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GEOLOGIC EVALUATION OF ANOMALIES BETWEEN LIKE-POLARIZED AND CROSS-POLARIZED K-BAND SIDE-LOOKING RADAR IMAGERY OF YELLOWSTONE NATIONAL PARK*

by

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Prepared by the Geological Survey
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**U. S. Geological Survey, Denver, Colorado

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By Gerald M. Richmond

Purpose.--The purpose of this report is to analyze from the point of view of surface geology certain anomalies noted between like-polarized and cross-polarized side-looking K-band radar imagery recorded over Yellowstone National Park and the northern part of Grand Teton National Park. The imagery was flown in the fall of 1965 under contract with the Westinghouse Electric Corporation. The flight strips are in a generally north-south direction and the direction of view is to the east and west alternately. I am indebted to my colleagues Gordon W. Greene and Harry W. Smedes for technical review and for explanations of radar imagery recording pertinent to this study.

Previous comparative studies of like- and cross-polarized radar imagery.--Cooper (1966) may have been the first to recognize that differences between like-polarized and cross-polarized radar returns could have geologic significance. He suggested that the observed differences in the imagery could be due to the glass content of the outcropping rock. Additional work by Gillerman (1967) failed to prove Cooper's hypothesis, and suggested that surface roughness, degree of weathering, amount and type of vegetation cover as well as the rock type may influence the radar return. Schwarz and Caspall (1968) showed that different kinds of rock outcrops can cause varying degrees of depolarization of a radar beam. They also suggested that other factors such as surface roughness may override differences in return due to variations in soil moisture.

Summary of general geology and geography.--The region of Yellowstone National Park can be divided into 14 areas of general geologic and geographic uniformity (fig. 1). An additional area (15) in Teton National Park is included because it exemplifies a specific condition of anomaly not observed in Yellowstone.

1. Absaroka Range: serrate crest over 11,000 feet high cut by steep cirques and cliffed upper valleys. Local relief commonly 2,000 feet. Lower valleys broadly open. Bedrock mainly flat-lying bedded andesitic volcanic breccia and conglomerate cut by local dikes and intrusive masses, and several distinct faults. Surficial cover includes angular blocky coarse to fine frost-rubble along divides; blocky angular to subrounded talus and avalanche debris on upper valley walls; small moraines in some cirque heads; stony glacial deposits, thick on lower valley walls and thin on foothill ridges; and some gravel deposits on valley floors.

2. Upper valley of Yellowstone River: steep-sided trough with cliffed walls 2 miles wide and 2,000 feet deep; locally bounded by late Quaternary faults. Walls of flat-lying bedded volcanic breccia and

conglomerate. Floor underlain by extensive fine-grained river sand and silt; coarse gravel and cobbles along streams. Valley bordered by succession of kame gravel terraces, local lake silts, large landslides and alluvial fans.

3. Valley of Lamar River: broad trough 2,000 feet deep and 2 miles wide. Steep to moderate slopes cut on coarse and fine volcanic alluvial and mudflow rocks; local basalt sheets. Floor underlain mainly by coarse bouldery river gravel. Local gravel terraces, lake silt terraces, alluvial fans and glacial deposits on lower slopes.

4. Two Ocean Plateau: rolling glaciated upland between 9,000 and 10,000 feet altitude; cut by steep cliffed canyons with cirques on north-facing sides. Upland surface mostly covered by thin glacial and frost rubble. Canyon floors thickly mantled with glacial deposits, talus and alluvial fan deposits. Bedrock is flat-lying andesitic volcanic mudflow breccia; distinct fracture pattern.

5. Mirror Plateau: rolling glaciated upland between 9,000 and 9,500 feet; mantled with thin glacial and frost rubble; bordered by short steep-cliffed canyons. Lower slopes mantled with talus and glacial deposits; bedrock is bedded andesitic volcanic, alluvial, lacustrine and mudflow rocks, basalt flows, and rhyolitic tuffs. Numerous late Quaternary faults.

6. Washburn Range: moderate to steep glacially smoothed mountains as much as 10,000 feet high; uplands mantled with angular to subrounded frost rubble. Slopes thinly covered with glacial debris. Bedrock consists of andesitic bedded volcaniclastic rocks, lava flows, and flow breccias.

7. Canyon of Yellowstone River: steep-walled valley, 500 to 1,000 feet deep and 1/2 to 2 miles wide. Upper sector cut in altered rhyolite; cliffed rim; lower slopes barren, pinnacled, and gullied. Lower sector cut in hard andesitic bedded volcaniclastic rocks; high cliffs along rim; lower slopes comprise forested blocky talus and ledges.

8. Southern edge of Snowy Range: Moderate- to steep-sloped mountains cut from gneisses and gently dipping Paleozoic and Mesozoic sedimentary rocks, locally faulted. Uplands thinly mantled and valleys thickly covered with glacial deposits.

9. Gallatin Range: moderate to steep slopes, numerous cliffs and ledges. Cut by steep-cliffed canyons and cirques. Bedrock includes granite, gneiss, diorite, gently dipping andesitic volcanic strata, intrusives and lavas, and gently to steeply dipping Paleozoic and Mesozoic sedimentary rocks. Several major faults.

10. Mountains in south-central part of Park: individual mountains between 9,000 and 10,000 feet in altitude; separated by moderate- to steep-sloped canyons 1,000 to 2,000 feet deep. Numerous ledges and cliffs,

smoothed by glaciers. Rocks mainly Paleozoic and Mesozoic sedimentary rocks--limestone, sandstone, and shale. Some areas of rhyolite tuff and basalt. Uplands much grooved and shaped by overriding glacier and mantled by thin glacial debris. Lower slopes mantled by thick glacial debris, and numerous large landslides in areas underlain by shale. Valley floors underlain by gravel, locally terraced.

11. Areas mainly underlain by rhyolite tuff, uplands slope away from center of Park; are cut by cliffed and commonly narrow canyons. Thin mantle of glacial deposits.

12. Central Plateau: broad rolling upland between 7,500 and 8,500 feet altitude. Mantled with thin glacial debris. Constructional topography reflects general shape of rhyolite flows. Numerous late Quaternary faults. Glacial streaming and rhyolite flow lines both evident.

13. Madison and Pitchstone Plateaus: broad rolling uplands between 8,000 and 8,500 feet altitude; topography clearly reflects general shape and pressure ridges of individual flows. Upland locally glaciated, but obvious scour restricted to plateau margins.

14. Yellowstone Lake Basin: Yellowstone Lake bordered by extensive thick deposits of glacial lake silt and terraced gravel and sand that commonly extend 120 feet to as much as 550 feet locally above the lake. Similar deposits occur extensively in Pelican Valley, north of the lake and along the Yellowstone River to the northwest, especially in Hayden Valley. Rock outcrops rare in these areas.

15. North part of Teton Mountains (Teton National Park): moderate to steep mountains from 8,000 to 9,000 feet in altitude, underlain by Paleozoic and Mesozoic sedimentary rocks: limestone, sandstone and shale, and local rhyolite tuff. Deep glaciated U-shaped canyons. Limestone forms most of the prominent barren slopes and ledges. Lower slopes and valley floors mantled with talus, avalanche debris and glacial deposits.

Vegetation cover.--Practically the entire region is forested. Areas underlain by rhyolite tuff or rhyolite flows and areas of thick lake silt, sand, and gravel (fig. 1, areas 10, 11, 12, 13) commonly support an open Lodgepole pine forest. Highland areas of volcanic breccia and conglomerate bedrock (fig. 1, areas 1, 6) support a thicker forest of spruce, fir, and pine except for mountain crests, which are barren. Mountains underlain by sedimentary rock, etc. (fig. 1, areas 7, 8, 9, 14), support open pine and spruce forest, thickest on north-facing slopes.

Mountain crests and high plateau uplands (fig. 1, areas 4, 5) and large valleys and basins (fig. 1, areas 2, 3, 13) are mainly open forest and grassland.

Some generalizations about the imagery.--One readily recognized feature of the imagery examined is that there are areas of no return (blackout areas) in rugged mountains or deeply dissected cliffed-canyon areas, facing away from the direction of view, such as the lee sides of steep slopes, cliffs, high ridges, peaks, and canyon walls; conversely, steep slopes, cliffs, etc., facing at a high angle toward the direction of view are areas of overreturn (whiteout areas). Though precise interpretation of the details of the geology (rock or cover material) is not possible in such areas, some idea of the geologic conditions can be estimated from the shape of the area, particularly for whiteout areas, and from comparison with the imagery recorded from adjacent slopes oriented obliquely to the angle of view. Where an intermediate return of imagery is recorded, considerably more geologic detail may be interpreted. The optimum conditions for geologic interpretation of the imagery are in regions of gentle to moderate slopes in which, though total relief may be great, local abrupt dissection is less than a few hundred feet.

Distribution of anomalies

Anomalies between the like-polarized and cross-polarized imagery (designated by "HH" and "HV" respectively in illustrations) examined were most abundant in cliffed mountainous regions, especially along the margins of whiteout areas. They were also abundant in certain steep-sloped or hummocky hill areas and in certain relatively flat areas commonly associated with wet ground conditions.

