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MARINER 9 PHOTOGRAPHS OF SMALL-SCALE VOLCANIC STRUCTURES ON MARS

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MARINER 9 PHOTOGRAPHS OF SMALL-SCALE VOLCANIC STRUCTURES ON MARS

Abstract

Surface features on the flanks of martian shield volcanoes photographed by Mariner 9 are identified as lava flow channels, rift zones, and partly collapsed lava tubes by comparisons with similar structures on the flanks of Mauna Loa shield volcano, Hawaii. From these identifications, the composition of the martian lava flows is interpreted to be basaltic, with viscosities ranging from those of fluid pahoehoe to more viscous aa.

Introduction

Mariner 9 photographs of Mars show a diversity of geological surface features unknown prior to the mission. Among the most striking features are the large shield volcanoes and other volcanic structures. Initial examination of the photographs reveals a wide range of types of volcanic activity, including eruptions of very fluid lavas that formed fissure flows, slightly more viscous lava which formed shield volcanoes, and viscous lava which resulted in steep-sided volcanic domes (McCauley, _et al._, 1972).

High resolution (~100 m) "B" frame photographs of martian volcanic terrains show many structures that can be identified as specific lava flow surface features, similar to structures observed in terrestrial basalt flows. This report interprets some martian surface features as basaltic lava tubes and flow channels through comparisons with similar-appearing terrestrial features. Lava tube and flow channel formation and geomorphology have been the subject of several recent reports (Greeley, 1971 a, b, and 1972; Hatheway, 1971; and Greeley and Hyde, 1972); these serve as the bases of comparison.

Lava tubes and channels have been identified in three regions on Mars: an area on the flank of Nix Olympica and near two unnamed crater complexes in the Elysium region of Mars. The three structures are identified as shield volcanoes by their summit craters (generally non-circular with irregular, fractured rims, some with multiple pit craters), individual flows on their flanks which generally radiate from the summit craters, and their broad shield-shaped profiles.

Nix Olympica

Nix Olympica (fig. 1) is more than 600 km in diameter and is the largest shield volcano identified. In some respects, it can be compared with Mauna Loa Volcano, Hawaii, in its origin, structure, and geomorphology. Both are constructional features that resulted from multiple eruptions of lavas fluid enough to flow tens of kilometers. Figure 2 is a "B" frame image of a flank section of Nix Olympica showing several of the flows, or flow units, that are probably typical of the type which built the shield. The flows are narrow (less than 1 km in this image), finger-like projections that appear to be thin. In comparison (fig. 3) the flanks of Mauna Loa are covered with long, narrow flows averaging 5 m thick. On Earth, the only common lava fluid enough to form this type of flow is basalt, both pahoehoe and aa varieties, with the fluid pahoehoe being the more common form.

Shown also in figure 2 (inset) is a flow containing a prominent, leveed channel. The channel is less than 200 m wide with narrow levees. Leveed flow channels are common in aa basalt flows, as shown in figure 4 on the flank of Mauna Loa. Levees develop by accretion of lava spilled out of the flow channel at times when the volume of lava erupted exceeds the capacity of the channel. Overflow of lava may spread many channel widths laterally beyond the channel, as evident on both the martian and terrestrial examples. On Mars, the overflow, which can be identified by its lighter tone and smoother texture, appears to truncate the older flows (fig. 2). Levees may develop in both pahoehoe flows and aa flows; however, aa levees are usually more pronounced (sharper and steeper), probably as a result of lateral forces within the active flow that shove cooled clinkers outward away from the axis of the channel.

Sharp, prominent levees generally do not form along pahoehoe lava channels. Instead, repeated overflows from the channel and subsequent accretion of thin sheets of lava result in the development of topographic ridges along the axis of the channel. These structures have been discussed in detail (Greeley, 1971a) and have been applied to the identification of lava tubes and channels of the Moon. Figure 2 shows a similar feature on Mars. This structure has been tentatively identified as a lava channel or partly collapsed lava tube (McCauley, et al., 1972). The low sun-angle illumination emphasizes the topographic ridge along its axis. This feature is compared to a flow channel-partly collapsed lava tube on the southwest rift zone of Mauna Loa (fig. 3). Both features are relatively straight (trending downslope) but have a high-order sinuosity superimposed along the course-line. The features are fairly constant in width and are nearly continuous. Discontinuous parts of the terrestrial feature represent sections of the flow channel that become roofed, similar to active flow channel formation observed during the eruption of Mauna Ulu (Greeley, 1971b). Constructional topography of both terrestrial and martian structures controlled the direction of later flows.

The structure on the flank of Nix Olympica is interpreted to be a flow channel developed in relatively fluid lava. Spill over from the channel resulted in lateral accretion of lava to form a prominent topographic ridge (but not lateral levees), which controlled the location of younger lava flows. Parts of the channel were roofed to form lava tubes, some of which remain intact. By analogy to terrestrial features, the lava may be pahoehoe basalt.

The Elysium Region

The Elysium Region of Mars contains two shield volcanoes photographed with the Mariner 9 "B" camera. Figure 5 shows one volcano with a summit caldera 11.6 km long and 8.2 km wide; figure 6 shows the other shield volcano and its summit caldera which is about 14.7 km in diameter. Radiating downslope from both calderas are hummocky ridges, crater chains, fractures, and slightly sinuous depressions. Many of these structures compare favorably with similar appearing features on Mauna Loa.

Large shield volcanoes are constructional features built by multiple lava eruptions from the summit region and from rift zones radiating from the summit. These eruptions may result in characteristic surface features. Figure 7 shows a fracture near the summit of Mauna Loa. It is traceable through a series of pointed, fusiform craters aligned in an arc trending away from the rim of the caldera. It appears to be primarily a tensional feature with secondary enlargement by lateral subsidence. Figure 8 shows a section of the southwest rift zone of Mauna Loa marked by fractures, chains of pyroclastic cones, and fissure lava flows. Fractures and eruptive fissures often serve as controlling structures in the formation of lava tubes and channels. For example, figure 8 shows a lava flow (and subsequent lava channel) which originated in one fissure, flowed freely downslope until it met a row of spatter cones built on another fissure along which it flowed until it again broke free. The resulting pattern in plan view is a depression with both sinuous and relatively straight elements. Several of the martian depressions have this configuration (fig. 5, "A", "B").

