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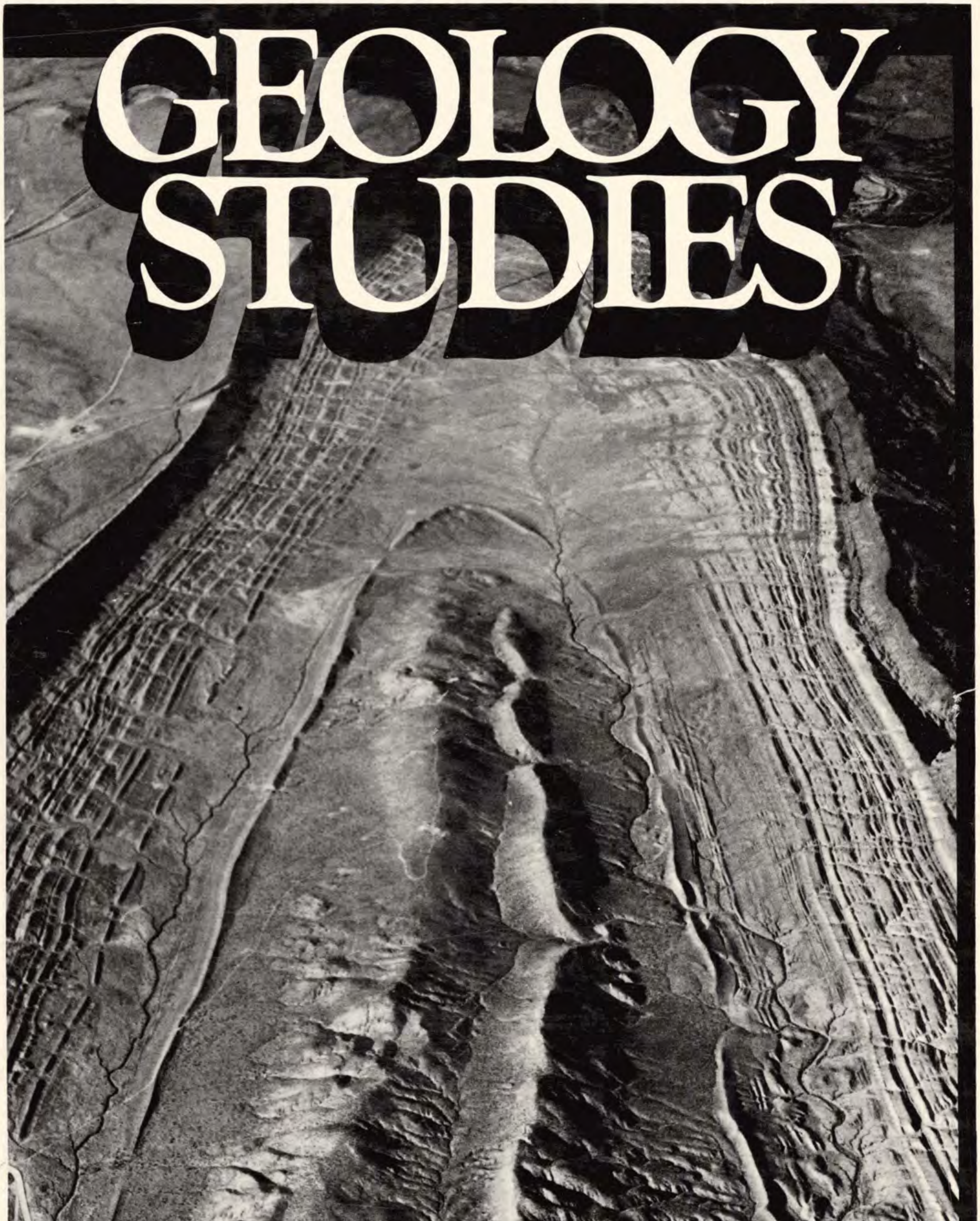
GEOLOGY STUDIES



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Cover: Virgin anticline near St. George, Washington County, Utah.

The Geomorphic Evolution of the Crater Hill Volcanic Field of Zion National Park*

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Abstract.—Four extrusions of basaltic lava occurred during late Cenozoic Time within the Crater Hill area of Zion National Park in southern Utah. The flows partly filled the Virgin River channel and its tributaries, resulting in the development of a lava dam and the relocation of the Virgin River channel and its tributaries to their present position.

Each basalt flow is classified, with respect to its relative age, on the basis of its stage of geomorphic development. This classification includes the relation of the basalt to the surface upon which it was deposited, superposition, amount of weathering and erosion to its original margins, general geomorphic appearance, and its height above the present stream channel. Using these criteria, the basaltic extrusions were divided into two stages and four substages.

The first stage of volcanism in the Crater Hill area is represented by basalts which now form high terraces partially covered by younger basalt flows. Using the Hamblin 1970 classification, this stage was divided into two substages which are in the same stage of geomorphic evolution as the Stage II basalts in the St. George Basin.

The second stage of volcanism is represented by basalts that are superimposed over older flows and have their original margins only partially dissected by erosion. These flows, within the Crater Hill area, are classified according to the classification of Hamblin (1970) as Stage III basalt flows.

Since the inception of volcanism, there have been 35 meters of downcutting by the Virgin River in the Crater Hill area, which has resulted in the development of an inverted valley. To better understand the patterns of geomorphic development which produced such inverted valleys, the stream table model was constructed which demonstrated clearly that the dominant process of erosion is headward until a new stream channel is formed near the flow margins.

INTRODUCTION

The Crater Hill volcanic field is located along the southern margin of the High Plateau Section of the Colorado Plateau. This area consists of a series of escarpments known as the Grand Staircase which rises from the Uinkaret Plateau north of the Grand Canyon to the Markagunt Plateau north of Zion Canyon. The Crater Hill area is situated on the south-facing cuesta formed on the Moenkopi Formation. Crater Hill is one of several late Cenozoic basaltic fields which were extruded along the margins of the Basin and Range Province and the Colorado Plateau.

The primary objectives of this study are: (1) to prepare a detailed map of the Crater Hill area showing the basalt flows and associated fluvial deposits, (2) to classify the basalt flows according to their stage of geomorphic evolution, and (3) to interpret the geologic history of the Cenozoic volcanism in the area.

Acknowledgments

I would like to express my sincere appreciation to many people who helped make this study possible. Special thanks are therefore extended to Dr. W. Kenneth Hamblin for his advice and assiduous interest in the study. Sincere thanks are also extended to Dr. Dale Stevens for his instructions on the operation of certain geomorphic processes. The encouragement and assistance of Dr. Harold J. Bissell in working with the stream table and writing suggestions are deeply appreciated. I am also grateful to Dr. Jess R. Bushman for suggestions in the field; to Robert C. Heyder, superintendent of Zion National Park and his staff; and to Dr. Wayne Hamilton, park geologist, for the use of the park facilities. Thanks go to Dr. Morris S. Petersen for his critical reading of the manuscript and for offering suggested changes. A debt of gratitude is owed to my mother for her support and encouragement in both the field and the office.

Location

The Crater Hill cinder cone is located in the southwest corner of Zion National Park, north of the small settlement of Grafton, Utah. The basalt flows which originate within the area extend 10 kilometers to the west of the park boundary, following the valley of the Virgin River, and cover approximately 14 square kilometers (fig. 1). The most accessible exposures are located between the towns of Virgin and Rockville and can be seen on the north side of Utah Highway 15 as a prominent, long, black ridge north of the road. The Crater Hill cone may be reached by an unpaved road which joins Utah Highway 15 approximately 3.8 kilometers east of Virgin, Utah.

Previous Work

The Crater Hill area was first described by Gregory (1950) as being one of the volcanic fields in Zion National Park. He considered Crater Hill to be in approximately the same stage of geomorphic evolution as Gray Knoll on Little Creek and Spendlove Knoll and Fire Pit on the Kolob Terrace, all of which are cinder cones. Gregory stated that the cinder cones and basalt flows within Zion National Park have been only slightly modified by erosion, indicating a relatively recent date for the volcanic activity in the area. He pointed out that the flows in the Crater Hill area came from more than one vent although the exact vent locations of the older flows were unknown. He also stated that the basalt flow which extends from Dalton Wash to Grafton may have had a vent near the present location near Utah Highway 15, 3½ kilometers west of Grafton. The youngest flows in this area were extruded from vents near the Crater Hill cone. Crater Hill consists mainly of pyroclastic material with slopes covered with lapilli fragments of scoriaceous lava and volcanic bombs. The flows associated with this cone extend south to a point near the Virgin River channel where they are superimposed over older basalt flows.

Threet (1959) mapped the Crater Hill area and described several interesting surface features such as large

* A thesis submitted to the Department of Geology in partial fulfillment of the requirements for the degree Master of Science, April 1976: W. Kenneth Hamblin, thesis chairman.