In terms of surface geology, the radar anomalies were noted in the following situations (total observations of each kind are given in parentheses):

1. Angular to subrounded, blocky to slabby talus rubble on steep slopes at the foot of cliffs. (9)

2. Cliffs formed of bouldery volcanic mudflow rock having a fine-grained matrix. The cliffs are considerably broken by fractures and display many narrow steep-sided gullies. The tops of the cliffs commonly are rounded. (29)

3. Similar to above, the cliffs are of rhyolite volcanic rock and are not as high. (4)

4. Combinations of cliffs and talus rubble. (23)

5. Low cliffs or series of ledges, in andesitic mudflow rock or in rhyolite flow rock, that project through an overlying thin rubble of boulder- to silt-sized fragments. (6)

6. Blocky frost rubble on steep upland slopes. (5)

7. Moderate slopes on nearly barren limestone and local sandstone having a rough surface texture due to closely spaced solution channels and pits about a foot in depth. (6)

8. Blocky, angular to rounded, boulder- to cobble-sized rubble on ridge crests and uplands. Deposits are thin, but cover the bedrock in most places. (9)

9. Thin stony sandy glacial debris covering rolling bedrock upland. Rock exposed only locally. (8)

10. Thick deposits of stony glacial debris forming elliptical hills trending perpendicular to view. (4)

11. Thick deposits of stony glacial debris on moderate to gentle slopes facing view. (5)

12. Hummocky plain underlain by cobble gravel. (4)

13. Wet meadows underlain by silt. (12)

14. Wet meadows underlain by cobble-gravel and sand. (8)

15. Wet meadows underlain by diatomaceous deposit. (3)

16. Wet meadows in association with hot springs. (6)

17. Hot spring areas associated with siliceous sinter. (4)

18. Gravel beach bars along lake. (1)

19. Waves on a large lake. (3)

It is important to note that all of these surface geologic conditions can also be observed on the imagery in situations where no anomaly between like- and cross-polarized imagery is recorded. In fact, the great majority display none. It therefore seems probable that some factor such as slope, surface texture, or direction of exposure relative to imagery view, rather than variety of rock or rock material, may be responsible for the observed anomalies and that, in this area, one or more of these factors occur more frequently under the surface geologic conditions listed than under others. In addition, it is possible that conditions other than surface geology, such as vegetation, may combine with or result from the surface geologic conditions to produce the observed anomalies. Also, it may be that some of the observed anomalies result entirely from factors that have no relation to the surface geology. Although the anomalies indicate something about the terrain and could readily be located by automatic color-combining on other electronic techniques, their use in interpretation is severely limited because there are so many variables and because there is a virtual lack of fundamental controlled experimental data. Such data are needed to guide in the evaluation of these many variables, some one or combination of which may be the explanation of any given anomaly.

Examples of anomalies

Anomalies in several of the above situations will be illustrated and discussed (figs. 2-16). Like-polarized and cross-polarized imagery are shown for each. For clarity, anomalies representing only one or at most three kinds of geologic situations are shown on each illustration. Anomalies representative of other geologic situations may be observed on some illustrations.

Figures 3 and 4: Absaroka Mountains and upper valley of Yellowstone River. West-looking imagery. Figure 4 shows details of the Trident Plateau in the SE corner of figure 3. All anomalies are on areas of cliffs (volcanic mudflow breccia) and associated blocky to subrounded talus rubble with a silt matrix. Solid arrows point to anomalies where the cross-polarized imagery shows less return, but thereby more information, than is recorded on the like-polarized imagery. On the latter, the anomalous areas record overreturn or whiteout. All of these anomalies are on east- or southeast-facing slopes. Broken arrows point to anomalies where the like-polarized imagery shows less return but thereby more information than the cross-polarized imagery on which there is overreturn, though not whiteout. All of these anomalies are on north- or northeast-facing slopes. Both kinds of anomalies occur on irregular ledges and cliffs, or on the upper parts of talus slopes where irregular rock outcrops project along gullies dissecting the talus. The slope is thus not only at a high angle to the direction of view but is developed on dense rock which is sufficiently broken and irregular that deflection and interference could be a significant factor in producing the observed anomalies.

Figures 5 and 6: Fox Park and headwaters of Snake River west of Two Ocean Plateau. East-looking imagery. An enlargement of the northern part (shown by outline) is shown as figure 6. The three arrows in figure 5 point to areas of thick glacial deposits forming elliptical hills oriented parallel to the direction of ice movement (drumlins). The like-polarized image shows more return and provides a better basis for interpretation than the cross-polarized image which is more uniformly dark. The hills at arrow 1 are 40 to 60 feet high; at arrow 3, 80 to 100 feet high. Arrow 2 points to irregular topography with a relief of 30 to 50 feet. Slopes are moderate to steep and forested. However, the west-facing slopes are drier, more bouldery and less forested than the east-facing slopes. No rock is exposed. The anomalies may be related to differences in the effect of the slope conditions on the return of like- and cross-polarized radar.

Figures 7 and 8: Southwest margin of Pitchstone Plateau and Bechler Meadows area. East-looking imagery. An enlargement of the area outlined along the middle west edge of figure 7 is shown in figure 8. Arrows point to a series of anomalies which show as areas of overreturn (near whiteout) in the like-polarized imagery and are undiscernible or only weakly discernible on the cross-polarized imagery. All of the anomalies are in meadows supporting thick grass and underlain by silty to gravelly material. They do not represent entire meadows, but rather parts of meadows. Most of the meadow areas are very wet throughout July and much of August. However, in some years parts of them dry out in August and September to produce a hard silty or barren gravelly surface. It is possible that the anomalies may represent overreturn in such hard dry areas surrounded by softer wet areas. However, it is not known why they are not more strongly recorded on the cross-polarized imagery.

Figures 9 and 10: Northern Teton Mountains in Teton National Park. West-looking imagery. Arrows point to anomalies in which the cross-polarized imagery records less return, but thereby more information, than the like-polarized imagery on which overreturn (near whiteout condition) is recorded. The anomalies are on southeast-facing slopes underlain mainly by barren rough-surfaced limestone ledges dipping west. The lesser return on the cross-polarized image might result from interference induced by the surface roughness of ledges having this particular orientation. Similarly rough-surfaced ledges of different orientation show no anomalies. However, neither do other areas of limestone ledges having similar slope orientation, roughness, ledge pattern and dip of the beds. The anomalies appear unrelated to the lithologic character of the rock, but may be related to surface roughness and slope orientation.

Figures 11 and 12: Area of the Central Plateau north of Shoshone Lake, including Midway Geyser Basin. East-looking imagery. The area outlined along the top of figure 11 is shown enlarged in figure 12. Distinct anomalies, in which the like-polarized imagery shows greater return than the cross-polarized imagery, represent hot spring areas and wet meadows in Midway Geyser Basin. Some of these hot spring areas have surface deposits of chips of siliceous sinter and are underlain by hard sinter deposits. Many of the wet meadows are underlain by soft but brittle mud that does not dry out in summer and is composed wholly of diatoms. Both areas support sparse grass and are surrounded by pine forest. However, the boundaries of the anomalous areas coincide only locally with forest-grass boundaries as shown on aerial photographs, and not all hot spring and wet meadow areas show as anomalies.

Figures 13 and 14: Area east of White Lake and Tern Lake north of Mary Bay on Yellowstone Lake. East-looking imagery. The area outlined in the western part is shown in figure 14. Arrows 1 and 2 point to areas of thick hummocky gravel (kame fields); arrows 3 and 4 to areas where wet meadows are underlain by a few feet of humic silt underlain in turn by gravel. In all four areas the like-polarized imagery records higher return than the cross-polarized imagery. The wet meadow gravel areas show as small whiteout spots. The gravel hummocks have moderately steep slopes and are 30 to 50 feet high. Arrow 5 points to a gravel beach bar in Mary Bay which shows greater return in the like-polarized than on the cross-polarized imagery. It may be that absorption by the gravel at arrows 1, 2, and 5 affect the return of the like- and cross-polarized radar differently: the difference in return from the wet meadows at arrows 3 and 4 may have to do with a roughness feature of the wet ground, possibly small mounds of bunch grass.

Figures 15 and 16: Same area as figures 13 and 14, but west-looking. The anomalies at arrows 1 and 2 show a similar degree of return but from opposite slopes from those recorded in figures 13 and 14. Arrows 3 and 4 show the same return as those on figures 13 and 14, indicating that the wet gravel meadows are flat. The gravel beach bar on Mary Bay, arrow 5, shows a somewhat greater return on the like-polarized imagery, but not nearly as much more as on figure 13.

References

Cooper, J. R., 1966, Geologic evaluation-radar imagery of Twin Buttes area, Arizona Test Site 15: U.S. Geol. Survey Tech. Letter NASA-28, 4 p., 2 figs.

Gillerman, E., 1967, Investigation of cross-polarized radar on volcanic rocks: Univ. Kansas, CRES Report 61-25, 11 p., 6 figs.

Schwarz, D. E., and Caspall, F., 1968, The use of radar in the discrimination of agricultural land use, in Proceedings of the Fifth Symposium on Remote Sensing of Environment: Ann Arbor, Michigan, Univ. Michigan, Willow Run Laboratories, p. 233-247.