Magmatic activity along rift zones may lead to the formation of chains of collapse craters. Three pit craters trend downslope from the summit region of Mauna Loa along the southwest rift zone (fig. 9). Another example is the Chain of Craters, Hawaii Volcanoes National Park, which is a row of pit craters along the east rift zone of Kilauea Volcano. Features "A" and "B", figure 6, and "C" of figure 5, may represent martian counterparts to the Hawaiian structures. Eruption of pyroclastics along rift zones leads to chains of pyroclastic cones and related summit craters, as shown in figure 10 of the northwest rift zone, Hualalai Volcano, Hawaii. None of the aligned martian chain craters appear to have raised rims, and it is inferred that they are pit craters, rather than pyroclastic cone craters. However, resolution of the martian pictures may be insufficient for detection of rims, especially if the rims are low or have been eroded.

Individual lava tubes and lava tube networks are also common flow features on shield volcanoes. Partly collapsed lava tubes usually can be identified on aerial photographs as chains of elongate craters (collapsed roof segments) originating in larger, irregular source craters. They trend generally downslope and are known to occur almost exclusively in pahoehoe basalt (Greeley and Hyde, 1972). Figure 11 shows an area of the southwest rift zone, Mauna Loa, with at least two vent areas. Vent "A" apparently gave rise to a lava tube traceable as a series of craters and a later lava channel-lava tube (now mostly collapsed) which crossed the earlier-formed lava tube. The vent area consists of a complex of irregular craters. Vent "B" is also an irregular crater with a partly collapsed lava tube-lava channel leading away from it. These features can be compared with martian structures "C", "D", and "E", figure 6.

Cut-off branches commonly develop along active flow channels and lava tubes. Figure 12 shows a cut-off branch along a partly collapsed lava tube in the Snake River Plains, Idaho. This feature can be compared with martian feature "F" of figure 6.

Summary and Conclusions

Many surface features on martian shield volcanoes, as observed on Mariner 9 "B" frame pictures, can be identified as lava flow channels, rift zones, and partly collapsed lava tubes by comparisons with similar appearing structures on the flanks of Mauna Loa Volcano and fluid basalt flows. Knowledge of the formational mechanisms for the terrestrial structures allows geological interpretations of the martian counterparts. Terrestrial lava tubes and channels form commonly in basaltic lava flows; lava tubes are restricted to fluid, pahoehoe lava; and sharp-leveed channels generally indicate viscous, aa lava. Thus, the presence of these structures on martian volcanoes suggests a basaltic composition and, to some degree, a comparatively low viscosity of the martian lava flows.

Although the general geomorphology and apparent structure of the martian features compare favorably with certain terrestrial structures, the martian features are generally larger. This same problem prevails in regard to the interpretation of certain lunar sinuous rilles as lava tubes and channels, although the lunar structures are still larger than the martian features. Differences in gravity may explain the larger lunar structures (Oberbeck, et al., 1969). The sinuous martian structures are intermediate in size between similar-appearing terrestrial and lunar structures, perhaps because of the "intermediate" gravity of Mars (between Earth and the Moon).

Future work calls for detailed quantitative analyses of terrestrial basalt structures to determine the control that chemical and physical characteristics of the flows and topographic slopes play on the development and geomorphology of the structures. With considerations of the difference between the martian and terrestrial environment, future geological interpretations may be possible for the martian structures on the basis of these detailed studies.

Acknowledgements

This paper benefited greatly from the helpful comments by Don Swanson, especially in regard to Hawaiian volcanology. This investigation was made with support from the Office of Planetology Programs, National Aeronautics and Space Administration Headquarters, through a research grant by NASA-Ames Research Center to the University of Santa Clara.

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Oberbeck, V. R., Quaide, W. L., and Greeley, R., 1969, On the origin of lunar sinuous rilles: Modern Geology, v. 1, pp. 75-80.

