Lava Pseudokarsts of Mount St Helens: The First Decade After the 1980 Eruptions

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Abstract

The pseudokarst of the Cave Basalt Lava Flow of Mount St Helens underwent only minimal direct impact from the 1980 eruptions of that volcano. However the caves and other pseudokarstic forms underwent a wide variety of impacts depending on their location and exposure to runoff of varying load and velocity. An entire new pseudokarst developed in ash cloud deposits and avalanche debris on the north side of the mountain. It continues to undergo rapid evolution.

Introduction

On May 18, 1980, deposition of avalanche debris and ash cloud material created a rapidly evolving, sharply localized volcanic pseudokarst in the valley north of Mount St Helens, Washington. A small quantity of directed blast material also is exposed on the surface of this study area.

Also beginning on May 18, 1980, complex eruptional and perieruptional events caused major surface and subsurface changes in the northern (upslope) part of the volcanic pseudokarst of the Cave Basalt Lava Flow, as defined by Greeley and Hyde (1972), on the south side of the mountain.

The writers initiated systematic observations on the Cave Basalt Lava Flow on June 22, 1980, and in the Spirit Lake Pseudokarst on October 9, 1982, including ground, subsurface, and aerial studies. As the rapidity of change decreased in both areas, the frequency of studies decreased to once per year toward the end of the first decade. Beginning July 1980, some of these observations were reported in numerous publications of the National Speleological Society and its Cascade and Oregon Grottos, the Western Speleological Survey, and the proceedings of Mount St Helens symposia of Eastern Washington University. We now summarize and analyze the findings of the first decade following the 1980 eruptions.

Part I: Cave Basalt Lava Flow Pseudokarst

Most of the major changes observed on and in the Cave Basalt Lava Flow pseudokarst were the result of perieruptional mudflows and other flood deposits, not tephra fall or earthquakes. Tephra fall from the 1980 eruptions measured several centimeters at the upper end of this lava flow (about five kilometers south of the 1980 crater rim) (Figure 1), two to three centimeters at the main entrance of Ape Cave (about 8.5 kilometers from the crater), and much less farther south. Additional tephra accumulations from October 1980 eruptions were not measured because of administrative restrictions on access but are believed to have been comparatively small. Tephra fall was vertical, with little eddying or drifting (Halliday, 1981, p 4). Only in the case of vertical or steeply sloping cave entrances did more than trivial quantities of tephra enter any cave. Some invertebrate fauna was affected by surface accumulations of tephra (Crawford, 1980) but the caves otherwise were not significantly impacted by the eruptions *per se*.

Figure 1 — U.S. Forest Service road and path at the main entrance of Ape Cave in June 1980 showing tan, powdery-appearing tephra on the ground and vegetation.

On the other hand, pluvial reworking of tephra and admixture with pre-1980 materials caused a succession of changes in the area above and below the ground surface. Some were minor, short-lived phenomena. Others were extensive and continued to evolve throughout the first decade of study.

In the summer of 1980 light rains resulted in early separation of a tan powdery tephra component which readily formed small local mud tongues, ponds, and flows above and below the ground surface (Halliday, 1981, p 4). Even when extensively mixed with pre-1980 materials on flood plains (see below), in favorable locations this tan component formed small but distinctive mud ponds and tongues on the surface throughout this decade of study. Underground, it was seen best in Ape Cave in the late summer and autumn of 1980 (Figure 2). Small amounts entered Ape Cave from the main entrance (and probably also through the upper two entrances which could not be studied under administrative restrictions). It also entered through two small ceiling cracks downslope from the main entrance. All these were the result of local runoff caused by light rain. Similar material later entered the part of the cave crossed by the Hopeless Cave Mudflow through several drip points, resulting in very small mud ponds in floor depressions. All these entry routes for tan mud entering Ape Cave sealed spontaneously within a few weeks.