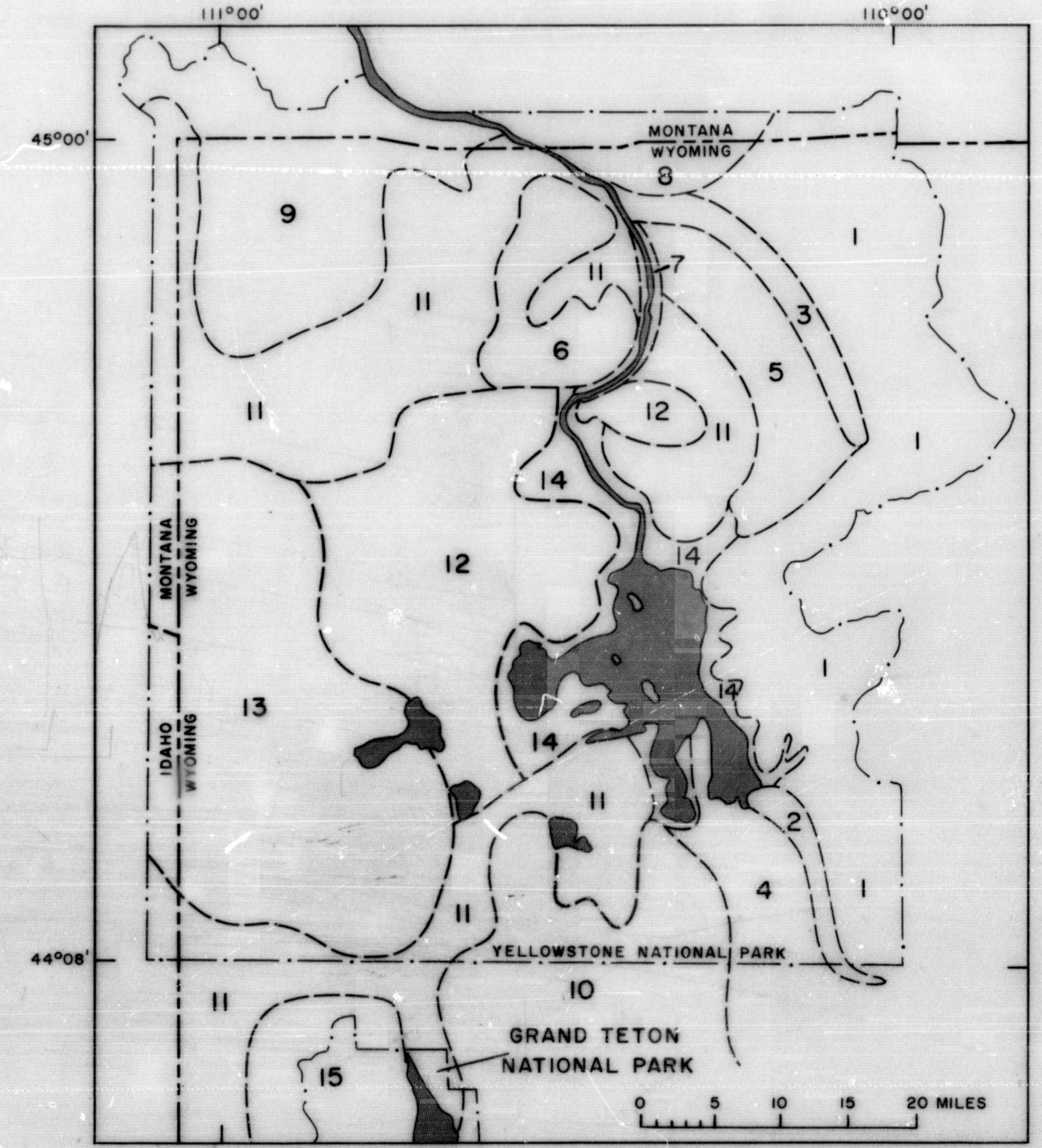

Figure 1.--Map showing areas of general geologic and geographic similarity described in text

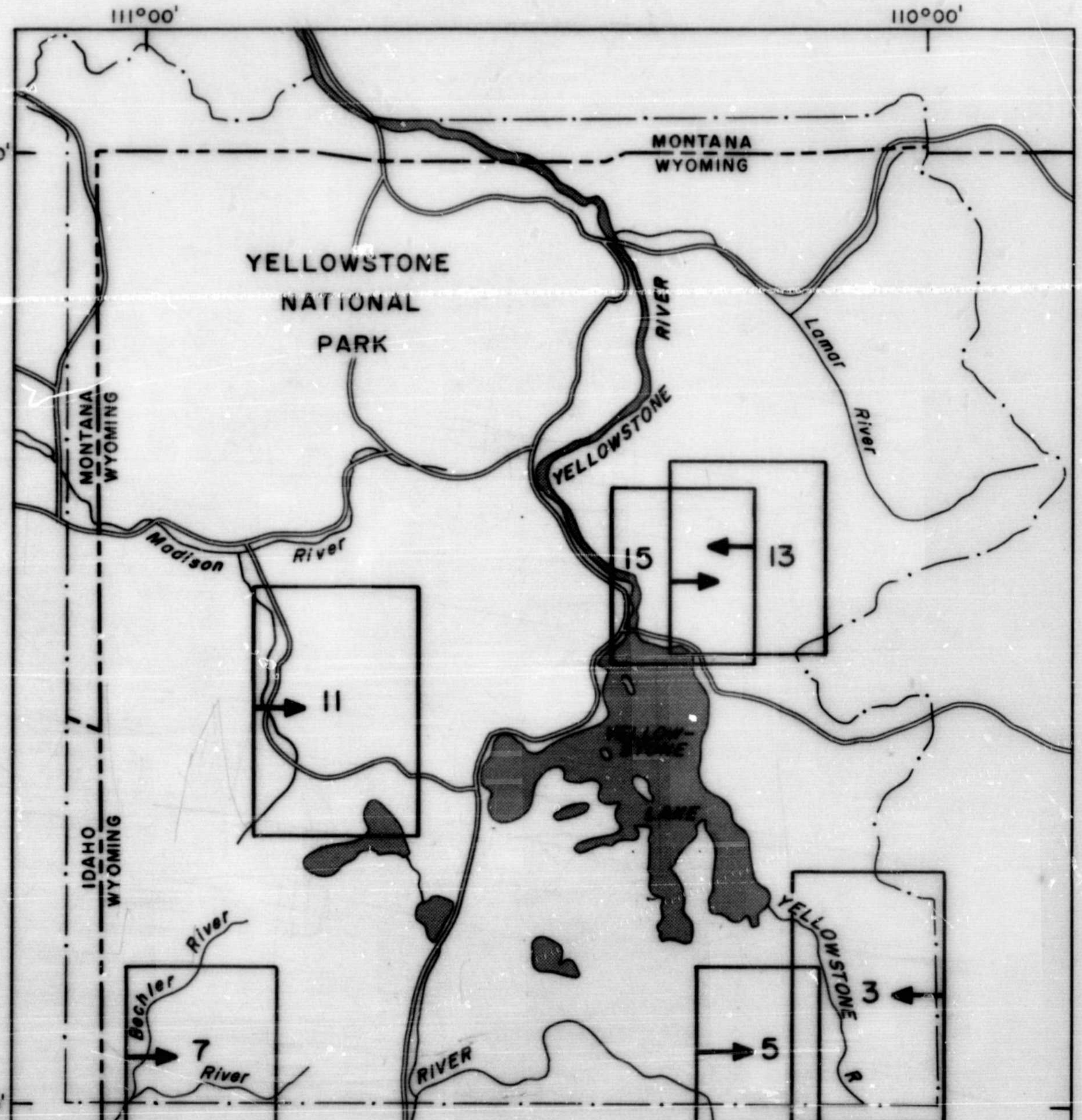

Figure 2.--Map showing location of images shown in figures 3-15. Arrows indicate radar "look" direction

Figure 3.--West-looking image of Absaroka Mountains and upper valley of Yellowstone River. Solid arrows indicate HV (cross-polarized) return less than HH (like-polarized). Dotted arrows indicate HH return less than HV.

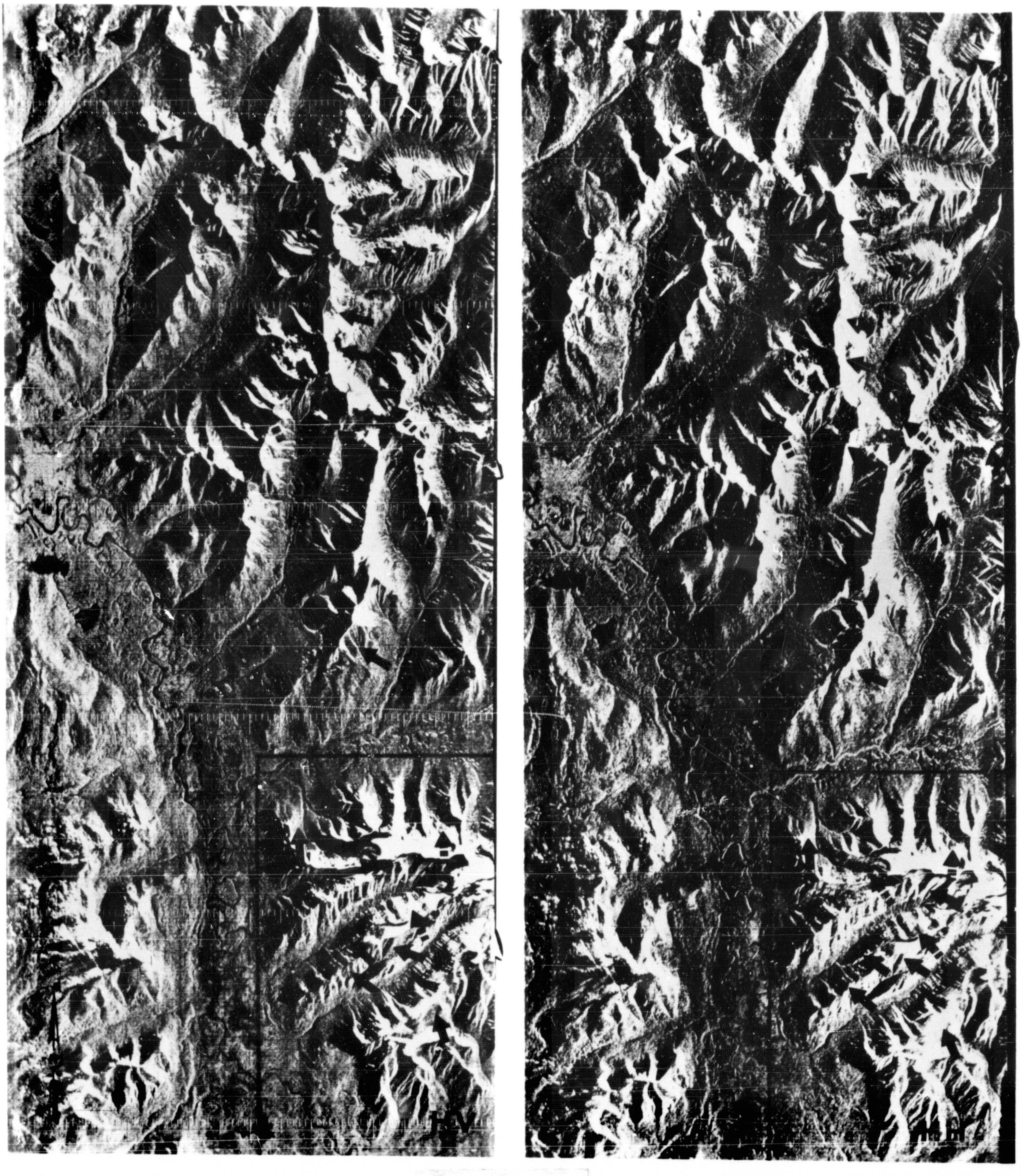

Figure 3

Figure 4.--Enlargement of the SE corner of figure 3, showing details of anomalies on the Trident Plateau.