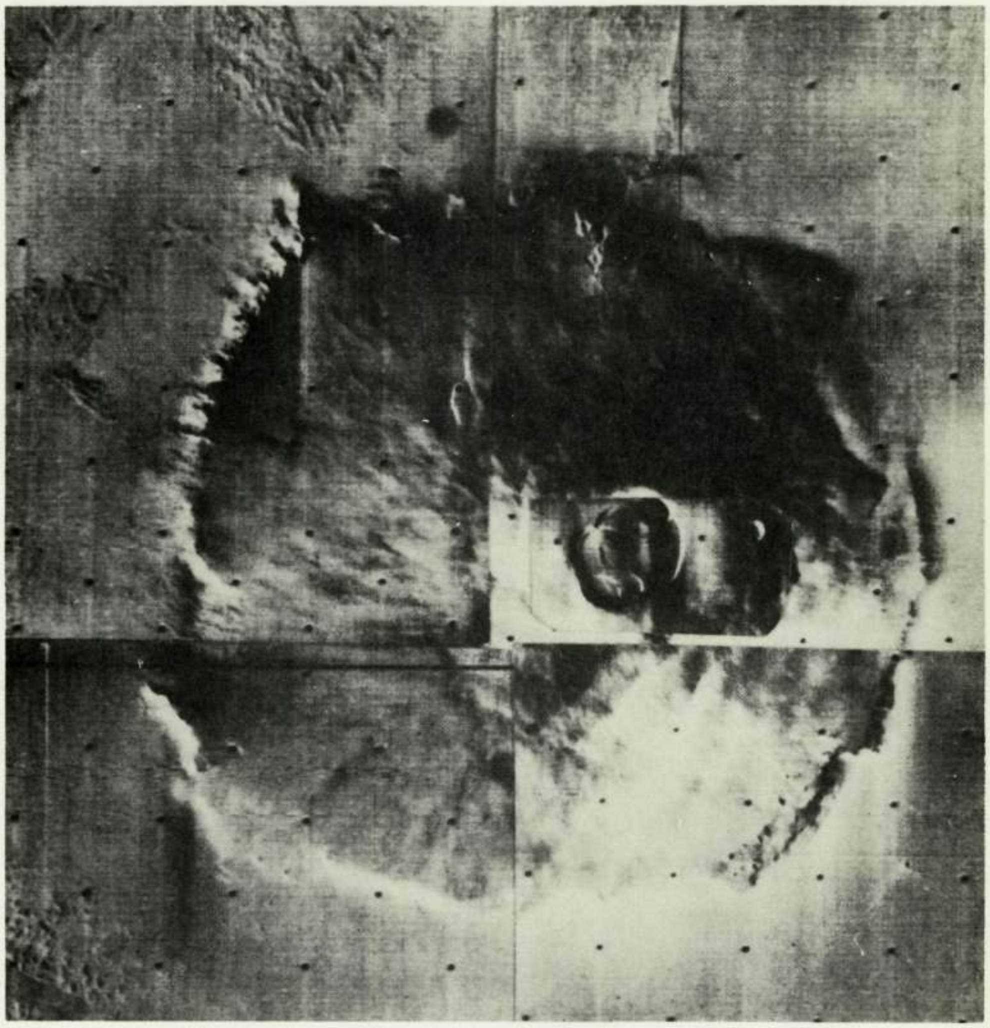

Figure 1. Mosaic of Mariner 9 photographs of Nix Olympica, a shield volcano more than 600 km in largest diameter, centered at about 18°N and 134°W on Mars. Area shown is about 750 x 700 km.

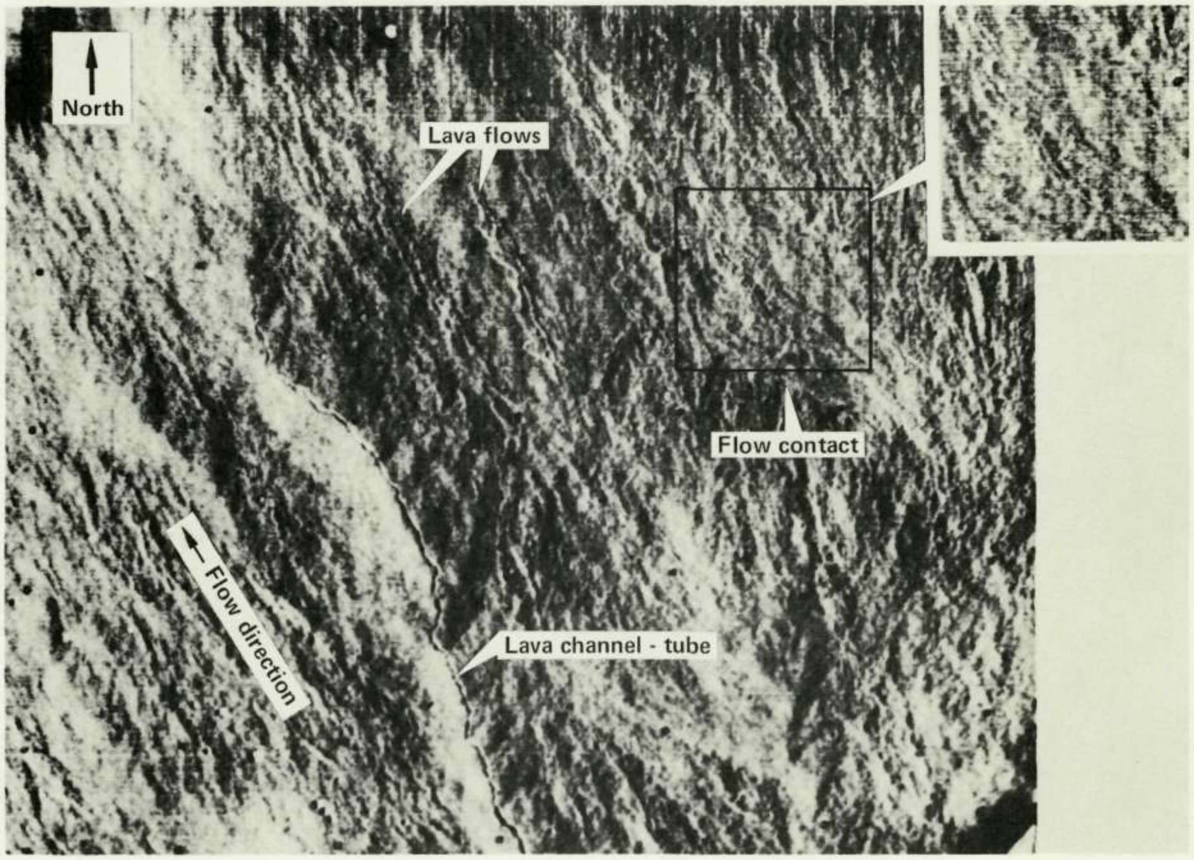

Figure 2. Mariner 9 "B" frame image of a region on the northwest flank of Nix Olympica, showing individual lava flows, partly collapsed lava tube - lava channel along the crest of a ridge, and leveed channel (inset). Flows from the leveed channel appear to truncate older flows. Area shown is 17 km x 21 km. Sun is shining from left to right.

