UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
[Reports - open file]

SOME ASPECTS OF REMOTE SENSING FOR CONSIDERATION IN PLANNING FOR ENVIRONMENTAL MONITORING OF THE ALYESKA PIPELINE, ALASKA

By Herbert E. Skibitzke

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Open-File Report 77-643

Menlo Park, California
1974

CONTENTS

ILLUSTRATIONS

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ABSTRACT

Remote sensing data were taken along a line surveyed for the building of the Alyeska Pipeline, Alaska, in the winter of 1973-74. The portion considered in this report is the area from the Yukon River south to Isabel Pass in the Alaska Range.

The occurrences of aufeis gave the appearance of four rather distinct modes of formation. In the area south of Big Delta, the icings occurred as seepage at the toes of the terraces and along the bottoms of the stream channels cutting into the terraces. In the Yukon-Tanana uplands, the icings occurred generally as seepage at the lowest points in the U-shaped valleys and along the surfaces of the streams in the tributary valleys incised into the rolling hills. The icings formed in the stream channels in both regions have similar hydraulic considerations as do the icings formed in the lower part of the valleys at at the toes of the terraces.

Aerial techniques of collecting data by photography and thermal imagery were tested in this setting as a basis for consideration in planning for potential environmental monitoring of the pipeline.

Introduction

The contract agreements between Alyeska Pipeline Company and the U.S. Department of Interior include a list of monitoring requirements to be performed by the Alyeska Company within the pipeline right-of-way. However, the installation of the pipeline may affect the environment outside the right-of-way in some places. These areas also should be monitored because of problems that possibly could develop. Automatic equipment, installed along the pipeline by the contractor, will monitor some aspects of the environment but this monitoring may not reflect conditions and trends much beyond the right-of-way. This is particularly true of conditions more than half a mile from the pipeline. Therefore, consideration should be given to synoptic monitoring using airborne remote-sensing systems to obtain desired information.

The setting in which various segments of the pipeline are located should be evaluated to determine the monitoring criteria. For instance, in areas of low-density population, intensive monitoring would likely be necessary because few people would be on hand to detect and report incipient and existing problems; whereas, in heavily populated areas the pipeline would usually be under observation and there would likely be rapid reporting if difficulties occur. Another consideration is that in a sparsely populated area, a pipeline disaster would not create such a hazard to human life as it would in a densely populated area, although environmental effects might be equally or more serious. Thus, population density is an important factor in the development of monitoring techniques. The Alaska pipeline, for the most part, is located in an area of low population density and may require a considerable amount of airborne surveillance in addition to the automated monitoring specified in the contract.

As hydrologic changes evolve as the result of planned and unplanned events associated with the pipeline, the slow reaction may leave the area vulnerable to environmental damage from the cumulative and sometimes sudden impacts. Thus, environmental data collected outside the immediate vicinity of the pipeline may be extremely valuable.

Very likely, considerable controversy will arise because of the pipeline's socio-economic and environmental effects. Clearly, therefore, data should be collected and retained to record changes that may result during the next decade or two. In addition, data should be analyzed quickly so that developing problems can be detected and remedial measures initiated as soon as possible. It is suggested, then, that the monitoring approach should provide a permanent record of the changes caused by the development of the pipeline, as well as to provide opportunity for timely response in terms of pipeline maintenance by analyzing and evaluating changes as they occur.

Severe winter weather and long periods of darkness add to the complexity of monitoring operations in Alaska. Darkness limits visual observation in the area where one of the more critical parts of the pipeline is located. Also, man's visual senses do not respond to heat changes, which are among the most significant requirements of the pipeline monitoring. Many instruments will record data on film or magnetic tape and can even allow observation of the data on a cathode ray tube as they are being acquired. The latter capability may be important because the instruments can reveal critical thermal variations that cannot be discerned by eye. The U.S. Geological Survey (USGS) has sensing instruments that combine the following capabilities: (1) data from parts of the electromagnetic spectrum may be observed visually on an instrument screen while the data are being recorded for permanent records, and (2) the magnetic tapes may also be used for more detailed office analysis.

Potential Techniques for Monitoring the Alyeska Pipeline

Much of the monitoring done today, other than by personal observation, utilizes photographic techniques, which are extremely potent because they record on film more detail than a man could possibly retain in his mind. Photographs also provide a permanent record for later analysis.

Photographic techniques also permit monitoring in a range that is outside the visual capability of the observer. As an example, photography can record data in the visual and ultraviolet portion of the electromagnetic spectrum as well as in the important near-infrared range (0.7 to 1.1 micrometers). Differences in plant life generally are fairly simple to identify on photographs using film sensitive in the near-infrared range. The photographic formats may be individual frames, usually 9- by 9-inch size, or a continuous strip of film.

Imaging systems, in addition to photography, make it possible to record information from parts of the electromagnetic energy range that cannot be recorded on photographs. Electromechanical processes are utilized in most of the imaging devices. For example, spinning mirrors focus emitted electromagnetic energy into detectors sensitive to the near-, middle-, and far-infrared as well as the microwave and visual ranges. Sensors used to detect emitted radiation or those responsive to active microwave energy (radar) do not require light and, therefore, they can be used effectively at night as well as during the day. For immediate viewing the image can be projected on a television screen at the same time as it is being recorded on film or magnetic tape.

Continuous strip photographic cameras take pictures by moving the film past a very narrow slit which is only a thousandth of an inch or less in width at a speed that is adjusted automatically according to aircraft speed. The result is a long continuous strip of photographs and there are no frames to piece together. The strip technique is particularly adaptable to very high speed photography where detail is required. Clearly, considerable time and effort may be saved in the evaluation process by using a long strip of film rather than resorting to the alternative approach of compiling a long mosaic from a large number of individual photographs. Using strip films, no overlap is required, thereby eliminating the waste of film. Because the centerline of the continuous strip photography can be made to coincide with the pipeline, no lateral overlap is required, greatly reducing the required number of photographs. The number of photographs becomes an important consideration in system-analysis design. To enlarge the detail of an individual photograph by a factor of two, the size of the photograph must be increased four times. Thus, in attempting to expand the center of interest along the pipeline on framed photography, the number of photographs must be greatly increased. As the number of photographs is increased, the effort and expense of piecing together data increases exponentially. By way of contrast, continuous-strip photography of the entire pipeline may be mounted on two rollers and viewed both in stereo and in planimetric detail. Presently (1974), there is no capability for immediate readout of film in the visual range for real-time analysis; however, television cameras operating in the visual range can furnish a continuous view of ambient conditions.

The continuous filmstrip approach is applied to almost all imaging techniques that are in use today. In the electromechanical imagers that operate in the 1- to 14-micrometer (infrared) range, which are becoming common now, all readout data are recorded on a continuous strip of film or magnetic tape. Frame-type film recording imagers are not now currently available.

The major differences among the types of imagery taken of the pipeline are shown by the three presentations of figure 1. (For purposes of this report, "figures" may be found in the Appendix. "Illustrations" are inter-leaved throughout the text, closely following the page of first reference.) Figure 1A is a planimetric photo taken with a 6-inch lens on a 9- by 9-inch frame. The part cut out of the photograph and replaced with slight separation coincides with the area depicted in the thermal imagery (figure 1B). The lines drawn on the frame photograph indicate the area shown in a segment of the continuous strip photograph (figure 1C). What cannot be shown so simply is that the frame photograph is but one of a long series of frames, each 9- by 9-inches in size. To reduce the effort of piecing individual frames together, photographs may be taken at relatively small scales. Thus, a wider area than is needed may be photographed at the expense of reduced resolution.

The thermal imagery of figure 1B is similar in appearance to photography, however, the data acquired are substantially different. Continuous strip photography is obtained using reflected light whereas thermal imagery is obtained by using emitted heat. The relative differences between photographs and images are illustrated throughout this report.

Thermal infrared systems that are designed particularly for use in helicopters scan forward in a panoramic view. In other words, oblique imagery in picture form may be acquired of the earth's surface and objects thereon, such as the pipeline. Thermal imaging systems would seem a particularly desirable tool for monitoring the pipeline in Alaska during the darkness of winter months because there would be opportunity to observe the pipeline for purposes of real-time data analysis whenever desired. In addition, images acquired on this type of detector can be stored on tape and reviewed at the field office at any time.

The USGS is currently experimenting with a forward-looking infrared system in a helicopter. In the thermal imagers used by the Survey, a record is made on film of the thermal energy emitted from the earth's surface in the 9- to 14-micrometer range. At the same time, the image is displayed on a large television screen in the aircraft as it flies over the ground, and it is possible to stop this display for detailed inspection. It is also possible to set a limiting device so that when a given temperature is exceeded, either on the high or low side, a circle around the thermal anomaly will appear on the film or the image on the television screen. This encircling device can be controlled by the operator and can permit identification of even minor thermal anomalies that may be undetectable by any other observation method. The location of the site would be marked to enable the airplane to return at a lower altitude for a more detailed examination of the area if desired. In addition to this type of real-time readout, ground receiving stations are available to accept data from most of the imaging equipment in use today. The image can be relayed to the field office where personnel can communicate with observers in the aircraft as the imagery is being acquired. However, radio range limitations would make it difficult to maintain radio communications over the entire length of the Alyeska Pipeline. Therefore, it would be more effective for the image to be viewed in the air by an environmental specialist who can also operate the instruments and record various observations relative to the data acquired.

Experimental Studies for Evaluation of Techniques

To evaluate techniques that could be used for the monitoring described above, several surveys were made along sections of the Alyeska Pipeline in mid-winter of 1973-74. A DeHavilland Beaver * equipped with a thermal imager and a

* The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

real-time display was used to monitor parts of the pipeline north and south of the Big Delta area. A Cessna 310 equipped with the continuous strip camera system was used to photograph the entire route.

The CAS-2 continuous-strip camera used on this project was designed and built during World War II. It was retained and converted for this purpose because there was no known new equipment available. In the conversion process it was necessary to relate the time constants of the radius of gyration of the camera to those in the recovery rate of the servos leveling the camera. This could only be partly accomplished before the photographs were made in Alaska so that considerable "roll" effect may be seen in some of the frames. This defect has since been corrected. In addition, standard planimetric photographs were taken with a KC-2 camera along a large part of the pipeline.

The data were analyzed and in June 1974, the area was revisited and photographed obliquely from an airplane at low altitude to provide a different view of the environmental characteristics that were imaged during the previous winter. Following are several examples of photography and imagery obtained. For each, an analysis of data from topographic maps, the thermal imager, the continuous-strip camera, and the planimetric camera is presented. Also, oblique color photographs taken at low altitude are furnished to allow comparisons with the data observed by remote sensing.

Formation of Aufeis* in the Central Region of Alaska Along the Alyeska Pipeline

Remote-sensing data were obtained along a line surveyed for construction of the Alyeska Pipeline. The part considered in this study is the area from the Yukon River south to Isabel Pass in the Alaska Range (illustration 1). The

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* Aufeis: A sheet of ice formed on a river flood plain in winter when shoals in the river freeze solid or are otherwise dammed so that water spreads over the flood plain and freezes. (Howell, 1960).

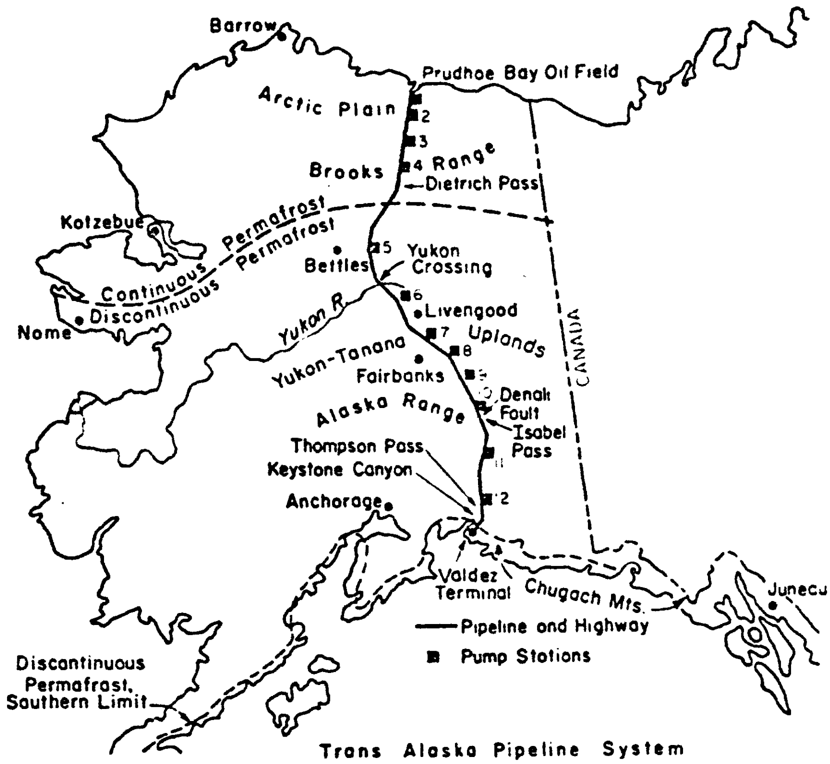


Illustration 1 -Map of Alaska indicating route of trans-Alaska pipeline system, including pump stations, major and specific physiographic and geomorphic features along the route, and the boundary between the continuous and discontinuous permafrost zones.

northern part of this area, which is north of the Tanana River, is in the Yukon-Tanana Highlands physiographic province and is characterized by maturely dissected rounded ridges. Scattered within the rounded ridges are discontinuous higher mountains (5000 to 6000 feet in elevation) projecting above the lower rolling hills. South of Big Delta the pipeline route enters the Alaska Range physiographic province. Between Big Delta and Isabel Pass, the pipeline lies mostly in galcial terrain that largely gives the appearance of a kame terrace. Many small lakes exist in this region. Even though the area has scant precipitation its soils are nonetheless very wet because of low evapotranspiration rates throughout central Alaska. South of Donnelly Dome the pipeline follows the foot of the terraces, with the lakes flanking the pipeline right-of-way.

The occurrences of aufeis in the winter of 1973-74 gave the appearance of four rather distinct modes of formation. South of Big Delta icings occurred as seepage at the toe of terraces and along the bottom of stream channels cutting into the terraces. In the Yukon-Tanana uplands icings occurred generally as seepage at the lowest points in the U-shaped valleys and along the surfaces of the streams in the incised tributary valleys. The icings formed in stream channels of both regions have similar hydraulic characteristics as do icings formed in the lower part of valleys and at the base of terraces.

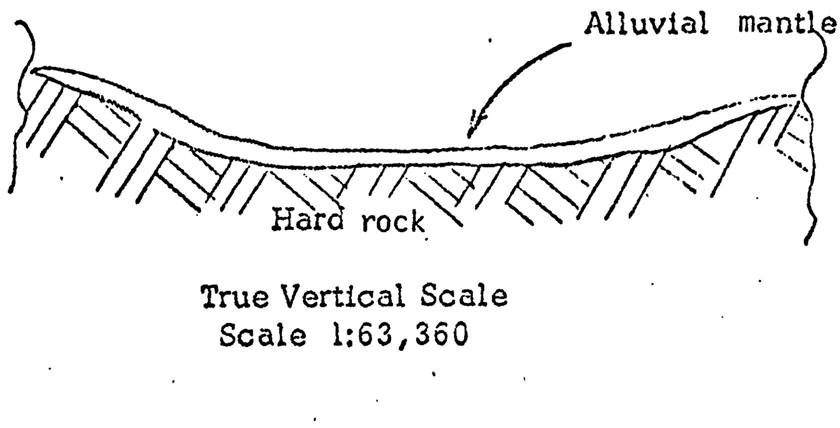
Aufeis Along Stream Channels

Overflow ice along stream channels is often ascribed to bottom freezing of streams which forces water to overflow and freeze at the stream surface. Infrared imagery shows that streamflow is generally discontinuous and occurs at ground-water discharge points. Even where aufeis is continuous, it is produced by the discharge of ground-water accumulating along the stream channel. Flow from the seeps and springs can only exist for a few hundred feet before freezing and, subsequently, an ice-layering process begins. The discontinuous nature of the ice may be seen in the thermal imagery of figure 11A as well as in several other images. The ice in the oblique photographs of figure 11B taken in June seems to show extensive ice-impacted reaches in the stream channel.

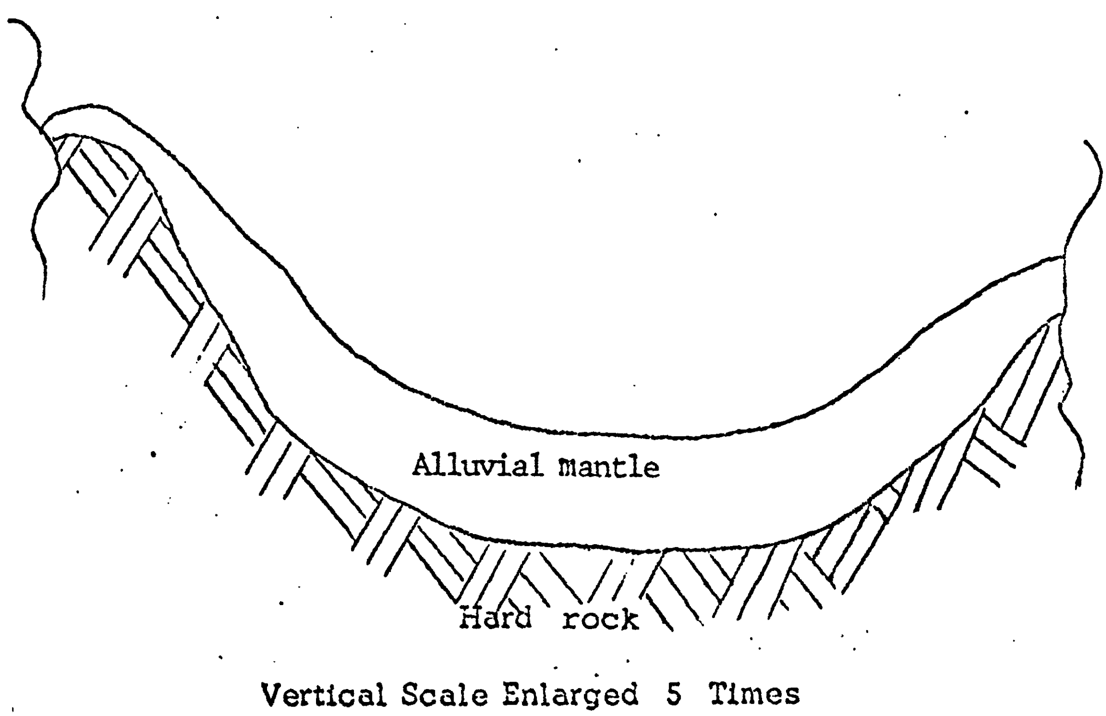
The uplands area flanking the pipeline is generally made up of rolling hills. The hills are mantled by alluvial materials of varying thicknesses from the top of the hills to the lower parts of the incised valleys. These ice-weathered slopes were formed by intense periglacial activity as may be inferred by pingos, solifluction slopes, mud flows, and terracing found throughout the area.

Simplifying the more complex geomorphic and geologic considerations, the valleys generally appear as shown at true vertical scale in illustration 2a. Sedimentary or metamorphic rocks (hard rock) form the lower part of the diagram and overlying these rocks is alluvium. The thickness of the alluvium varies but averages about 200-feet, with rapid thinning at the hilltops.

The alluvial mantle is of considerable concern to construction and engineering projects in central Alaska. Low evapotranspiration keeps the soils in a near saturated state most of the time Extensive areas are, as a result, frozen all of the time creating permafrost conditions to great depths. Above the permafrost zone soil pore spaces are frozen in winter but thaw in summer. This is termed the active layer. Intrapermafrost water moves within the permafrost in channels kept perennially thawed by relatively warm ground water. Below the permafrost, in the unfrozen hard rock, water movement occurs in fractures, joints, and solution channels. A description of the occurrence of ground water in permafrost regions of Alaska has been presented by Williams (1970).



Illustration(2a)- Cross section through typical valley, drawn to true scale.



Illustration(2b)- Cross section of Illustration(2a) with vertical scale enlarged five times.

The alluvial mantle is continually saturated with either ice or water. The vertical scale of illustration 2a makes it difficult to portray ground-water flowlines, therefore, the vertical scale was enlarged five times as shown in illustration 2b. Using this exaggerated scale, hypothetical summer ground-water flow lines are shown in illustration 3, which is highly idealized. Intrapermafrost water is often found particularly where the permafrost bottom is considerably above the bedrock. Frequently, isolated ice masses are found in the active zone. However, the generalization (illustration 3) remains essentially correct because it illustrates the fundamental process of water movement in the alluvial mantle.