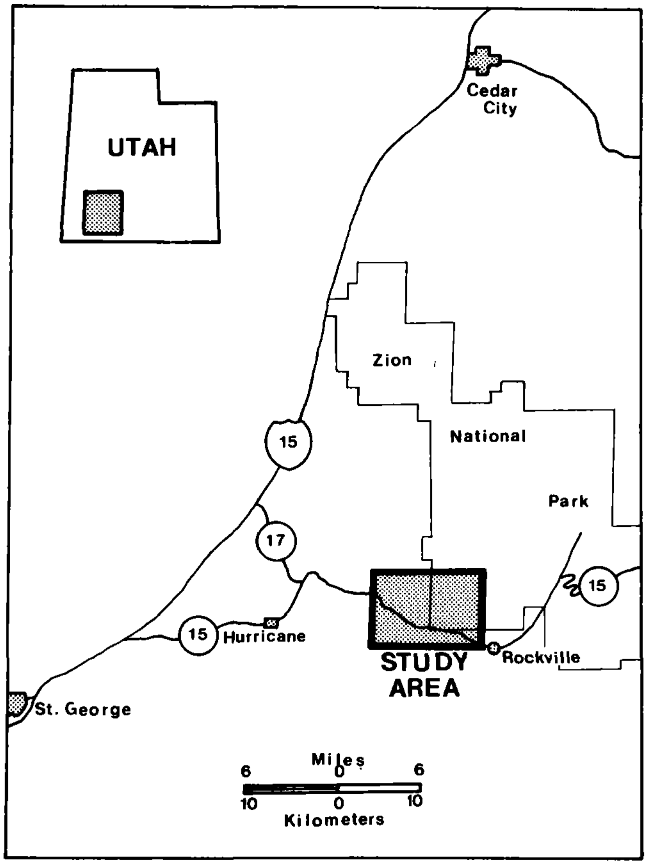

FIGURE 1.—Index map showing the location of the Crater Hill area.

viscous flow corrugations and the presence of faults in the area. He disagreed strongly with Gregory and concluded that the extrusion in the Crater Hill area consisted of one eruption from a vent near Crater Hill. He prepared a series of block diagrams showing his interpretation of the geomorphic development of the field and its relation to the Virgin River. Threet pointed out that most of the volcanic eruptions within Zion National Park were associated with joints or were fault controlled; but Crater Hill, in contrast, was associated with a small monocline, which, when traced to the south, is faulted south of the Virgin River. Threet, using the classification developed by Colton in 1937 and modified by Koons 1945, classified the flow in the area as a Stage III basalt flow.

Methods of Study

The Crater Hill area was mapped on low altitude aerial photographs on a scale of 1:20,000. Margins of the basalt flows were studied in as much detail as possible, and critical locations not clear on the aerial photographs were noted for further study in the field. Field work consisted of checking the photo mapping and studying critical relations where relationships could not be determined from the photographs. Flow direction, flow margins, and surface features of each flow were mapped. Samples from each of the basalt flows were collected and labeled. The thickness of the flows was measured using a hand level, and the size and shape of each flow were determined by measuring their dimensions on topographic maps at scales of 1:24,000 and 1:30,000. Associated features, such as consolidated gravels and faults within the area, were also mapped and studied. An aerial survey of the Crater Hill area was made, using light aircraft flying at altitudes of 100 to 1,000 meters. Thus, the writer was able to check field mapping and to take oblique aerial photographs. Information acquired in the field and from the study of the aerial photographs was compiled on a topographic map at a scale of 1:24,000. All samples collected in the field were studied with the use of a binocular microscope. Thin sections of the critical flow units were studied to determine the type of basalt present in the Crater Hill area.

Field work was supplemented by a laboratory study of the evolution of inverted valleys using the stream table at the Brigham Young University Sedimentation Laboratory. The study was made in an attempt to more clearly identify the processes active in the development of topography where a normal drainage system is interrupted by local extrusions of lava. Results of the stream table study were used in the interpretation of the geomorphic evolution of the Virgin River drainage in the Crater Hill area.

OBSERVATIONS ON THE EVOLUTION OF INVERTED VALLEYS GENERATED BY A STREAM TABLE

The Brigham Young University stream table was used to construct a model for the geomorphic evolution of an inverted valley. This stream table, with its large size and capacity to be manipulated in various ways, is better suited than the typical flume for simulating geomorphic processes. The working part of the table is 2.5 meters wide, 7 meters long, .35 meters deep, and is adjustable vertically so that simulated drainage slopes can range up to 20 degrees. The depth of sand in the table is .10 meter. The settling tank attached directly to the stream table is 2 meters wide and has a depth of 1 meter.

In preparing the stream table, medium-grained sand was used to simulate nonresistant sedimentary rock. A special mix of one part cement to seven parts sand was prepared and mixed with sufficient water to make a fluid similar in viscosity to a basalt flow. Upon hardening the cement resembled the more resistant basalt.

The basic experiment was designed to allow a channel to develop a stream profile in a state of quasi-equilibrium (fig. 2). The stream pattern formed by the flowing water contained a series of slight meanders. The gradient was inclined at an angle of 15 degrees (fig. 3).

After a stream channel had been established at quasi-equilibrium, the special mix of cement, which had the viscosity approaching that of a basalt flow, was poured into a segment of the stream channel (fig. 4).

The cement simulated the effect of a basalt flow on the morphology and future development of a stream channel. After hardening, the cement was sprayed with white paint to enhance the visual contrast between it and the darker sand. A discharge of water, equal to that which originally cut the channel, was again introduced and a sequence of time-lapse photographs was taken showing the evolution of the drainage now modified by the simulated basalt flow.

The important events recorded in this experiment are as follows: Water, upon reaching the location where the cement had blocked the channel, developed a small lake

FIGURE 2.—The stream table was prepared by leveling the sand in such a way that it sloped toward the center of the stream table, where a straight channel was marked to guide the development of a "natural" channel.

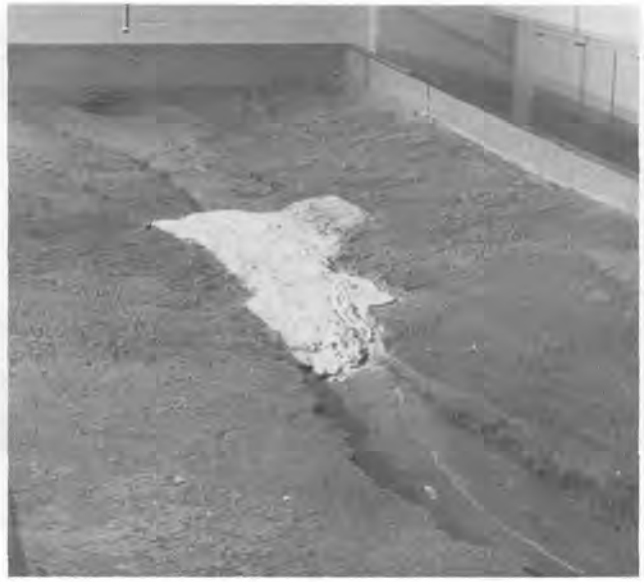

FIGURE. 4.—Cement was mixed into a viscous fluid, poured into the stream channel, and allowed to harden simulating a basalt flow and cone. The cement represented the more resistant basalt, and the sand represented the less resistant sedimentary rocks.

FIGURE 3.—The stream table was operated for a period of time, and a stream profile developed that was in a state of quasi-equilibrium.

FIGURE 5.—The stream was allowed to operate at the same rate of discharge. Immediately the water began to pond behind the "lava flow," and sediment was deposited within this simulated lake.

(fig. 5) and then moved along the lower edge of the simulated basalt flow vigorously eroding the sand along the contact with the cement (fig. 6). Erosion was most rapid at the lower end of the cement-filled channel, where the water reentered its old channel, because of the steeper gradient. With time, headward erosion resulted in the migration of the nickpoint upstream, along the side of the simulated basalt flow (fig. 7, 8). During this period of time, sediments accumulated in the lake that formed behind the cement (fig. 9). As headward erosion moved the nick-point along the margin of the cement, a new gradient was established which had the same profile as that developed by the original stream (fig. 10). Deposition had occurred along the lower edge of the cement-filled channel in order to establish a profile of equilibrium. After a short period of time, the stream table developed another profile in quasi-equilibrium and then slowly began downcutting (fig. 11). Downcutting continued to lower the entire stream gradient and to develop a stream pattern which more closely approached a state of equilibrium. Meandering also oc-

FIGURE 6.—Water overflowed along the margin of the "basalt" dam and reentered the original channel at the end of the flow. Headward erosion progressed very rapidly along this margin, as can be seen by the simulated rapid falls. Deposition also occurred at the front of the cement-filled channel in order to build up the gradient to a profile that developed a state of equilibrium.

FIGURE 7.—Headward erosion moved the nickpoint further upstream along the margin of the "basalt" which established a smoother stream gradient similar to that produced by the original stream.

FIGURE 8.—Undercutting occurred along the margin of the "basalt" by the meandering of the stream, and the nickpoint migrated further upstream almost to the lake.

FIGURE 9.—Headward erosion and downcutting caused the stream channel, along the margin of the "basalt," to reach the level of the stream channel before the extrusion.

FIGURE 10.—As the stream reached the level of the original gradient, quasi-equilibrium was approached. The "basalt" was left as an isolated ridge along one margin of the new channel.

FIGURE 11.—Near the end of the experiment the lower margin of the "basalt" slumped into the new valley, and further modification was largely due to mass movement and slope retreat. The stream channel can be seen along the lower margin of the "basalt flow," and the smooth stream gradient can be noted.

curred to the stream pattern causing the widening of the stream channel.