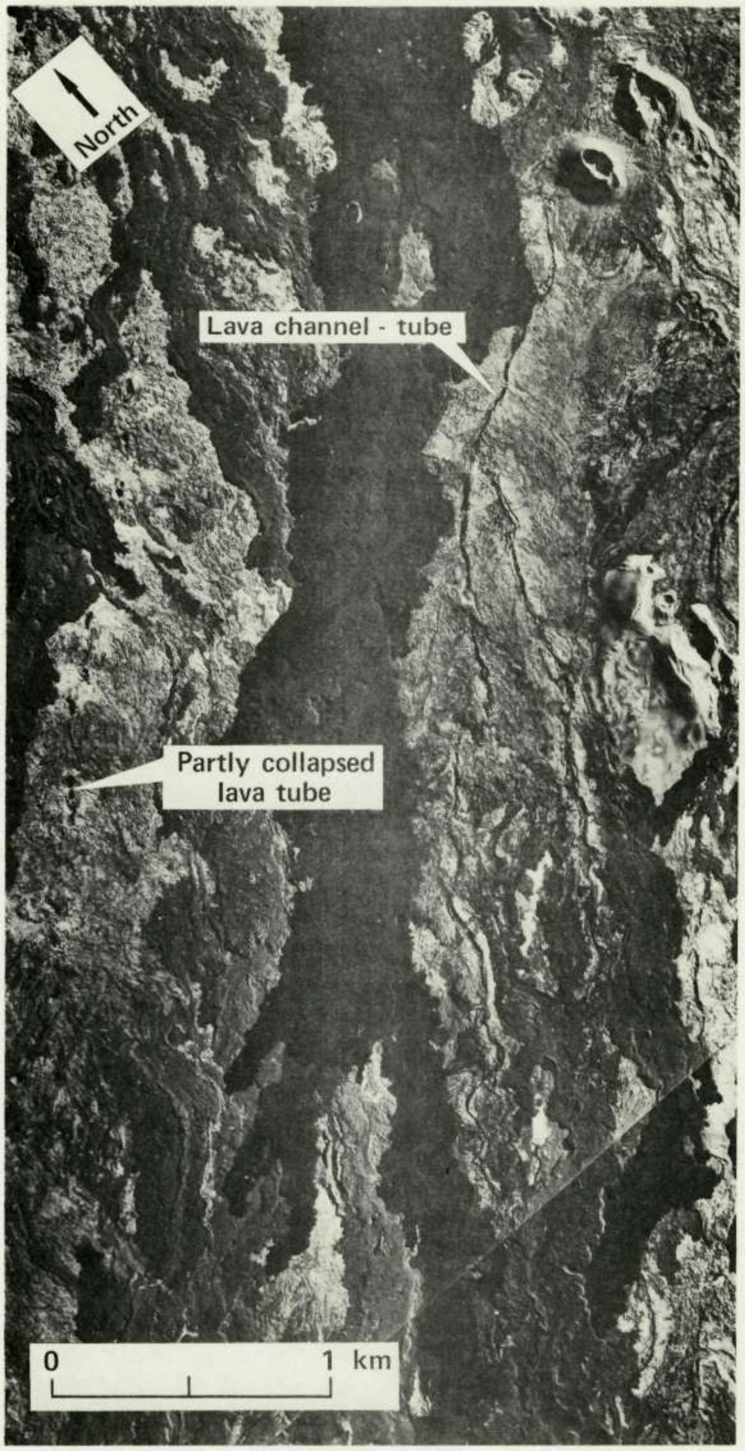

Figure 3. Southwest rift zone, Mauna Loa, showing typical flows that have constructed the shield volcano and a section of a partly collapsed lava tube and a lava channel. The rift zone trends north-south diagonally across the upper right-hand corner of the photograph.