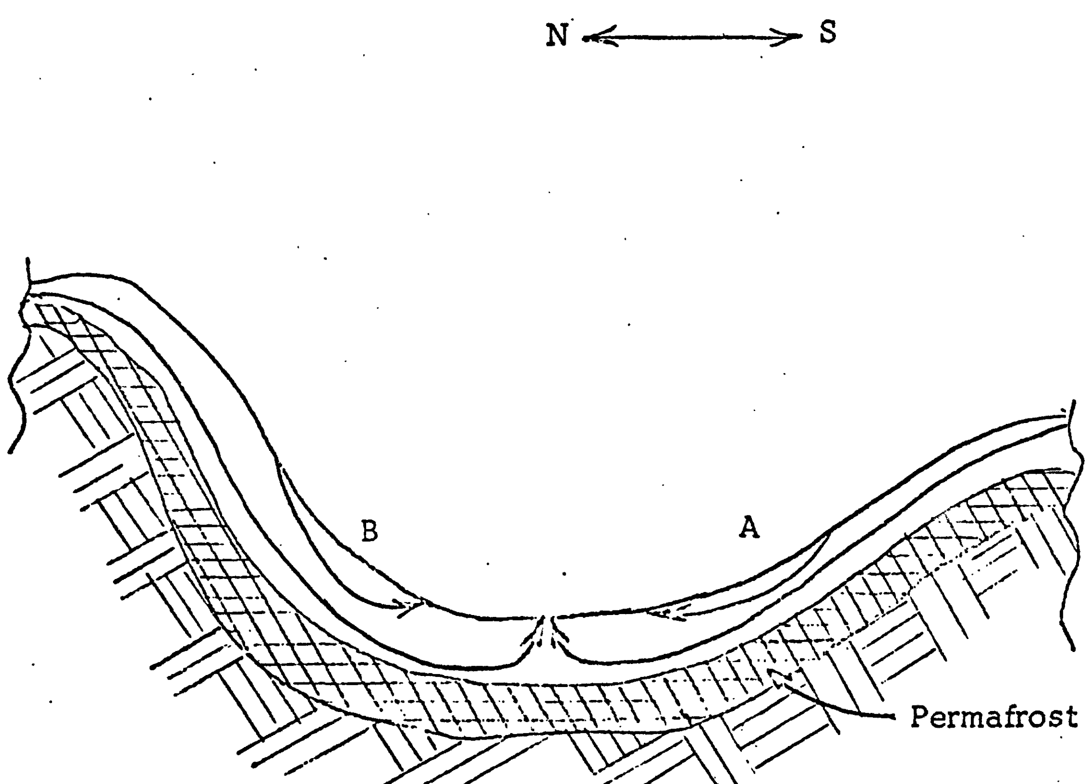
During the summer, the flow below points A and B (illustration 3) is from seeps, which ranges from just enough moisture to keep the surface wet to small springs. Deep surface indentations produce more discharge at gully heads than at nearby shallow headcuts.

With the onset of winter the active zone begins to freeze, starting at the higher parts of the north-facing slopes. Surface freezing tends to create a confining layer over the entire alluvial aquifer. The area upslope from point A freezes, and this causes recharge to cease. Indeed some ground water moves upward as the result of capillarity and the freezing process. However, pressure heads within the unfrozen part of the ground-water system are maintained so that the water continues to move downgradient toward the valley bottom.

Later the area below point A begins to freeze and ground water moving toward the valley bottom is cut off. The same process occurs subsequently along the south-facing slopes. Finally, much of the alluvial ground-water reservoir is frozen, greatly diminishing water movement through the system.

Where the temperature of ground water is above the freezing point as it leaves the aquifer, the water will flow out of the ground and freeze some distance away from its discharge site. Where discharges are insufficient to

Illustration (3) - Diagram of idealized summer ground-water flow lines
(vertical scale exaggerated).



Summer ground-water flow lines

prevent freezing at the spring, the water will freeze and seal the exit.

Deeper ground water is farthest from the freezing land surface and is insulated by the overlying soils, rocks and alluvium. The deeper ground water tends to rise to the surface beneath stream channels where streamlines join. Thus, channel banks would seem to be prime areas for aufeis to form. Deeply incised stream channels would increase the potential for aufeis formation. Icings were found predominantly in the central part of the study basins because of the processes described above.

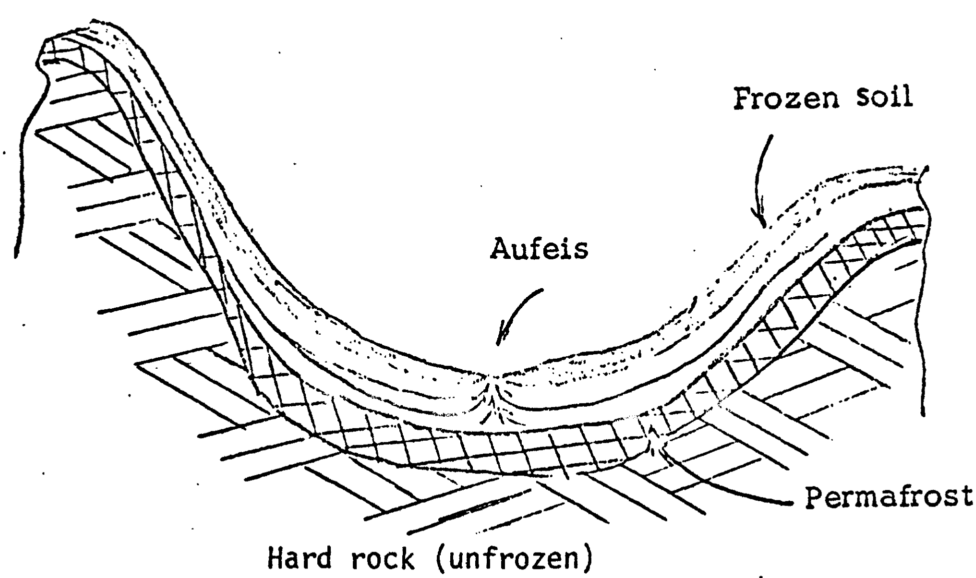
The hypothetical sequence in winter is shown, again idealized, in illustrations 4 and 5. Finally, in most cases the whole body of water freezes and flow ceases. This will vary from area-to-area depending upon recharge rates, size of the ground-water reservoir, severity of the winter, and other factors.

Knickpoints higher on the slopes penetrating beneath the water table would create seeps permitting aufeis to form at such locations. Essentially the same conditions where steep valley side slopes are deeply incised by tributary valleys are shown in illustration 6.

Terrace slopes have many of the same hydraulic characteristics. The major difference is that the concentration of flow lines leaving a terrace are centered at the point of highest hydraulic gradient, as shown in illustration 7 at point A. The concentration of ground-water flow at the base of deeply incised channels results in relatively high temperatures and discharges, thus generating favorable conditions for aufeis formation.

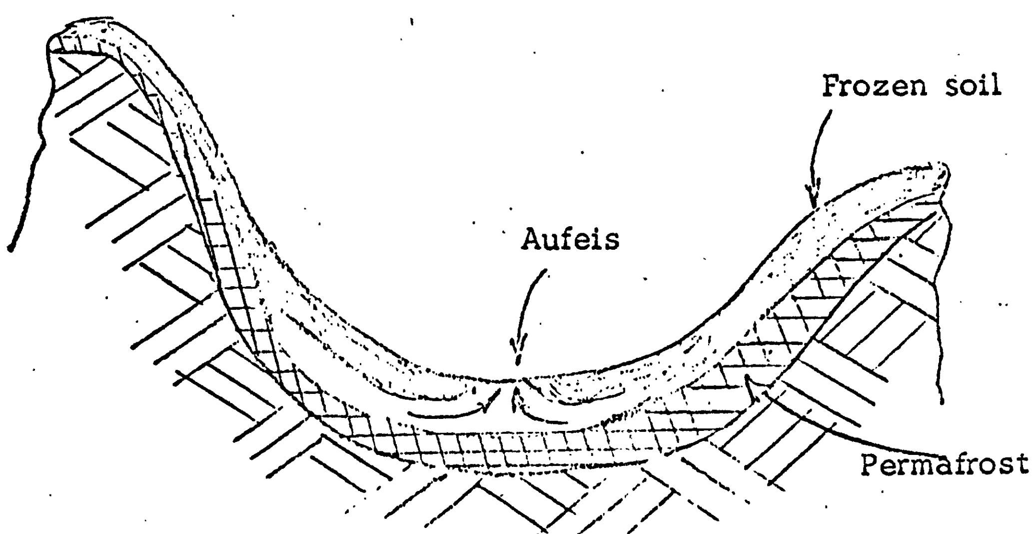
In the southern part of the study area, some south-facing slopes have little or no permafrost. This condition will not greatly alter the occurrence of icings since it is generally indicative of a thicker active zone. The material above indicates where icings may be expected, and the following discussions demonstrate findings in this regard as a result of this study.

Illustration (4) - Diagram of idealized early winter ground-water flow lines.



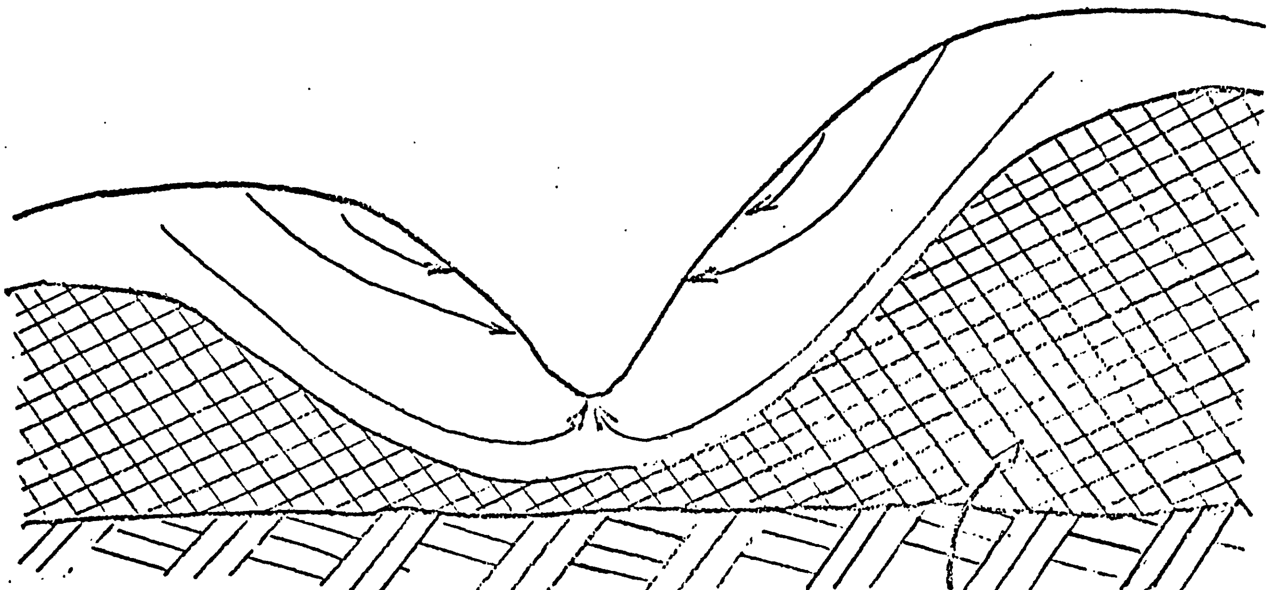
Early winter ground-water flow lines

Illustration (5) - Diagram of idealized late winter ground-water flow lines.

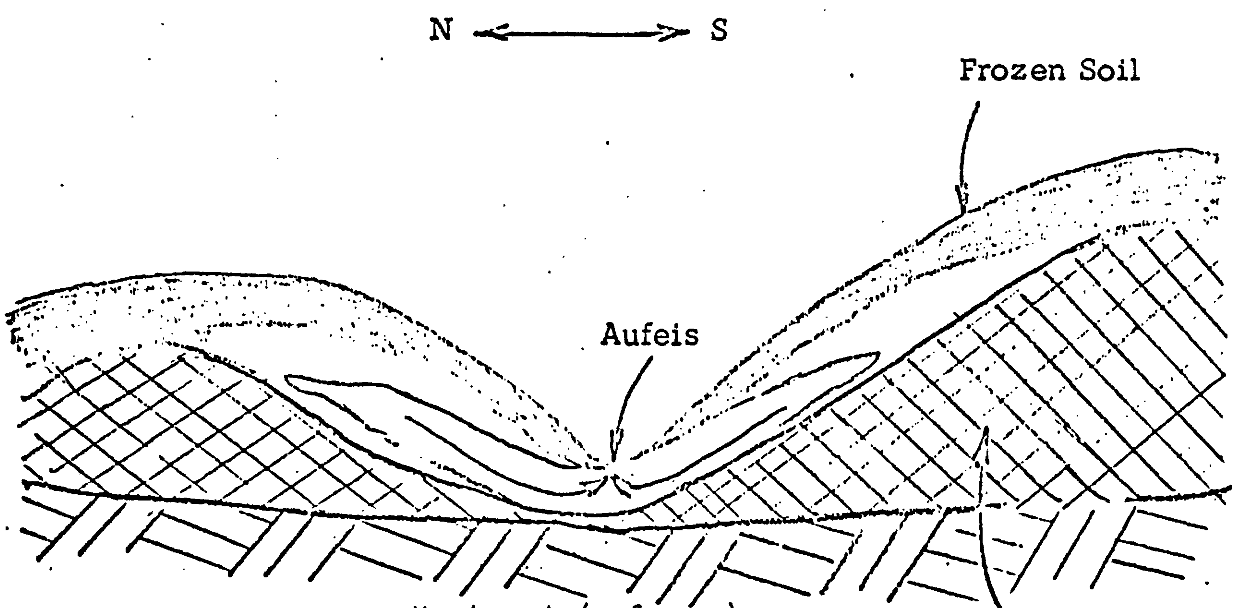


Late Winter Ground-Water Flow Lines

Illustration (6) - Diagram of idealized summer and early winter ground-water flow into incised streams.

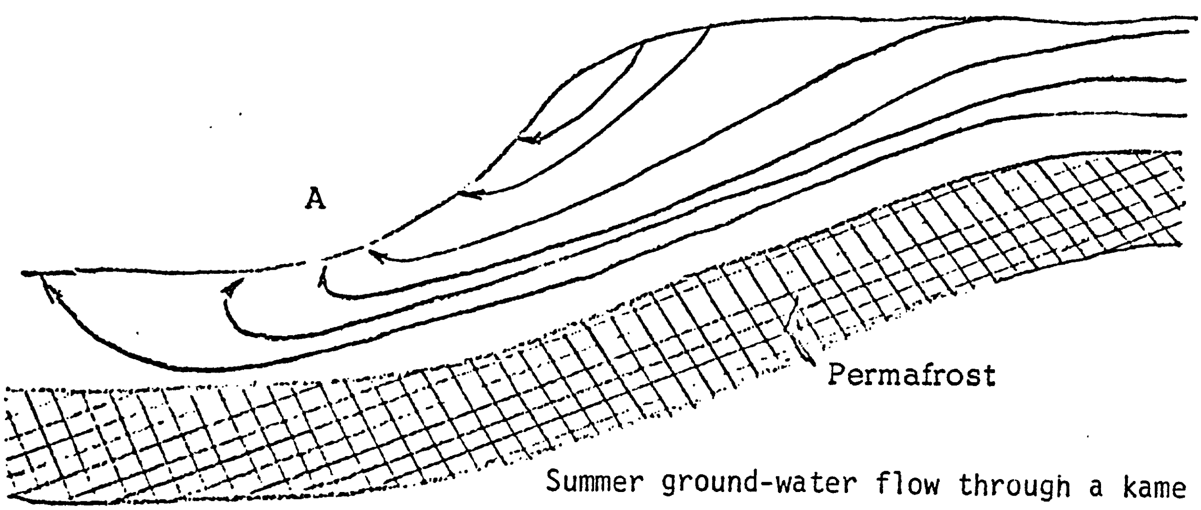


Summer Ground-Water Flow Into Incised Streams

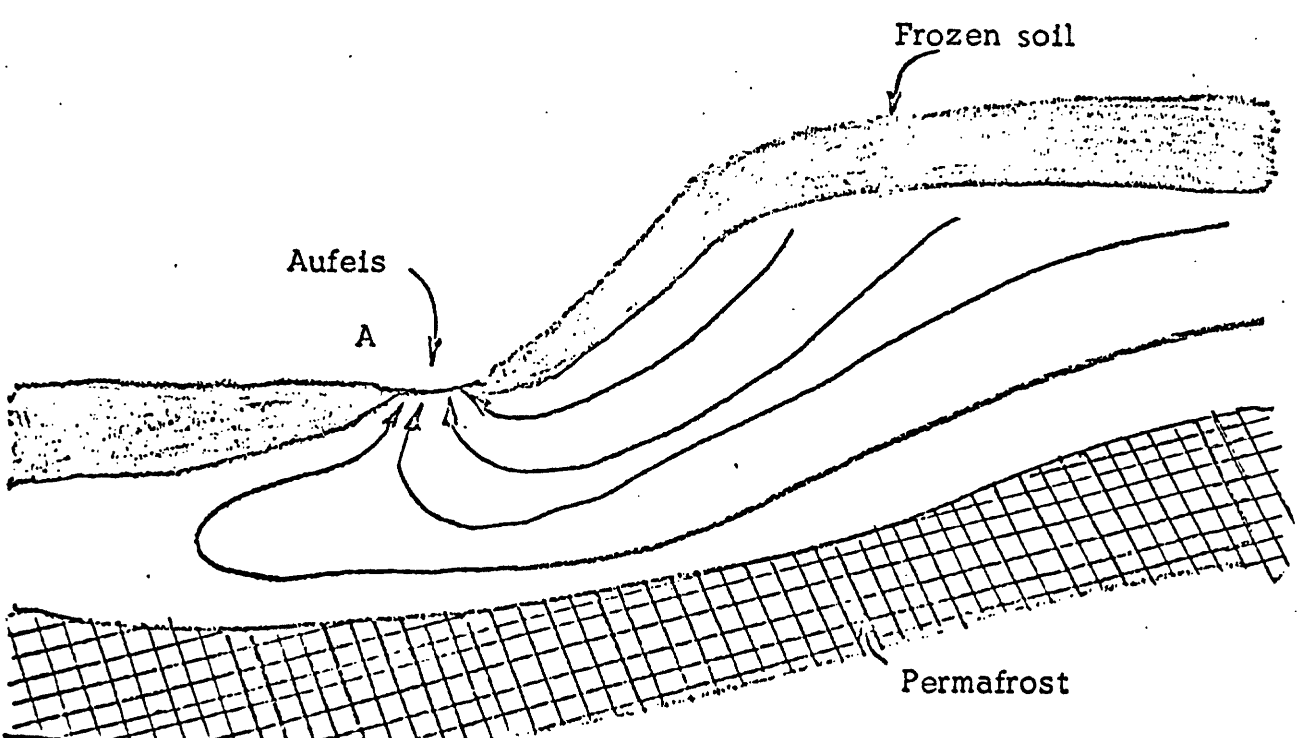


Early Winter Ground-Water Flow Into Incised Streams

Illustration (7) - Diagram of idealized summer and early winter ground-water flow through a kame terrace.



Summer ground-water flow through a kame terrace.



Early winter ground-water flow through a kame terrace.

Icing near 5-Mile Camp, Section 36, T13N, R11W (Mile 342-343)

The icing in section 36 T13N R11W is illustrated in four different types of imagery and maps, but is most clearly depicted in the thermal imagery of figure 2A. The icing in the northeast corner of section 36 is the result of dispersed seepage on the near toe of a slope. The lake in the southern part of sections 35 and 36 may be seen on the left side of the image and also on the quadrangle sheet Livengood D-6 (figure 2C). Behind the seepage area, the terrain rises from 500 feet near the icing to a summit of about 2590 feet, 6 miles to the north.