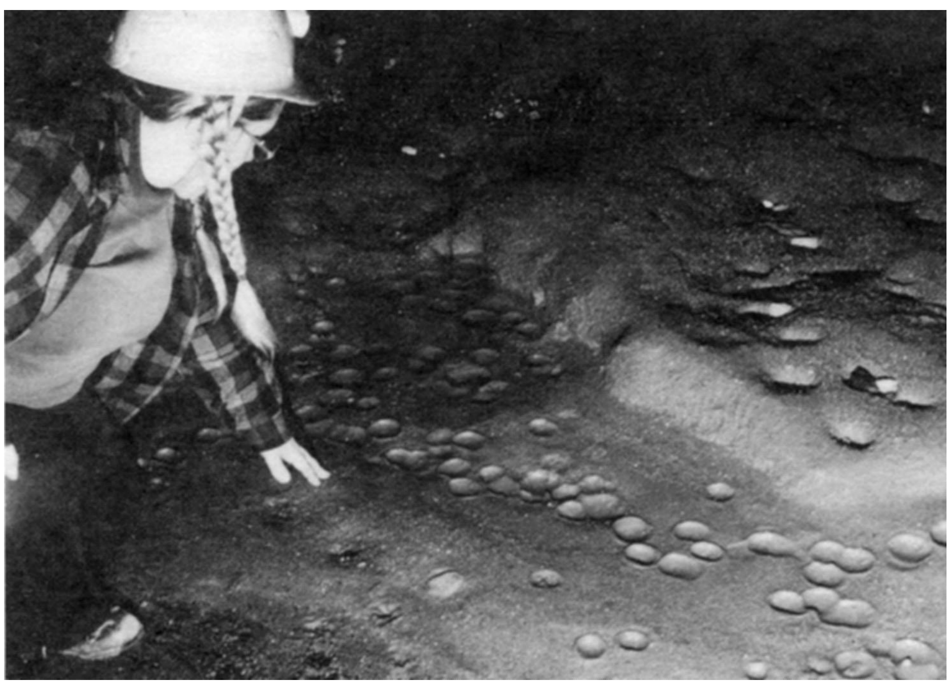

Figure 2 — Drip cavities in the unconsolidated gray tephra tongue in Ape Cave. Note the different appearance of drip cavities in partially consolidated pre-1980 flood deposits in the background.

Figure 3—Aerial view of the Gremlin Cave Mudflow in 1986. The upper entrance of Gremlin Cave is in the clearcut in the lower left part of the photo. The lower entrance is at the edge of the mudflow below the center of the photo. Road 81 cuts diagonally across the upper left of the photo and the main Road 81 Mudlfow cuts across the road in upper right center.

On June 22, 1980, the entrance sink of Hopeless Cave was half-full of tan mud and tongues of similar material (together with small pebbles of pumice) were photographed entering non-spelean swallets about 200 meters northeast of Hopeless Cave. In addition, they carried small quantities of sand. Also on that date a wide, thin mudflow consisting primarily of tan mud was observed covering about 100 meters of Forest Service Road 81 (formerly Road 818) on the east edge of the lava flow, about six kilometers from the new crater. In this locality numerous small boulders and some pre-1980 material derived from local headward erosion was incorporated in it. Similar material was observed in two convergent, newly-eroded gullies about one kilometer farther upslope. Downslope from Road 81, one small tongue of this mudflow was found entering Little Peoples Cave. About 250 meters upslope from the main entrance of Ape Cave, in the drainage axis of the upper part of this lava flow, a mudflow ponded by another Forest Service road appeared to be composed almost entirely of the tan tephra component. Administrative restrictions (Halliday, 1981) precluded investigation of the dry stream course between the Road 81 Mudflow and this mudpond.