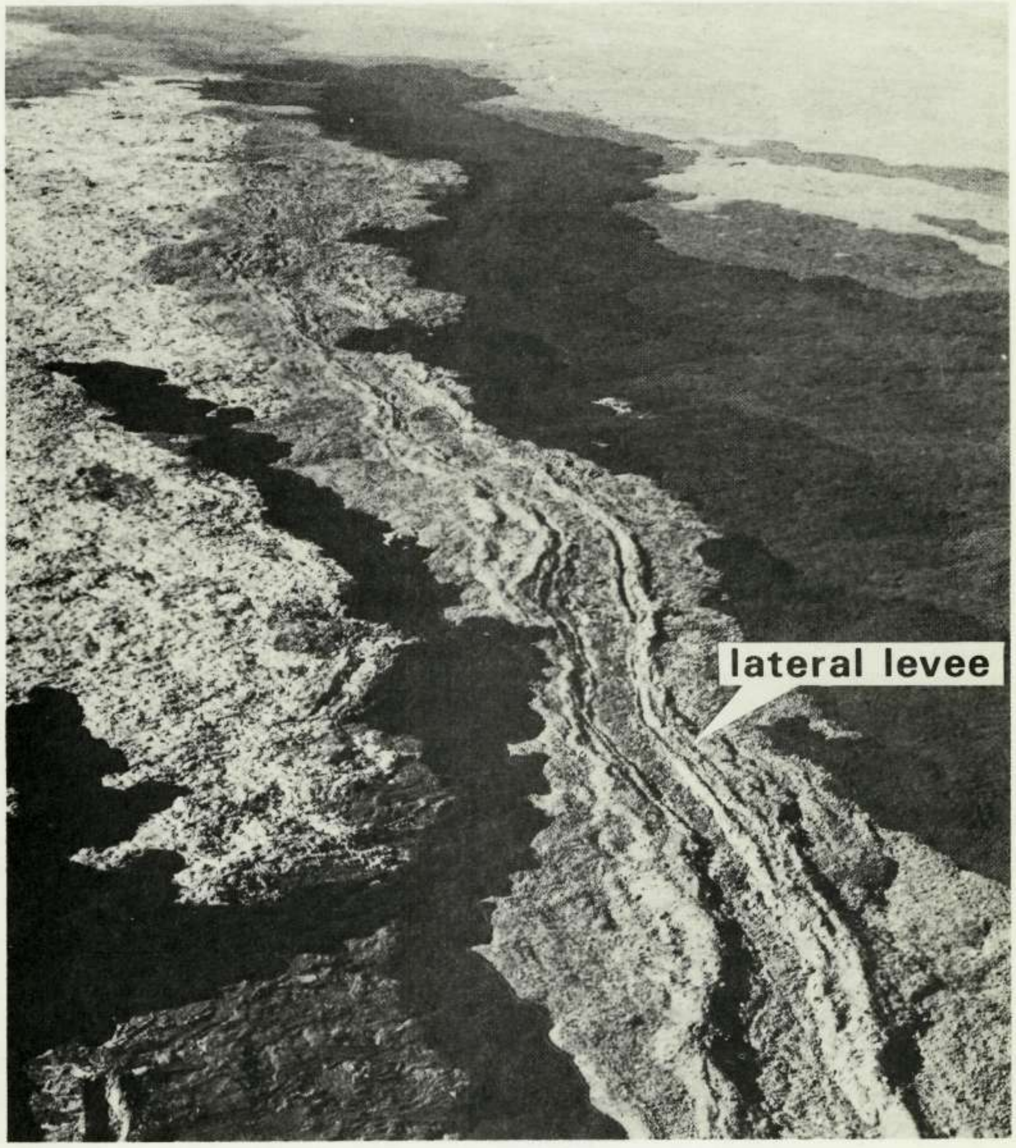

Figure 4. Flank region of Mauna Loa showing typical leveed flow channel developed in aa basalt flow. Channel is about 10 m wide.

B

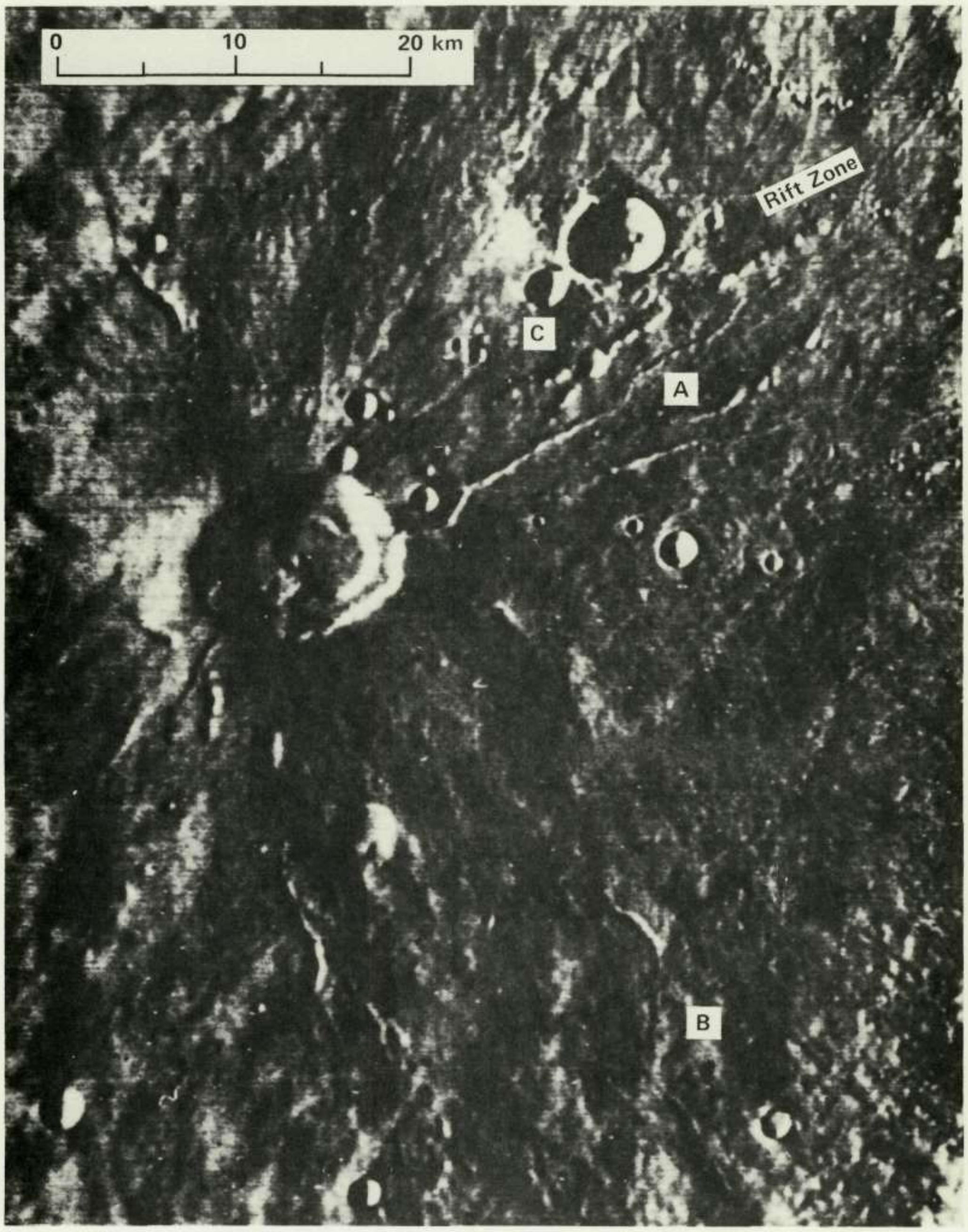

Figure 5. Elysium region of Mars
Mariner 9 "B" frame showing a summit caldera and radial flow features. "A" and "B" are interpreted to be flow channels with segments controlled by fractures; below "C" is a chain of rimless craters interpreted to be pit craters aligned over a rift zone. Sun is shining from left to right.