The photograph of figure 2B is a north view from behind the small lake south of the icing. High country may be seen to the north. The icing is located at the upper end of the three drainage channels leading into the small lake. The availability of this seepage has caused or permitted the growth of a different type of tree as can be seen by the color change in the photograph. The icing is at the upper limit of this color change. The three drainage channels leading from the icing site can be plainly seen on the frame photograph of figure 2D. North is in the upper right side of the picture. This photograph and the topographic map show the nature of the area of recharge.

The area immediately above the icing is rough terrain that probably is accepting a small amount of recharge. If imagery had been obtained near the highland it would have shown other similar icings. The area is one of deep permafrost, probably to a depth of more than a hundred feet. There must be a well developed active zone during the summer months, at least at some locations, to allow recharge to occur. The lake seems to have been affected for some time by the spring which caused the icing. Hence some recharge must be occurring above the spring and ground water and is moving either above the permafrost or between the layers of permafrost. The ground water does not appear to have a steep gradient because it seemingly is intercepted by the toe of the slope but not by the incisions of the drainage to the north. The condition is probably widespread along the base of the mountains in this area.

Pipeline crossing at the Chatanika River (Mile 429)

The pipeline crosses the Chatanika River at about mile 429 on the section line between sections 29 and 30, T3N R1W (figure 3C). The area is a meander belt located in the flat mid-part of a U-shaped valley. There are many cutoff meanders, one of which, lying mainly in section 30, acts as a source of a possible icing.

The location of ground-water seepage that had occurred during the 1973-74 winter can be seen on the thermal image of figure 3A. A thermal variation of plus 10°C from the local ambient temperature saturates the imager and areas with this characteristic would appear white on the film. In early February 1974, when the imagery was taken, ground temperatures were extremely low because of the cold weather during the preceding several weeks. The water upwelling through the cutoff meander was at freezing or slightly above; hence, the imager observed it as a white pattern on the positive print.

By comparison, on the frame photograph No. 109 (figure 3E), the water flowing over the ice can be seen as a dark line. The meander is located in the lower center of the photograph. The completely frozen valley can be seen clearly in this photograph. The strip of thermal imagery covered a width of only about 4,000 feet. The large-scale coverage, of course, is necessary to acquire the data at the desired detail.

Figure 3D is a strip photograph of the same area. The detail is good, but this photograph was taken in April 1974, when ice on the river had begun to melt.

The warmer temperatures at that time precluded the detection of icing to indicate the location of ground-water seepage. The pipeline route is along the right side of the strip photo.

Figure 3B is an oblique photograph taken in June 1974. The cutoff meander can be clearly seen in the center of the photograph. The water in the meander is deep orange in color but all other water in the area is dark -- almost black. Oxidized iron contained in the ground-water system probably produced the orange color.

Details regarding the seasonal occurrence of icing can be seen in fugures 3A, 3B, 3D and 3E. Figure 4 is drawn to illustrate the phenomenon in late winter. This figure represents a cross section from northwest to southeast, from the cutoff meander upward through the hillslope located in section 32. The ground-water source is probably hillslope deposits overlain and underlain by talik or suprapermafrost near the surface. This area either has no ice cover in summer or the ice cover is discontinuous. The alluvial mantle, therefore, accepts recharge during the summer which then moves downslope toward the central part of the valley. During warm months there is probably a considerable amount of seepage along the hillslope and in the valley floor. But during winter, surface freezing causes an impermeable layer to cover the suprapermafrost layer (or the talik, depending on the situation). It seems that in this area the only point of discharge for the hillslope is the cutoff meander. Because of the upwelling of the warmer ground water this discharge point is kept open and flow continues even during the winter.

There may be concern that development of structures, buildings and other facilities in this area could melt away the confining layer and allow discharge at new locations in the winter. This may, of course, result in icing. These developments, by disturbing the radiation processes at ground surface, could retard the process of soil-freezing and possibly allow ground water to seep over a large area which could cause additional icings.

Icing in Silver Gulch (Mile 438 - 439)

The imagery of February 1974, shows considerable icing in Silver Gulch which is located about 2100 feet east of the pipeline (figure 5). The pipeline here descends steeply (700 feet per mile) in the southern part of section 36 T2N R1W. Silver Gulch runs north and south almost along the center line of the section.

Icings may be seen as the white patterns in the lower left corner of the thermal imagery of Silver Gulch (figure 5A). The continuous strip photograph (figure 5D) shows the gulch and icing as does the frame photograph of figure 5E. Figure 5B is an oblique photograph of this site taken in June of 1974. In this photograph the view is to the north from a location south of the gulch. In June 1974, the thick ice that had formed during the winter had not yet melted.

A comparison of the various views of Silver Gulch shows that thermal imagery is the most effective technique for identifying icing. However, at least in early summer, the ice residue can be identified by photographs. The topographic map (figure 5C) shows some details of the hydrologic characteristics of the area. Silver Gulch is an erosional indentation into a dissected ridge oriented along an east-west axis. Deeper indentations are found flanking Silver Gulch where Fox Creek and Silver Creek penetrate the same ridge.

Accordingly, the stream in the bottom of Silver Gulch is probably not the major ground-water discharge conduit for the ridge to the north. Instead it seems that streamflow in the gulch is the result of the movement of ground water down the flanking canyon walls of the gulch.

Pipeline Route near Donnelly Dome (Mile 550-555)

Several warm areas representing the formation of icings where the pipeline crosses the Richardson Highway just southwest of Donnelly Dome may be seen on the thermal imagery. The areas of interest lie in sections 32 T13S R10E and in sections 5, 8 and 17 of T14S R10E, depicted on the Mt. Hayes Quadrangles C4 and D4 (figure 6C).

Figures 6A.1, A.2 and A.3 are prints of thermal imagery. The first and longest strip of imagery (A.1) depicts an area starting at about the center of section 32 and extending southward to about the center of section 5; the second (A.2) is in about the center of section 8; and the third (A.3) is located near the center of section 17.

At this location the pipeline route lies along the base of what is probably a kame terrace. The topographic map (figure 6C) shows many lakes on the upper surface of the terracelike deposits. Figure 6B is an oblique photograph and figure 6D is a frame photograph of the area of interest.

Figure 6A indicates the difficulties in interpreting thermal imagery made when temperatures are extremely low. Although the sun was shining about seven hours a day during the time this imagery was taken, it was low in the sky at all times, being a little over ten degrees above the horizon at noon. Despite the very low temperatures, solar radiation can heat surfaces that face directly toward the sun at mid-day. For example, two frozen lakes may be seen in the far left part of the imagery. To the right of these lakes is a large white area (a) probably produced by the heating of the southern side of a small tree-covered hill. Further to the right, in the upper part of the figure are two areas (indicated by arrows b and c) where ground water is believed to be seeping at a rate sufficient to keep its discharge route thawed out. The ground water spreads out over the frozen ground, refreezes and builds a continuously thickening layer of ice. Two similar areas where icings were being formed are shown (arrows d and e) in figures 6A.2 and 6A.3.

There are marked differences between the imagery of the hillside and the imagery of the icings. The hillside imagery has an irregular appearance. The trees can be seen as well as a thermal shadow on the north side of the hill. The icing images are not as irregular as the sun-facing hillsides, but appear as a gradual transition from the deep white of the center of ground-water flow to the diffuse extremities where water freezes and ice cools to ambient temperature.

The physical occurrence of the icing is shown in the diagram of figure 7. Ground water in this area of Alaska is probably contained in the active layer. The thickness of the permafrost is unknown. It is possible that beneath the active layer, ground water remains unfrozen in cracks and fractures but most probably there are many feet of permafrost below the talik. The environmental impacts of man's activities doubtless will be modified somewhat by the thickness of the lower permafrost.

Ground water accumulates in the active layer and in the suprapermafrost area as lakes thaw. Ground water moves down-valley, and gradually seeps into stream channels along the boundary of the kame terraces during the warm period of the year. In winter, seepage occurs only at those sites where sufficient heat flow is carried by the ground water to keep a discharge route thawed. Seasonal freezing often results in water-table conditions during summer and artesian conditions during winter. If additional heat is absorbed as the result of ground-cover changes or artificial heating, new discharge sites may develop, possibly resulting in new icings. In the area where ground water is contained in intrapermafrost zones, added heat may accelerate the icing and also reduce soil stabilization which could cause hillside slumping.

Icing near Tolovana River Crossing (Mile 390-391)

A small icing site appears in the imagery of an area near the Tolovana River crossing (figure 8A). The recharge furnishing the water seems to come from the slopes of the rolling hills east and west of the site. General conditions in the vicinity of the icing are shown in the frame photograph of figure 8C. The site can be seen clearly on the strip photograph of figure 8D although the image is affected by considerable uncompensated roll.

The regional topography is shown on the Livengood B-4 topographic map (figure 8E). An oblique photograph (figure 8B), taken in June 1974, shows the icing as a light spot in the river channel in the center of the photograph about three-fourths of the way up. The oblique photograph was taken southwest of the site looking northeastward. The conditions causing the icing are believed to be similar to those shown in illustration 6.

Icing near Globe Creek Crossing (Mile 409)

An icing, formed where a small creek cut into the hillside about a mile north of Globe Creek, seems to be quite heavy and is readily apparent in the thermal imagery of figure 9A. The icing is one of many found where the pipeline route is located at the toe of a hill near Wickersham Dome. The site can be seen on the topographic map (Livengood B-3) of figure 9E and in the frame photograph of figure 9C. An oblique photograph (figure 9B), taken in June 1974, shows substantial residual ice. The strip photograph of figure 9D appears to have too much uncompensated roll to be useful in interpretation.

Icings along the toe of a hill to the northwest of Wickersham Dome (Mile 404-409)

Several icing sites appear along the southwestern slope of a hill near Wickersham Dome, one of which has been described above. The area is where the pipeline route is located just above the toe of Wickersham Dome. The lowest part of the valley is further to the west along the Tataline River.

The imagery was originally taken in one strip, starting with figure 10A.1 which begins almost at the Tatalina River and continuing from the top of the imagery in a southeasterly direction to figures 10A.2 and 10A.3. However, there is a gap between figures 10A.2 and 10A.3.

The locations of four icing sites are shown on the frame photographs of figure 10B and the topographic map (Livengood B-3) of figure 10C. This is an area where additional investigation would be of interest because in June 1974, extensive icings were forming where creeks flowed toward the south and southwest. The sites in this imagery are examples of situations of the type shown in illustration 6.

Ground water was not only moving through the active zone but also through the intrapermafrost and probably below the permafrost as well. Data were not obtained in the lower part of the valley. Icings likely were forming along Tataline Creek because it is believed that recharge from high on the hillside is conveyed to the deeply incised streams on the flank of Wickersham Dome. Fround-water discharge is large enough so that it probably continues all winter. Water movement can be seen more clearly in the imagery taken along Aggie Creek and in the areas ot the south.

Icings in the Vicinity of Aggie Creek (Mile 412-416)

The icings in the vicinity of Aggie Creek lie high up the slopes of Wickersham Dome. Dreeks in this area are cut into the rolling hills surrounding Wickersham Dome. There is more ground-water flow of the type causing aufeis (illustration 6) here than in any other area covered by the flights during the spring of 1974.

The thermal imagery (figure 11A) shows the icing locations clearly. In addition, the imagery shows the flow in the creeks to be a succession of ground-water discharge sites rather than continuous flow. However, the oblique photographs (figure 11B), taken in June 1974, are misleading in that they show the aufeis to have the appearance of a frozen stream.

The regional topography is shown in the map of figure 11C, and the details of the area can be seen in the frame photograph (figure 11D). It would be of interest to survey the areas to the northeast and to the southwest by thermal imagery in the coldest part of the year. This might reveal considerably more about the hydrology of the ground-water system and of the controls on aufeis formation.

References

Howell, J. V., Coordinating Chm., 1960, Glossary of geology and related sciences: American Geological Institute, 2nd edition, p. 19.

Williams, J. R., 1970, Ground water in the permafrost regions of Alaska, U.S. Geol. Survey Prof. Paper 696, 83 p.

APPENDIX

Figure 1A.	*Frame photograph illustrating area of coverage as compared to thermal imagery and strip photography.*
Figure 1B.	*Thermal (infrared) imagery illustrating coverage as compared to figure 1A*
Figure 1C.	*Continuous strip photography illustrating coverage as compared to figure 1A*
Figure 2A.	*Thermal imagery of area near 5-Mile Camp*
Figure 2B.	*Oblique, low altitude photograph showing area of icing on toe of slope*
Figure 2C.	*Livengood D-6 quadrangle showing area of icing in section 36 T13N R11W*
Figure 2D.	*Planimetric photograph showing three channels leading from icing site*
Figure 3A.	*Thermal image showing icing in cut-off meander of Chatanika River*
Figure 3B.	*Oblique, low altitude photo showing cut-off meander of figure 3A*
Figure 3C.	*Livengood A-2 quadrangle showing icing site*
Figure 3D.	*Continuous strip photograph showing area after thawing in April 1974*
Figure 3E.	*Frame photograph of January 17, 1974 depicting icing*
Figure 4 .	*Cross section illustrating source of icing*
Figure 5A.	*Thermal image of icing in Silver Gulch*
Figure 5B.	*Oblique, low altitude photograph, June 1974, showing icing site*
Figure 5C.	*Fairbanks D-2 quadrangle of area in which icing site occurs*
Figure 5D.	*Continuous strip photograph of Gulch and icing site*
Figure 5E.	*Frame photograph of Gulch and icing site*

Figure 6A₁. Thermal imagery illustrating

(a) temperature rise caused by low-angle sunlight on hillside

(b) icings caused by groundwater seepage

(c) icings caused by groundwater seepage

Figure 6A₂. Thermal imagery showing icing caused by groundwater seepage

Figure 6A₃. Thermal imagery showing icing caused by groundwater seepage

Figure 6B . Oblique photograph of area near Isabel Pass where thermal imagery of Figures 6A was made

Figure 6C . Portions of quadrangle sheets Mt. Hayes C-4 and D-4, showing area imaged in Figures 6A, B, and D

Figure 6D . Frame photograph of area imaged in Figures 6A and B

Figure 7 . Diagram illustrating physical occurrence of icing

Figure 8A . Thermal imagery showing icing near Tolovana River Crossing

Figure 8B . Oblique photograph of icing

Figure 8C . Frame photograph of area surrounding icing site

Figure 8D . Strip photograph showing icing site despite considerable uncompensated roll

Figure 8E . Topographic map Livengood B-4

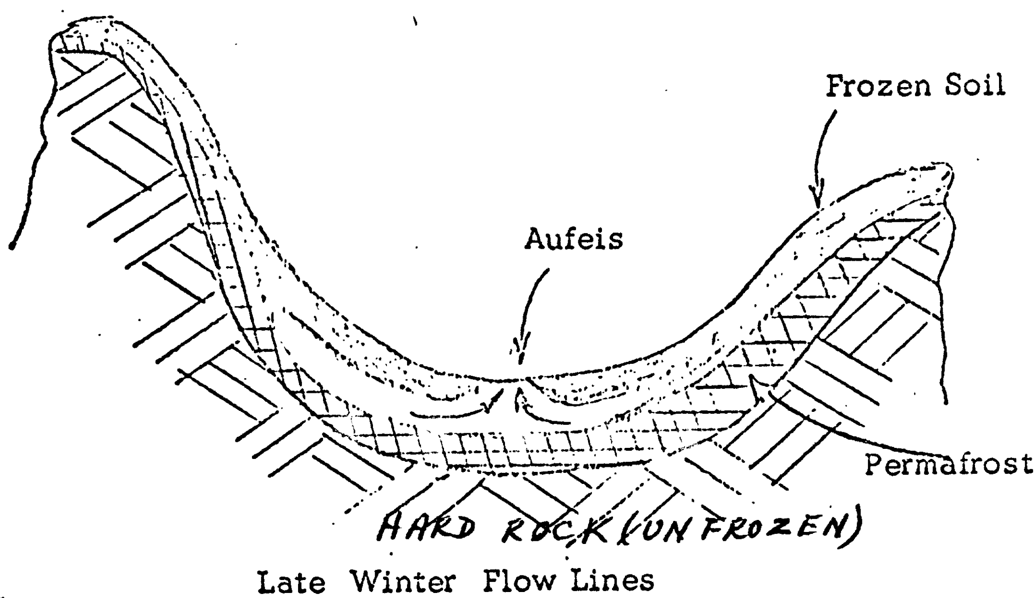
Figure 9A . Thermal imagery showing icing near Globe Creek Crossing

Figure 9B . Oblique photograph made in June 1974 showing residual ice

Figure 9C . Frame photograph of area surrounding site

Figure 9D . Example of strip photography with too much uncompensated roll to be useful for interpretation

Figure 9E . Livengood B-3 topographic map



Label as indicated. See p. 9 RS.

Figure 4 -- Cross section illustrating source of icing.

Figure 10A$_1$. *Thermal imagery showing icings along southwestern slope of Wickersham Dome*

Figure 10A$_2$. *Thermal imagery showing icings along southwestern slope of Wickersham Dome*

Figure 10A$_3$. *Thermal imagery showing icings along southwestern slope of Wickersham Dome*

Figure 10B . *Frame photograph showing area of icings*

Figure 10C . *Livengood B-3 topographic map showing location of icings*

Figure 11A . *Thermal imagery showing icing locations in vicinity of Aggie Creek*

Figure 11B . *Oblique photographs, June 1974, showing icing locations in vicinity of Aggie Creek*

