SEISMIC MEASUREMENTS ON THE TAKU GLACIER

by

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AERIAL VIEW of TAKU GLACIER - JULY 1949.

SEISMIC MEASUREMENTS ON THE TAKU GLACIER

The Taku Glacier, which flows out of the Juneau Ice Field, is in the southeastern part of Alaska about thirty miles east of Juneau. The Juneau Ice Field covers an area of several hundred square miles and extends across the international boundary into Canada. The Taku Glacier is peculiar in that it is the only one of the many that emanate from the ice field that is advancing along its front, while the other glaciers from the same source are either retreating or remaining stationary. This condition has been under investigation during the past summer as a part of the Juneau Ice Field Research Project sponsored by the American Geographical Society.

A knowledge of the thickness of the ice on Taku Glacier was deemed a most important phase of this study and Stanford Research Institute was asked to furnish personnel and seismic equipment for these measurements.

Previous Attempts at Ice Measurements

During the past decade there have been many attempts to measure the thickness of glacier ice by means of conventional seismic equipment using both refraction and reflection techniques, sonic equipment using frequencies up to several hundred cycles, resistivity measurements, and even radar, with generally unsatisfactory results by all methods. While certain of these methods are ill-adapted to the problem, there seemed to be no real reason why the refraction and reflection seismic technique should not give satisfactory results, particularly in view of the exceptionally good results that were obtained in 1934 on the Ross Shelf Ice.[1] In an analysis of the conditions to be encountered in work on glaciers, for the most part, the same factors limit the use of conventional shot hole seismic technique on the ice as where it is desired to obtain shallow reflections in oil field exploration. Some of the characteristics of the conventional shot hole seismic technique which merely impose certain limitations in oil field exploration make it not only impractical to obtain the shot holes on glaciers but difficult to use them even if they could be readily drilled.

To most geophysicists it would seem that making measurements of the thickness of the ice on glaciers by conventional shot hole reflection technique should be extremely simple. It should not be difficult to drill the necessary shot holes, the ice should transmit seismic energy very well, there may or may not be a snow or névé cover corresponding to a weathered layer, the low density ice should be resting on solid rock below of much greater density, and no such depths are involved as is the case in the oil fields; but let us examine each of these more carefully.

The Drilling of Shot Holes

The drilling of shot holes for seismic work on glaciers has discouraged many investigators and many techniques have been proposed, including hand- and power-operated drills and electrically heated devices for melting holes in the ice. The results from such holes as have been drilled by one means or another, have not yielded results as satisfactory as had been hoped.

The Ice Transmits Well

The transmission of energy through the ice is very good; in fact, in this respect it is about equivalent to the limestone on the Edwards Plateau in Texas which has thus far successfully resisted the application of conventional reflection techniques. The attenuation of energy in the solid ice of Taku Glacier was so low for both the longitudinal and transverse waves that it was very helpful to use a system whereby it was possible to separate these two energies having such widely differing velocities.

Snow Cover Comparable to Weathered Layer

As in the case of the Edwards Plateau, there may or may not be a relatively thin lower velocity layer on the surface. In the case of snow and névé on glaciers, the density and velocity will cover a wider range, but in general there will be a more gradual transition which should be a more favorable condition. The seismic velocity in the snow may cover almost the complete range from the velocity of sound in air to the 12,900-foot velocity for solid ice.

The Ice-Rock Interface

The density ratio between the ice and the underlying rock is much greater than will be found in subsurface horizons in most oil field exploration. However, since the seismic velocity in ice is 12,900 feet per second, or almost identical with the rock on which it rests, the difference in density loses much of its significance. The ice-rock interface, therefore, even though it may be very sharply defined, is in general not a very good reflecting horizon.

Reflections Are Not Deep

In ice field and glacier measurements, the ice thickness will in general be less than 1500 feet and in many cases will be very much less. With a velocity approximating 13,000 feet per second, the arrival time of the reflections will be so early on the records that they will likely be completely masked in the first arrivals from shot holes even though extremely small charges are used.

The chief difficulty encountered in the earlier work was the inability to send enough energy into the ice to get a usable return without having the reflection hidden by the high amplitude of the first arrivals. Prior to the present work, the explosives used to create the seismic wave were either placed on the surface of the ice or snow or buried only a short distance below the surface.