On August 23, 1980, a larger mudflow with a different appearance was found in and around the lower entrance of Gremlin Cave. This was part of a mudflow complex crossing Road 81 about one half of a kilometer east of the western edge of the lava flow and about one kilometer northwest of the Road 81 Mudflow, about seven kilometers from the crater (Figure 3). It appeared to arise independently of the Road 81 Mudflow, and was named the Gremlin Cave Mudflow. In contrast with the tan mudflows cited above, the Gremlin Cave Mudflow was gray in color and generally was sandy to gravelly in consistency. In Gremlin Cave it formed a thin slurry with some gravelly elements (Halliday, 1981, p 6, and 1986, Fig 4). Some of it probably was pre-1980 material.

On August 23, 1980, the tan-colored mudflat on and alongside Road 81 in the eastern part of the lava flow was found partially covered by a pond of welded tuff. Its maximum thickness was a few centimeters. Part of it had a reddish tint suggesting incorporation of a pre-1980 material not observed elsewhere at any time. Welded tuff also was found lining the principal gully along the east boundary of the lava flow one kilometer upflow from the pond (Figure 4). Here it lacked any red tint.

All the above phenomena were destroyed or heavily modified by several days' heavy rain at the beginning of November 1980. The gully which had been lined by welded tuff was enlarged by a factor of more than ten, and all trace of the welded tuff lining was destroyed. A series of new, nearly parallel gullies incised Road 81 in most of its course across the lava flow. A sloping flood plain incised by dendritic gullies was deposited atop and on both sides of the road. Locally, trees were debarked more than two meters above the surface of this new plain. Near the road, boulders as much as one meter in diameter were left wedged between trees more than a meter above the new ground surface.

Figure 4—A shallow stream gully along the east side of the upper part of the Cave Basalt Lava Flow in August 1980 showing the welded tuff lining.

Since early November 1980 the geomorphic history of this pseudokarst has been the reworking of the 1980 materials plus addition of much additional pre-1980 material washed into the area by subsequent rains. In and upslope from the pseudokarst, runoff is very rapid because of the slick, bare surface resulting from tephra fall and pluvial deposits. Vegetation is returning locally, but much of the surface still is easily degraded by comparatively low velocity runoff. Deposition continues to predominate as far downslope (south) as the narrows of the lava bed at the lower end of Ape Cave. However, some erosion by low-load stream flow has been noted both above and below ground, with continuing frequent reworking of deposits. Tongues of coarse- or fine-grained floodplain material have been observed enlarging and lengthening at different times and at different rates. Several such tongues now cross Road 81 east of the Gremlin Cave Mudflow. With comparatively light rainfall, small tongues and ponds of tan and gray fine-grained material still leach out of the stream deposits but characteristically are quickly overrun by coarse-grained material.

Following installation of a protective barrier near the lower entrance of Gremlin Cave, its lower entrance crawlway reopened spontaneously. A succession of very small terraces reaching the ceiling of another crawlway about 100 meters downslope suggests that it also became plugged and reopened spontaneously. In the lower entrance area, degradation has been predominant since 1983 or 1984. On one visit when several centimeters of snow remained on the surface, an active snowmelt stream was observed eroding sandy stream deposits in the cave. Unconsolidated gray mud appeared briefly in Ape Cave, much like the initial slurry in Gremlin Cave.

As the main Road 81 Mudflow increased in bulk, one of its tongues entered the vertical lower entrance of Sand Cave then buried it and backfilled nearly all

As a result of this heavy rainfall, the general color of the countryside changed dramatically (Halliday, 1981, p 6). Prior to the heavy rain, the general color was a uniform tan, including the vegetation, to which tephra clung tenaciously. The texture of the ground surface was powdery. After the rain, the natural color of the vegetation returned except for moss and low ground cover which were still covered. The ground surface varied from light to dark gray, depending on how much fine-grained gray tephra had been leached. In areas lacking major flood deposits, the texture of the ground surface changed from powdery to gravelly.

As far south as the narrows of the lava flow near the lower end of Ape Cave, the landscape became dominated by new flood plains or tongues of flash-flood deposits. Hopeless Cave and the adjacent flat were buried in a wide flood plain two to three meters thick. Locally, this was termed the Hopeless Cave Mudflow. Had its crest been a few centimeters higher, part of it would have overrun a Forest Service road near Hopeless Cave and entered Ape Cave (Halliday, 1981, p 6).