Figure 11C . *Livengood A-3 topographic map showing area of icing*

Figure 11D . *Frame photograph showing details of area of icing*

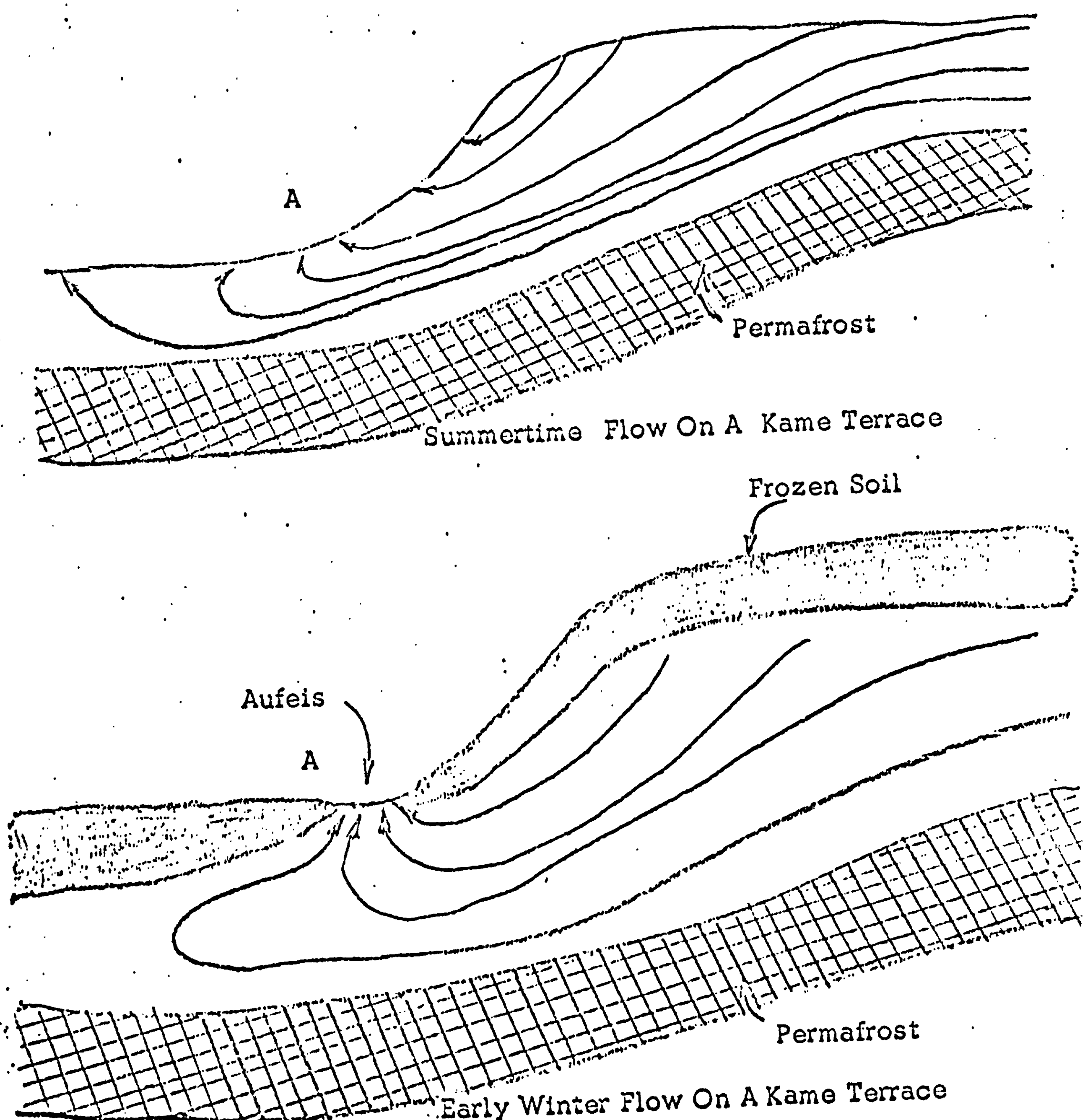
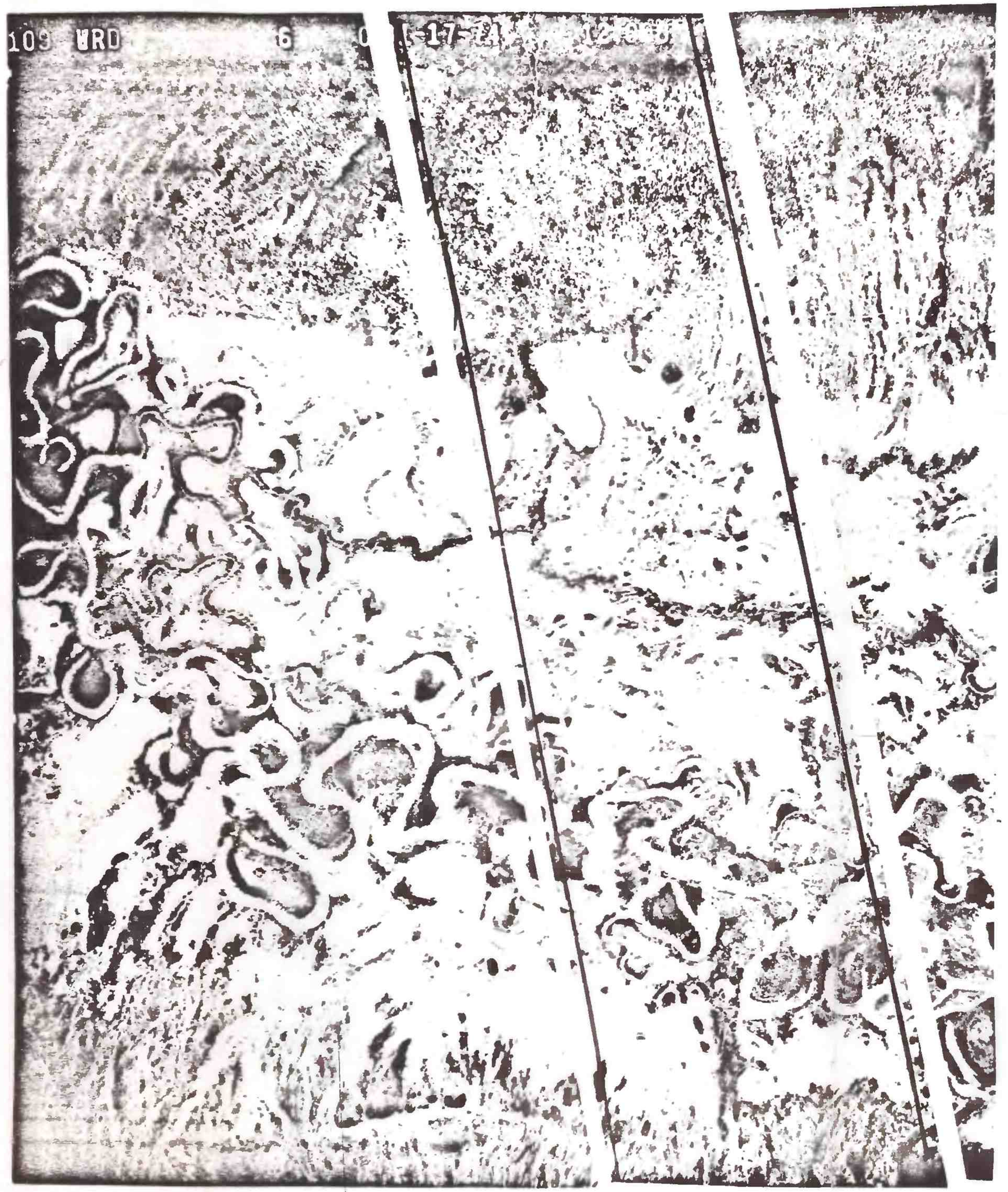
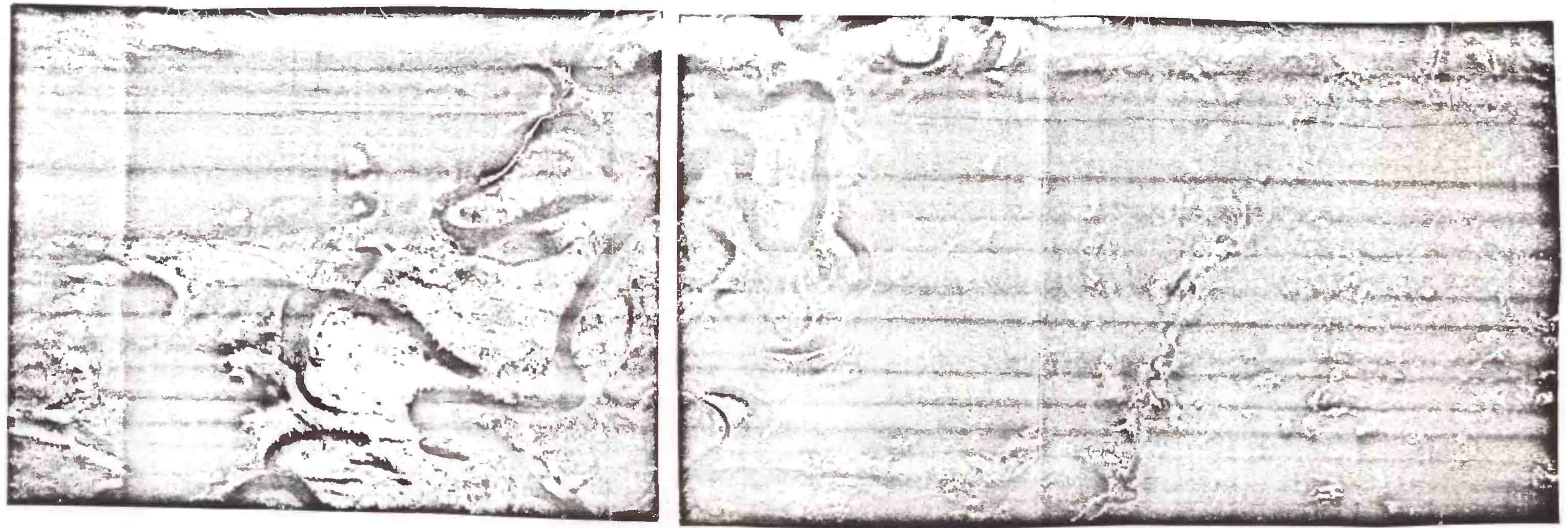


Figure 7 -- Idealized ~~Diagram~~ diagram showing physical occurrence of icing.

RL.



1 A



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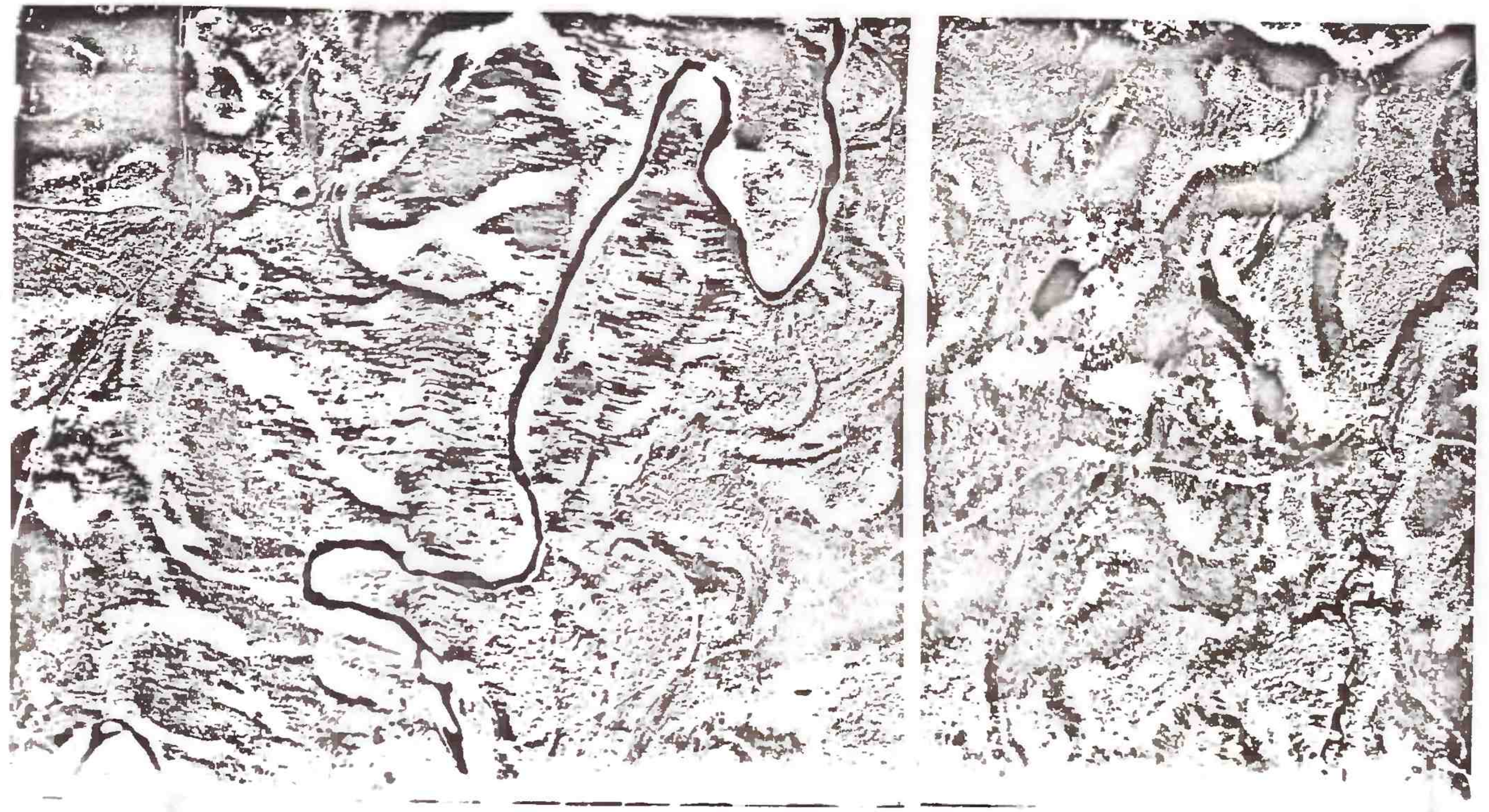


1 C

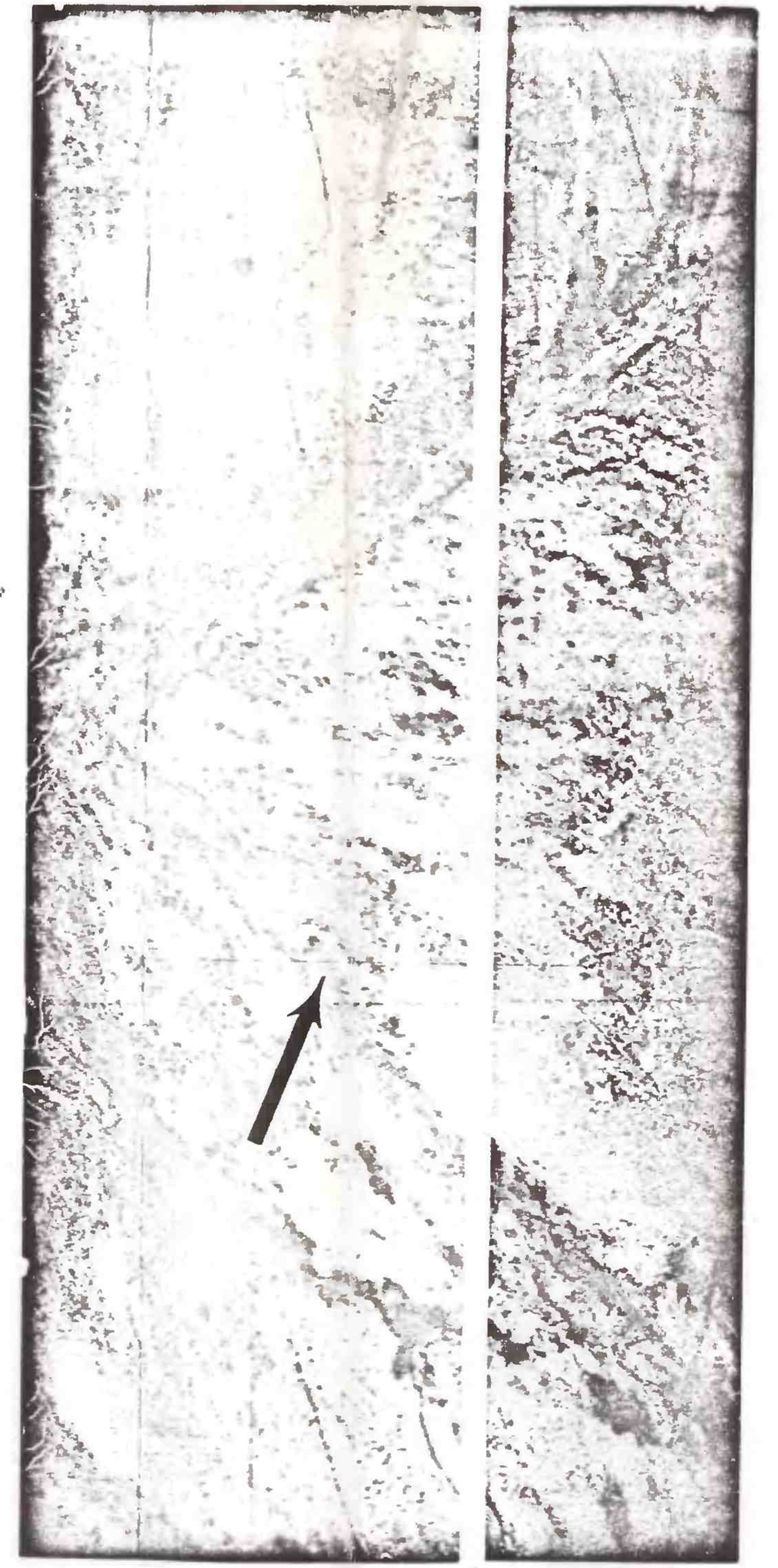
Fig. 1A 9-by 9-inch frame photograph taken with 6-inch lens. Cut-out section in center of photograph is equivalent to the area covered in the strip of thermal imagery (Fig. 1B).

Fig. 1B Thermal (infrared) imagery of the area covered in cut-out portion of figure 1A.

Fig. 1C Continuous strip photography of area outlined on figure 1A.

72-643

10 A$_1$



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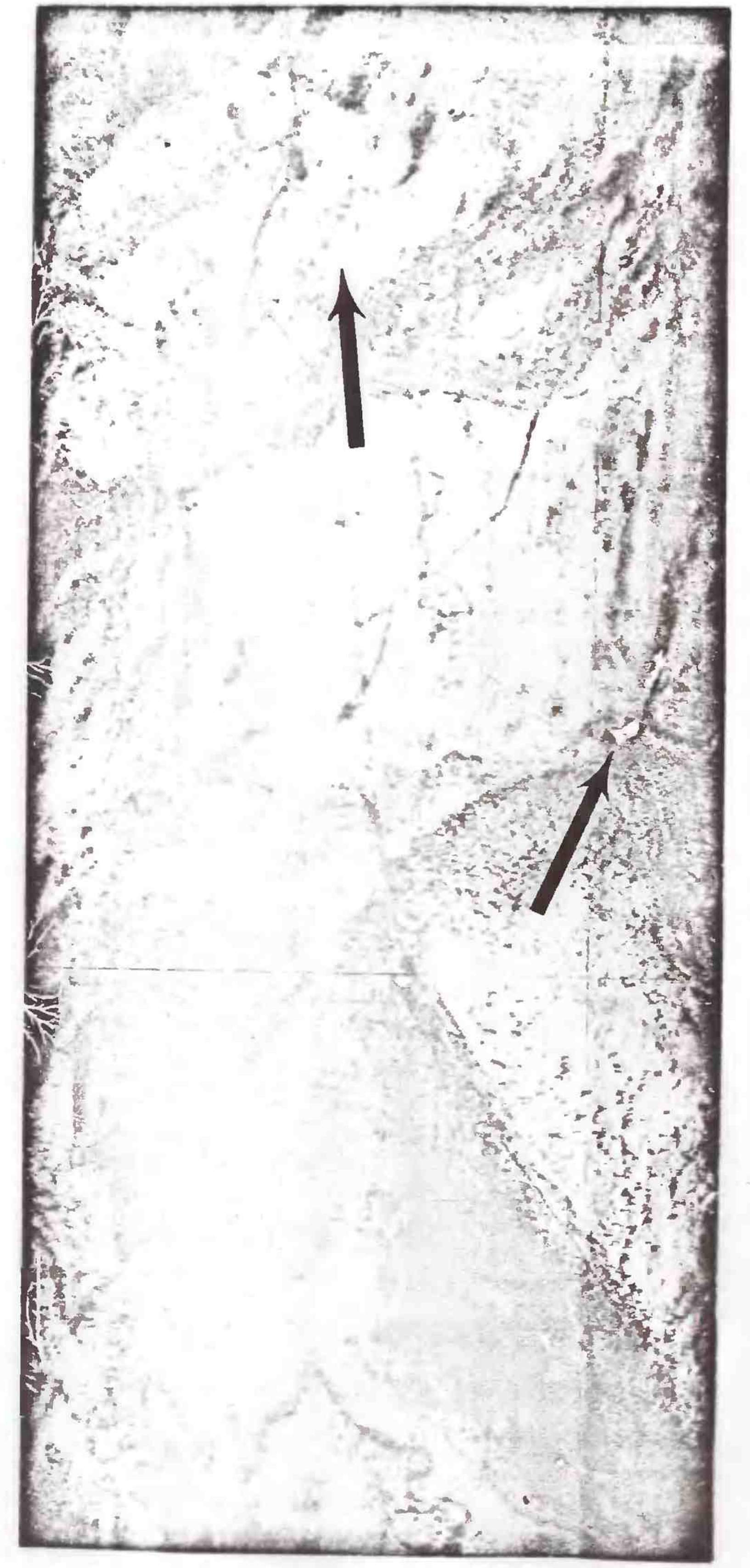
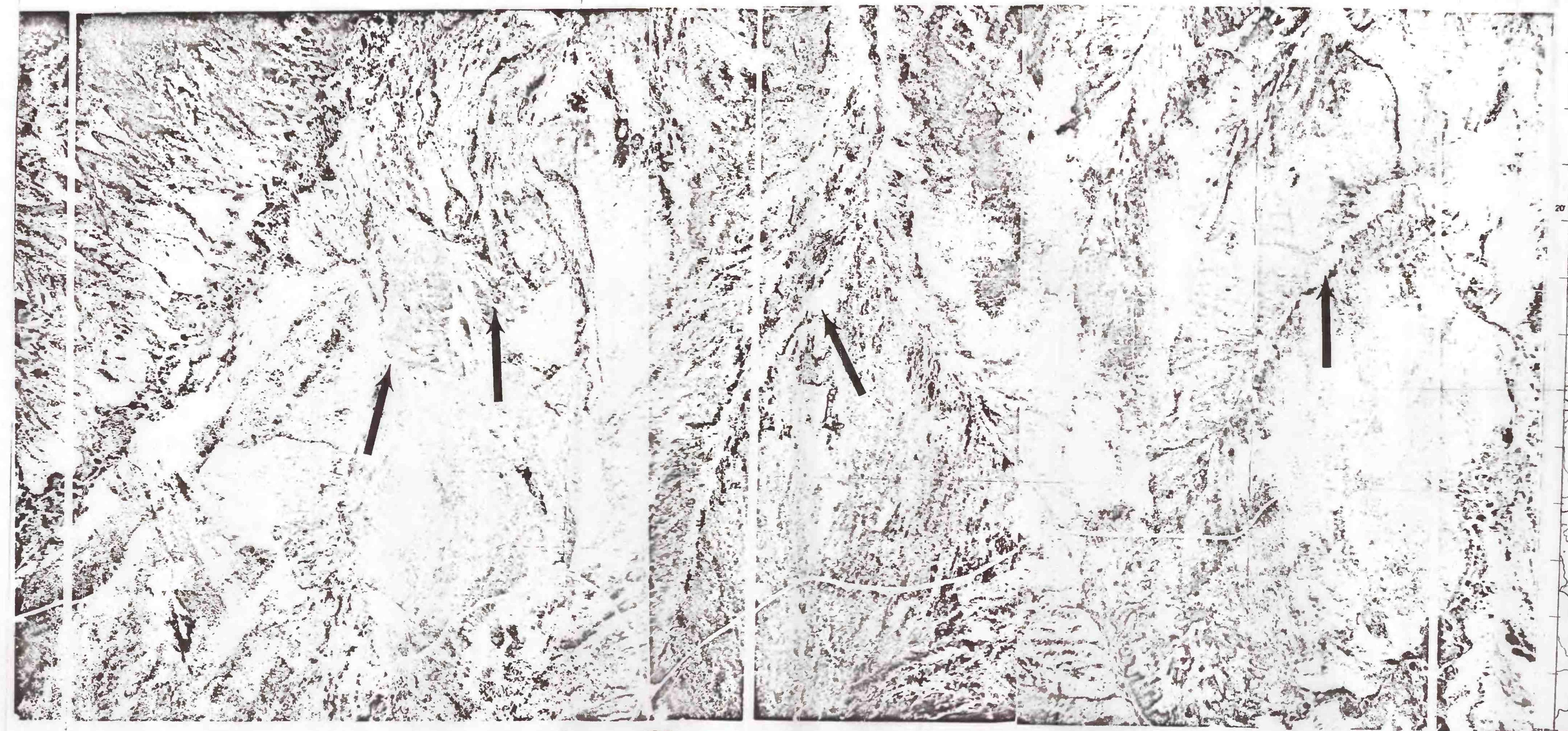