The stream table model simulated the evolution of inverted valleys in many respects although it had some significant limitations. The sand in the stream table was homogeneous whereas sedimentary rocks, which the sand represented, are rarely if ever homogeneous. Resistance to erosion of the sand was much less than that of the sedimentary rocks, and the cement was proportionately more resistant than the basalts which it was representing. The internal structure of the basalt flow, having columnar jointing, is different from the homogeneous cement used in the study. Columnar jointing in the basalt would permit the margins of the basalt flow to be removed by mass movement more easily than the cement when undercutting occurs. No attempt was made to duplicate the exact field relations on a smaller scale in the stream table. Fluctuations in the volume of water that passed through the stream table were not monitored, and no attempt was made to simulate the time factor involved in erosion. These experiments did, however, focus attention on the major processes in the evolution of topography where interruptions in the normal sequence of events are produced by local volcanic activity. Especially informative was the sequence of events which occurred in the development of an inverted valley, as well as the processes involved in its origin and evolution. These processes were headward erosion, downcutting, and slope retreat. Headward erosion was the dominant process in the development of stream channels along the flanks of the basalt flows as the nickpoint migrated upstream. Vigorous downcutting was the dominant process operating in the channel until a new profile of quasi-equilibrium was established; and slope retreat occurred by undercutting after the stream had developed a meandering pattern.

CLASSIFICATION AND DESCRIPTION OF THE BASALT FLOWS IN THE CRATER HILL AREA

Previous Classification

Several classification systems have been developed for studying the geomorphic evolution of basaltic volcanism on the Colorado Plateau. Colton (1937), in his classic paper on the San Francisco volcanic field, was one of the first to study an entire volcanic field and map the flows according to their relative ages. He recognized that five distinct volcanic episodes were present and could be differentiated on the bases of (1) the height of the basalt flow above the surrounding erosional surface, (2) the amount of dissection which had occurred along the original flow margins, and (3) the presence or absence of original surface features and cider cones.

Colton pointed out that the oldest flows in the area, which he called Stage I basalt flows, had their margins eroded back so that the original extent of the flow could not be determined. The flow features of these basalts have characteristically been eroded, and the cinder cones and pressure ridges have been removed. Stage I flows remain as topographically high terraces. Stage II basalt flows of Colton have been subjected to less erosion than those of Stage I, and the approximate original outline of the flow can be recognized. Surface features of Stage II flows are highly dissected as are those of Stage I; however, remnants of spatter cones can commonly be recognized. Stage III flows retain their original margins and surface features, but they are highly weathered and slightly dissected. Pressure ridges and spatter cones can be recognized. Stage IV flows retain their original margins, and the surfaces of the flows are essentially unmodified. Cinder cones and pressure ridges are characteristic features preserved in this stage of volcanic activity although they, too, have been dissected and modified by erosion. Stage V basalts still retain their original flow margins and surface features, but they lack visible evidence of erosion or dissection and can generally be traced to their source.

A later classification system, used on the Colorado Plateau, was that developed by Koons (1945) in his study of the Uinkaret Volcanic Field north of Grand Canyon. He used the same basic criteria developed by Colton but recognized only four episodes of volcanism on the Uinkaret Plateau.

Further modification of the geomorphic classification of flow units was done by Hamblin (1963, 1970) in his work with the basalt flows in the St. George Basin and on the Shivwits Plateau. Hamblin concluded that the basic criterion for the determination of different ages of basalt flows was the relation of the flows to the surfaces upon which they were deposited. Hamblin's Stage I flows include lavas that were deposited on an ancient erosional surface which exhibit no apparent relation to the present drainage system. These flows now exist as high, isolated mesas and buttes. Hamblin's Stage II flows consist of lavas deposited on the surface developed by the present drainage system during earlier cycles of erosion. Stage II basalt flows now exist as elongated inverted valleys trending roughly parallel to the present drainage. (Both Stages I and II of Hamblin would be classified as Stage I by Colton.) Stage III flows include those deposited on the surface of erosion carved by the present drainage system. These flows occupy the present stream valleys, and their original margins are relatively undissected except by erosion although locally some dissection may have occurred. Stage IV flows occupy the present drainage system and are so recent that erosion has not had enough time to establish new drainage patterns or to modify the flow to any significant degree. Original surface features of the flow, such as pressure ridges or flow corrugations, remain essentially unaltered. Additional subdivisions within each stage are possible on the bases of superposition, amount of dissection to the original margins, general geomorphic appearance, and height of the basalt flow above the present stream channel. Hamblin's classification system has great flexibility, can be used in areas of widely differing geomorphic settings, and was adopted for this study.

Classification of Crater Hill Flows

Two major stages of extrusion are clearly recognized in the Crater Hill area. According to the system developed by Hamblin, these flows would be classified as Stage II and Stage III flows. Stage II basalts have been modified by erosion and now form inverted valleys. Stage III flows were erupted into the present drainage system and have been only slightly modified by erosion (fig. 12). Stage I and Stage IV basalt flows are not found in the Crater Hill area. Radiometric dates for the basalt flows in the Crater Hill area were not available at the time of publication, so they are not given in this paper.

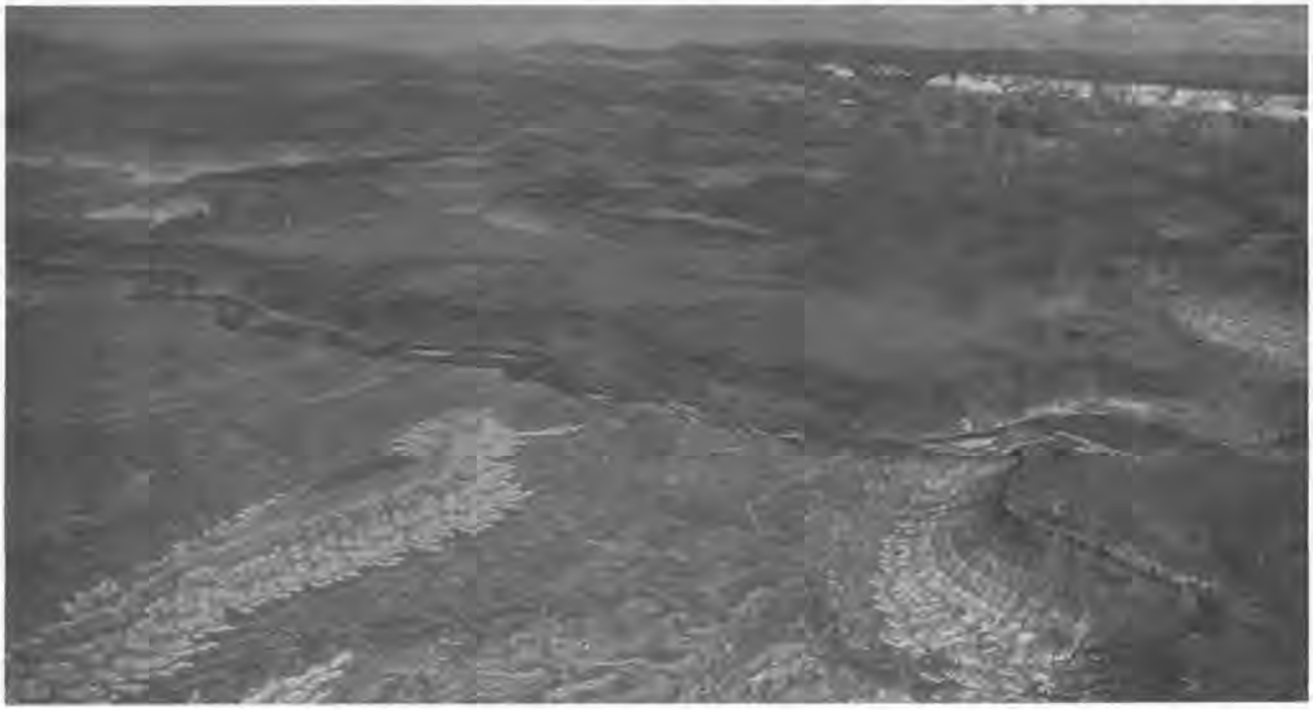

FIGURE 12.—Aerial view of the Crater Hill area looking north, showing the southern margin of this area and the Stage IIIa basalts overlying the Stage IIa basalts. The cinder cone is in the immediate background.

Stage II Basalt Flows.—Stage II basalts in the Crater Hill area formed a capped terrace along the north side of Utah Highway 15 between Dalton Wash and Coalpit Wash. These basalts have been partly covered by younger basalts in the area so that some distinguishing characteristics are locally obscured. Two substages of the Stage II basalt flows can be recognized on the basis of their elevation above the present drainage system. These flows are labeled Stage IIa and IIb.