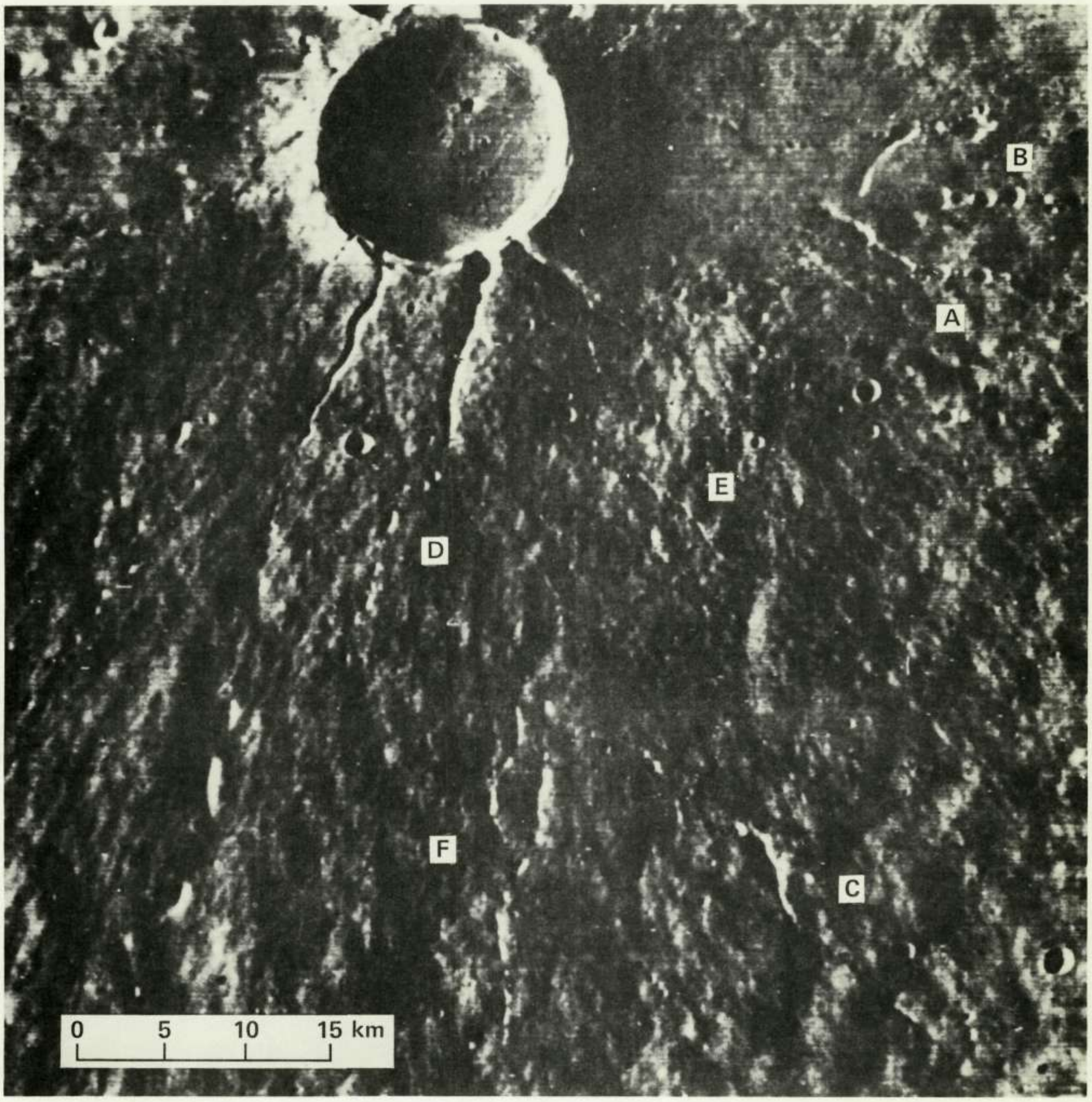

Figure 6. Elysium region of Mars. Mariner 9 "B" frame showing a summit caldera with radial structures originating from the crater which are interpreted to be fractures that have been modified by lava flows. "A" and "B" are crater chains interpreted to be vents along rift zones; "C", "D", and "E" are interpreted to be sections of partly collapsed lava tubes; "F" is a lava tube with a cut-off branch. Sun is shining from left to right.