To a lesser degree, the Gremlin Cave Mudflow also took on the characteristics of a sloping flood plain. The cave slurry mentioned above was replaced by sandy to gravelly inwash. This new inwash temporarily blocked the lower entrance crawlway. Similar material entered Little Peoples Cave from a new tongue of the Road 81 Mudflow.

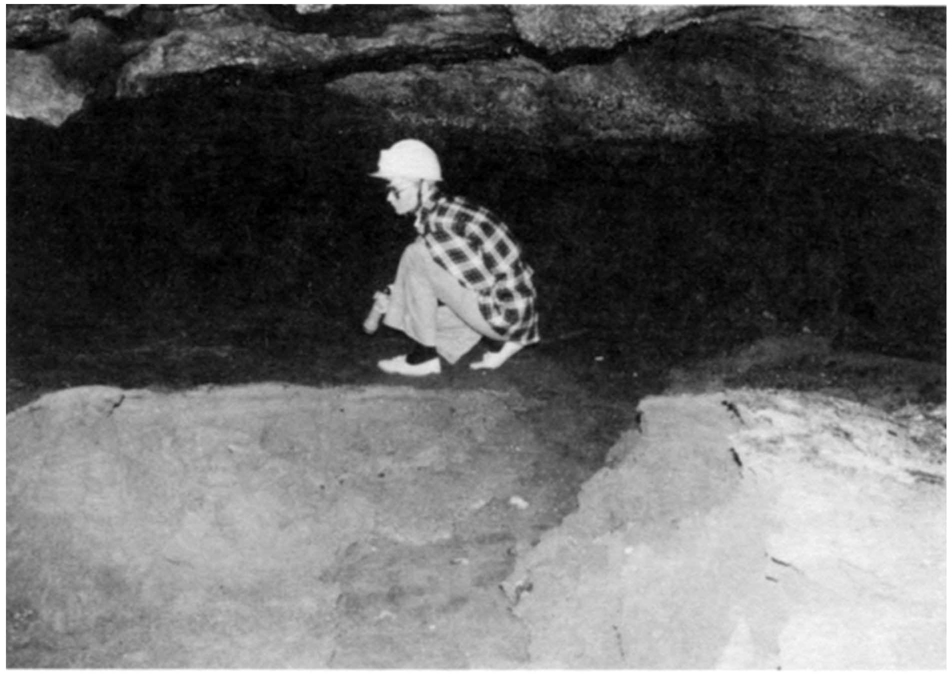

Figure 5—Mud flow tongue which invaded the upper entrance of Sand Cave showing the canyon incised by later low-load high-velocity water. Behind the caver is backfilling from the lower entrance. Originally this was walking passage, now filled.

the upslope section of the cave. A smaller tongue of the same mudflow entered the upper entrance of the cave several months later. It deposited a sandy tongue about one meter high and several meters long. Subsequently this sandy tongue has undergone several small episodes of minor erosion by low-load local runoff (Figure 5).

About 200 meters upslope from Sand Cave, the small vertical entrance of a previously unknown cave was found washed open on October 25, 1981. Named Mud Pond Cave for its most prominent feature, this cave was observed in 1982 and 1983 but on June 3, 1984, it was found reburied and presumably filled.

The Hopeless Cave Mudflow has enlarged and undergone especially notable repeated reworking. It also has propagated downslope, with additional ponding on the narrow neck of the lava flow near the lower end of Ape Cave. Some mud swallets not associated with any known cave developed in that area beginning around 1987.

On March 7, 1981, a different phenomenon was observed in an aggradation-free area between Gremlin Cave and Flow Cave: three resurgences of tan-colored mud. They were found only on that date and their source could not be identified.