The Stage IIa basalt flow in the Crater Hill area extends from a point north of Grafton in a linear pattern along the old Virgin River channel to Dalton Wash (fig. 12). This flow has minor lobes which extend up Dalton Wash, Coalpit Wash, and the Virgin River channel (fig. 13). The elevation at or along the crest of this basalt flow decreases from the cinder cone located on the lava flat northwest of Grafton to Dalton Wash on the west and Coalpit Wash on the east. The northern margin of this flow and much of its surface have been covered by a younger Stage III basalt. The probable vent for this eruption is preserved as the highly dissected cinder cone, composed of large volcanic bombs and pumice (fig. 14), located on the lava flat northwest of Grafton. The younger Stage III basalt flowed around the cinder cone so that it rises as an "island" surrounded by younger lavas. Stage IIa flow has a thickness of about 200 meters and is approximately 6 kilometers long. The original surface features have been removed by erosion, and dissection has occurred along its original margins. Meandering of the Virgin River has resulted in the undercutting, slumping, and subsequent removal of the southern margin of this flow. Dalton Wash has developed a channel through part of this unit, and the southern margin of the flow has been dissected by a series of stream channels. Its drainage patterns were then disrupted by later basalt flows which were extruded in the vicinity. Remnants of the central part of the collecting system are represented on the map by a series of indentations along the southern margin of the flow. Columnar jointing, found in this basalt flow, has a width of about 60 centimeters. Associated with this basalt is a series of stream gravels at the same elevation, which extends from the southeastern margin of the Crater Hill area to the town of Rockville (fig. 15). These gravels consist of lenses of sand interbedded with boulders and cobbles (fig. 16).

Stage IIb basalt forms a low ridge near the Virgin River channel along the southwest margin of the Crater Hill area (fig. 17). This flow has its original margins highly dissected and its original surface features removed by erosion. Having been covered by subsequent basalt flows, its vent location cannot be determined (fig. 18). It forms a small remnant of an inverted valley 25 meters above the present drainage and also outcrops along the west side of Coalpit Wash near the northeast margin of the area. Both outcrops are partly covered by the same subsequent basalt flow. The flow is 30 meters thick and is characterized by small columnar joints. Along the western margin of this basalt is a series of poorly sorted gravels, which, when traced north into Dalton Wash, cover part of its surface. The Stage IIb flow has a lower elevation and is thinner than the Stage IIa flow, and its columnar jointing pattern is different.

Stage III Basalt Flows.—Stage III basalt flows in the Crater Hill area are relatively undissected and are superimposed over a large part of the older basalts. They were extruded on the surface eroded by the present drainage system, and stream dissection is just beginning to occur along their original margins. Pressure ridges and large flow

FIGURE 13.—Lobes of the Stage IIa basalt extend from the southwest corner of the Crater Hill area. The Stage IIIa flow is superimposed over the Stage IIa basalt.

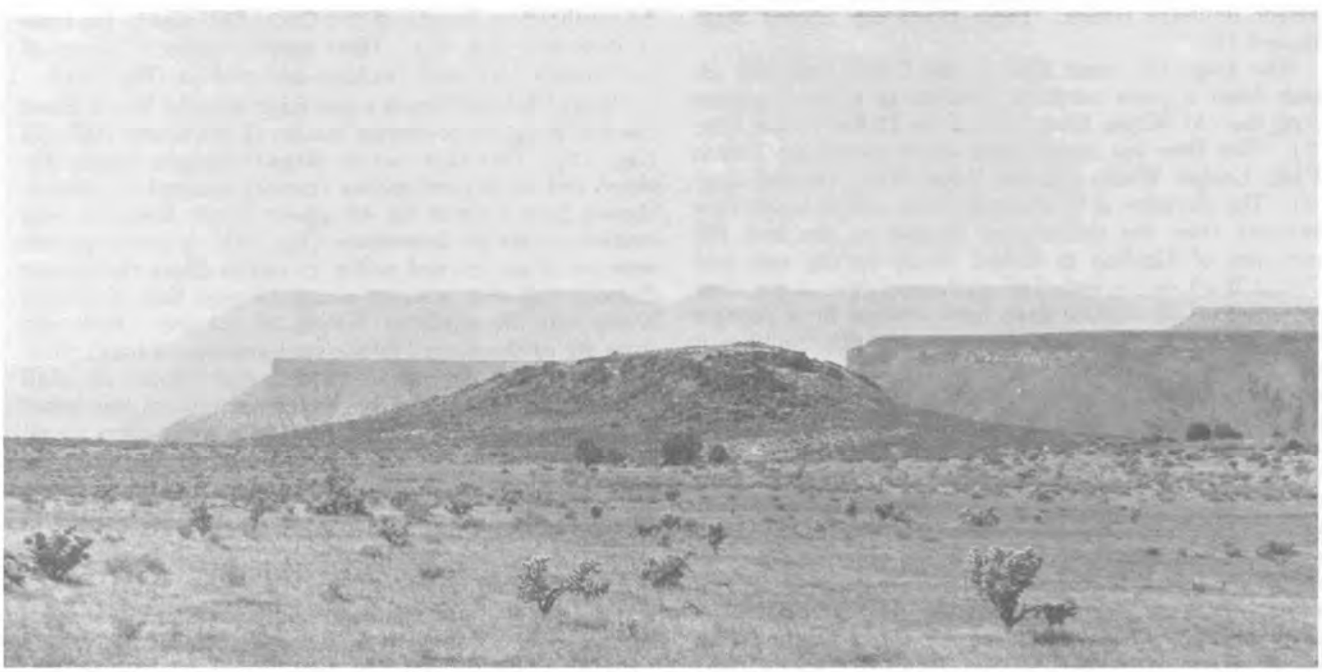

FIGURE 14.—Remnants of a cinder cone that mark the possible location of the vent for the extrusion of Stage IIa flow. The cone consists of large volcanic bombs and cinders interbedded with small basalt flows. Surrounding the cone is the surface of the Stage IIIa basalt flow.

FIGURE 15.—Remnants of the stream gravels deposited in the Virgin River channel before, during, and after the eruption of Stage IIa basalts. The linear nature of these stream gravels, which extend from the southwest corner of Crater Hill to the town of Rockville, shows the location of the Virgin River channel before the eruption of the Stage IIa flow.

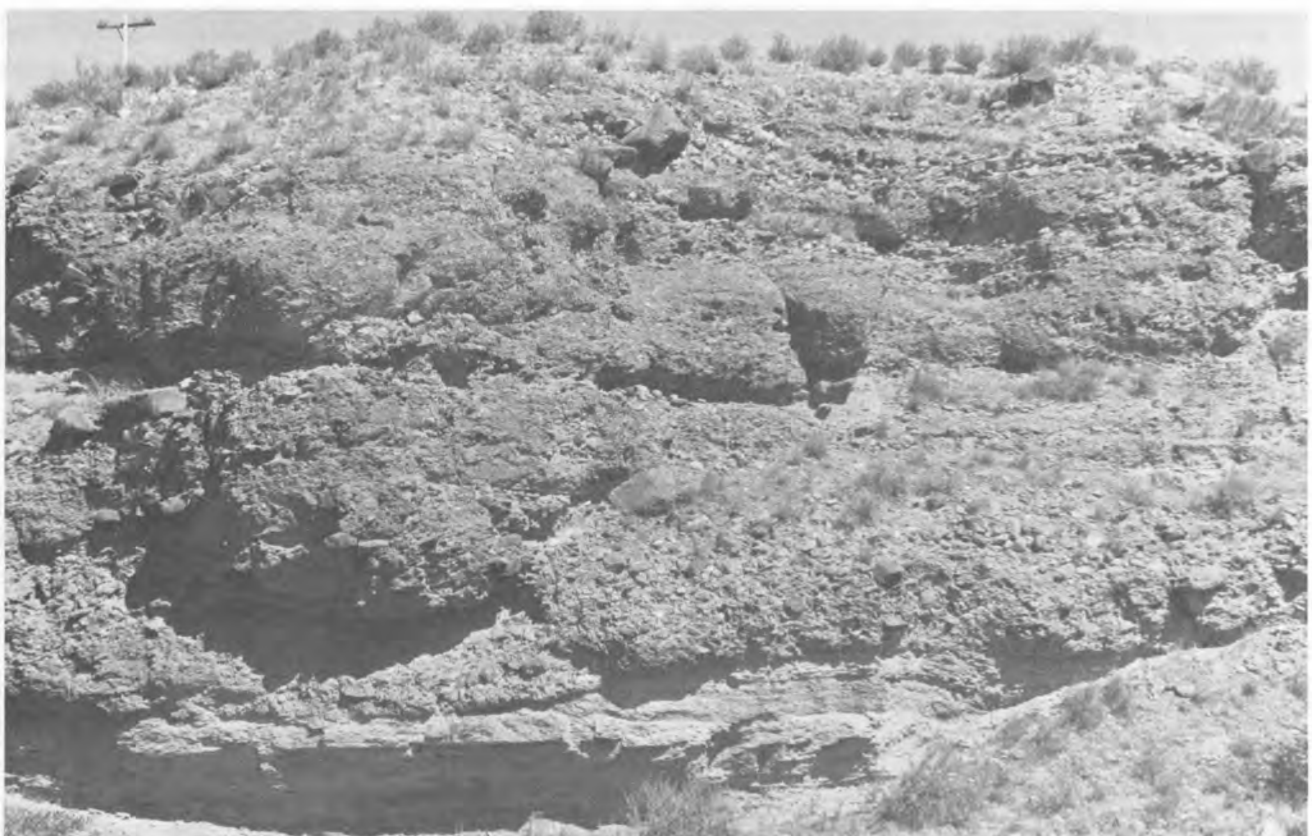

FIGURE 16.—Sedimentary structures in the stream gravels near the southeast margin of the Crater Hill area. The lenticular nature of the stream gravels can be seen near the bottom of the photo.

FIGURE 17.—View looking east at the western extent of the Crater Hill basalt flows. The Stage IIIa flow is superimposed over the Stage IIb flow and caps the ridge to form an inverted valley.