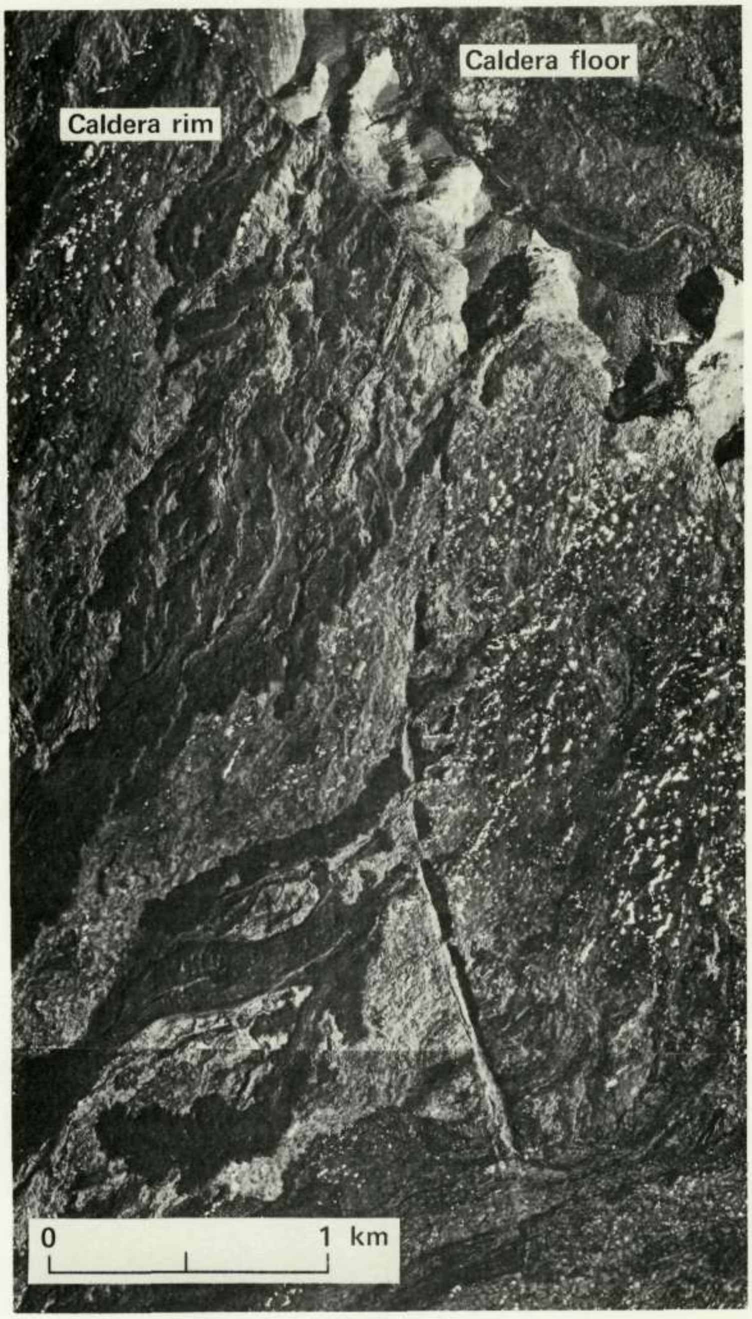

Figure 7. Aerial photograph of a section of Mauna Loa shield volcano in the summit region, showing a prominent fracture on the rim of the caldera. Sun is shining from right to left.

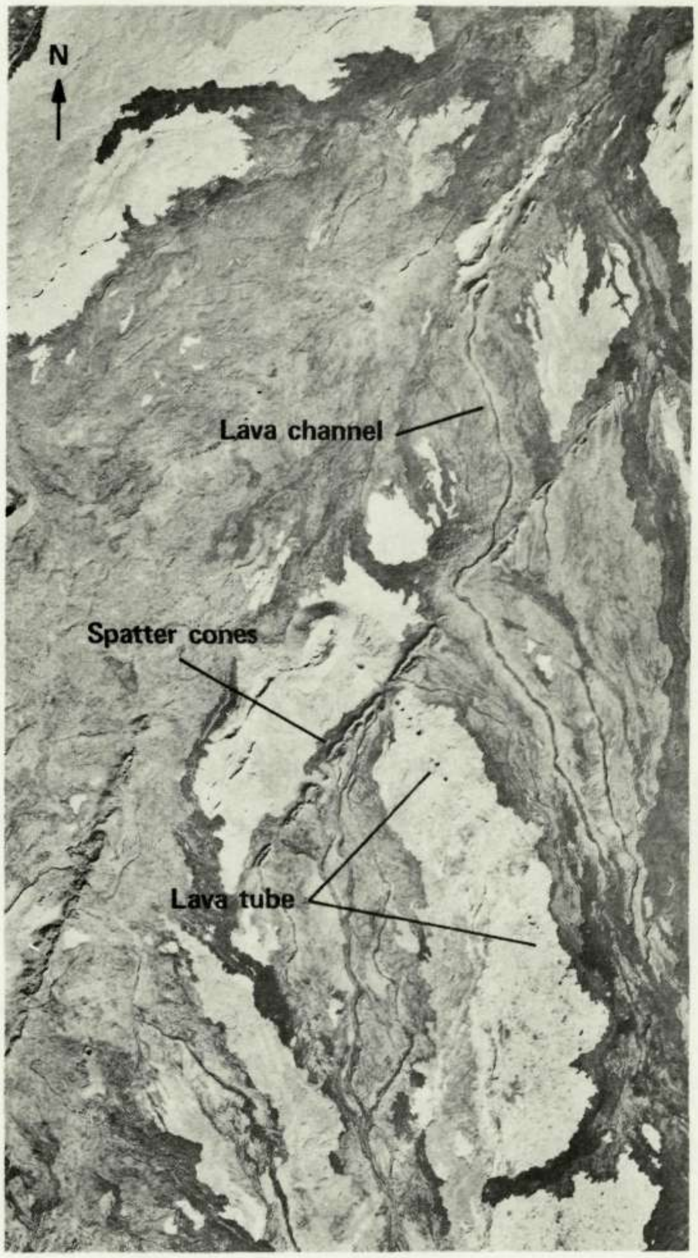

Figure 8. Southwest rift zone, Mauna Loa, cuts diagonally across photograph from upper right corner to lower left; spatter cones and pyroclastic cone craters are aligned over the rifts; fissure lava flows developed lava tubes and channels. Part of the channel course was influenced by one of the rifts. Other lava tubes and channels than those identified are visible.