At the end of the first decade of study, nearly all of the impacts of the eruptions were upslope from the narrows of the lava bed near the lower end of Ape Cave. South of this point a narrow gully extends downslope from the mud pond previously mentioned. Initially it courses along the west edge of the lava flow then crosses its western arm and parallels the west side of Green Mountain (a kipuka in the lower part of the lava flow). It drains all surficial runoff of the northern part of the lava flow. Except for a few small overflow areas of this gully, and minor local residuals of tephra fall, the southern part of the Cave Basalt Lava Flow shows no significant alteration by the 1980 eruptions and perieruptional events.

Part II: The Spirit Lake Pseudokarst

Beginning October 9, 1982, we began observations on what we call the Spirit Lake Pseudokarst. This is a distinctive, sharply localized area located at and near the former outlet of Spirit Lake, about five kilometers north of the new crater. It comprises most of the Spirit Lake blockage as defined by Glicken *et al.* (1989). The pseudokarst is about one kilometer long (north-south) and 1.5 kilometers wide (east-west). It is immediately east of the depression called Pumice Pond which was the site of spectacular immediate post-eruptional ablation. All except its northwestern tip is 200 to 300 meters south of the buried stream course of the north fork of the Toutle River (Lipman and Mullineaux, Fig 129). None of the features or processes below appear related to the buried stream course.

Figure 6—Aerial veiw of Spirit Lake Pseudokarst looking south taken in 1983. Brownwater Sink (left) and Greenwater Sink (right) are near the center. Two conical "craters" are to the right of Greenwater Sink. Three small sinks are present above and left of Brownwater Sink. At the right edge of the photo are two shallow closed depressions partially cut off by the edge of the photo. The lower (northern) one is heavily modified by construction work on the Spirit Lake Drainage Tunnel seen extending across the lower part of the photo. Ice Sink is near the right edge, below the center.

Other closed depressions exist in the extensive post-eruptional surfaces of this drainage basin, but are scattered and much smaller than those described below. It is the assemblage of large and small closed depressions and other pseudokarstic phenomena in this sharply circumscribed area that merits its identification as a specific geomorphic unit.

Recent publication of detailed geological and hydrological studies of this area (Glicken *et al.*, 1989) has greatly clarified understanding of its origin, nature, and features. But the field studies in that 1989 report terminated in October 1984. The topography of this area has continued to evolve rapidly and extensively. Some of the maps, descriptions, and interpretations in the 1989 report are in need of updating.

When we first observed it in 1982, the surface of this pseudokarst consisted of a gently rolling pockmarked slope of finegrained May 18, 1980, ash cloud deposits from which rose hills consisting of shattered fragments and blocks of the old north flank of Mount St Helens. Some showed surprisingly little contortion of pre-eruption stratigraphy. Some minor directed blast deposits are present near the north edge of the pseudokarst area and some minor reworked undifferentiated pyroclastics near its south edge, but neither has any part in the findings and processes described here. All its pseudokarstic features are in one or more of the units of the debris-avalanche deposits of May 18, 1980, or the ash cloud deposits which immediately followed, or both. Geological terminology in this report is that of Glicken *et al.* (1989).

In this topography we found closed depressions of several types and sizes, sinking ephemeral streams, centripetal drainage, karren, vertical shafts, natural bridges, and (later) one horizontal cave about 15 meters long. Glicken *et al.* (1989) noted that its ridges were as high as 230 feet and the closed depressions as deep as 150 feet. The largest type of closed depression here characteristically has different components of the May 18, 1980, deposits in different segments of its walls. These have the appearance of irregularly rounded sinks with wide, flat bottoms.

The slope and rapidity of erosion of each part of the walls of these large sinks is determined by the type of 1980 material present at that location. Blocky areas of the dark colored "andesite-and-basalt unit" of the avalanche produced comparatively steep, fairly erosion-resistant slopes. Less steep and less resistant slopes are seen where the wall is a less blocky portion of this unit or the grayer "older-dacite unit." The tan ash cloud deposit forms either gentle or near-vertical slopes. While it is highly vulnerable to pluvial erosion, it characteristically forms short-lived vertical or steep fracture faces. The largest closed depression (along the northeast edge of the pseudokarst) has only a low ridge of ash cloud material forming most of its northern rim. It may be breached within a few years by headward erosion of a branch of the ephemeral stream course which forms the north margin of the pseudokarst.