10 A$_3$



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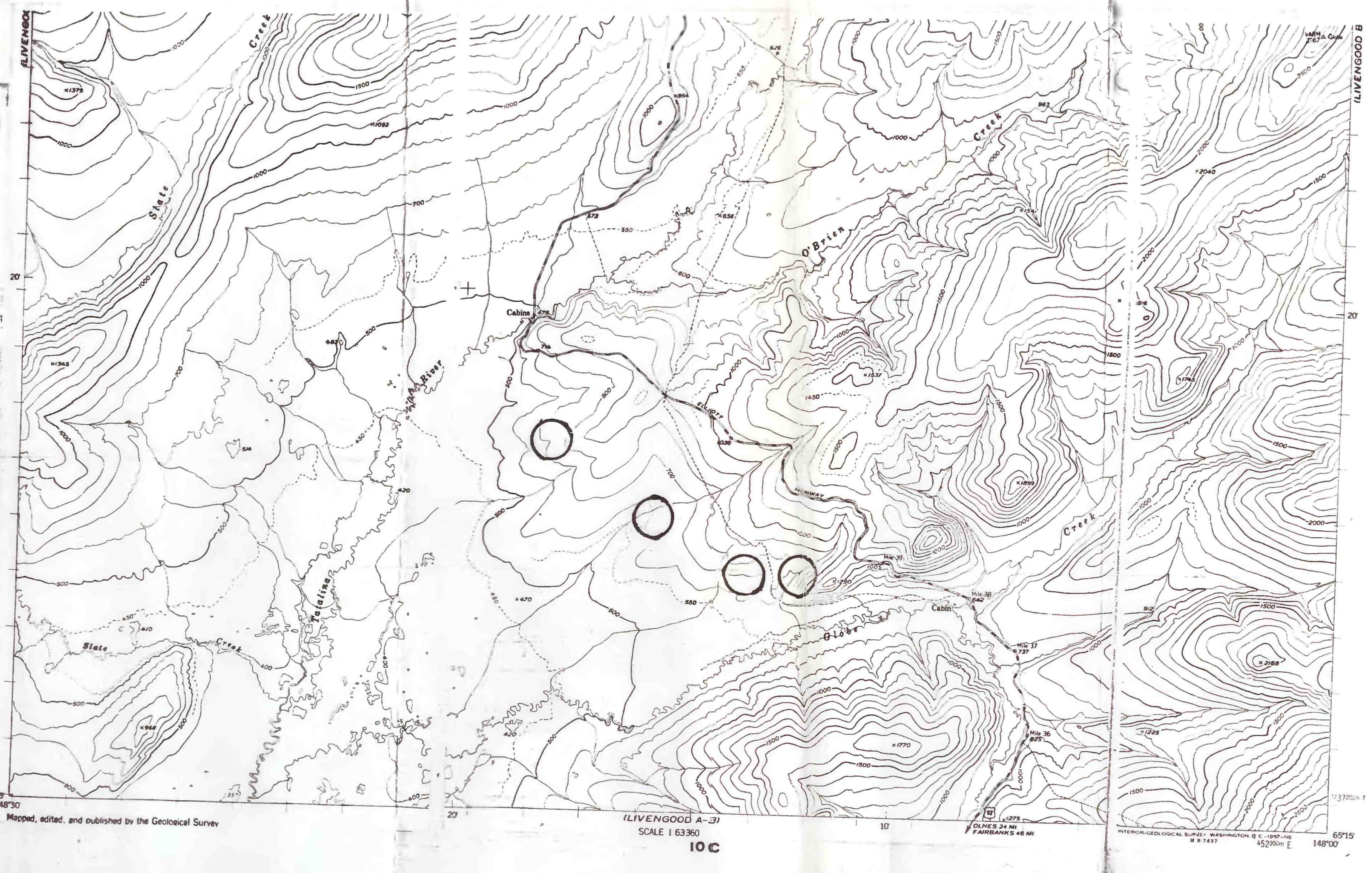


10 C

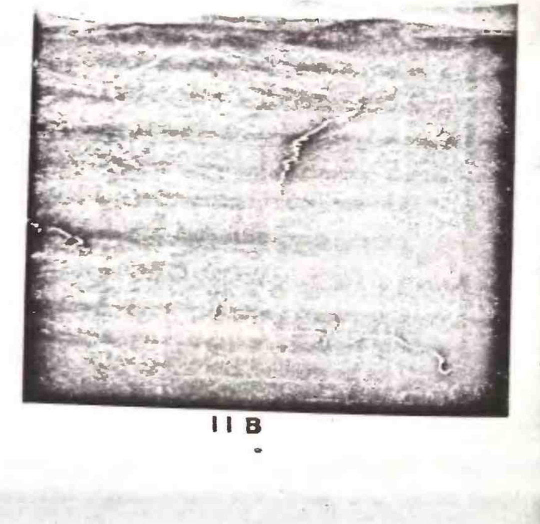
Figure 10A$_1$) Thermal imagery showing
10A$_2$) icings along southwestern
10A$_3$) slope of Wickersham Dome

Figure 10B Frame photograph showing area of icings

Figure 10C Livengood B-3 topographic map showing location of icings

77-643

11A



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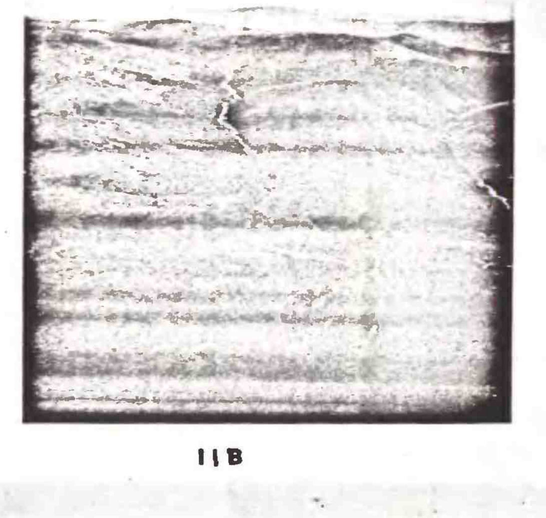

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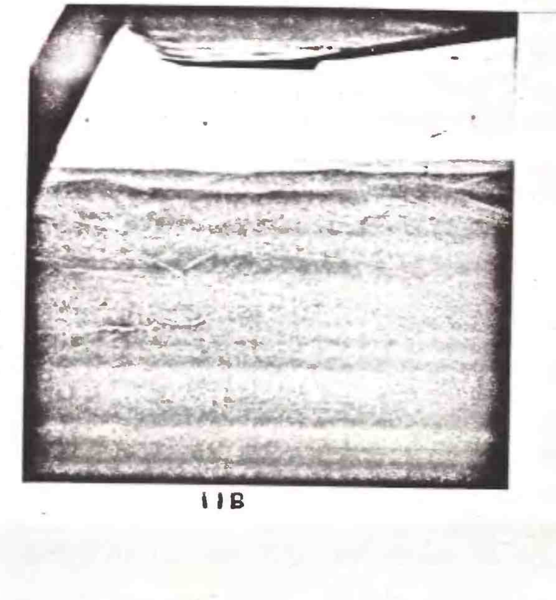

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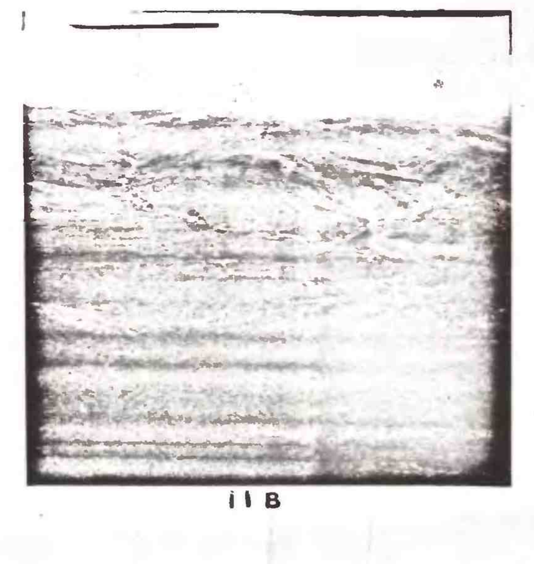

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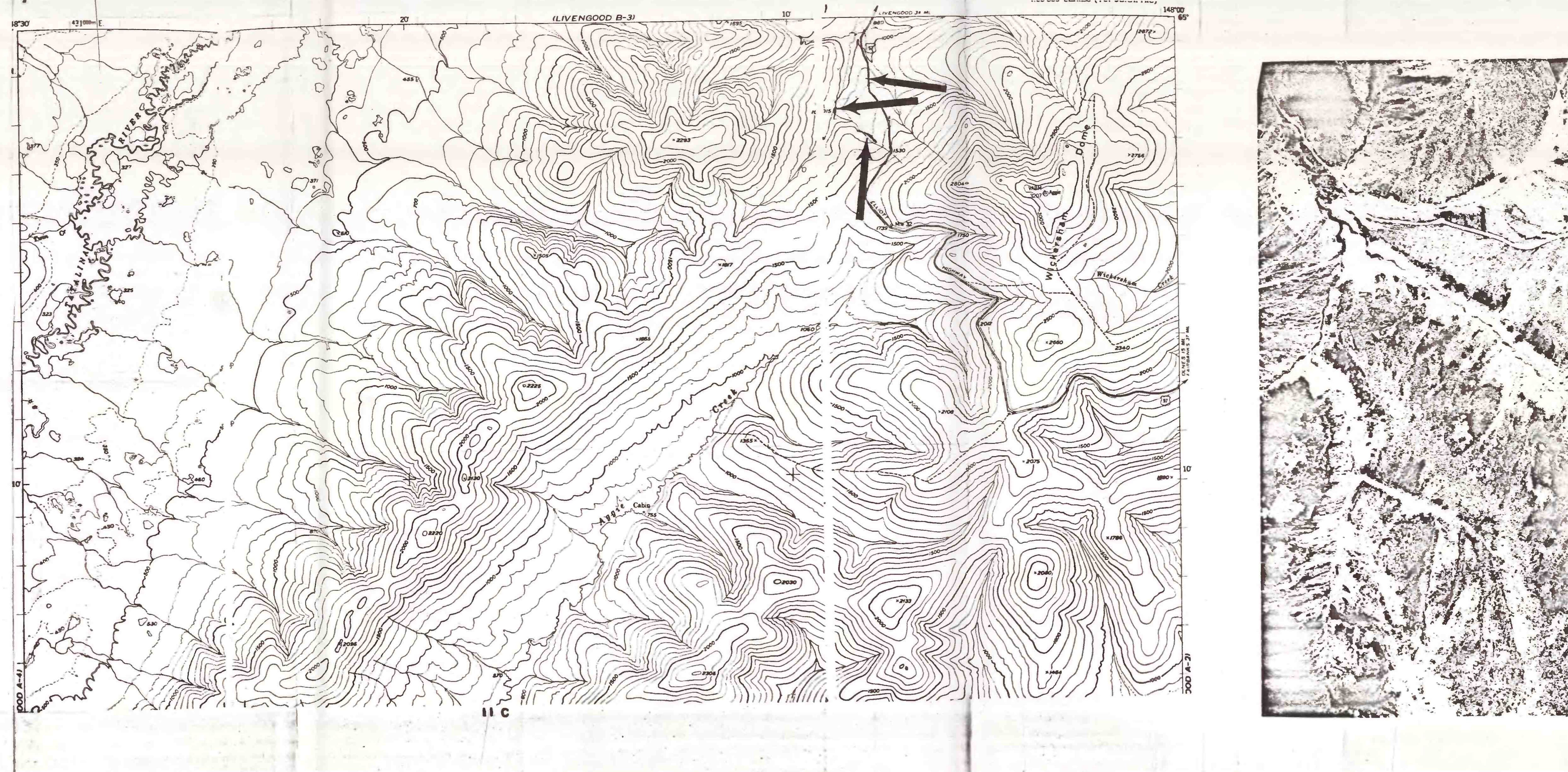


11C

11D

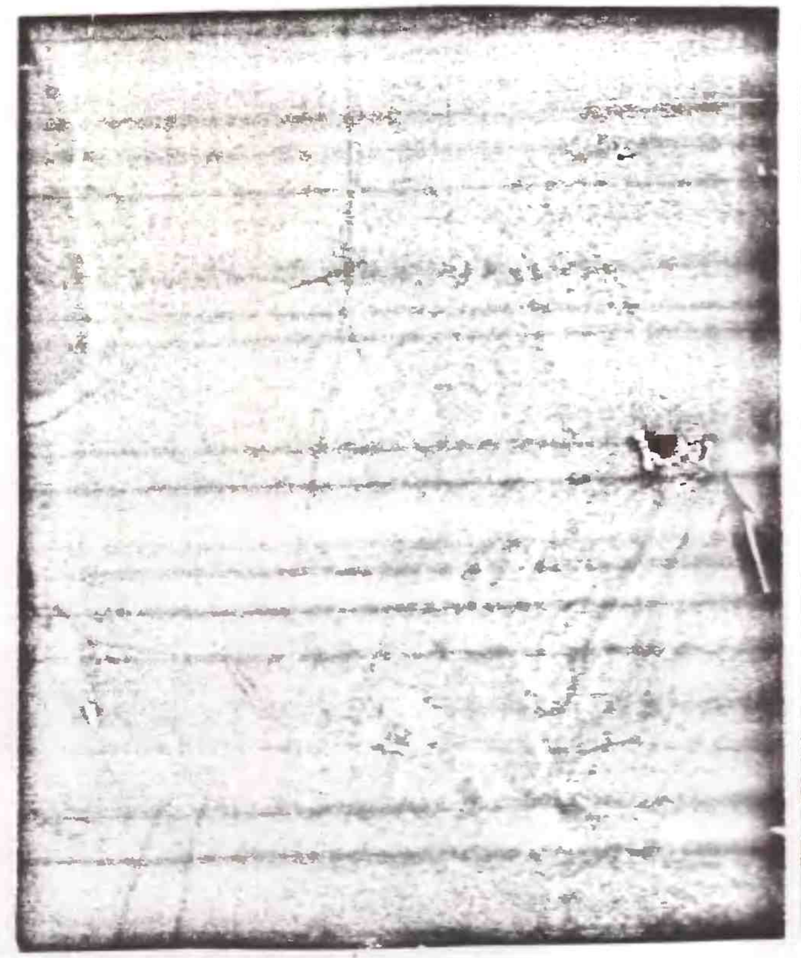
Figure 11A. Thermal imagery showing icing locations in vicinity of Aggie Creek.

Figure 11B. Oblique photos, June 1974, showing icing locations in vicinity of Aggie Creek.

Figure 11C. Livengood A-3 topographic map showing area of icing.

Figure 11D. Frame photograph showing details of area of icing.

77-645



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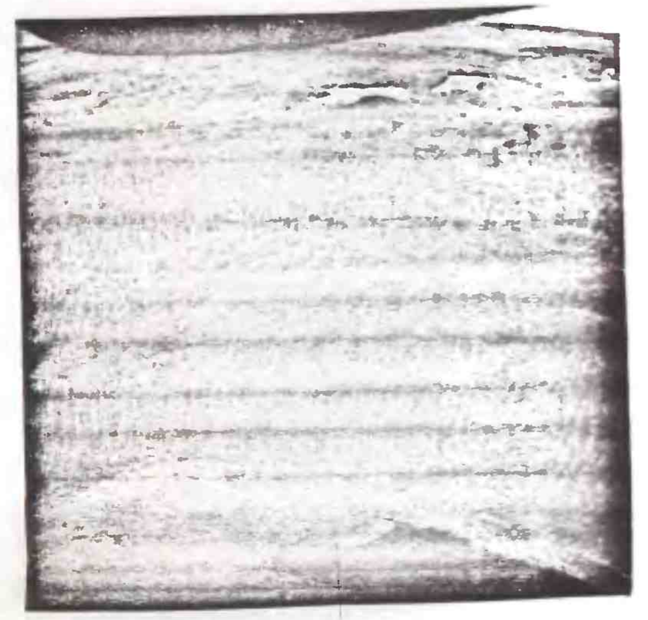
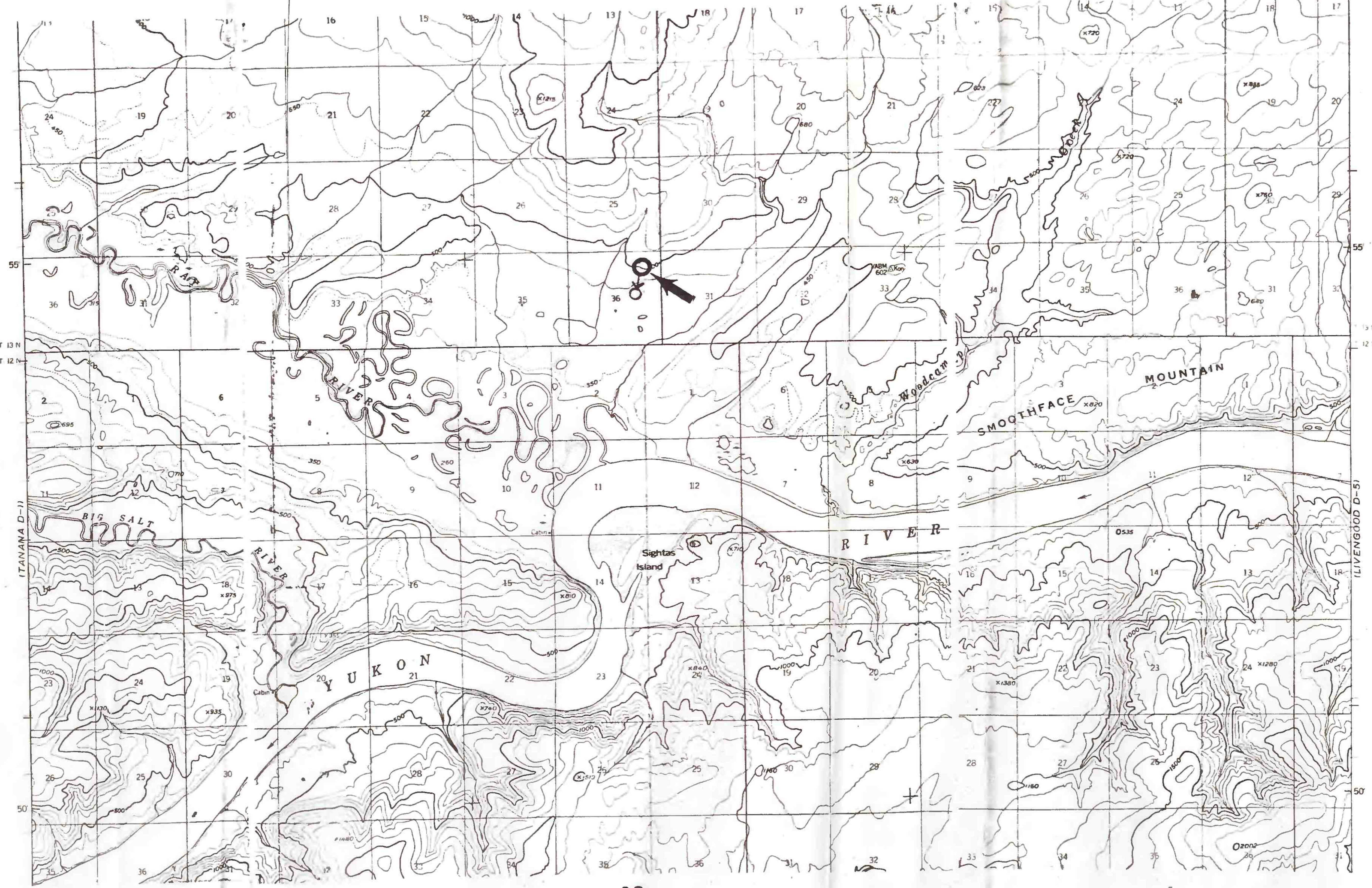


2B



2C

2D

Figure 2A. Thermal imagery of area near 5-Mile Camp. Note icing in right center of image.