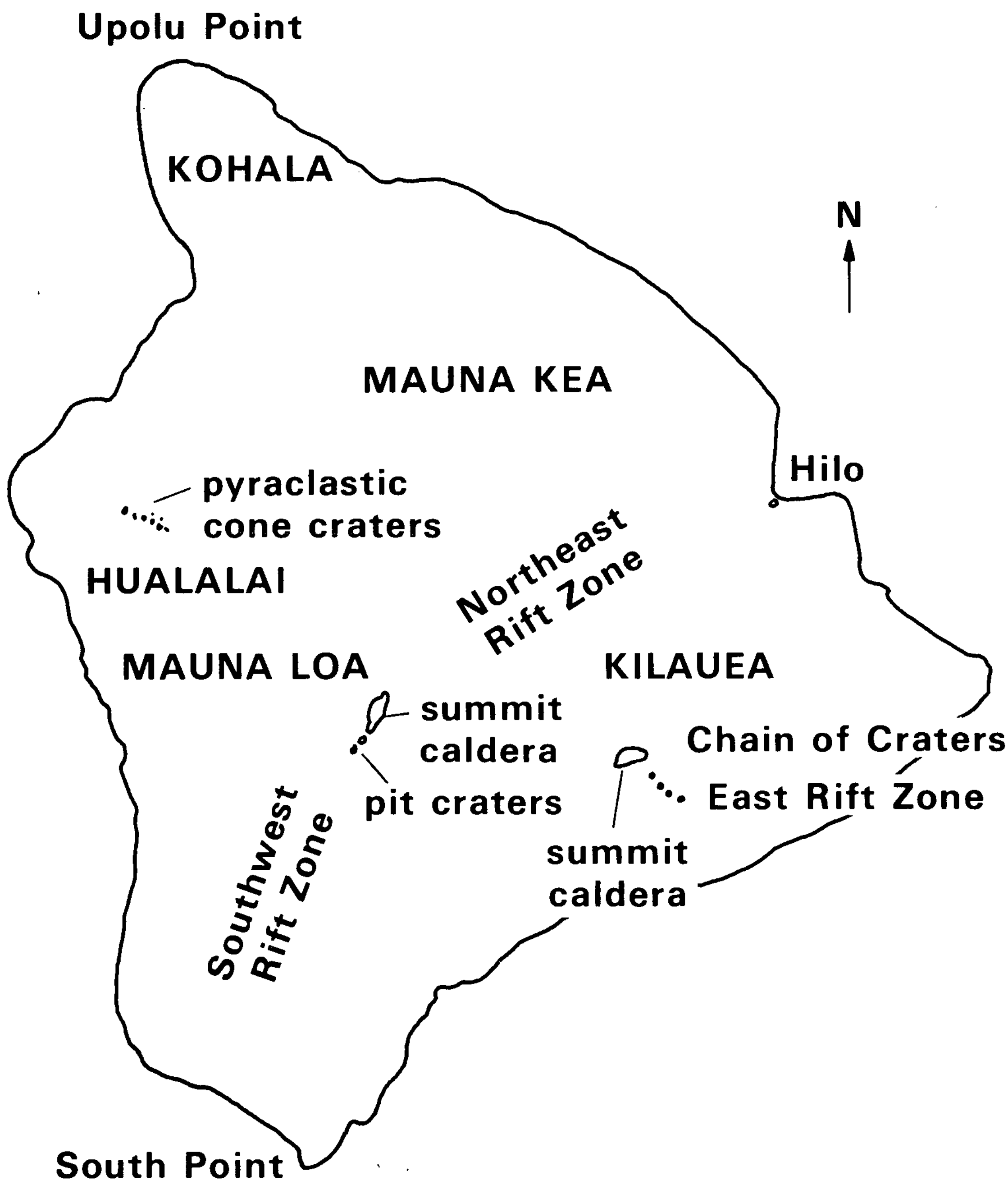

Figure 9. Map of Hawaii showing the five shield volcanoes composing the island (Kohala, Hualalai, Mauna Kea, Mauna Loa, and Kilauea) and the main rift zones of Mauna Loa. Island is about 145 km from Upolu Point to South Point.

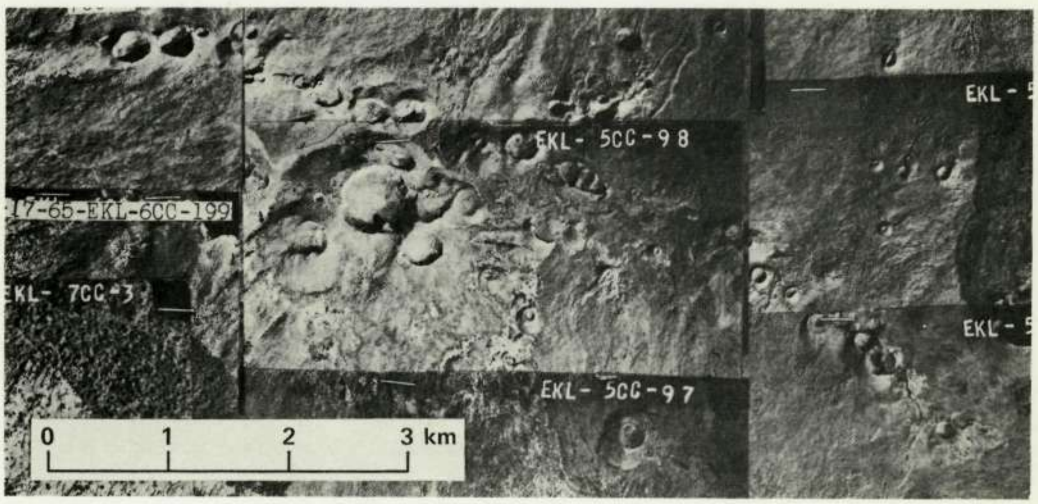

Figure 10. Uncontrolled mosaic of part of Hualalai shield volcano showing pyroclastic cone craters of the northwest rift zone.

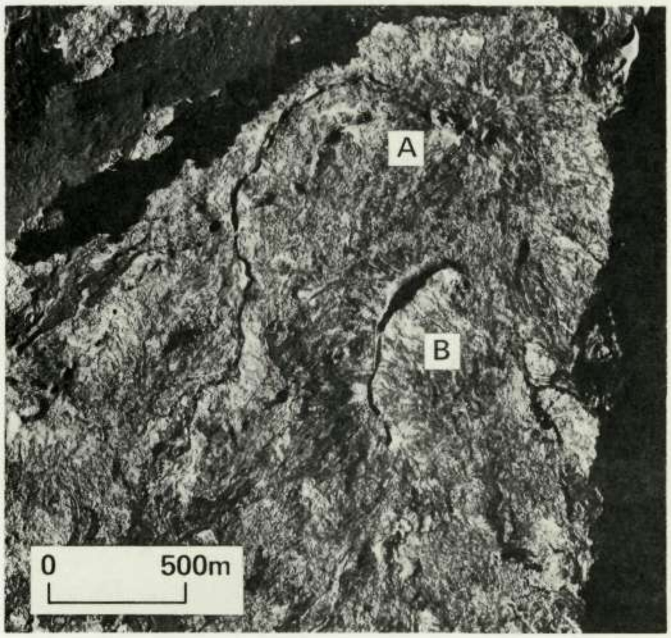

Figure 11. Southwest rift zone of Mauna Loa, showing "A" vent with lava flow channel-tube overlying older, partly collapsed lava tube near the same vent, and "B" vent with a lava channel-tube. Sun is shining from right to left.

Figure 12. Section of partly collapsed lava tube with cut-off branch, Snake River Plains, Idaho.