Five major sinks of this type have been identified in the study area. Their floors are aggrading rapidly, and are composed primarily of reworked ash cloud deposits (Figure 6). About two meters aggraded in the easternmost one ("Brownwater Sink") between October 1982 and summer 1983.

Figure 7—Same view as Figure 6 taken in 1985. Water is present in Brownwater and Greenwater Sinks and in one of the three sinks to the southeast but they are still separate. Also a shallow pond is present in the large, shallow southwestern sink. Ice Sink is larger and shallower.

In October 1982, the floor of the second large sink from the east ("Greenwater Sink") was similar in nature. In the summer of 1983 it was quite different, with a crust several centimeters thick overlying quicksand. In some areas it undulated alarmingly underfoot.

Prior to 1984 small parts of these two sinks and another near the southwest corner of the pseudokarst contained shallow seasonal ponds. Since 1984 the ponds have been permanent and, in the case of Brownwater Sink and Greenwater Sink, the ponds have occupied the entire sink floor (Figure 7). It is not known whether their surfaces all represent the same water table. The smallest example of this type of sink, about 200 meters west-southwest of Greenwater Sink, has never been observed with a pond. The large shallow sink at the northwest corner of the pseudokarst was badly disturbed by construction activities but has begun to show shallow internal sinks at its eastern end which vary in location and size from year to year. Here it is separated from Greenwater Sink only by a low divide of ash cloud deposits which appears likely to be a very short-lived feature.

Prior to ponding, the floors of Brownwater Sink and Greenwater Sink showed numerous short-lived pseudokarstic phenomena including isolated vertical pipes up to 3 meters deep and 1.5 meters in diameter (Figure 8). At times, multiple strand lines of pumice pebbles and large internal sinks were present. In October 1982 an ablation pocket more than two meters in diameter was observed in the southeast wall of Brownwater Sink (Figure 9). Fewer and smaller examples of vertical pipes and strands were noted in the large shallow sink at the southwest corner of the study area. In Greenwater Sink, inner sinks seen in 1983 appeared to be the result of impact of a single blocky rock slide onto the plastic crust (Figure 10) (Halliday, 1986).

In these flatbottomed sinks, the locations of vertical pipes and internal sinks differed from year to year. The feeder gullies of the sinks were stable in position but not in size, widening markedly from year to year (predominantly in ash cloud deposits). Feeder gully depths consistently decreased due to rapid degradation of ash cloud surfaces plus aggradation of floors of the gullies and sinks. Their walls tended to remain steep to vertical due to block slumping. Rapid headward erosion of the gullies was characteristic. U.S. Corps of Engineers personnel attempted to halt headward erosion of a large gully at the northeast margin of Brownwater Sink by bulldozing large rocks into it. This pro-

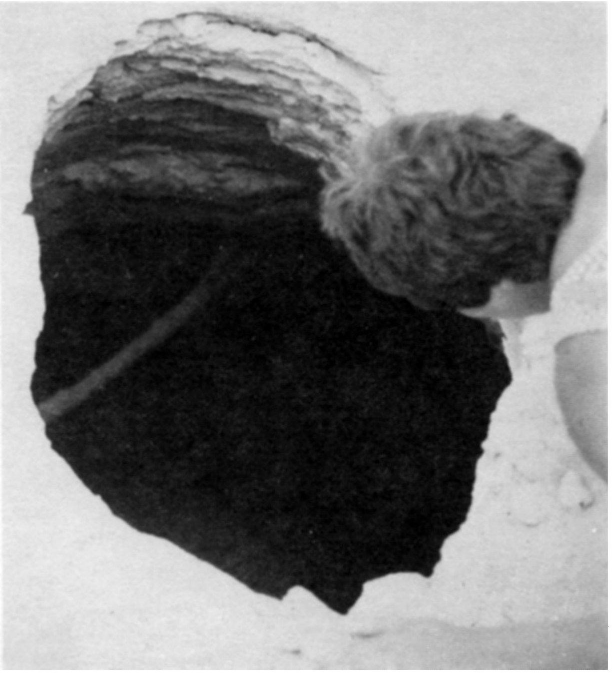

Figure 8—Looking down a vertical pipe in the floor of Brownwater Sink in 1983. Seen more than a meter below the surface is an electrical cable that was on the surface one year earlier.