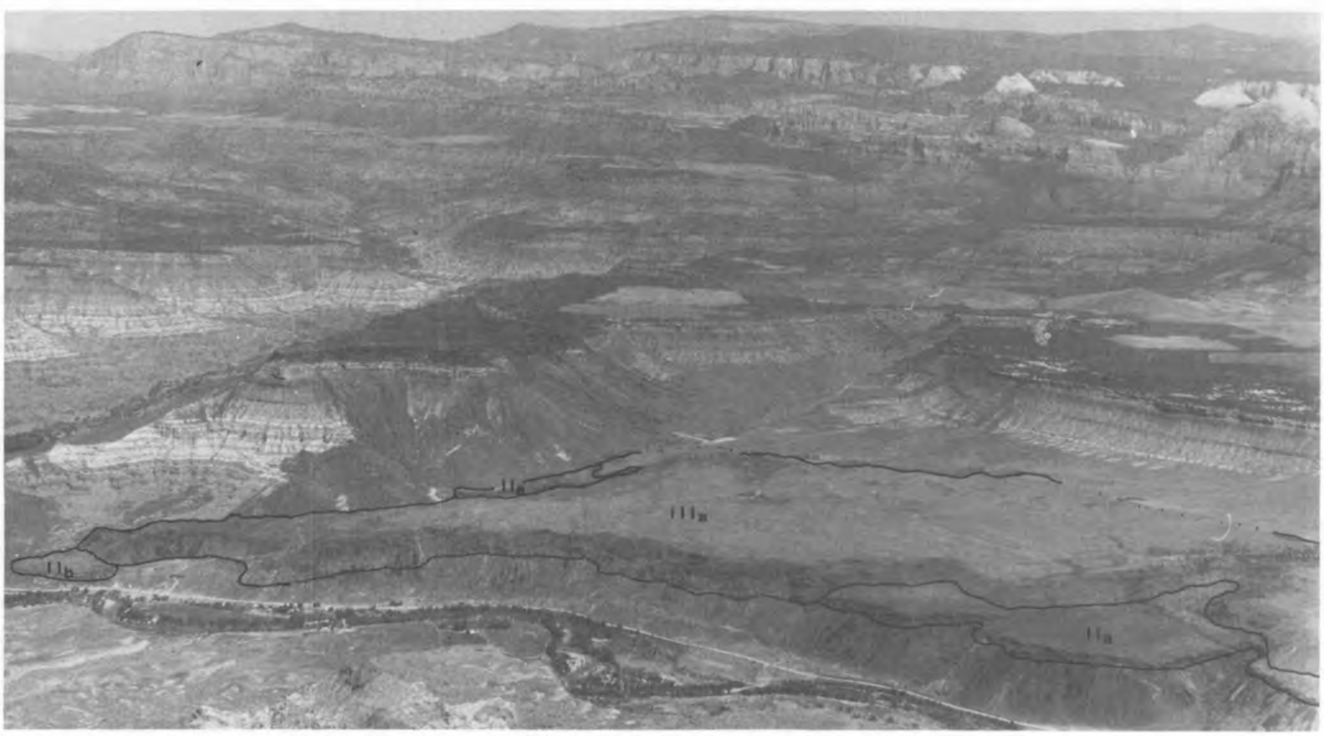

FIGURE 18.—Stage IIIa basalts can be seen superimposed over the Stage IIa and Stage IIb basalt flows. The linear orientation and flow direction of the Stage IIIa basalt flow indicate the location of ancestral Coalpit Wash.

corrugations are present. This stage can be divided into two substages of volcanism, Stages IIIa and IIIb.

The Stage IIIa basalt flow is the most extensive in the Crater Hill area. It has an L-shape, having been extruded from a location southeast of Crater Hill where it moved southward to the Virgin River, then west along the northern margin of the Stage IIa basalt to Dalton Wash (fig. 12). This flow has three minor lobes: two extend east, and the other extends north from the Crater Hill cone. Lava from this flow cascaded into the Virgin River at a point three kilometers west of Grafton near the mouth of Dalton Wash. Sinuous ridges are located along both margins of the basalt south of Crater Hill and are interpreted to be basalt levees 3 to 15 meters above the major part of the rock body (fig. 19). Stream dissection is beginning to occur locally along the original flow margins.

The Virgin River has partly removed the lava which cascaded into it northwest of Grafton and has undercut the southern margin of this flow near Dalton Wash. Original margins of the flow are partly preserved, and the surface features, such as large flow corrugations and pressure ridges, are present. East of Crater Hill the vent location can be observed. The Stage IIIa flow shows three zones of columnar jointing: a lower colonnade, which consists of narrow columnar joints 9 to 15 millimeters thick; entablatures consisting of rosettelike structures; and an upper clinker surface, or upper colonnade.

A younger basalt flow mapped as Stage IIIb (fig. 19) is superimposed over the Stage IIIa extrusion in the area of Crater Hill. It was erupted in association with the development of the Crater Hill cone and has two major lobes. One flowed southeast for a distance of one kilometer from Crater Hill, and the other flowed northeast an equal distance (fig. 20). The northeastern lobe consists of three

FIGURE 19.—The Crater Hill cone, looking from the south. Remnants of the Stage IIIa basalt, which represent natural levees, can be seen on both sides of the flow. The flat area between these two ridges in the central part of the photo represents the Stage IIIa basalt flow.

FIGURE 20.—The Crater Hill area, looking toward the southwest. Lobes of basalt, Stage IIIb, extend from the northeast side of the area. Coalpit Wash can be seen along the left side of the photo. The location of ancestral Coalpit Wash can be recognized by the linear nature of the Stage IIa basalts in the foreground. The 120 degree bend in Coalpit Wash, near the margin of the basalt flow, is further evidence of the location of ancestral Coalpit Wash.

minor flow units which have the same amount of dissection and overrode each other. The original margins of this basalt flow are partly preserved, and flow corrugations and pressure ridges are present, indicating flow direction.

Cinder Cones

There are three cinder cones in the Crater Hill area. The oldest, located on a lava flat northwest of Grafton, has been highly dissected by erosion. The second oldest is located east of Crater Hill and was associated with the extrusion of Stage IIIa basalts. The youngest and best preserved cone in the area is Crater Hill. It is composed of scoria and volcanic bombs and was formed in conjunction with the Stage IIIb eruption. It is 233 meters higher than the basalt flows in the area, has been breached by erosion, and is presently being dissected. There are five patches of cinder located northeast and three patches of cinder immediately east of Crater Hill. All have been dissected by erosion.

The results of this study show that the Crater Hill volcanic field is more complex than was suggested by Threet and consists of four flows extruded into the Virgin River channel modifying the drainage pattern. This supports the earlier conclusion of Gregory, who suggested that multiple flows are present in the area.

Faulting

Faulting in the area took place before the inception of volcanism and therefore does not offset any of the basalt flows. However, as was pointed out by Threet (1959), faulting on the Colorado Plateau has controlled the location of volcanism. The presence of the fault that extends across Grafton Mesa into the Crater Hill area may have been the controlling factor for volcanism within this area. The cinder cone on the lava flat west of Grafton and the cinder cones associated with Crater Hill offer further support for the theory that this fault controlled the volcanism because they follow its projected lineation. Likewise, this faulting may have partly controlled the location of ancestral Coalpit Wash, which developed along the same projected line.

The major fault, which extends into the Crater Hill area, can be mapped across Grafton Mesa and exhibits reverse drag similar to the reverse drag seen on the Hurricane fault (Hamblin 1965). It can be traced to the southern margin of the area, where it has been covered by basalts. If it were projected into the Crater Hill area, it would follow the northern trend of the Stage IIIa basalt flow that filled ancestral Coalpit Wash. The indication could mean that ancestral Coalpit Wash developed along this fault. Of the two additional faults located northwest of Rockville, one extends into the northwest corner of the Crater Hill area but does not offset the Stage IIIa basalt flow. It may have controlled the development of a tributary to Coalpit Wash. The other can be traced across Scoggins Wash but does not intersect the Crater Hill area.

Preliminary Petrography

In hand samples the basalts of the Crater Hill area are black and fine grained. They contain phenocrysts of olivine from .5 to 1 millimeter in size. The weathered surface of the basalts is a reddish brown to black color, and the olivine phenocrysts are dark brown. Vesicles in the basalt are filled with calcite.

Upon preliminary microscopic investigation of the four thin sections made from basalt samples collected in the area, there is no obvious difference in the composition or flow structure of the basalts in the Crater Hill area. All samples are porphyritic, fine-grained basalts with large phenocrysts of olivine. Microphenocrysts of plagioclase and pyroxene are found, together with oxides and glass in the matrix. Olivine phenocrysts are subhedral in shape, whereas the pyroxene and plagioclase are euhedral to subhedral and form laths ranging in size from .01 to .03 millimeter. The oxides are disseminated throughout the groundmass. Plagioclase phenocrysts are oriented in such a manner that their long dimension is parallel to the flow direction of the basalt; they are classified as olivine besalts. Further petrographic and geochemical work is needed to determine their exact composition.

VOLCANIC HISTORY OF THE CRATER HILL AREA

Prevolcanic Topography

Prior to the inception of volcanism, the topography of the Crater Hill area was one in which several small tributaries, the ancestors to Dalton, Coalpit, and Scoggins Washes, entered the Virgin River in a manner very similar to the drainage pattern which had developed east of the Crater Hill area between Grafton and Springdale (fig. 21).