Poulter Seismic Method of Geophysical Exploration

It was thought that the Poulter Seismic Method, which is finding wide acceptance in the petroleum industry, and in which the explosive is placed on metal stakes and detonated in the air, might eliminate many of the difficulties encountered with the conventional shot hole technique on the ice. This seismic method is the direct outgrowth of work begun by Dr. Poulter while on the Second Byrd Antarctic Expedition (1933-35). Its development has been the result of a very intensive research program extending over a period of several years, first by the inventor and subsequently under the sponsorship of the Institute of Inventive Research and conducted at the Armour Research Foundation of Illinois Institute of Technology, the Southwest Research Institute, Engineering Industries, Inc., the Republic Exploration Company, and the Stanford Research Institute.

Under this research program the method has developed into a complete system which affects virtually all phases of seismic exploration. Through the selection of the size, shape and type of pattern of charges, a seismic impulse is generated having the proper frequency to be transmitted well and develop a good reflection, thereby permitting the use of a nearly flat response recording system.

Instrumentation

The instrument used was a Unitized Portable Seismograph built by the Technical Instrument Company of Houston, Texas, with specially modified filtering. The camera and a bank of twelve amplifiers were enclosed in the same stainless steel case and fitted with a waterproof cover when not in use. The camera had twelve geophone traces and one time break trace.

The records were made on 15 cm. paper, and conventional .01-second timing lines were recorded on the records with heavy 0.1-second lines and medium .05-second lines. The paper magazine holds a 200-foot roll of 15 cm. paper and is pulled through the camera by a governor-controlled electric motor at the rate of 24 inches per second. It is picked up in a receiver which is automatically light-trapped by a serrated knife for removal to the dark tank for development. The amplifiers are hermetically sealed in individual metal containers which can be easily removed and replace.

Power for the camera-amplifier unit was furnished by a motor-generator unit in a watertight case. This case fitted over a 6-volt automotive type storage battery and connected to it with spring loaded probes.

A single lightweight geophone was used per trace connected by cables to the "input box." The input box is a stainless steel box which could be sealed weathertight and contained test meter for cable and instrument testing as well as plug-in pannel for cables and telephone lead.

Detonation of explosive was accomplished with condenser-blaster housed in a box matching the input box. This box also contained a cap tester and a terminal panel for connecting cap, timebreak lead and telephone line.

A two-cycle, one-cylinder gasoline engine driven battery charger was used to recharge the storage battery.

A small stainless steel tank fitted with four half-gallon cans and a lightproof canvas cover was used for developing the records in the field.

This equipment, plus tools and supplies, was mounted on a small 7-1/2-foot man-hauled sled. The sled was fitted with a weathertight wooden box mounted just forward of center for tools, spare parts, and supplies that needed most protection. On the outside of this box snap hooks were mounted on which geophones were hung while traveling. On top was a stand for holding cable reels while reeling in or unreeling. Just forward of this tool box was mounted the camera-amplifier unit so it could be operated without removing it from the sled. The power unit was carried on the front end of the sled so it could be easily removed and set alongside the camera for operation. Just behind the tool box was a large canvas "tank" in which was carried the powder, cable reels, and miscellaneous units of the equipment. On the after-end was mounted the dark tank for developing the records in the field. Fastened underneath the dark tank and trailing behind the sled was the sledge meter consisting of a bicycle wheel with a cyclometer for measuring distance traveled.

Lower Taku Glacier is especially well suited for experimental and calibration work, not only because it is readily accessible but also because the thickness of the ice is known with a fair degree of accuracy over an area of several square miles. This is made possible because Taku Glacier has advanced a few miles over the past years and the contour of the bottom had previously been determined. Although the surface was traversed by many deep crevasses which made surface travel extremely difficult, these were not entirely without their advantages for our experimental and calibration work, since they greatly simplified the problem of obtaining a great variety of experimental conditions with a minimum of difficulty. By early July, when this work was started, there is very little snow left on the surface of the lower glacier, and although the surface is composed of a coarse crystalline mass of disintegrating ice, its density is essentially unity, and with the exception of the crevasses, it can be considered solid blue ice almost entirely free from stratification.

First Seismic Camp on Taku Glacier

The seismic party and equipment were first transported to a point on the terminus of Taku Glacier on the fifth of July by small boat where it was possible to unload directly on the ice. The equipment was man-hauled to a comparatively level place on the ice where a continuous block of ice could be found which was long enough so that the shot point and geophone spread could be set up without having crevasses cross between the geophones or between the geophone spread and the shot point.

The location of the shot point was so selected that the charges could be placed above the surface, on the surface, in shallow shot holes drilled in the ice with or without water tamping, or in a comparatively deep crevasse without varying the distance or relative position of the shot point from the geophones. The elevation of the shot point was 230 feet above sea level with a rather uniform uphill slope to an elevation of 250 feet at the far end of the spread.