duced no significant change in the rate of headward erosion.

In 1982 three shallow sinks were noted in ash cloud deposits in the southeast section of the pseudokarst (Halliday, 1986, Fig 5). In 1990, no trace of any closed depression remained in this area. The sinks were replaced by dendritic branches of a feeder gully of Brownwater Sink. The first stage in this small area of centripetal drainages was headward erosion by small gullies in the wall of the lowest of these three sinks. This breached the lower walls of the upper two sinks so that they briefly drained to the lower example. Then headward erosion by the feeder gully of Brownwater Sink integrated this entire sub-area into the drainage of Brownwater Sink.

Figure 9—Internal sink in Brownwater Sink in 1982. This was not present in 1983.

Quite different in appearance from the type of closed depression just discussed are four steep-walled conical "craters." Each is entirely walled with blocky avalanche debris (part of the margin of some is composed of ash cloud deposits). All of these "craters" are smaller than the smallest of the "sinks." They are radially symmetrical and are 15 to 100 meters wide at the surface. The largest (a few dozen meters west of Greenwater Sink) has a small flat of sand at the bottom. They have the appearance of "phreatic-explosion pits" (Lipman *et al.*, 1981, p 509 and Plate I) but no aprons or other accumulations of ejecta could be found atop ash cloud deposits on their rims (also, aprons appear to be absent in the supposed examples depicted in Figure 288 of that reference). We concur with Glicken *et al.* (1989) that the mechanism of formation of both the "sinks" and "craters" is "problematical." The conical "craters" may be steam vents on a grand scale. The large flat-bottomed sinks appear to have been formed by a combination of constructional processes (emplacement of ridges of debris-avalanche deposits), differential compaction of loosely packed debris-avalanche deposits, and ablation of transported glacier fragments. Ephemeral post-eruption large-scale ablation like that at nearby Pumice Pond cannot be ruled out.

Figure 10 — Collapse features on the floor of Greenwater Sink in 1983 showing an impact sink from blocky avalanche and a pond in the largest internal sink (upper left).

Ablation sinks in this study area characteristically were extremely ephemeral features. Only one ("Ice Sink") verified example was present for more than one year. Ice Sink is an inner sink in the western slope of the large closed depression on the northwest margin of the study area. It was not present in October 1982 and opened in early summer 1983. An ice wall was photographed in July 1983 (Glicken *et al.*, 1989, Fig 8) but was covered by slumped hillside material 20 to 30 centimeters thick in August 1983 (Halliday, 1986, Fig 9). Since then it has increased in width but its depth has decreased. The depth of fill overlying any residual ice is not known. Much smaller collapse-type ablation sinks were observed especially in the low hill southwest of Ice Sink in 1982 and 1983. Without exception these were in ash cloud deposits but their walls and floors were mostly underlying debris-avalanche deposits.