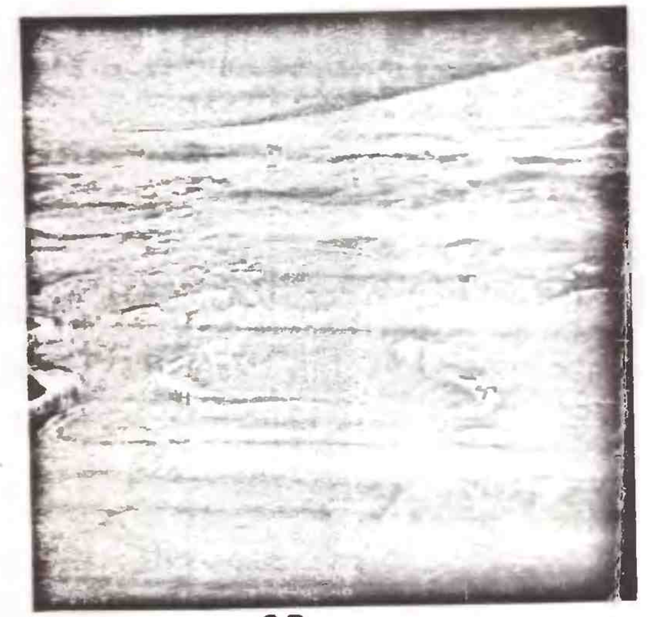
Figure 2B. Oblique, low-altitude photo showing area of icing on toe of slope.

Figure 2C. Livengood D-6 quadrangle sheet showing area of icing in section 36 T13N R11W.

Figure 2D. Planimetric photo showing these channels leading from icing site.

77-643

3A



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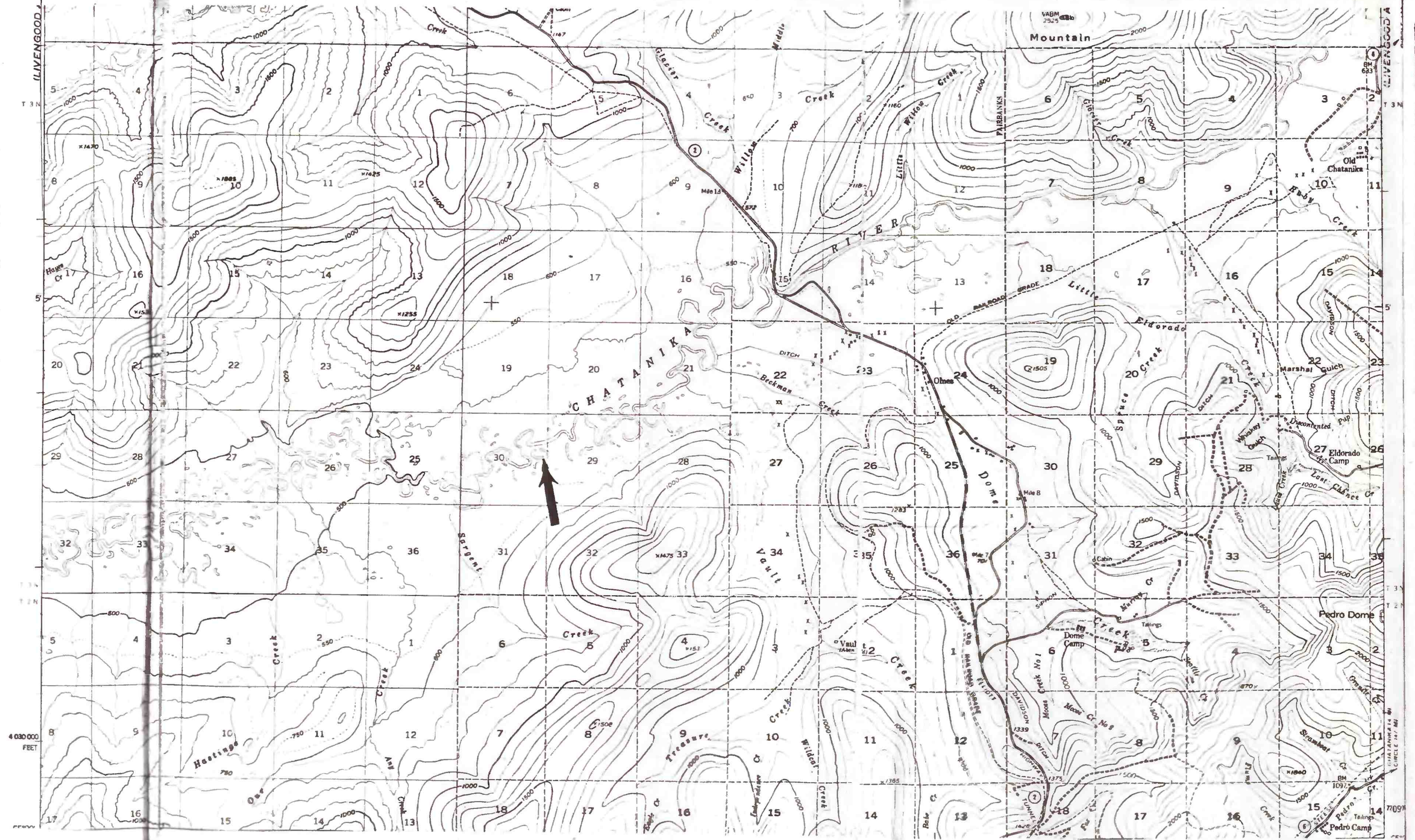

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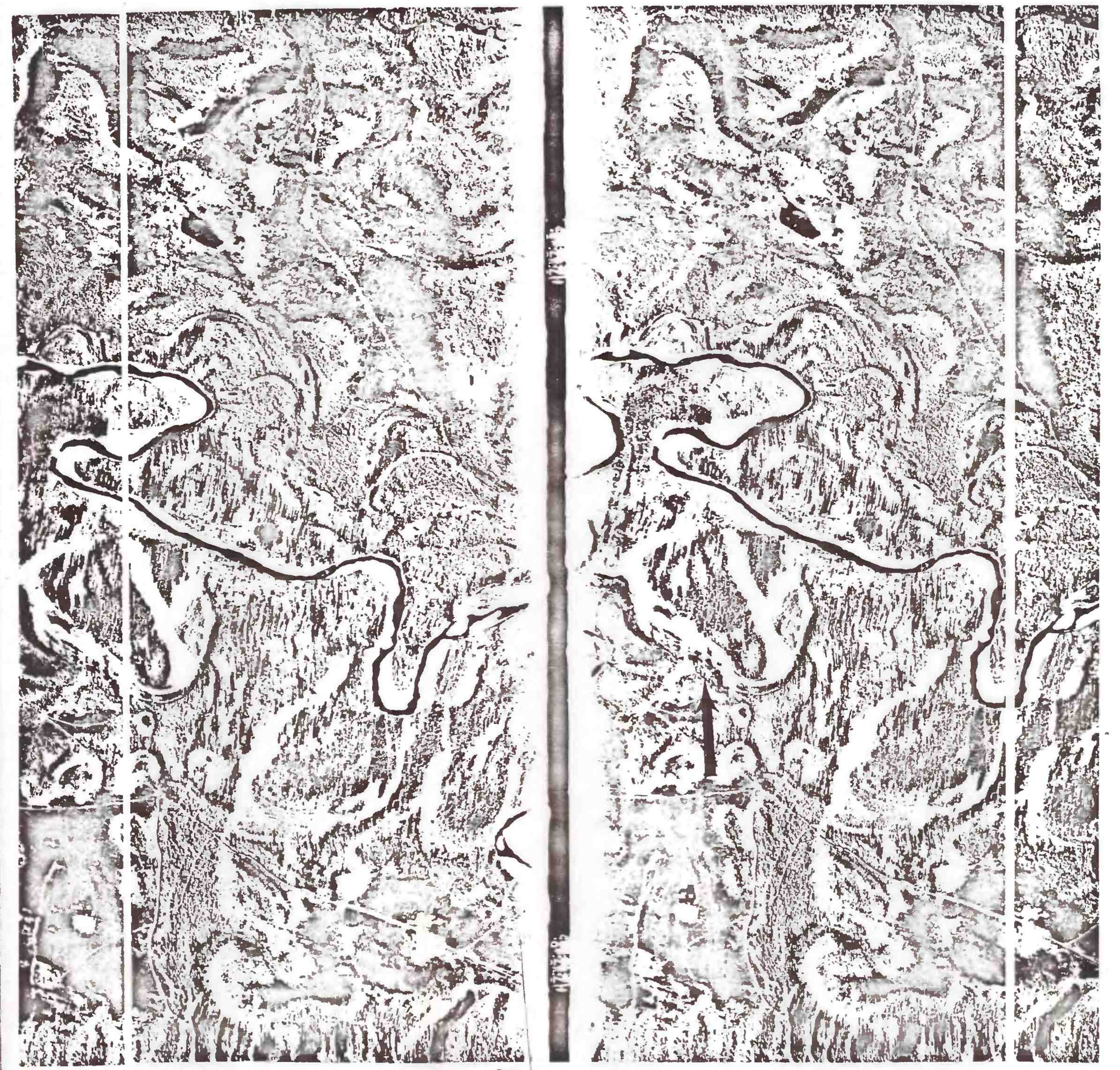
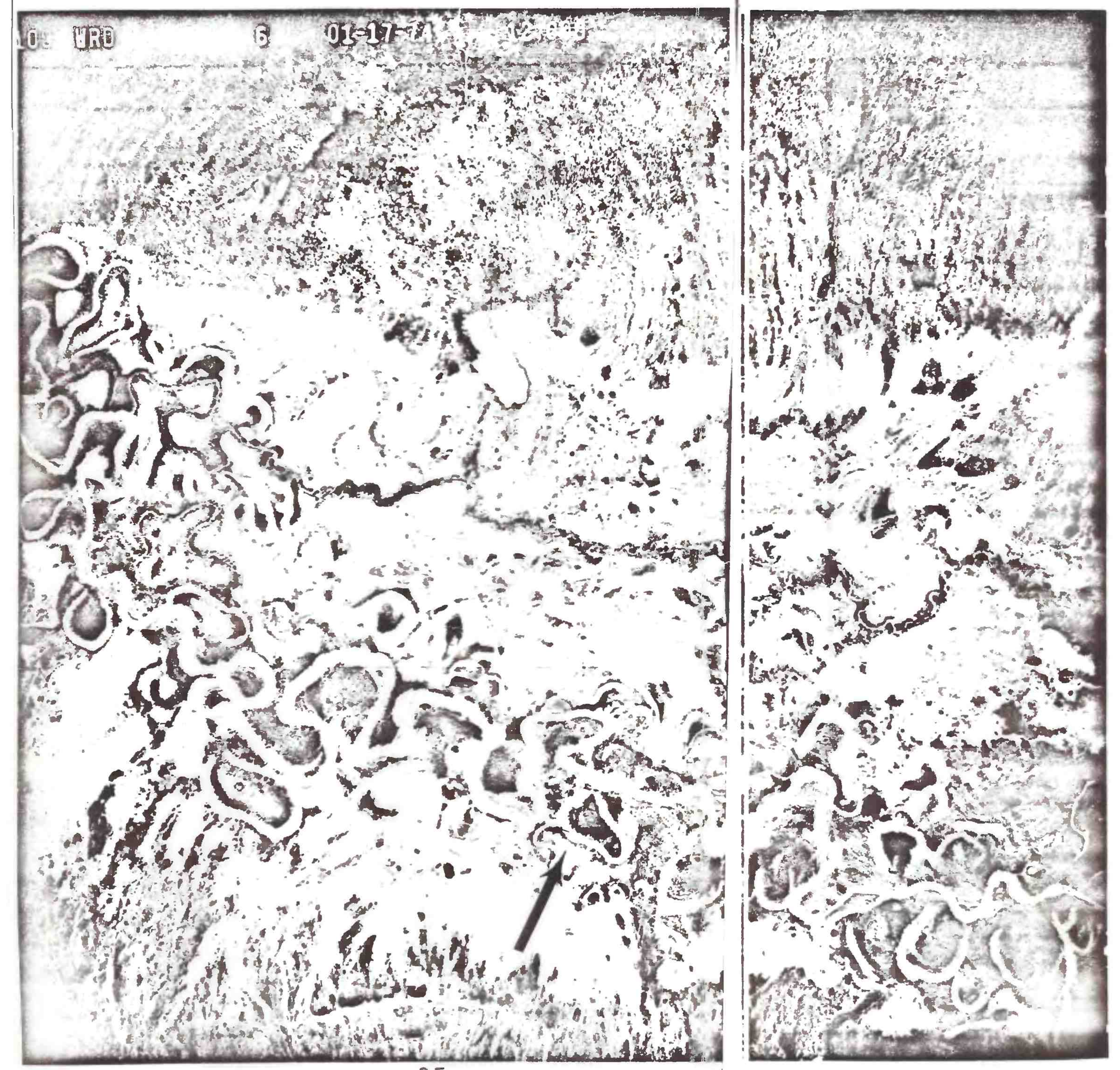


3D



3E

Figure 3A. Thermal image showing icing in cut-off meander of Chatanika River.

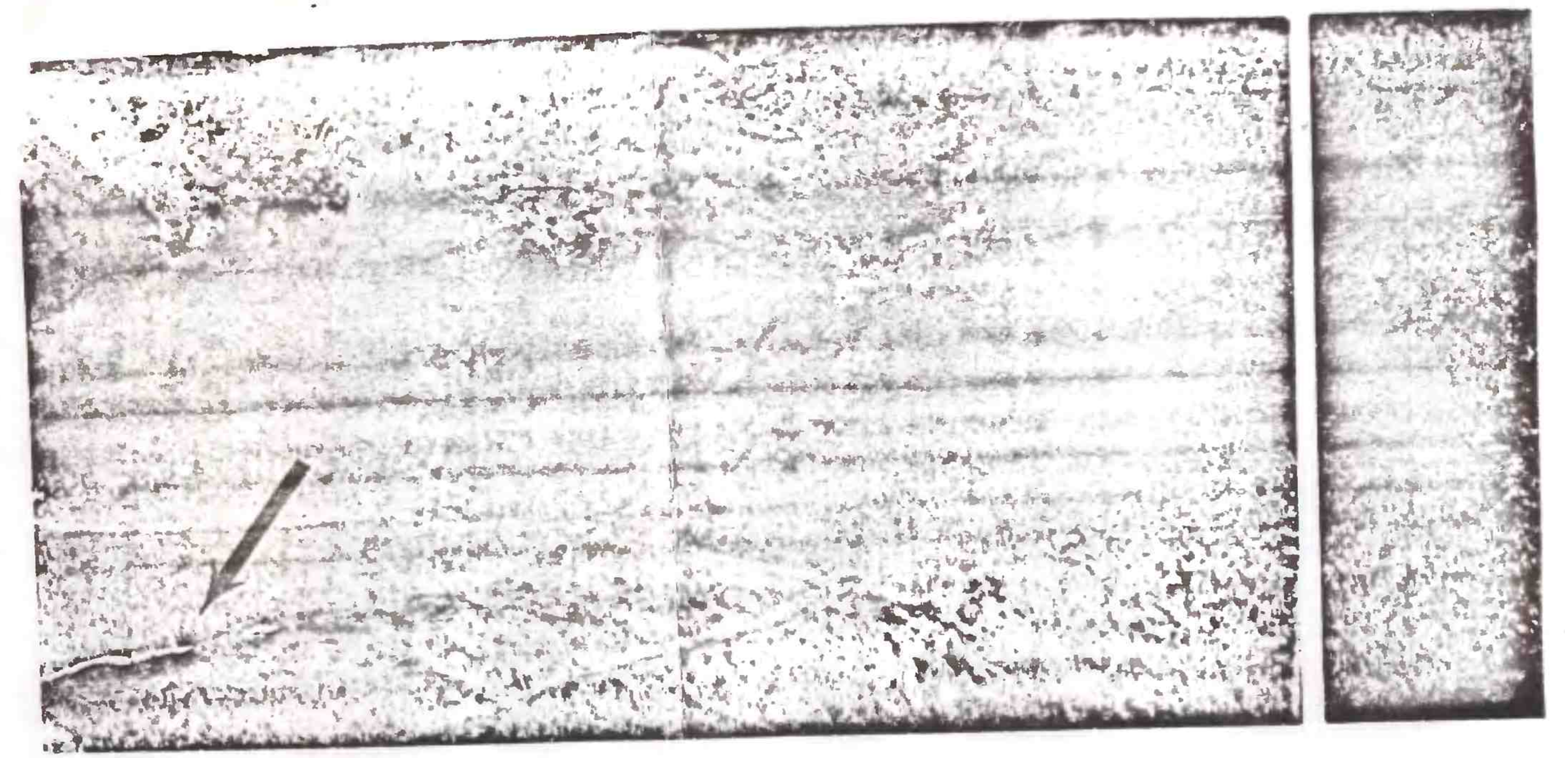
Figure 3B. Oblique photo taken from low altitude showing cut-off meander of Figure 3A. Orange color of water is caused by iron content of groundwater.

Figure 3C. Livengood (A-2) quadrangle sheet. Arrow points to icing site.

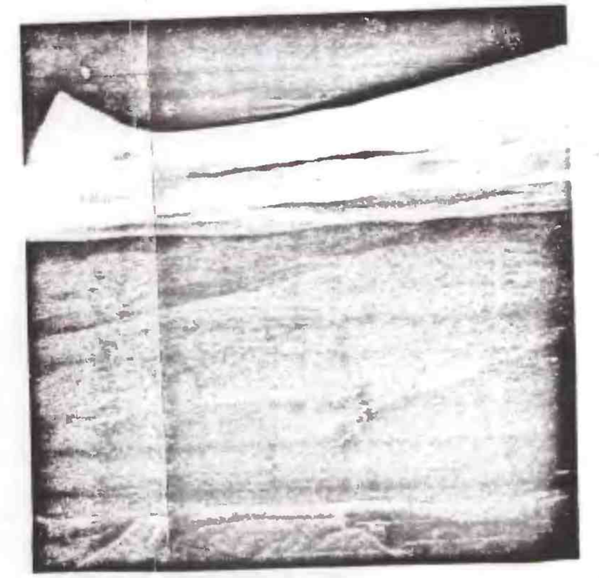
Figure 3D. Continuous strip photograph made in April 1974 shows area after thawing.

Figure 3E. 9 by 9 inch frame photograph made January 17, 1974. Icing appears as dark line, representing water flowing over the ice.