Dalton Wash entered the Virgin River east of its present location and established a quasi-equilibrium gradient. Coalpit Wash developed a stream pattern to the west of its present course which was later filled with basalt. The part of Coalpit Wash that was filled by a basaltic extrusion has been termed ancestral Coalpit Wash. This channel can be projected along a course that likely followed a fault near the edge of the flows. Scoggins Wash occupied a position near its present location, but it flowed directly into the Virgin River. It was not until later, fol-

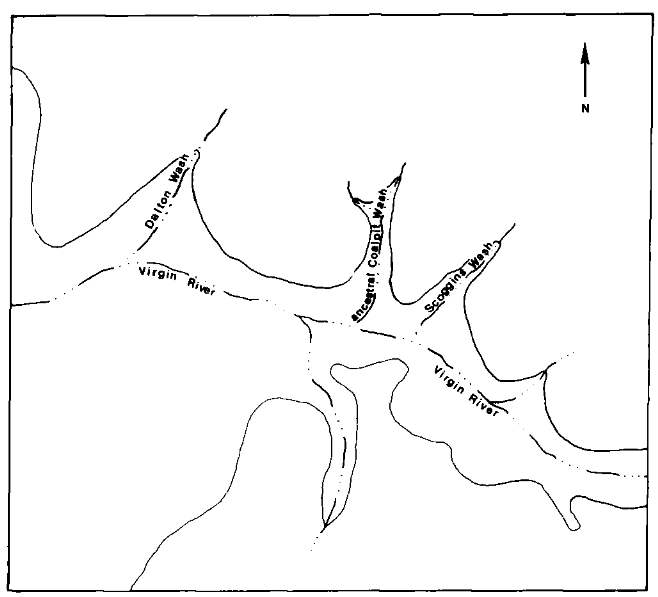

FIGURE 21.—The Virgin River drainage as it would have appeared in the Crater Hill area before the inception of volcanism.

lowing the extrusion of the Stage IIIa basalt flow, that Coalpit Wash was forced to enter the lower segment of Scoggins Wash.

Stage IIa Eruption

The first volcanic extrusion in the Crater Hill area is believed to have been erupted from a vent in the vicinity of the lava flat northwest of Grafton (fig. 22). The isolated knoll in the center of this lava flat represents the eroded remnant of the cinder cone; it contains lava bombs interbedded with cinder and basalt. The lava was extruded into the Virgin River and flowed three kilometers down the ancestral Virgin River channel. Lobes of this basalt flow extended short distances up Dalton Wash, ancestral Coalpit Wash, Scoggins Wash, and up the Virgin River channel. As this flow blocked the Virgin River, it formed a lava dam that resulted in the development of a lake.

Erosion of Stage IIa

Stream sediments were deposited in the lake, and a new channel for the Virgin River was established along the southern margin of the flow (fig. 23). The cone from which the lava was erupted was located near the southern margin of the basalt flow. An important modification of the drainage was the redevelopment of the ancestral Coalpit Wash which formed a new drainage pattern along the northern margin of the Stage IIa basalt flow. This new channel was to act as a major route which prevented younger flows from entering the Virgin River. The Stage IIa basalt flow, during this period of time, was left as an isolated linear ridge that extended seven kilometers west of Grafton.

Stage IIb Eruption

The Stage IIb basalts were erupted from a location near Crater Hill; one lobe flowed down ancestral Coalpit Wash to a location where Dalton Wash enters the Virgin River channel; a second lobe flowed a short distance up ancestral Coalpit Wash (fig. 24). There are no cinder cones clearly associated with this eruption. The evidence, which suggests that Stage IIb basalt came from a location near the present Crater Hill, is based on the position of a later basalt, which flowed down the same channel and overlies this older flow. The later ponding of Stage IIIa basalt on top of the Stage IIa basalt flow indicates that the drain-

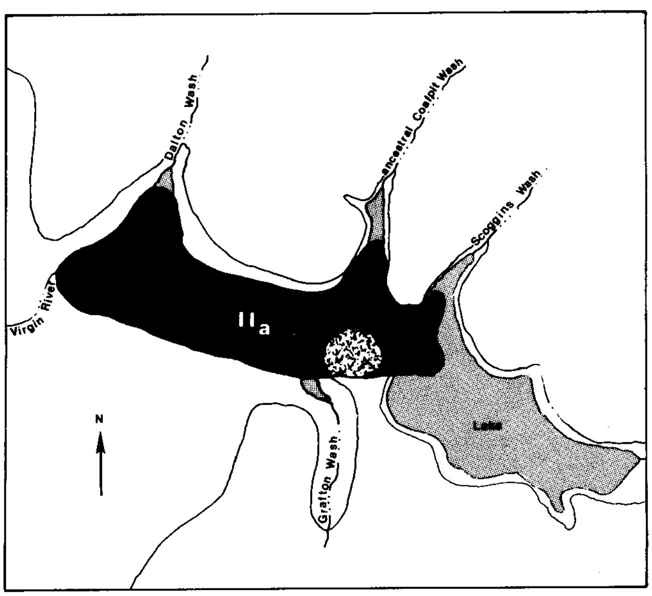

FIGURE 22.—Extrusion of the Stage IIa basalt. The flow blocked the Virgin River and formed a temporary lake which was subsequently filled with sediment.

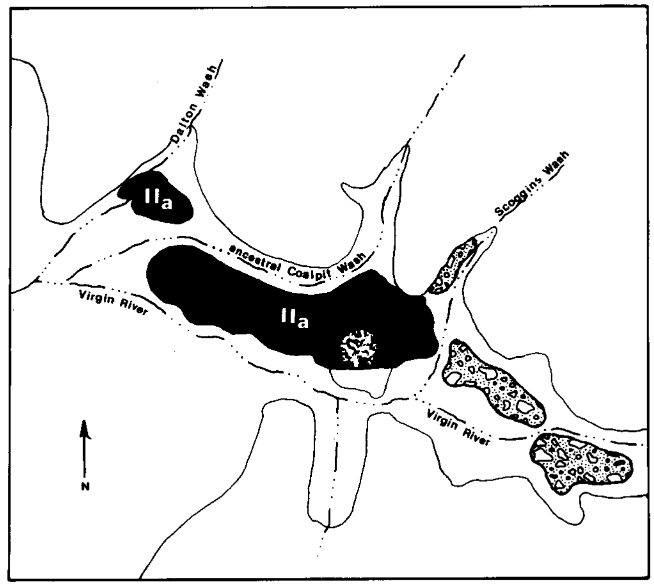

FIGURE 23.—Erosion of the Stage IIa basalt flow developed a valley along the northern margin of this basalt flow by Coalpit Wash. The lake was filled with sediment, and the Virgin River developed a new stream channel along the southern margin of this basalt flow.

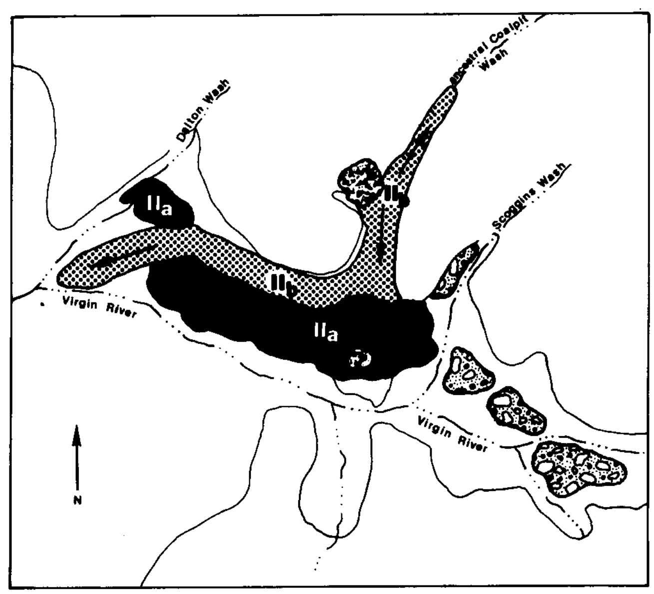

FIGURE 24.—Extrusion of the Stage IIb basalt. The lava entered ancestral Coalpit Wash and flowed down the drainage which had developed on the north margin of the Stage IIa basalt flow. The lake deposits continued to be dissected by the Virgin River and its tributaries.

age along this northern margin had been filled with an earlier basalt flow, and subsequent erosion did not develop a drainage pattern along the margins of the Stage IIb basalt flow. Had the cinder cone associated with this eruption been located near the present location of Crater Hill, it would have been covered by cinder and basalt from later eruptions.

Erosion of Stage IIb

The period of erosion which followed the Stage IIb eruption resulted in the continued removal of basalts from the southern margin of the Stage IIa flow (fig. 25). Stream dissection continued to modify the margins of the Stage IIa basalts, resulting in the development of a dendritic stream pattern on the basalt flows. This stream pattern was later disrupted by the Stage IIIa eruption. Headward erosion redeveloped ancestral Coalpit Wash along the northern and eastern margins of the Stage IIb basalts.