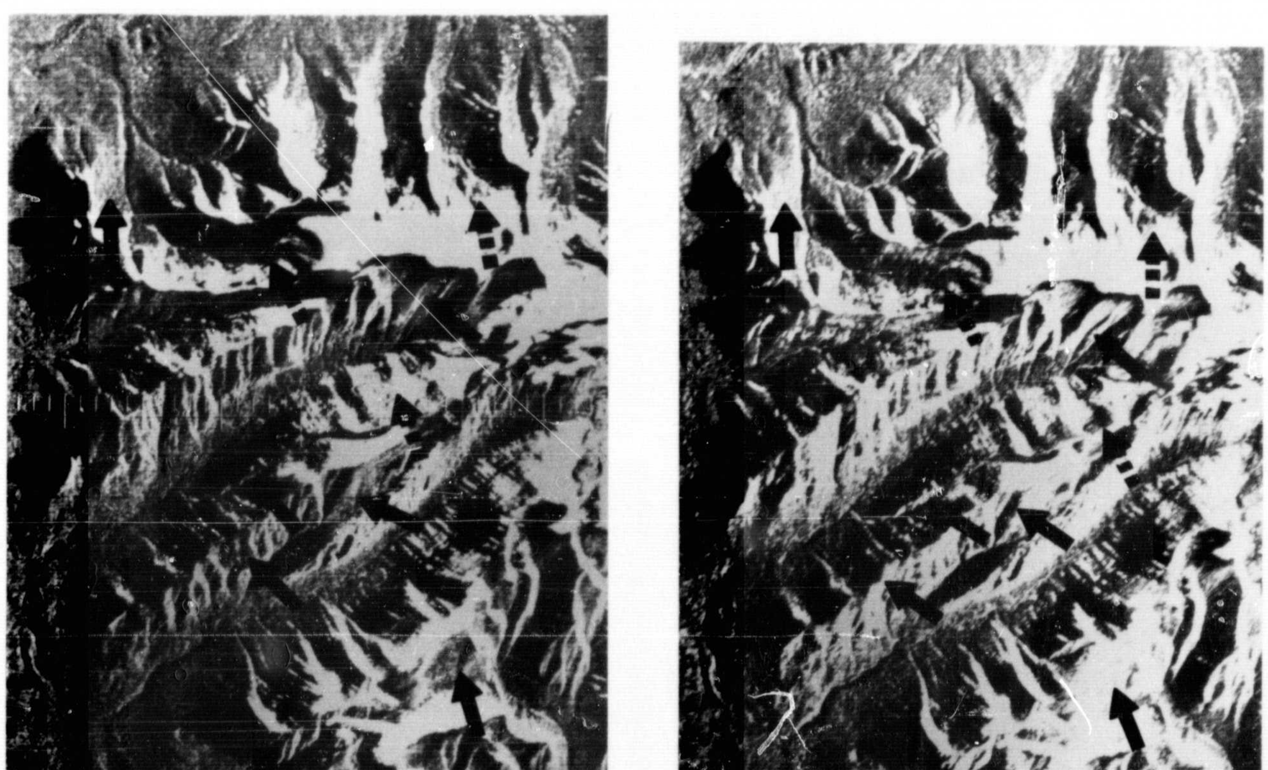

Figure 4

Figure 5.--East-looking image of Fox Park and headwaters of Snake River, west of Two Ocean Plateau. Numbered arrows referred to in text.

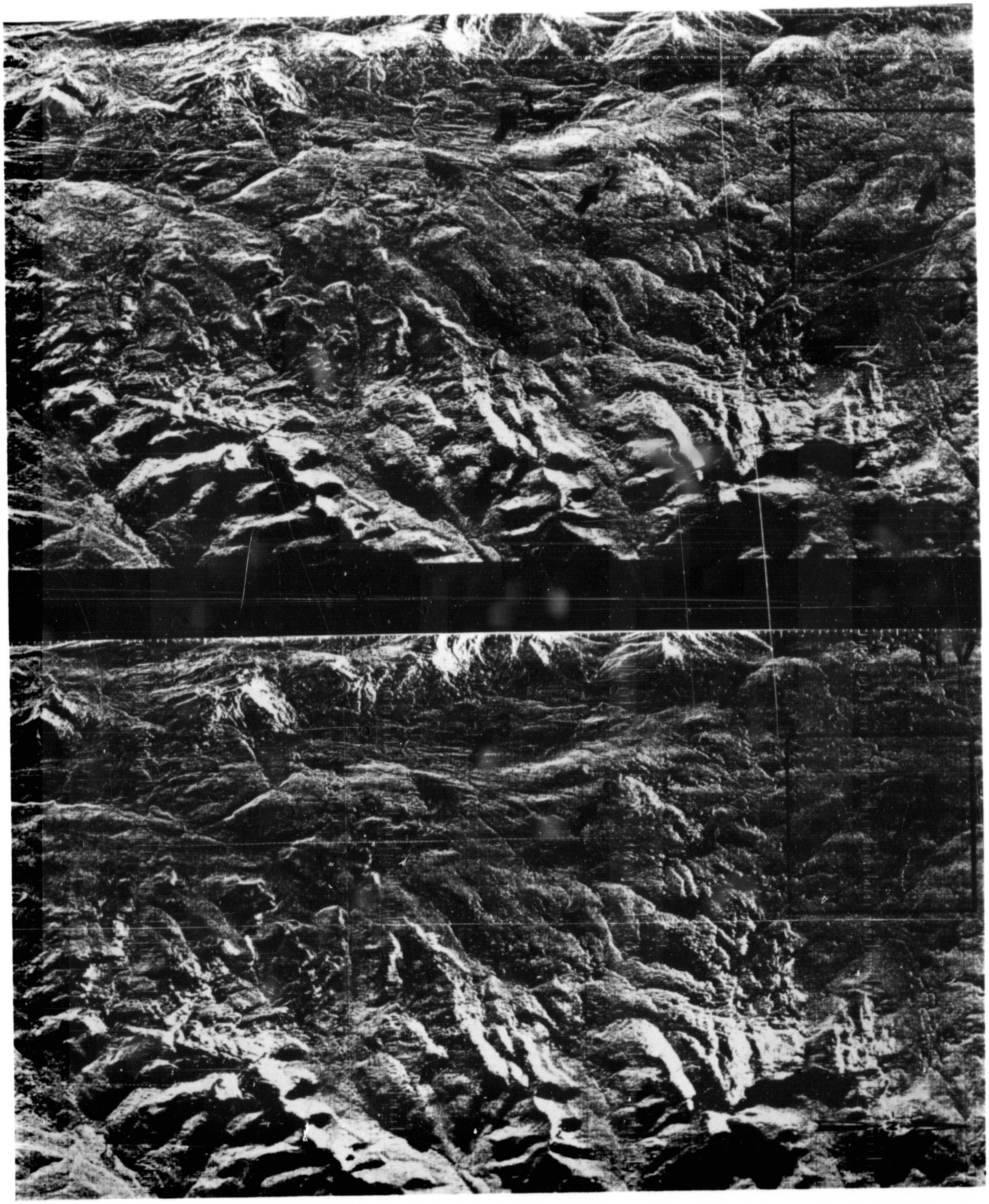

Figure 5

Figure 6.--Enlargement of the northern part of figure 5.