A specific type of vertical shaft was entirely limited to thick ash cloud deposits commonly occurring in dendritic or linear groups. Originally we included them with the type of vertical pipe found in the floors of the large flat-bottomed sinks. Now we consider them to be a type of pipe typical of "badlands pseudokarst" and have observed similar examples in South Dakota, Arizona, and Nevada. In the Spirit Lake Pseudokarst they are found on ash cloud flats and slopes of gentle to moderate gradient (Figure 11). Almost invariably a gully or sink wall is nearby and roughly parallel to their alignment (Halliday, 1986, Fig 11). These shafts occur along the

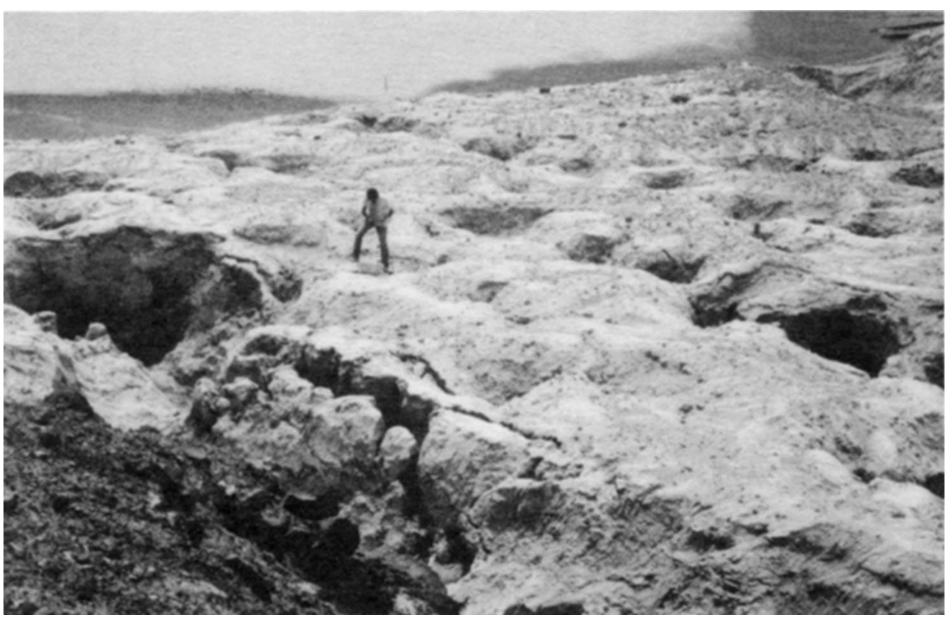

Figure 11 — Badlands pseudokarst in ash cloud deposits north of Brownwater Sink showing aligned shafts and gullies.

course of deep, narrow gullies that have become roofed by block slumping followed by pluvial erosion. Their maximum width is about two meters and maximum depth is about five meters.

Ephemeral local runoff enlarges the bottoms of these gullies, soon causing block slumping, collapse of slumped blocks, widening, and development of parallel cracks which repeat the process. Headward erosion occurs as high-velocity water enters the upper end of each crack. Following the concepts of Parker (1963) and Parker and Jenna (1967) we consider this to be stress crack piping.

We found one cave 15 meters long extending from the bottom of one such shaft to a gully. It persisted for two years despite widening of the shaft and gully. A little "flowstone" of ash cloud particles was present.

Because of the friable nature of their walls, only a few of these pits could be descended safely except where recent erosion had opened a sloping ingress. All were observed to have vertical or overhanging walls of homogeneous ash cloud material. In every case traces of a central ceiling crack were found in the ceiling of grottos or natural bridges at one or both ends of the shaft.

With rainfall, these shafts enlarge and coalesce, re-establishing gullies. Especially stable examples are located in flats north of Brownwater Sink and on the northwest wall of the shallow closed depression near the southwest corner of the study area. The surface of both areas is undergoing rapid degradation, however. Probably both will disappear within the next few years. Similar shafts are developing in ash cloud deposits on the south side of Coldwater Ridge north of the study area.

Perhaps due to minor case-hardening, some horizontal pipe orifices in the sides of large gullies have been observed to be more stable than the gullies themselves or the vertical pipes up-slope from them. At the southeast corner of the study area, a short natural bridge was open (or temporarily closed by slumping and streamwash) from 1982 through 1990. Meanwhile the gully behind it widened from a mere crack to more than two meters and the cliff face receded several meters.

The landscape of the Spirit Lake Pseudokarst continues to evolve and follow-up studies are planned for 1995 and 2000.

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