Stage IIIa Eruption

Stage IIIa basalt was erupted from a location to the immediate southeast of Crater Hill, then flowed south-

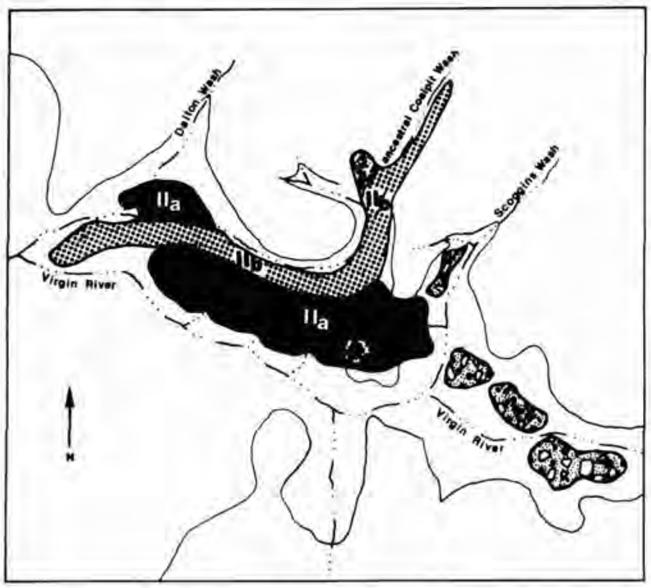

FIGURE 25.—Erosion of the Stage IIb basalts. Stream erosion developed a drainage pattern on the Stage IIb basalt flow, and an important new valley was developed along the northern margin of the Stage IIb basalt flow in ancestral Coalpit Wash.

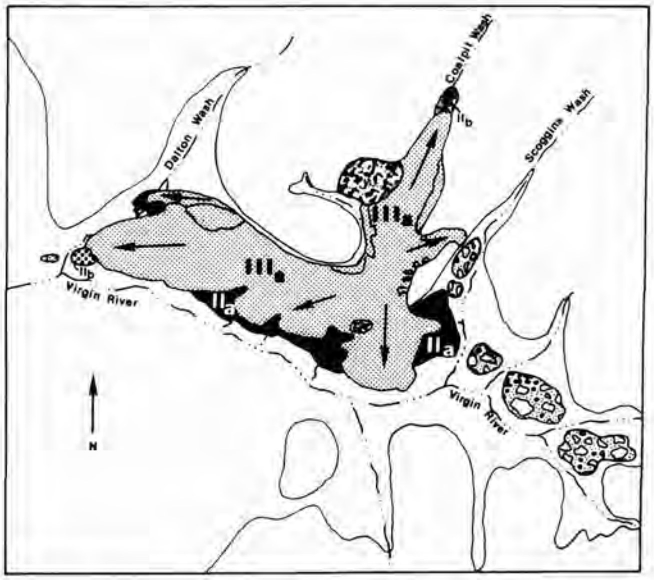

FIGURE 26.—Extrusion of the Stage IIIa basalt. The lava followed the ancestral Coalpit Wash drainage along the northern margin of the Stage IIa basalt flow. This flow was the most extensive in the Crater Hill area.

ward two kilometers where it was partly ponded as a result of the low gradient and the high viscosity of the basalt (fig. 26). Four major lobes of basalt were formed which can be seen along the eastern margin of the Crater Hill area. During the ponding on top of the Stage IIa basalt flow, some basalt flooded over a mesa and cascaded into the Virgin River three kilometers west of Grafton (fig. 27). The flow then moved west along the northern margin of the Stage IIa flow and on top of the Stage IIb basalt to a point near the intersection of Dalton Wash and the Virgin River. As the eruption ceased, lava continued to flow from under the ponded area forming a lava tube. Ultimately the hardened surface of the lava collapsed leaving natural basalt levees on both sides of the flow. These are represented by the high ridges of basalt that extend south from Crater Hill to the lava flat.

Alternate Hypothesis for Stage IIIa Basalt Levees

An alternate hypothesis in the development of Stage IIIa basalt flow should be considered (fig. 28). The high ridges located on both sides of the Stage IIIa basalt flow

FIGURE 27.—A view of the eastern margin of the Crater Hill area showing the Stage IIIa basalt flow superimposed over the Moenkopi Formation. The location of the former Virgin River channel can be recognized in the center of the photograph by stream gravels which extend to the margin of the Stage IIa basalt flow. Crater Hill is on the right side of the photograph.

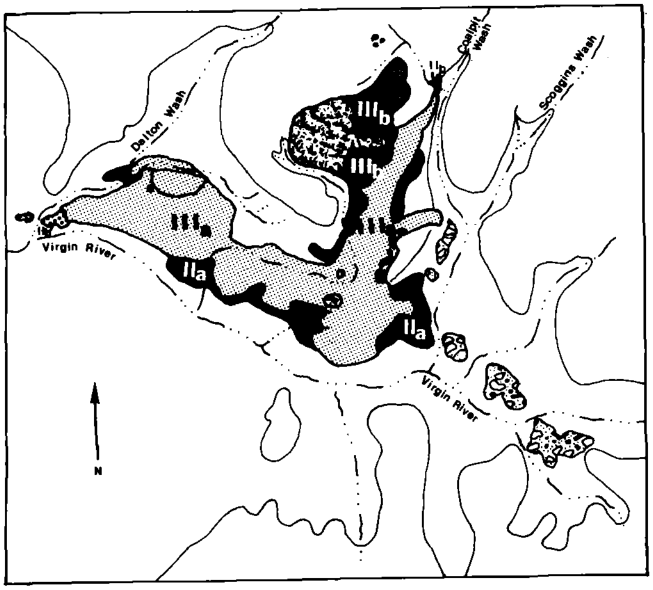

FIGURE 28.—Alternate hypothesis for the Crater Hill area. The sinuous ridges along the margins of the Crater Hill area between Crater Hill and the lava flat can be interpreted as being remnants of an earlier flow.

could be remnants of another basalt flow which has been dissected by headward erosion and downcutting of ancestral Coalpit Wash. The eruption of the Stage IIIa basalt could have flowed down the channel which had developed through the center of this basalt flow. This course of events would result in the same isolated remnants now seen in the area. The ridges along the margin of this basalt flow are 3 to 15 meters above the Stage IIIb basalt which may be too high for natural basalt levees. If these remnants represent an older flow, it would be the oldest flow in the area.

Erosion Stage IIIa

During the period of erosion that followed the Stage IIIa eruption, Coalpit Wash was relocated to its present location along the eastern margin of the Stage IIIa basalt flow (fig. 29). The Virgin River removed the basalt which had cascaded into its channel and continued to undercut the southern margins of the Stage IIIa, Stage IIa, and Stage IIb basalt flows. A drainage pattern then began to develop on the basalt flow itself. The tributaries to Dalton Wash began to develop a drainage pattern on top of the Stage IIIa basalt. Sediments were deposited on the northern margin of the Stage IIIa flow as a result of a lack of drainage there.

Stage IIIb Eruption

The last volcanic eruption to occur in the Crater Hill area was the eruption of the Stage IIIb basalt flow (fig. 30). These basalts were erupted from a vent that underlies Crater Hill and flowed on both sides of the cinder cone built by the Stage IIIa eruption. This basalt flow had two lobes; one extended southwest from Crater Hill and overlies the Stage IIIa flow. The other flowed down the slope of the Shinnarump conglomerate, following the tributaries of Coalpit Wash; however, it did not reach Coalpit Wash. This lobe can be divided into three flow units

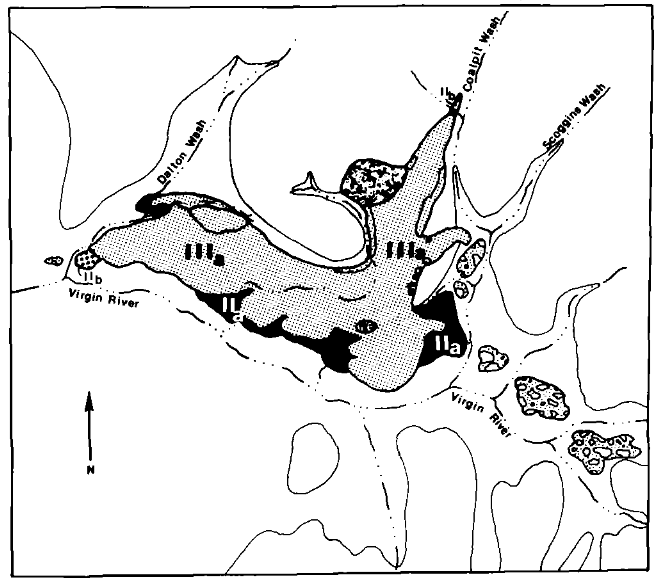

FIGURE 29.—Erosion and development of a drainage pattern on the Stage IIa basalt flow.

which were erupted close to the same time and have about the same amount of dissection. They could represent short periods of extrusion. Crater Hill represents the most recent vent in the area. The patches of cinder north of Crater Hill possibly represent isolated remnants of a thin layer of cinder that was deposited around the Crater Hill cone as a result of wind action or changes in lava fountain direction for short periods of time.