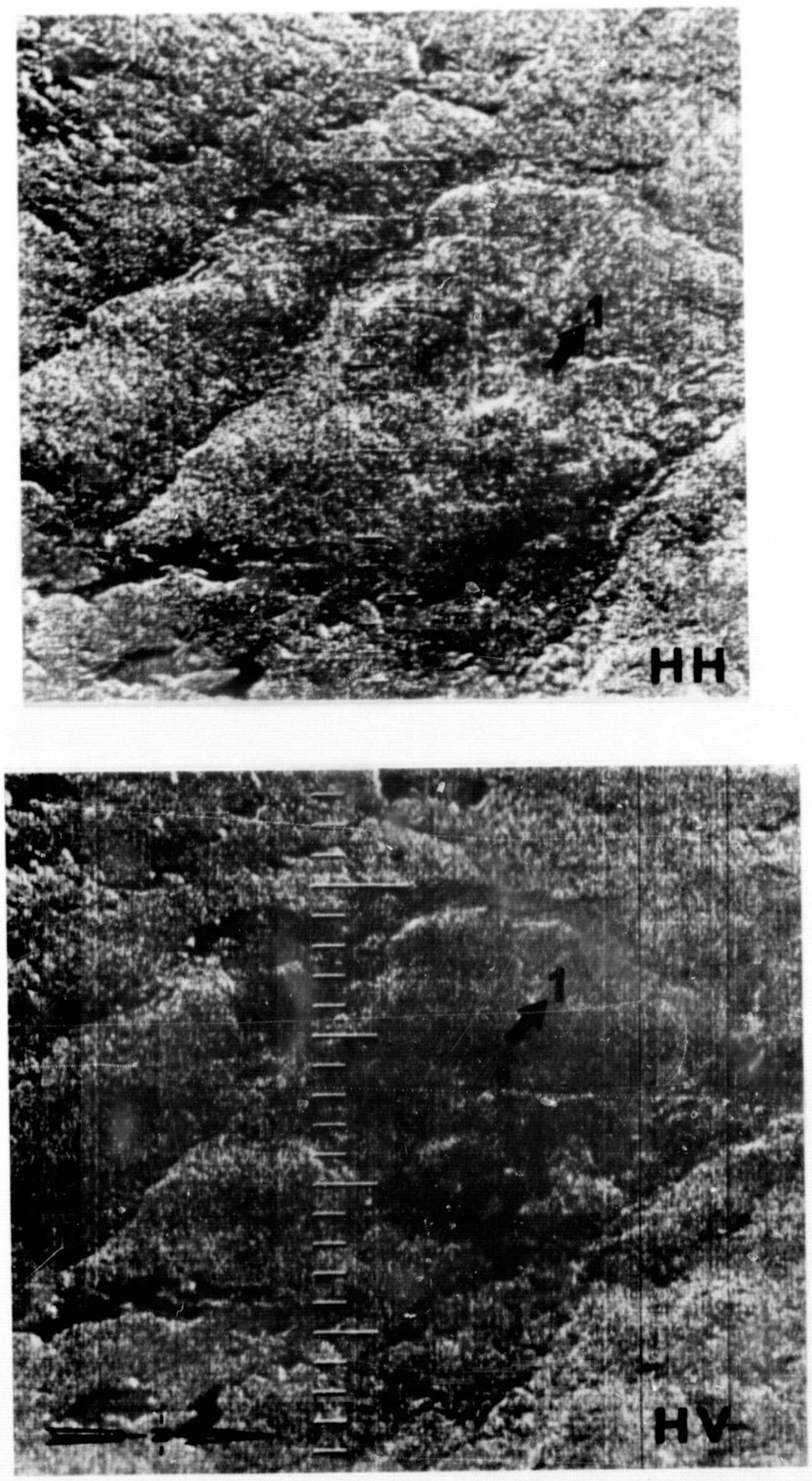

Figure 6

Figure 7.--East-looking image of southwest margin of Pitchstone Plateau and Bechler Meadows area. Arrows indicate anomalies which show as overreturn on HH return and are undiscernible or only weakly discernible on HV return.

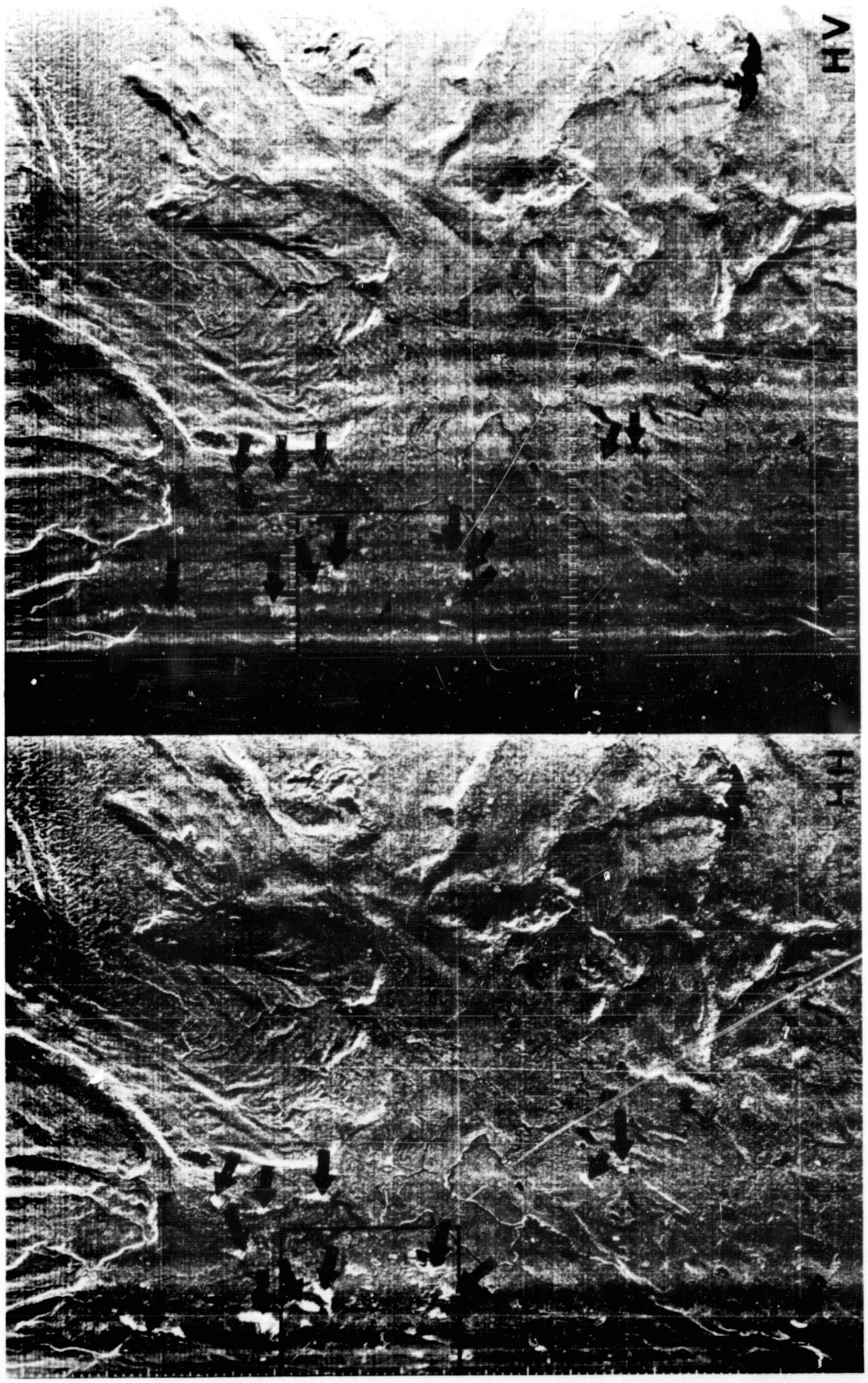

Figure 7

Figure 8.--Enlargement of the middle west edge of figure 7.

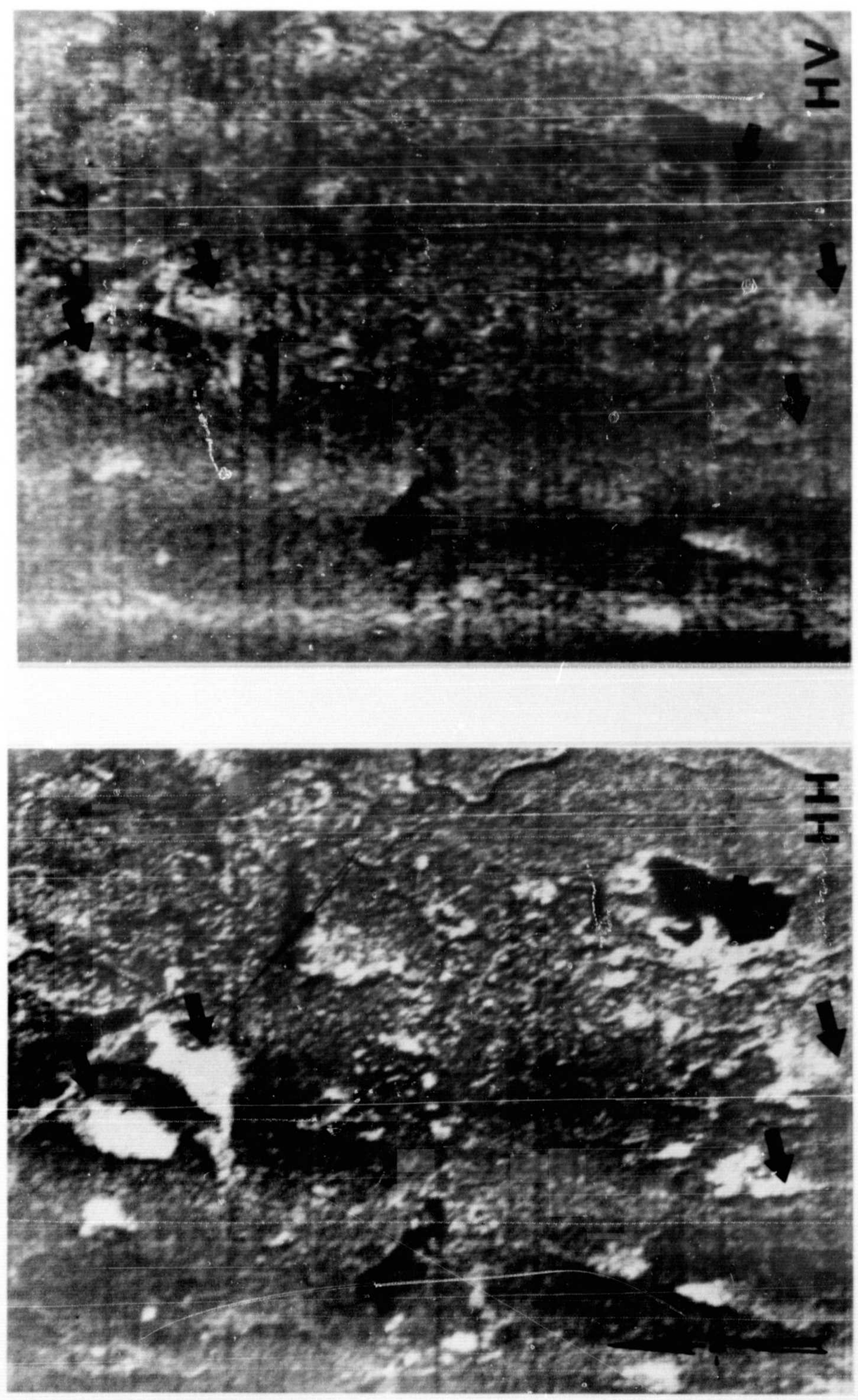

Figure 8

Figure 9.--West-looking image of the northern Teton Mountains. Arrows indicate anomalies in which the HH image shows whiteout because of intensity of return and the HV return is less intense but records more information.