Velocity Determination

A basic necessity in any seismic work is an accurate knowledge of the velocity of the seismic wave in the material to be measured. This is gained in ordinary seismic work for petroleum exploration by lowering a geophone in an oil well and detonating charges near the surface. Since the depth of the geophone is known and the time of arrival of the seismic wave can be accurately measured, it is possible to arrive at the velocity of the wave in the media.

It was very early recognized that there were at least three different types of wave motion in the ice, a high velocity compression wave, a shear wave, and a Rayleigh wave, the latter two having about one-half the velocity of the compression wave.

A review of the literature reveals a very wide range of seismic velocities and in some cases the existence of different types of wave motion has not been recognized. A wide range of values are to be found in the literature and the following are representative:

	Feet/Second	Feet/Second
[2]Brockamp & Mothes, Austrian Alps	11,800	5,430
[3]Goldthwait, Crillon and Klooch Glacier, Alaska	9,900-15,000	4,300-6,000
[4]Poulter, Ross Shelf Ice, Antarctica	11,000-12,900	2,900-5,200
[5]Northwood & Simpson, Seward Ice Field, Alaska	7,300-8,200	6,700
[6]Salt, Seward Glacier, Alaska	7,250-10,500	4,600-6,660
[7]Peterson, Point Barrow, Alaska	12,300	6,500
Poulter, Allen & Miller, Taku Glacier, Alaska	12,960	6,620

but values approximating 13,000 feet per second can be obtained in large masses of solid clear blue ice.

Horizontal Velocity

For the determination of horizontal velocity, attempts were made to select large continuous blocks of ice having no transverse crevasses, although it was in general impossible to select distances of more than a few hundred feet without containing some closed cracks crossing between the shot point and the geophones.

Horizontal velocities below the maximum crevasse depth are essentially the same as the vertical, but near the surface, even in apparently solid ice, the horizontal velocities may be appreciably less than 12,900 feet per second.

Vertical Velocity

For our vertical velocity determination we were rather fortunate in discovering a dry moulin into which a charge was lowered to a depth of one hundred and fourteen feet. A spread of geophones was placed on the surface near the moulin to record the arrival time of the energy at the surface. Several shots were made in the moulin and a rather accurate determination of the velocity was obtained. The ice surrounding this moulin was examined by lowering a bright light down into it, and it was found to consist of clear blue ice free from stratification of any kind so far as could be detected by this inspection. The results showed a velocity of 12,900 feet per second for the compression wave in ice. This velocity was used for all depth determinations made during the summer. The necessary correction was determined for the low surface velocity on the measurements that were made in the névé zone. By means of this technique it was also possible to calculate the approximate variation in seismic velocity and névé density with depths.

By means of setting geophones out in pairs, one in a vertical position and the other in a horizontal position, we were able to determine that the high velocity wave was a compression wave, but that there were both shear waves and Rayleigh waves present in the low velocity energy. Perhaps not generally recognizing the fact that there is such a wide range of velocities and different forms of wave motion in the ice and snow of glaciers is one of the things that has caused a great deal of confusion in the attempts that have been made to apply seismic methods to the determination of ice thicknesses on glaciers.

For the purpose of studying the different wave forms, a crevasse was selected which was in excess of fifty feet deep and which was about ten feet wide at its widest place. The walls of this crevasse merged together at one end so that the ice surrounding the crevasse formed one continuous mass of solid ice. The width of the crevasse became quite narrow at a depth of thirty feet. This and other crevasses provided an opportunity to study the directional distribution of the different types of waves as well as their phase and velocity relations.

Thus the whole problem of distribution of energy in a vertical plane became very simple without the necessity of drilling deep holes into the ice. Charges were suspended at different positions in the crevasse and the geophones distributed on the surface of the ice. The entire experimental set-up had been rotated through 90 degrees, the vertical wall of the crevasse representing the normal horizontal surface and the horizontal surface representing the vertical plane. The depth of the charge in the crevasse corresponds to the offset of the charge normal to this simulated vertical plane. A nearby parallel crevasse even provided a reflecting horizon. From these experiments the following conclusions could be drawn with respect to charges detonated above the surface.

1. The maximum intensity of the compressional wave is normal to the surface under the charge (normally vertically downward).

2. The minimum intensity of the compressional wave is along the surface.

3. The maximum intensity of transverse waves is horizontal along the surface.

4. The low velocity transverse waves were so low in intensity normal to the surface that they were not detected.

5. Both the horizontal shear wave and the reflected compressional wave produce a vertical displacement of the surface.

6. The reflection from an ice-air interface produces in a longitudinal wave a change in phase of 180 degrees.

7. On no occasion were we able to identify positively reflections of shear waves from ice-rock or ice-air interfaces, but the latter was apparently present as background noise particularly in the case of charges buried in the ice.