Erosion Stage IIIb

Since the last eruption within the Crater Hill area, erosion has removed much of the thin layer of cinder which once surrounded the cone (fig. 31). A new drainage pat-

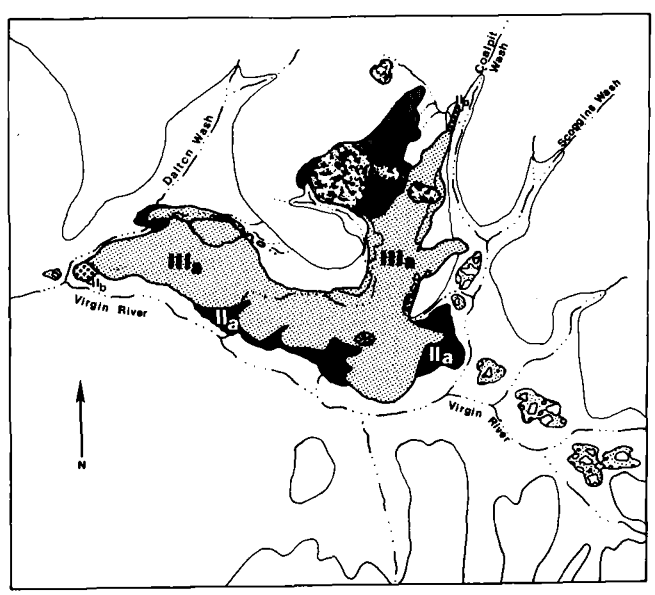

FIGURE 30.—Extrusion of the Stage IIIb lava and the development of Crater Hill.

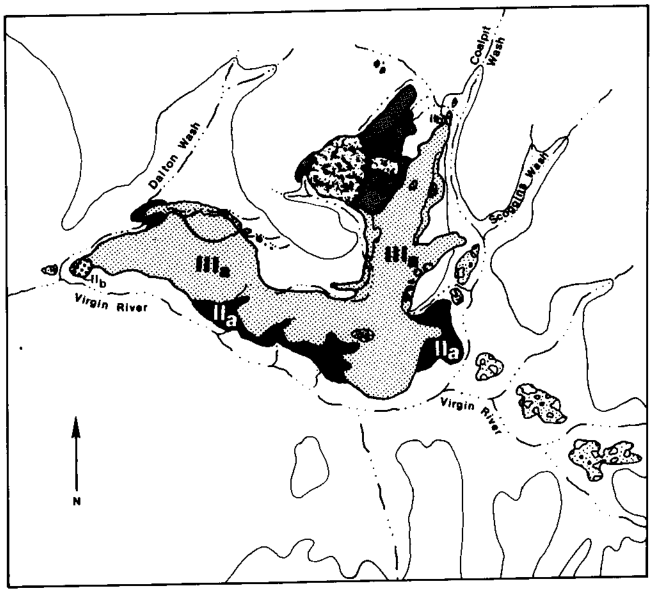

FIGURE 31.—Development of a drainage pattern on the Stage IIIb basalt flow.

tern is beginning to develop on the Stage IIIa basalt flow, and undercutting by the meandering of the Virgin River channel has continued to the southern margin of the Crater Hill area. Tributaries to Dalton Wash are beginning to develop a drainage pattern along the northern margins of the Crater Hill flows (fig. 32).

CONCLUSIONS

The Crater Hill area of Zion National Park had two major periods of volcanism, each having two extrusions. The length of the periods can be determined only with the aid of radiometric dates. According to the Hamblin (1970) classification system, the extrusions were classified as Stage II and Stage III basalt flows. These two stages were subdivided on the bases of superposition, amount of dissection to the original margins, general geomorphic appearance, and height of the basalt flow above the present stream channel.

The first extrusion in the Crater Hill area is considered to be in the same stage of geomorphic evolution as the Stage II basalt flows in the St. George and Uinkaret volcanic fields. It contains two flow units; the first, Stage IIa, erupted and filled the Virgin River channel with basalt from a point 2 kilometers northwest of Grafton to Dalton Wash, and formed a lava dam that blocked the drainage of the Virgin River. This flow now exists as an intermediately high inverted valley that extends along the north side of Utah Highway 15 from Grafton to Dalton Wash and is 35 meters above the present Virgin River channel. Its vent is preserved as an eroded cinder cone on the lava flat west of Grafton.

The second extrusion, Stage IIb, came from an unknown vent and is seen as a low ridge along the southwest margin of the Crater Hill area. Younger basalt flows in the area have erupted from cones near Crater Hill and have flowed over the top of this older flow, covering many of the critical relations.

The third volcanic eruption, Stage IIIa, came from a source near the present Crater Hill. This lava flowed along ancestral Coalpit Wash where it ponded on top of the Stage IIa basalts. This ponding resulted in two lobes of basalt; one flowing to the east; the other to the north. The major lobe of the lava turned west and flowed down ancestral Coalpit Wash to a point near the intersection of Dalton Wash and the Virgin River. This flow now caps much of the Stage IIa and Stage IIb basalts and forms a high basalt capped ridge along the north side of the Virgin River between Grafton and Dalton Wash.

The fourth extrusion, Stage IIIb, was associated with the development of Crater Hill. It had two prominent directions of flow; one lobe extends southeast from Crater Hill one kilometer; the other northeast one kilometer toward Coalpit Wash. Crater Hill represents the last active vent of this eruption. This crater was responsible for the tephra found around Crater Hill.

The Crater Hill area can be interpreted as having four basaltic extrusions which originated from vent locations throughout the Crater Hill area. A lava dam was formed by the first of these basalt flows. It displaced the Virgin River to its present location. The Crater Hill cone is left as evidence of the most recent volcanic activity in the area.

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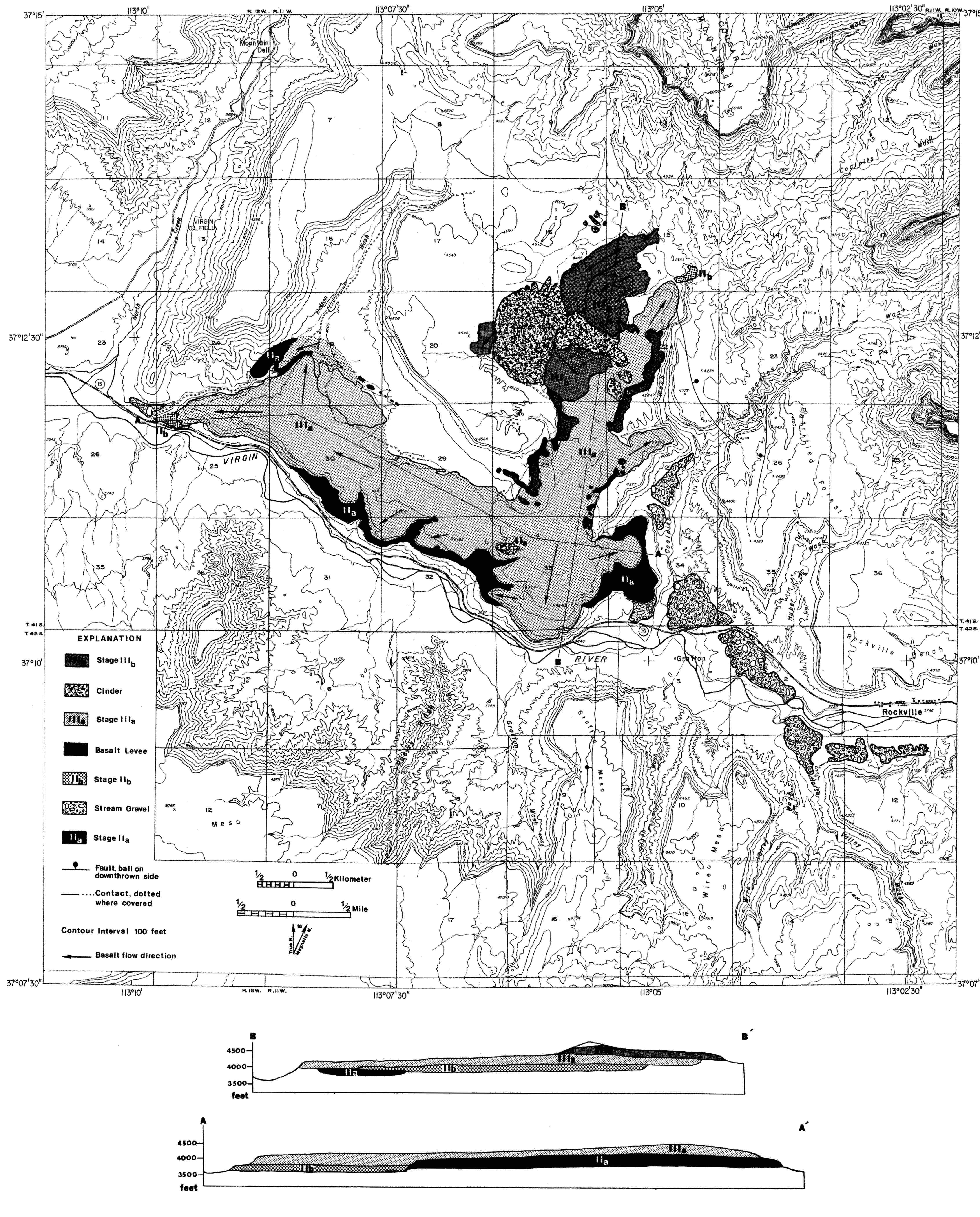
FIGURE 32.—Geologic map of the Crater Hill area of Zion National Park.



GEOLOGIC MAP AND SECTIONS OF THE CRATER HILL VOLCANIC FIELD OF ZION NATIONAL PARK, UTAH

by

R. LaRell Nielson

1976