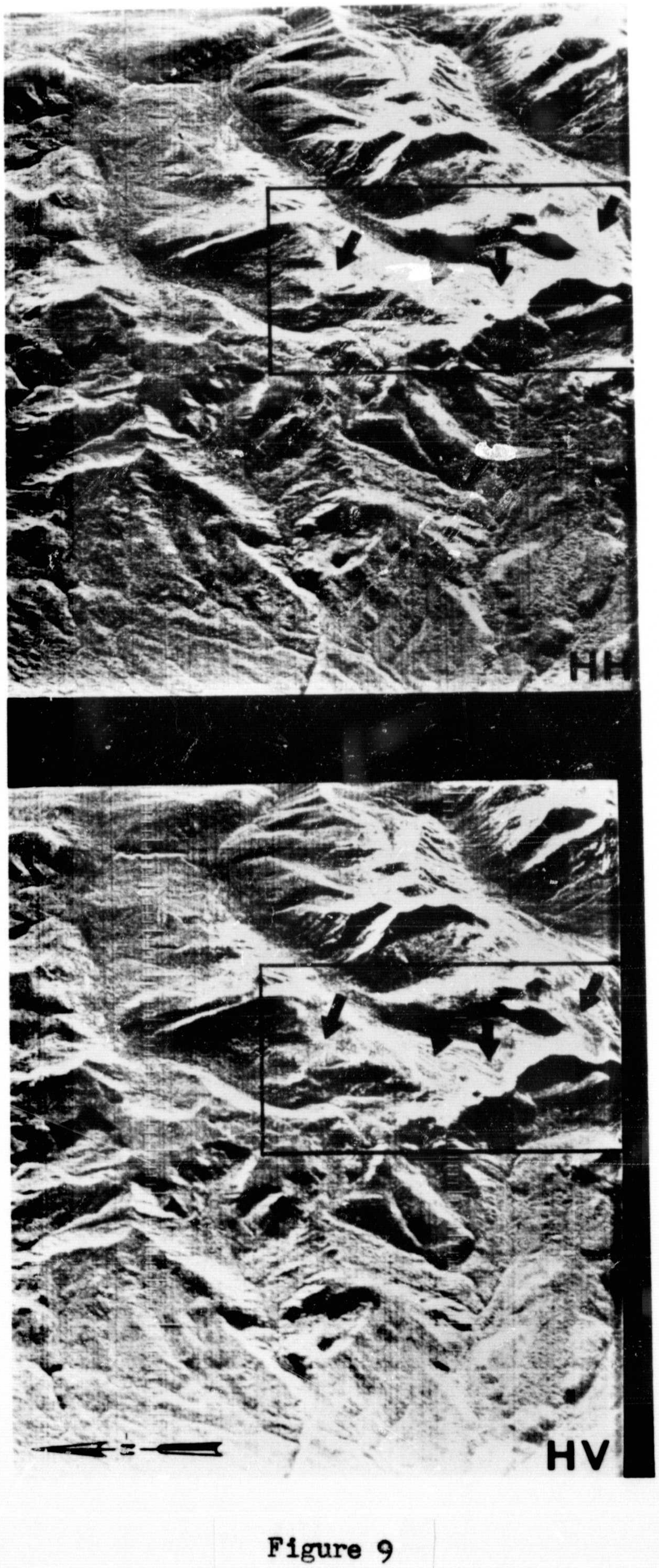

Figure 9

Figure 10.--Enlargement of central part of figure 9.

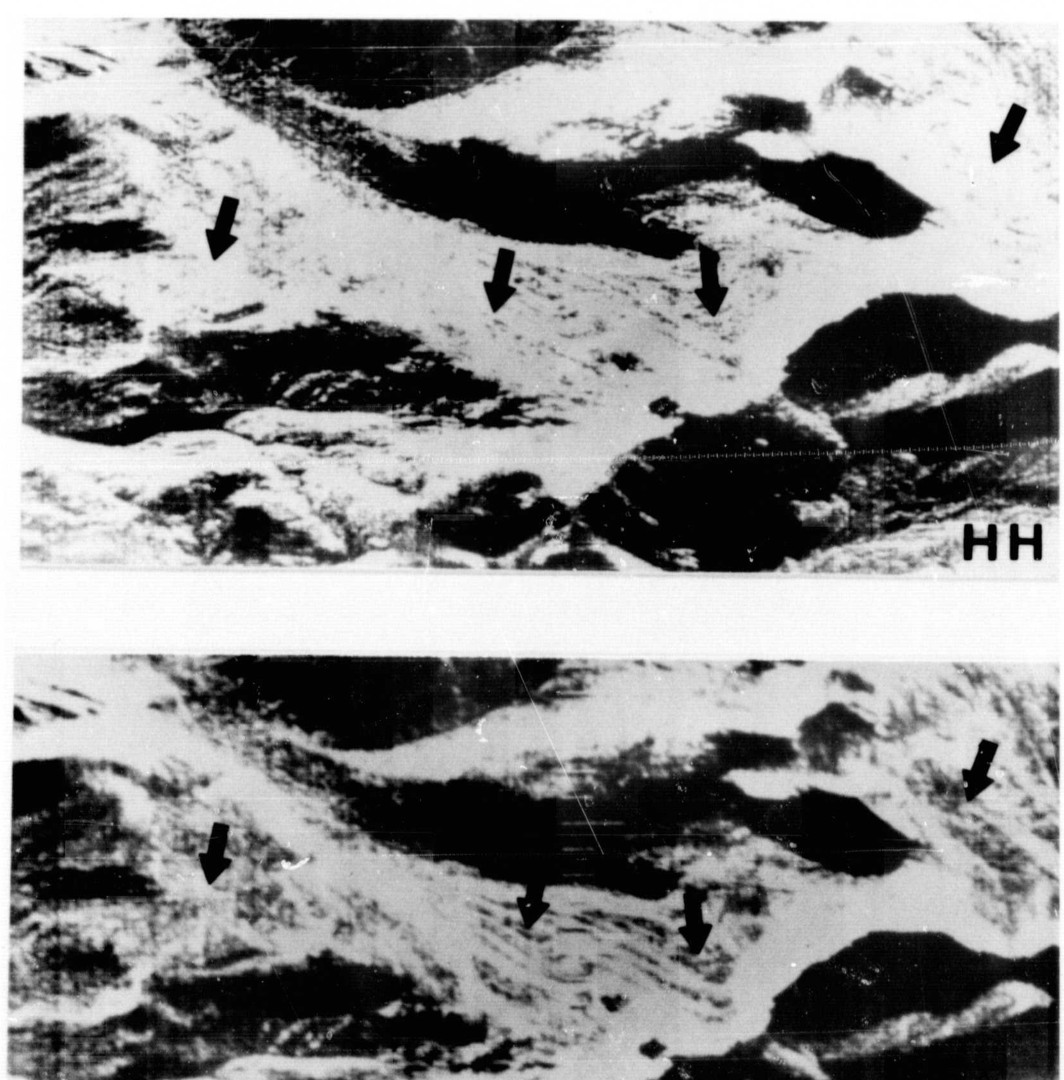

Figure 10

Figure 11.--East-looking image of the Central Plateau north of Shoshone Lake. Arrows indicate anomalies described in text.

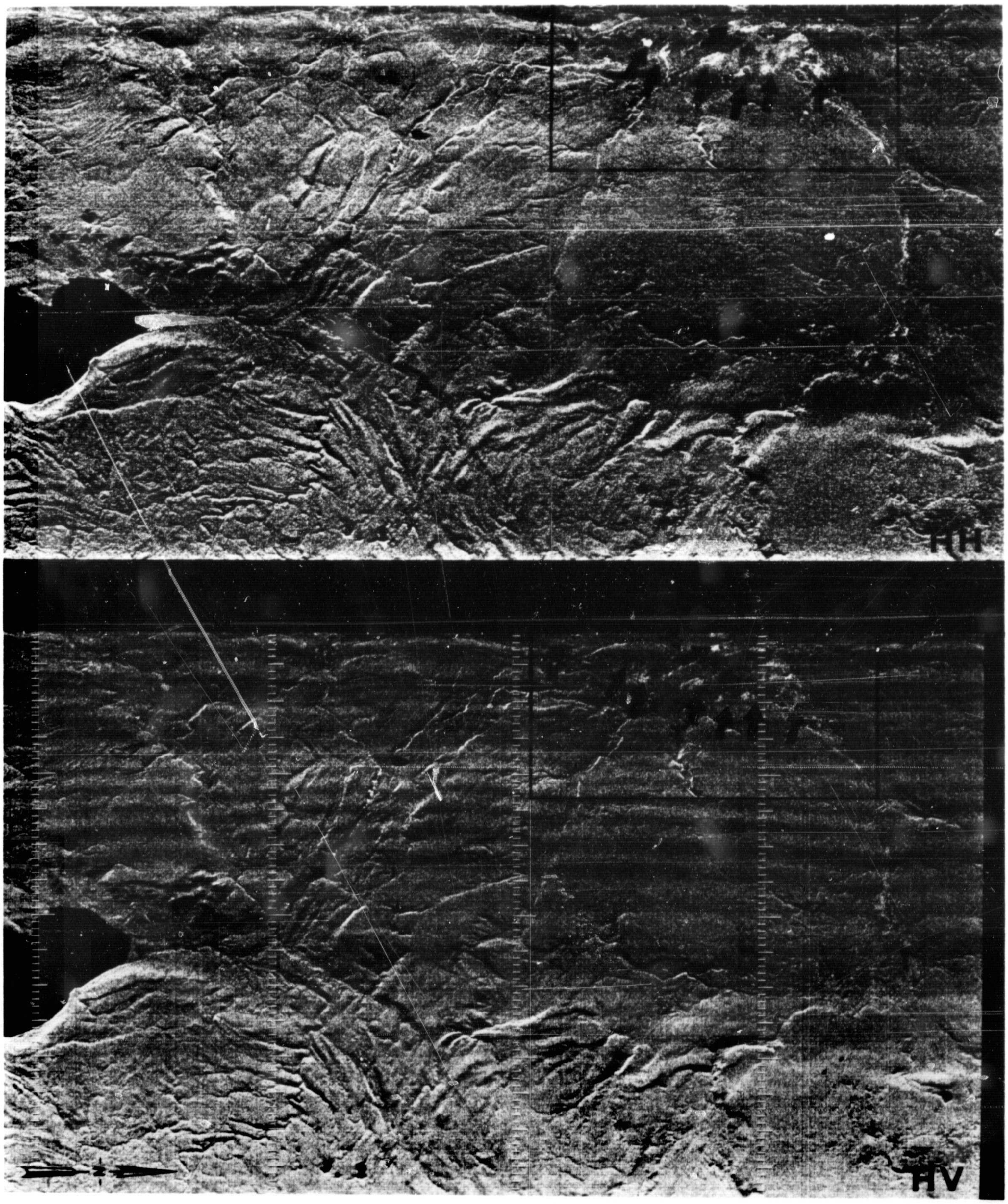

Figure 11

Figure 12.--Enlargement of the west part of figure 11.