77-643



5A



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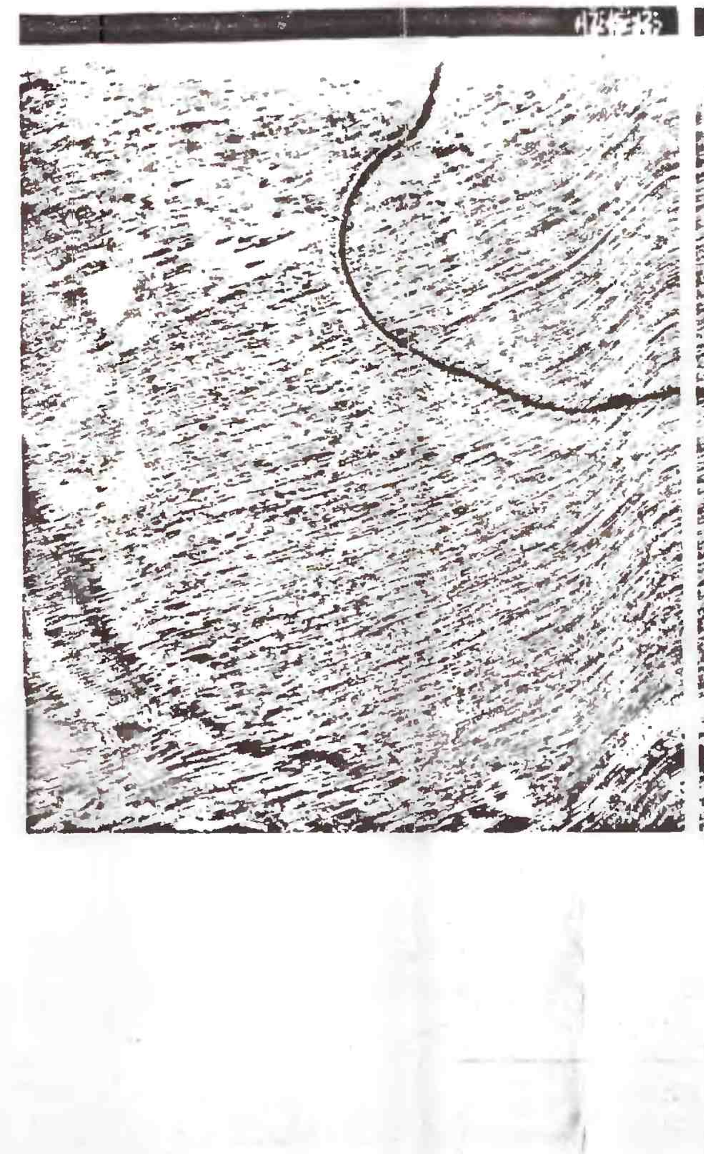
5C



5D

5E

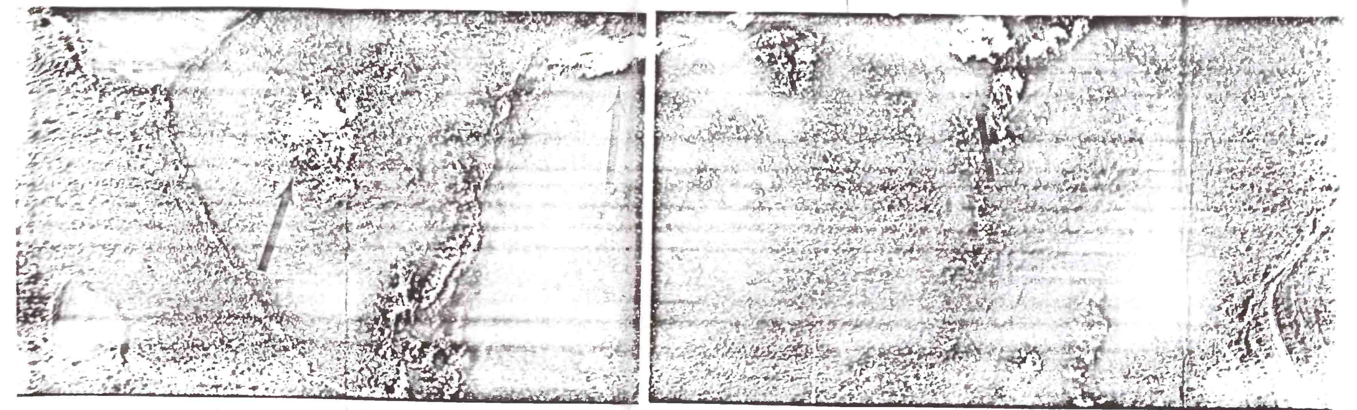
Figure 5A. Thermal image showing icing in Silver Gulch.

Figure 5B. Oblique, low-altitude photograph, June 1974, showing site of icing.

Figure 5C. Fairbanks D-2 quadrangle sheet showing area in which icing site occurs.

Figure 5D. Continuous strip photograph showing Gulch and icing site.

Figure 5E. Frame photograph. Gulch and icing site appear in upper right side of picture.



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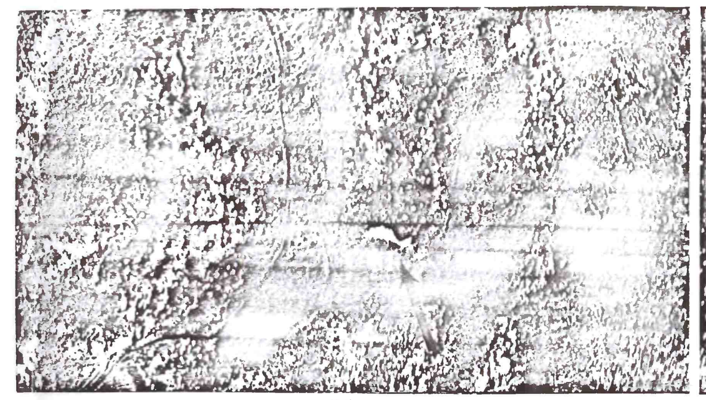

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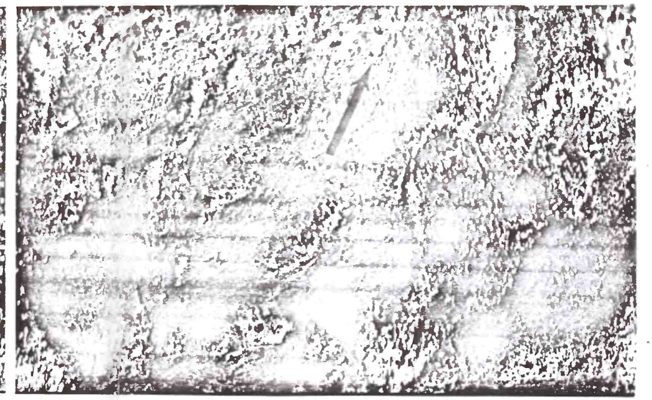


6A3

Figure 6A1. Thermal imagery illustrating (a) temperature rise caused by low-angle sunlight on hillside, and (b) and (c) icings caused by groundwater seepage.

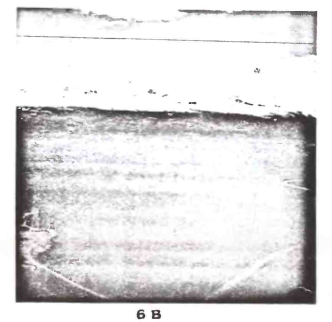
Figure 6A2. Thermal imagery showing icing caused by groundwater seepage.

Figure 6A3. Thermal imagery showing icing caused by groundwater seepage.

Figure 6B. Oblique photograph of area near Isabel Pass where thermal imagery of Figure 6A was made.

Figure 6C. Portions of quadrangle sheets Mt. Hayes C-4 and D-4, showing area imaged in Figures 6A, B, and D.

Figure 6D. Frame photograph of area imaged in Figures 6A and B.



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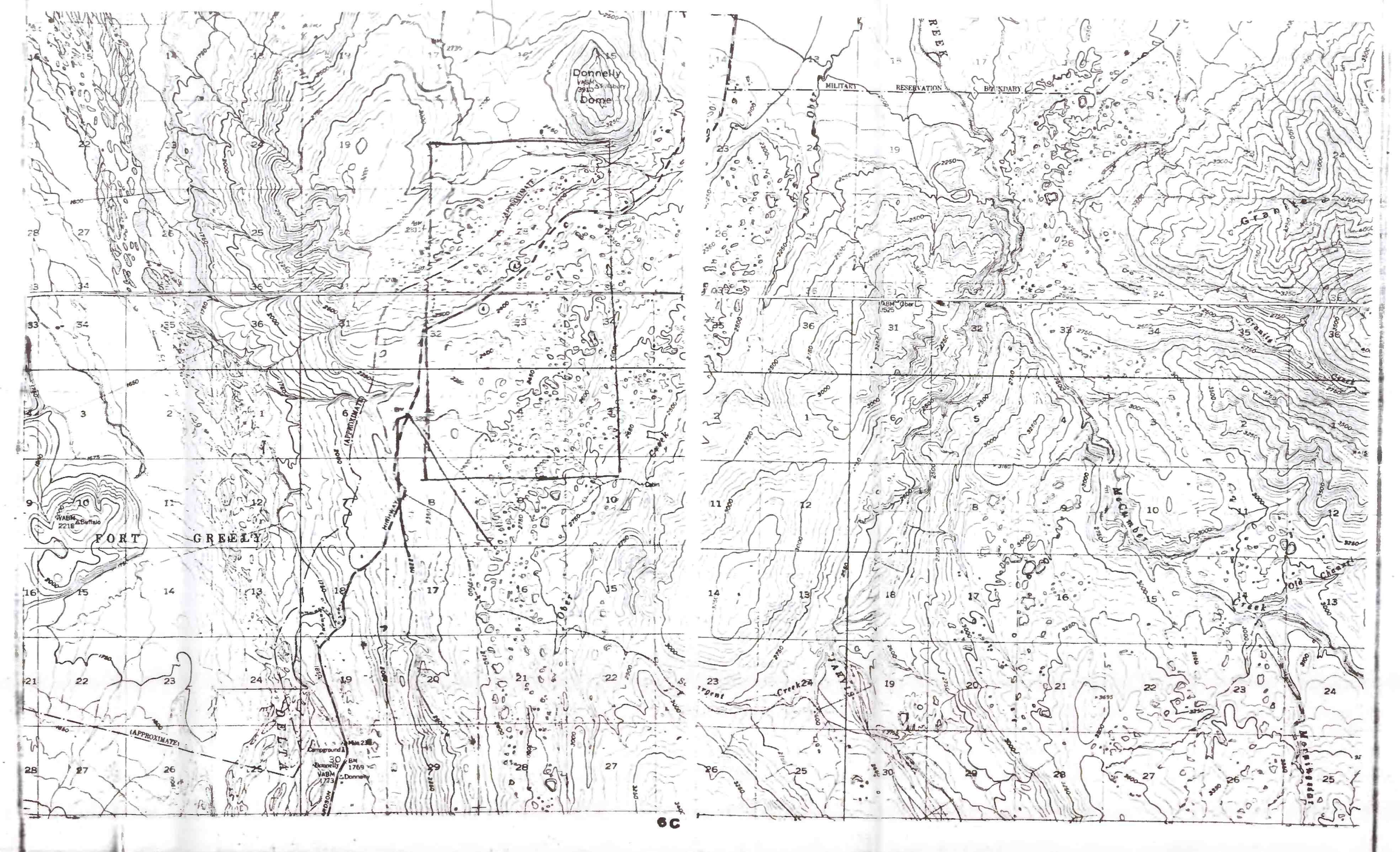

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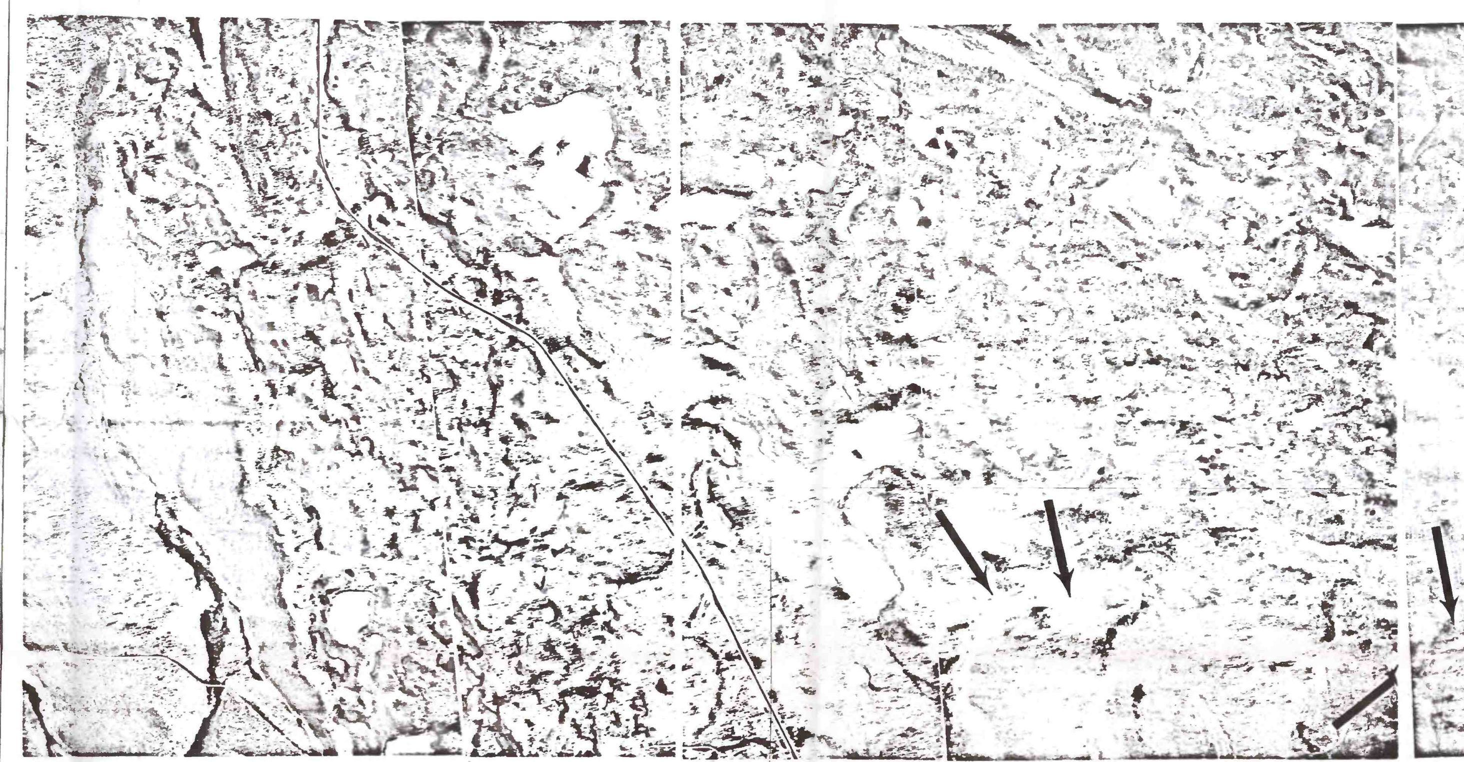
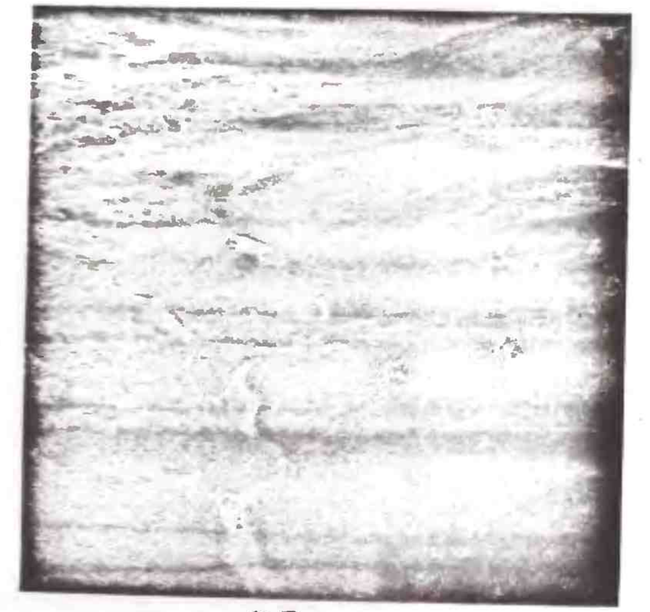


6D

6E

8A



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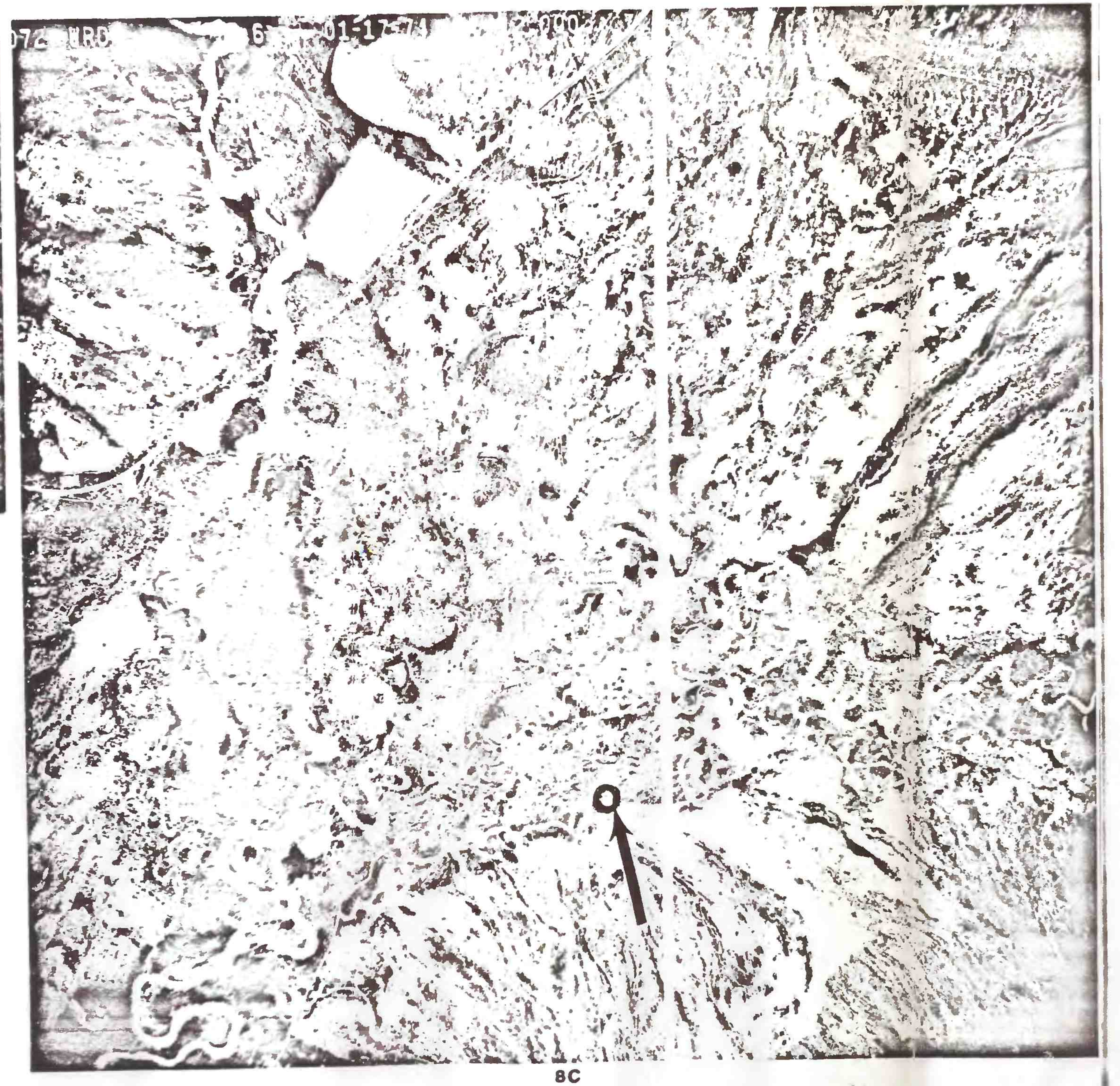


