 21.

2. As noted in previous correspondence, the north- facing cliff of inscription rock between about markers 17 and 20 is considered a relatively high risk area because of the presence of relatively fresh slabbing and the assumption of more pronounced freeze and thaw action on the north-facing exposure. The Park should maintain the existing policy of restricting access to this portion of the trail during periods of freezing and freeze and thaw activity. Careful visual inspection of the cliff face by trained Park staff should be done prior to re-opening the trail in the Spring, and following any periods of freeze and thaw or extreme temperature variation. Consideration should also be given to temporarily closing this portion of the trail during and following periods of heavy rain.

3. The areas of concern for possible slab failure noted above trail markers #4 and #11 should receive a closer inspection by a climber suspended by rope from above. Soundings by tap-

ping with a hammer or pry bar can be used to distinguish if the slabs are firmly attached or perhaps contain significant fracturing behind the slab. Any slabs found to be unstable should be scaled from the cliff. Re-routing of the existing trail below the slab area near marker #4 to bypass the area directly below the slabs is a practical alternative to reduce potential risk, as no inscriptions are present at that location. However, because the locations of the slabs are high on the cliff and increase the potential for rock bounce, it is probably not practical to re-route the trail far enough away to eliminate the hazard altogether.

4. Woodpecker Rock is not considered by this review to be as serious a risk as other areas, primarily because of the location of the trail relative to the rock feature. However, re-routing of the asphalt-surface trail further to the north and west of the existing trail would be a relatively simple matter. Such re-routing would provide a larger buffer zone between visitors and the potential impact area should sideward toppling of the large rock formation occur.

5. Previous recommendations that Park trails be closed during and shortly after heavy rains should be continued or implemented. Inspection of the trail should be done by Park staff before re-opening.

6. A detailed log of rockfalls should be maintained by the Park. Notation of the location, size, time of occurrence (as closely as can be estimated), and weather conditions should be recorded. Any correlation between rockfalls and weather/temperature conditions that might emerge from the data may help identify times when increased caution would be warranted.

7. Instrumental monitoring of the large, split monolith between markers #12 and #13 should be re-initiated as soon as practical. Although there is no evidence that the central fracture is currently widening, this is one area of the Park where instrumental monitoring could be of possible value in assessing the potential hazard. Long-term background data is necessary to determine if movement is occurring, or to look for acceleration of movement, which could indicate approaching failure.

A combination of both mechanical measurement and electronic sensors is recommended. The installation of an array of six monitoring pins, three on each side of the central fracture, should be installed on the south face of the column. The distance between the pins would be measured periodically by a sensitive dial or LCD display gage (accurate to 0.02 mm). The pins should be arranged in a rosette pattern, such that the distance between three sets of pins would be measured. In this way the amount and direction of relative movement in the plane of the pins (approximately perpendicular to the fracture) can be determined. The pins should be placed as high as can safely be installed and subsequently reached for measurement using an extension ladder (approximately 10-12 m above the ground surface). While measurement of fracture separation would be best made near the top of the column, the accuracy and resolution of the instrument is sensitive enough that movement can be detected at heights reachable by extension ladder, thus eliminating the need of a technical rock climber.

In addition to the mechanical pins, it is recommended that a dual-axis inclinometer be installed on the north face of the outer rock column. It appears that access to a suitable location for mounting the inclinometer on the rock surface can be gained through the large fissure just behind trail marker #13. The services of a professional rock climber would be advisable to complete the installation. Lead wires for readout of the inclinometer could be located at the base of the cliff behind the fence at marker #13. The location of the inclinometer on the north side of the monolith will shield it from daily exposure to the sun, and thus reduce the effects of daily temperature excursions on the instrumental readings.

Depending on availability of funds and feasibility, the installation of a cable-extension position transducer (wire extensometer) should also be considered for installation across the fracture on the north side of the monolith. Both the inclinometer and extensometer would be read periodically with a hand-held readout unit from the base of the cliff near the trail.

The advantage of the mechanical pins is that the installation is essentially permanent and measurements can be obtained at any time in the future. Data can thus be obtained without relying entirely on electronic devices, which sometimes may fail. The advantage of the electronic devices is that readings can be obtained without the need to climb to the instrument location and, if dictated by later circumstances, could be hooked up to a data logger for automatic remote monitoring and alarm reporting capabilities. The use of both the mechanical and electronic monitoring options also provides a level of redundancy that is important in such applications. It is estimated that the mechanical measuring device, inclinometer, and an extensometer as well as the readout units can be obtained for around $2000. Installation could be accomplished in 1 to 2 days.

The services of a consultant or NPS staff specialist in rock mechanics or rockfall hazards should be retained to analyze and interpret the data. Park management, in consultation with such experts, should develop a plan of action based on results of the instrument monitoring.

Finally, it is the author's belief that Park visitors should be advised of the potential risk from rockfall when viewing the inscriptions and traversing the trail near the cliff. The Park trail guide warns of rattlesnakes that are occasionally seen in the area and also warns of the dangers of lightning, but contains no reference to possible rockfall hazards. As a rule, the general public is neither well versed nor appreciative of geologic processes and the potential dangers from geologic hazards such as rockfalls. The presence by the NPS of a well-maintained visitor trail could be interpreted by many to indicate that there is no risk involved in touring the base of the cliff. Although rockfalls are very rare and apparently no one has been injured or killed during the history of the Park, visitors should be apprised that rockfall is an inherent part of the geologic processes at work within the Park. Such educational information could be provided to the visiting public in a manner that would not cause undue alarm or prevent most people from enjoying the historic inscriptions and beautiful sights that are part of El Morro National Monument.

REFERENCES

Wachter, Bruce G., 1978, Geologic Analysis of Rock Deterioration at Selected National Park Service Archeological Sites, Western Archeological Center, Tucson, Arizona.