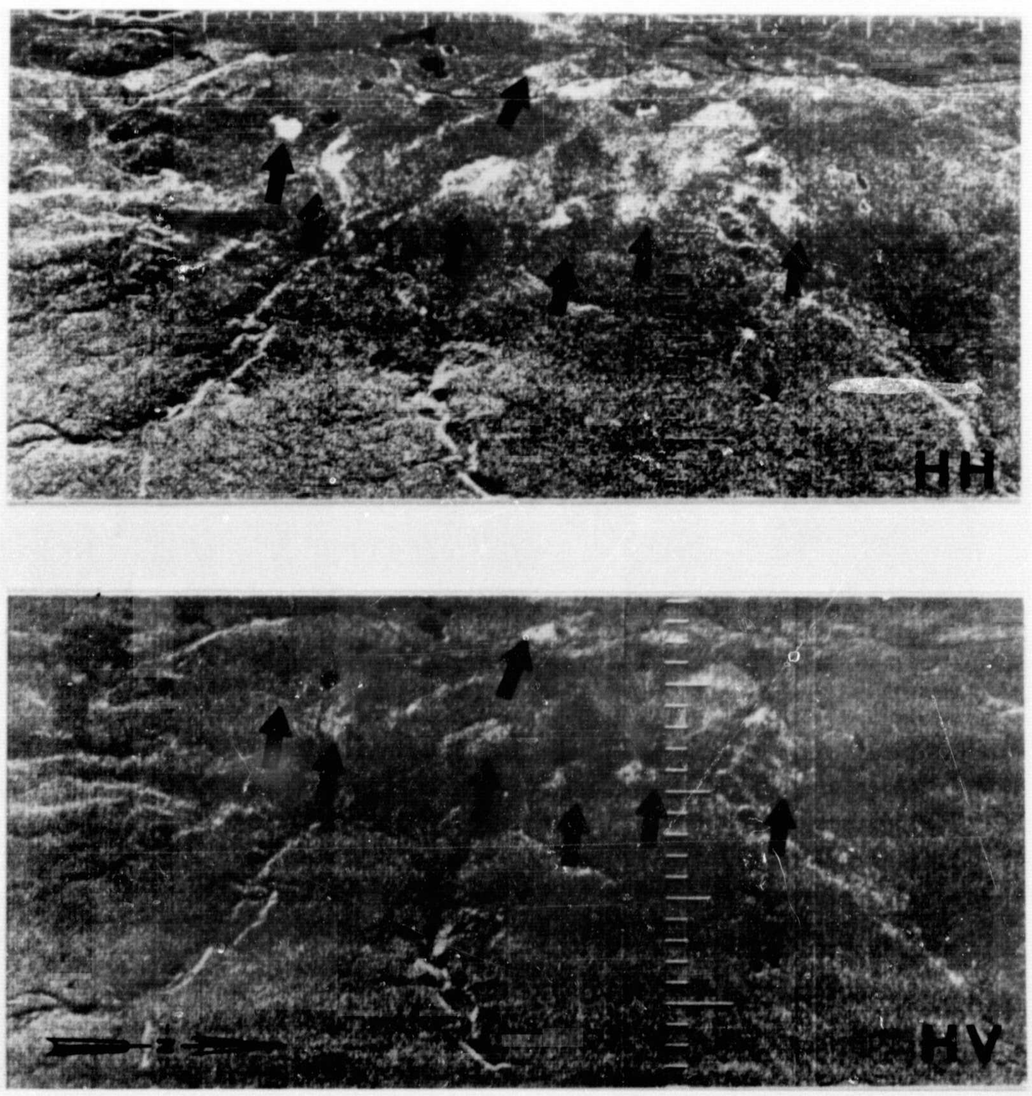

Figure 12

Figure 13.--East-looking image of area east of White Lake and Tern Lake, north of Mary Bay on Yellowstone Lake (lower left corner). Numbered arrows indicate anomalies described in text.

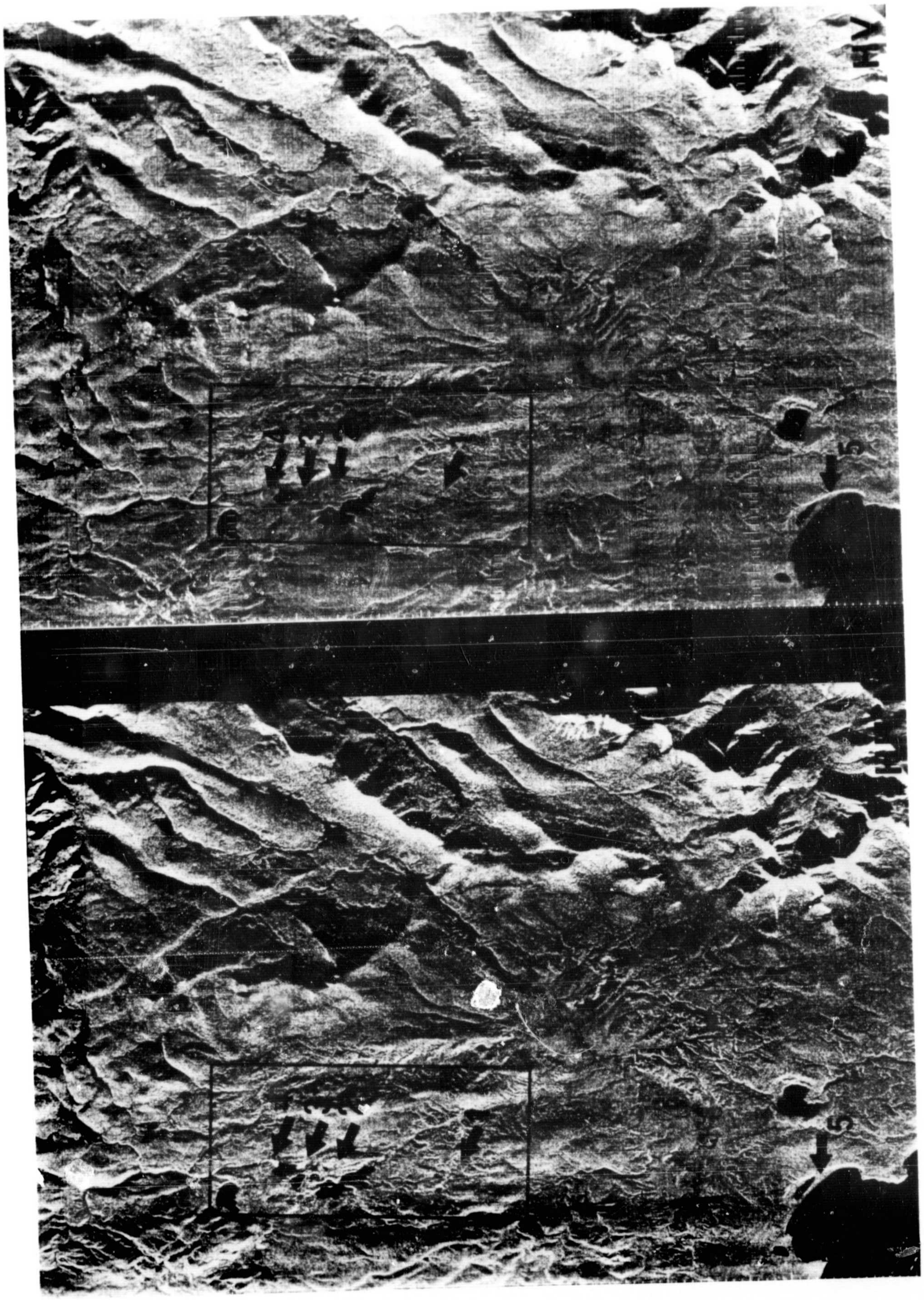

Figure 13

Figure 14.--Enlargement of the western part of figure 13.