8C

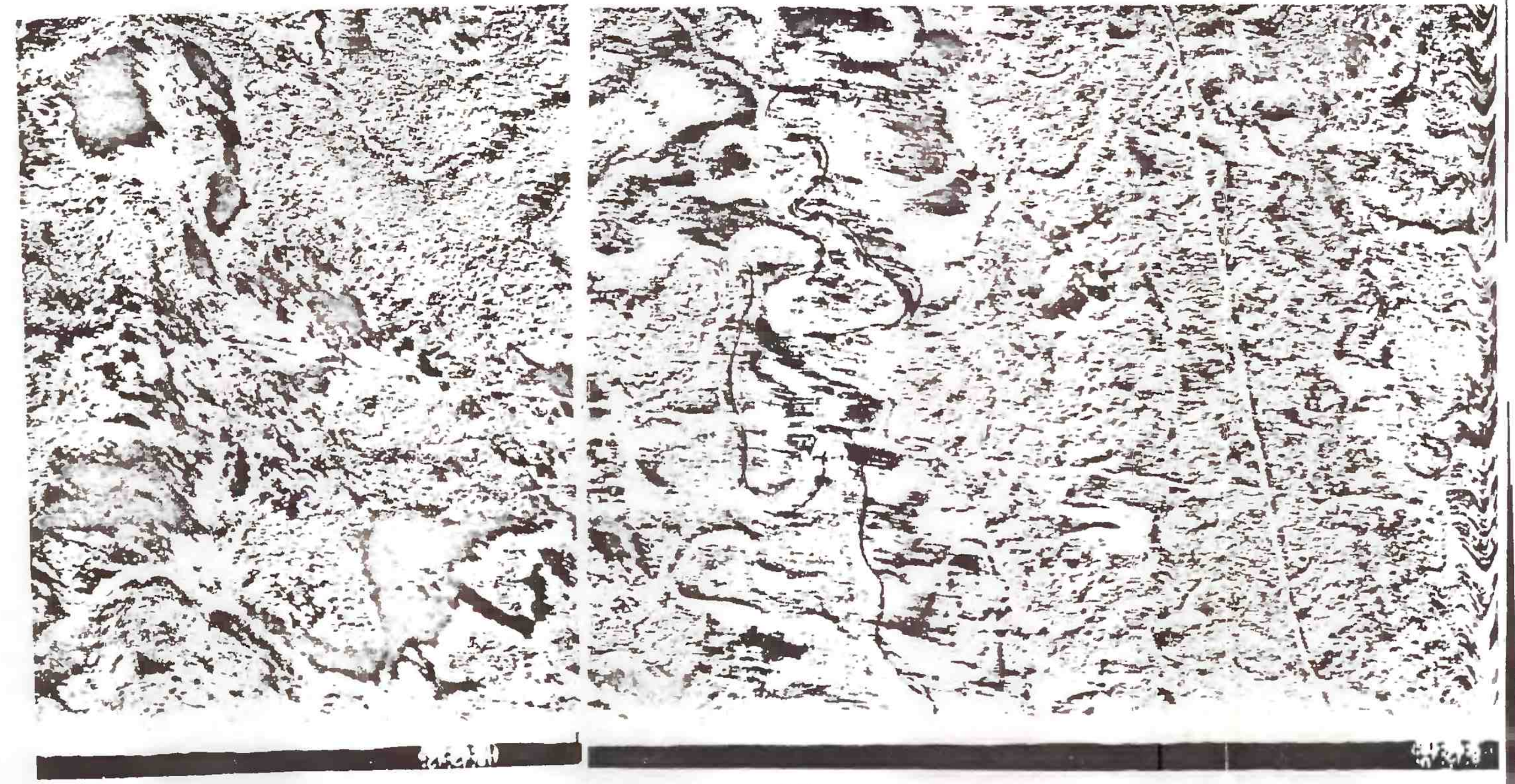
Figure 8A. Thermal imagery showing icing near Tolovana River Crossing

Figure 8B. Oblique photograph of icing site

Figure 8C. Frame photograph of area surrounding icing site.

Figure 8D. Strip photograph showing icing site despite considerable uncompensated roll

Figure 8E. Topographic map Livengood B-4



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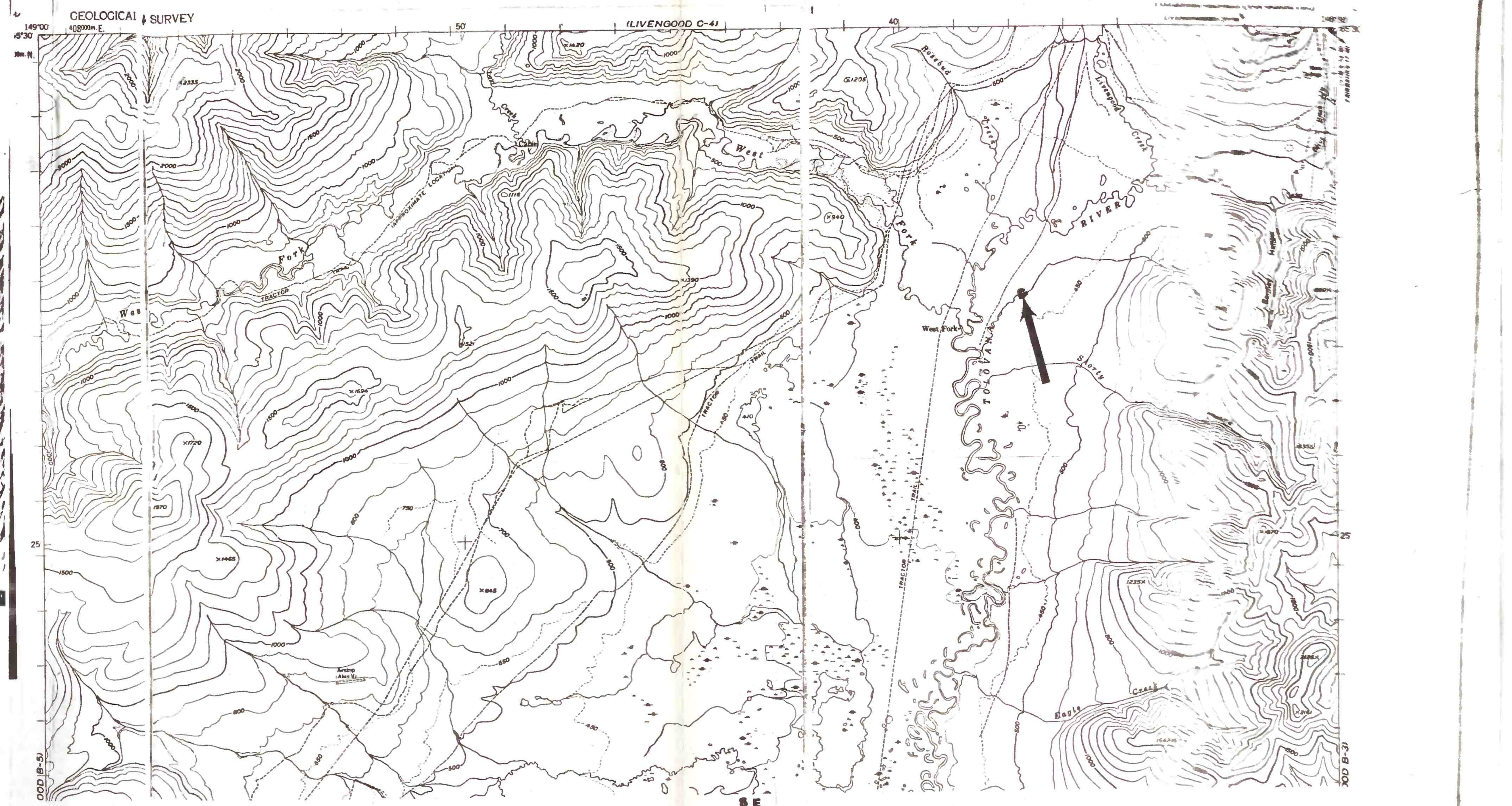
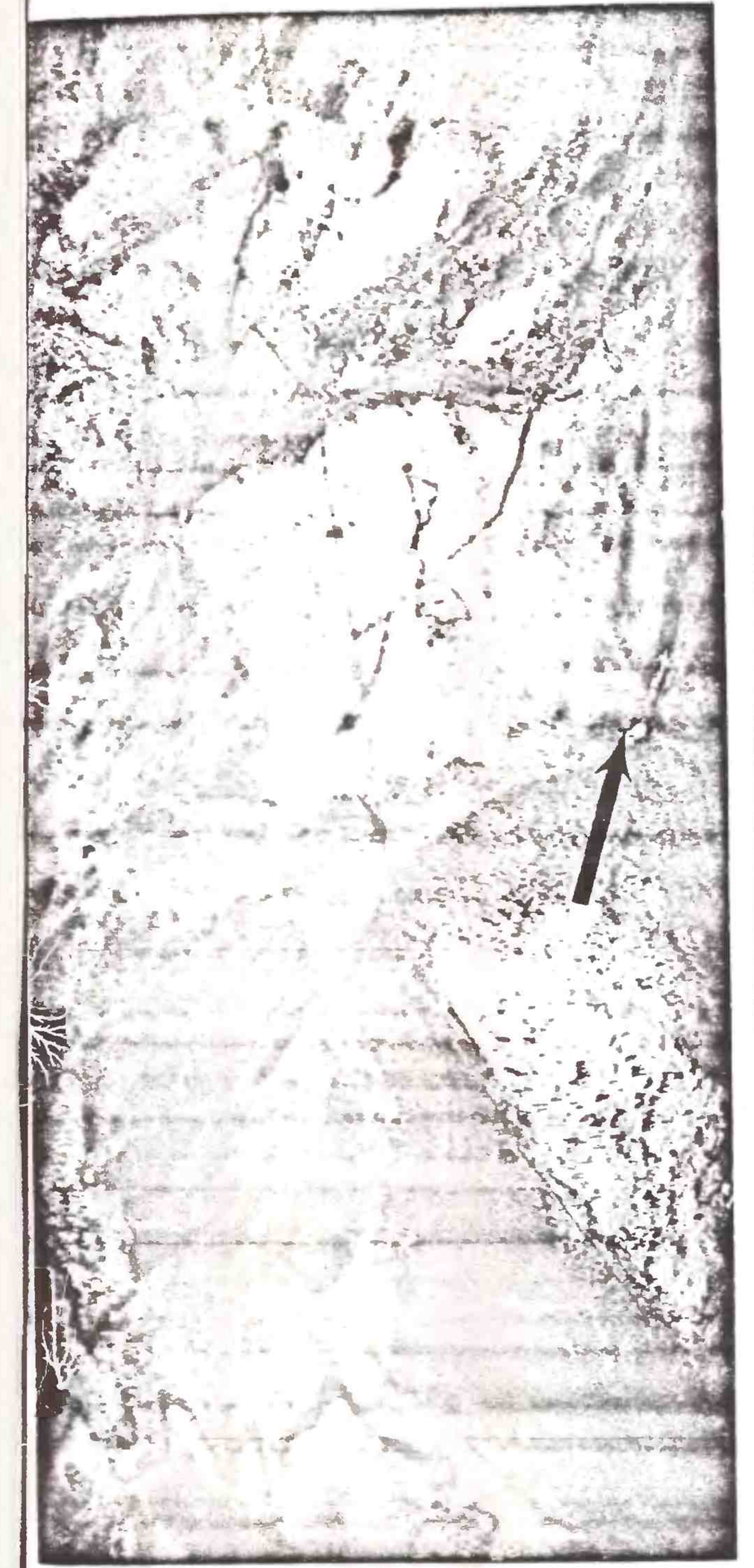
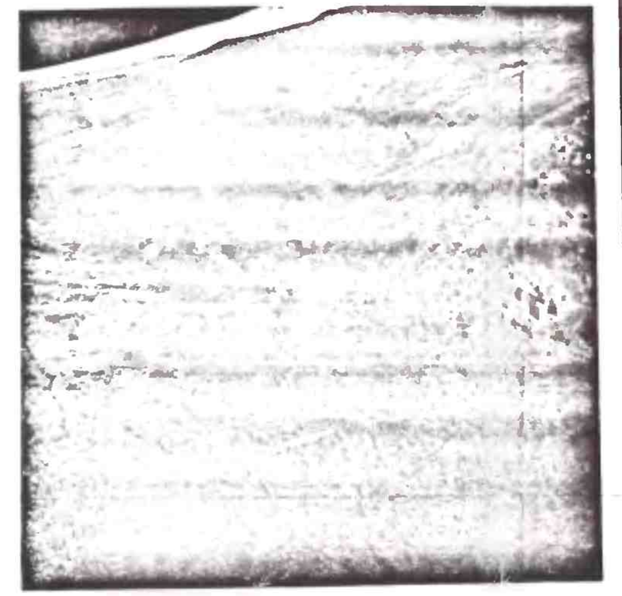


8E

77-648

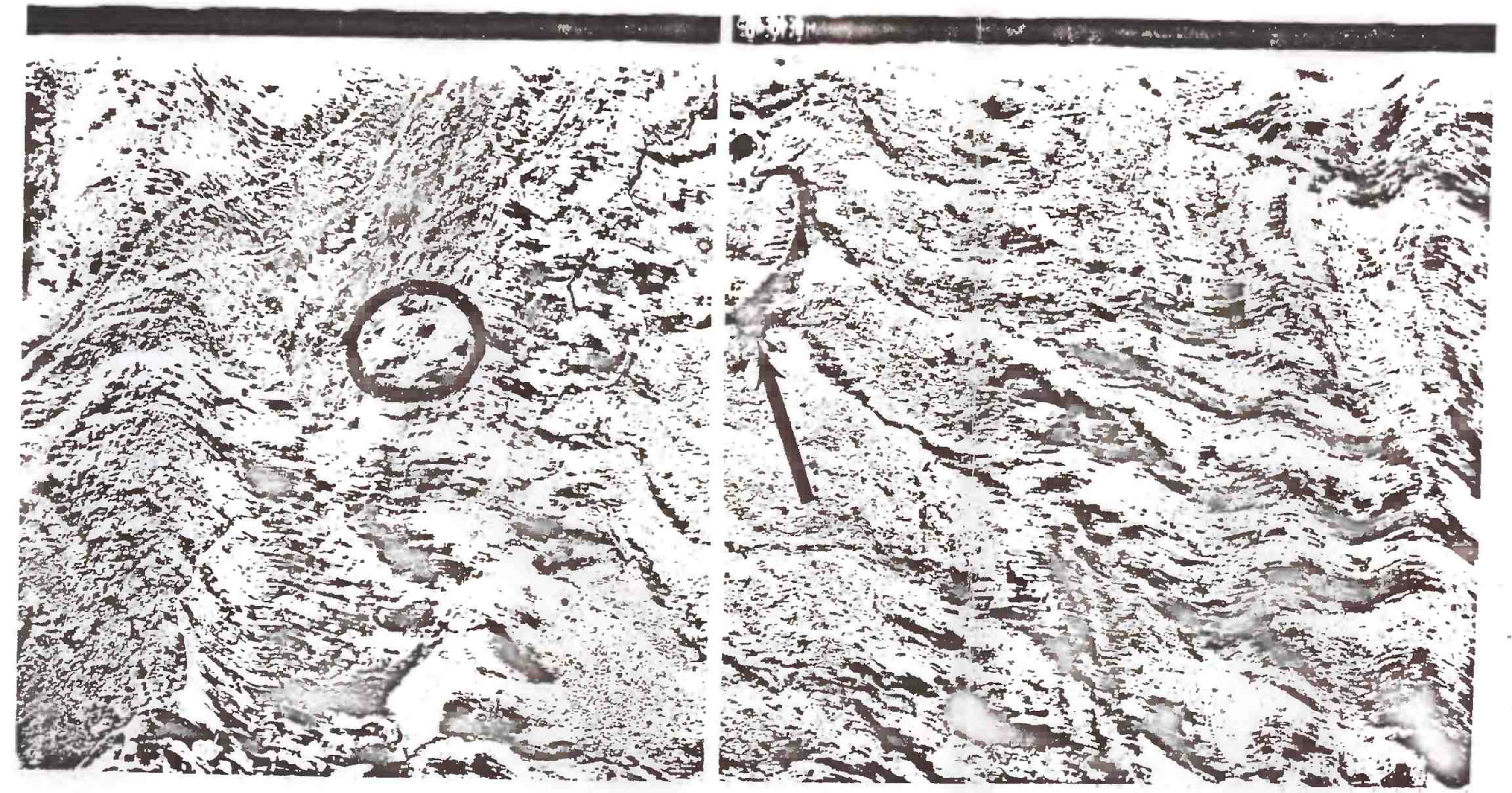


9 A

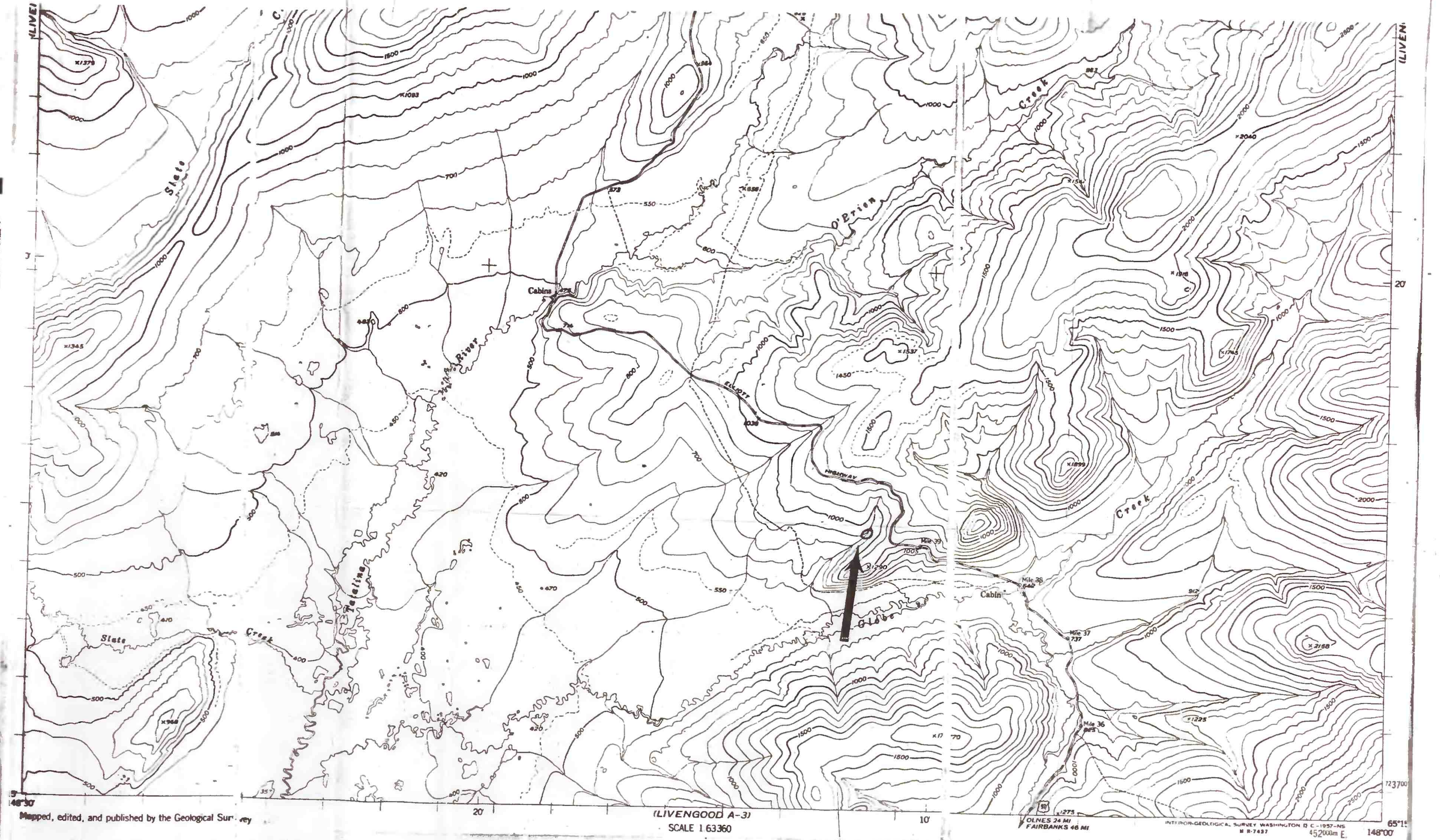


9 B

9 C



9D



9 E

Figure 9A. Thermal imagery showing icing near Globe Creek Crossing

Figure 9B. Oblique photograph made in June 1974 showing residual ice.

Figure 9C. Frame photograph of area surrounding site.

Figure 9D. Example of strip photography with too much uncompensated roll to be useful for interpretation.

Figure 9E. Livengood B-3 topographic map.