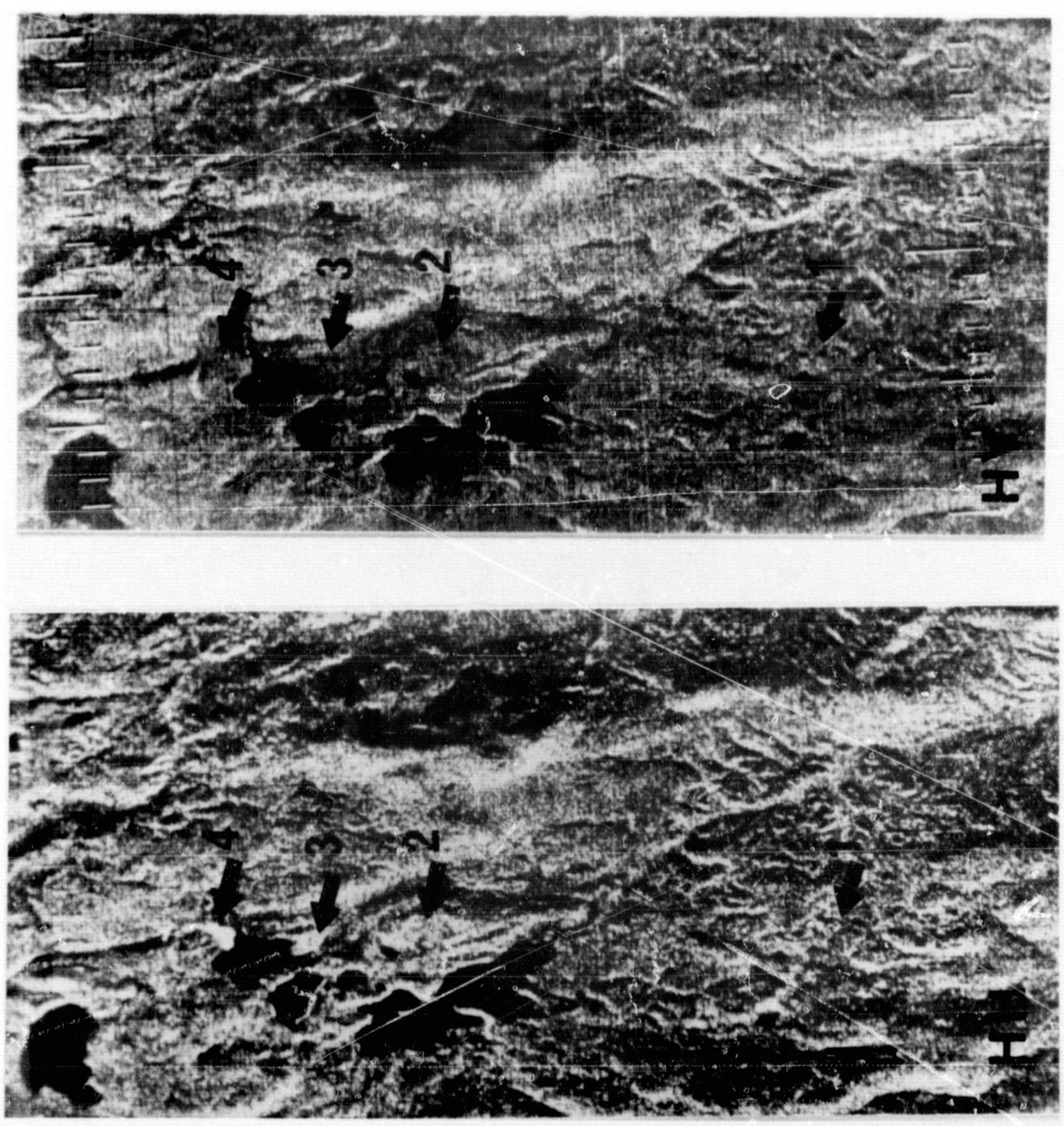

Figure 14

Figure 15.--West-looking image of area north of Yellowstone Lake that is also shown in figure 13.

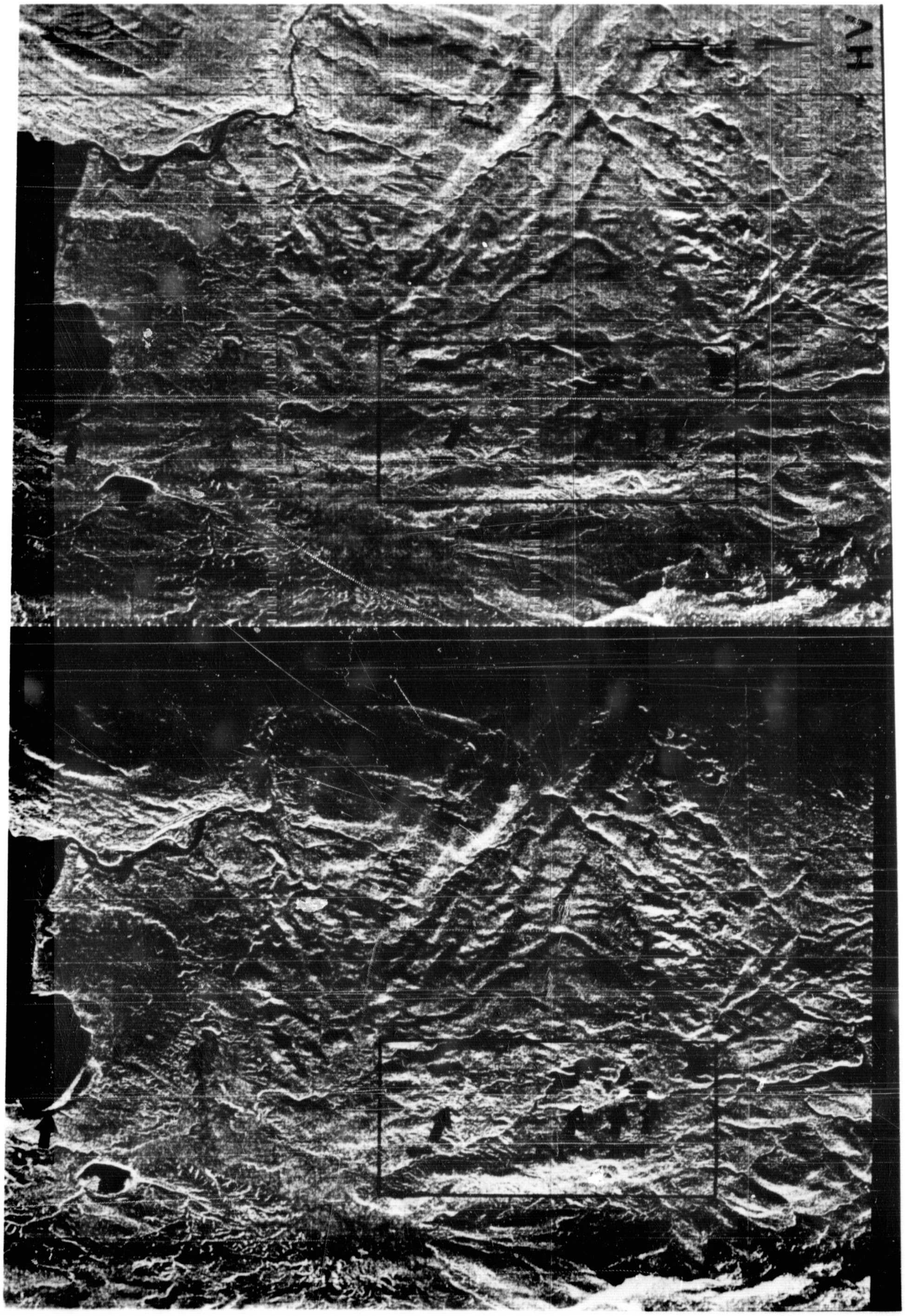

Figure 15

Figure 16.--Enlargement of the eastern part of figure 15.

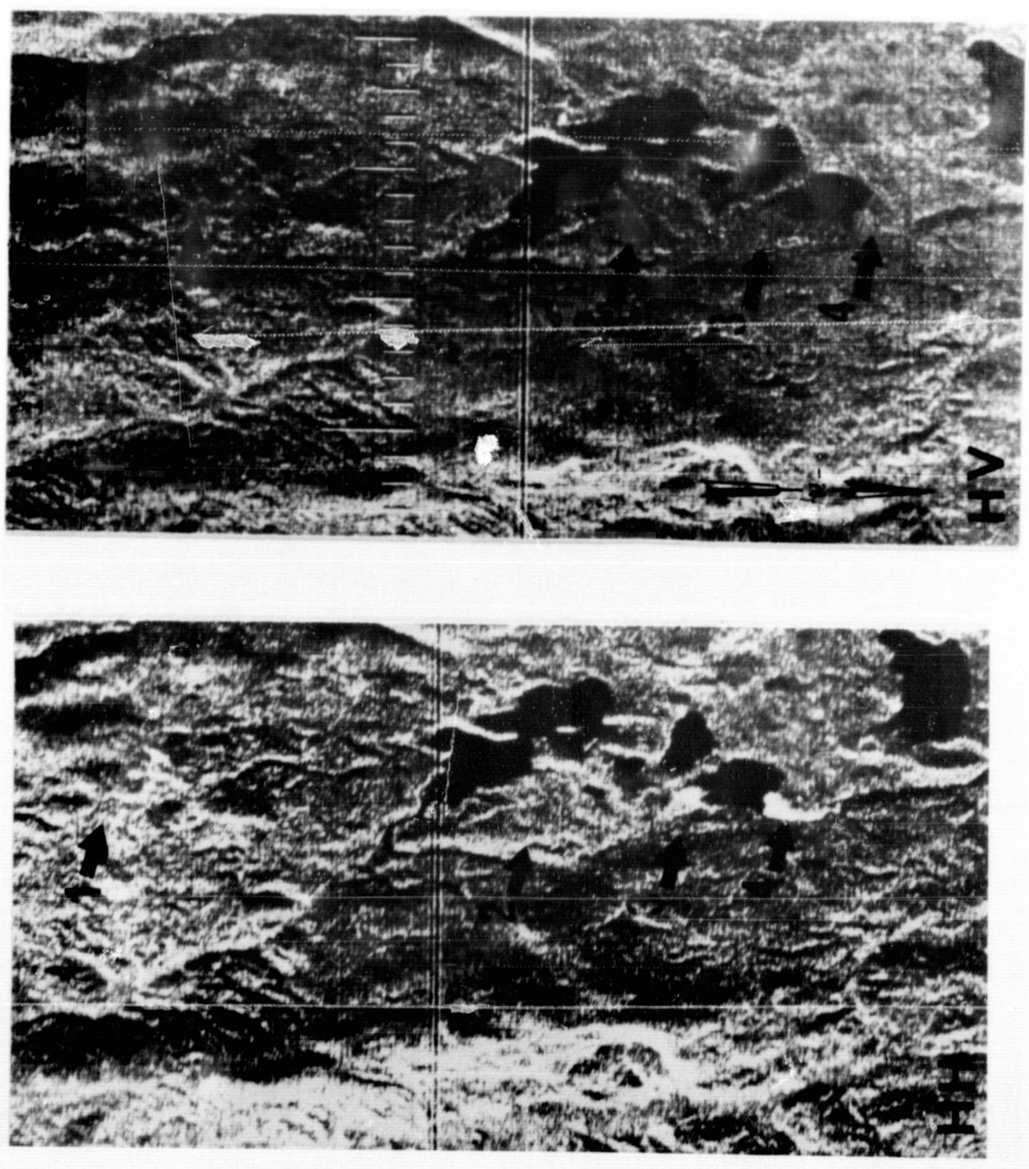

Figure 16