The presence of three types and velocities of wave motion from charges buried in the ice in any manner near the surface or in deep crevasses is particularly confusing; however, with the charges suspended above the surface only the compression wave is directed downward to produce reflections from the bottom. The Rayleigh wave is, in general, absent and the shear wave travels primarily along the surface, thereby greatly simplifying the interpretation of the records.

Field Procedure

Two lines of six geophones each were placed in the form of a cross with a spacing between geophones of twenty-five feet. A single geophone was used for each trace. The lines of geophones were oriented so that the first six geophones were parallel to any predominant crevasse or crack that was present in the ice or snow. The other line was placed at right angles to the first line. The geophones were placed on or just below the surface, care being taken to ensure a firm base for each.

Elevations of the ice surfaces were obtained with the use of a small hand altimeter which was frequently checked against sea level during the time that we were working on the lower part of the glacier, Sea level adjustments were secured from the U. S. Weather Bureau Station in Juneau for the dates and times for which the readings were made in the upper ice field.

The location of the stations on the lower Taku Glacier were obtained by taking bearings on various reference points with a Brunton compass and plotting this on a vertical, photographic map of the area. This procedure was necessary because the very rough surface condition made it necessary to travel a very circuitous route from one station to the next. The mountains on both sides of the lower glacier were very steep and produced a very sharp air echo from the detonation of the charges. This proved to be very useful for obtaining the approximate distance that the party had traveled cross-glacier from station to station.

The recording equipment was located far enough away from the shot point so that the air wave would not strike the instrument until after all reflections had been recorded. Any microphonics that may occur in the recording system would thereby be prevented from confusing the record. This, of course, necessitated the use of a 150-foot extension on the geophone cables and a telephone cable between the shooter and the observer for coordinating the firing of the charge and the operation of the recording equipment. The records were developed immediately to make sure that they were satisfactory before moving on to the next station.

The névé surface in the upper ice field where three of the four lines of stations were occupied was smooth enough so that the seismic party could travel in a straight line across the ice field without interference from crevasses. This permitted the use of the sledge meter for determining the spacing between stations.

Explosive and Pattern Array

Two types of explosives were used, but purely from a matter of availability. They were surplus military explosive C-2 and 60% High Velocity dynamite. Since both types of explosive were being used and it was necessary to use a seismograph type cap that would detonate the very stable C-2, the No. 6 Western Cartridge seismic caps were used. Since the dynamite has a somewhat lower detonation velocity than the C-2, slightly larger charges of dynamite were required.

Several different types and sizes of patterns of charges were satisfactorily used. For work on the solid blue ice of the lower glacier single charges of as small as one ounce mounted on a metal stake six to eight feet above the surface gave quite satisfactory records. On the upper ice field where the ice had a snow and névé cover of as much as sixty feet, seven-charge patterns of as large as one-half pound per charge were used of a total of three and one-half pounds per shot. In some cases where a single charge was used, it was placed at the center of the cross-spread, but multiple-charge patterns were always used with an offset distance of from 300 to 500 feet.

In all cases the most satisfactory records were obtained using an offset pattern charge having frequency characteristics corresponding to the frequency of the reflection. The charges are arranged in a hexagonal pattern with one charge at the center, thus making the distance between charges the same throughout the pattern.

In order to obtain the best results, a pattern is selected which generates a seismic wave having a frequency most readily transmitted through the ice and reflected from the lower surface. Curves for the selection of the proper pattern frequency are based on experimental work conducted at the Calaveras Field Laboratory of the Stanford Research Institute.

In all instances the records that were made in this manner were superior to the other method. Time and lack of man-power did not permit the use of the offset pattern for all the work on the névé, but the records secured by both methods are of sufficiently good quality to permit confidence in the profiles.

Character of the Glacier Surface

The terrain below the névé zone is quite crevassed and much of it was impossible for the seismic equipment, but on portions of it the crevasses were sufficiently narrow to permit the movement of the sled across them. There were also areas of "pressure ice" through which travel by sled was most difficult and it was necessary to scout ahead for possible routes.

Icefalls and pressure areas prohibited movement of the equipment by sled from the lower flacier to the areas to be shot in the névé zone. The equipment was transported to the terminus of the glacier after completion of the work on the blue ice where it was placed on a small boat for transfer to an airplane equipped with pontoons for shipment back to Juneau. From there it was transported to the upper ice field by ski plane.

The surface of the névé zone is relatively smooth and generally free of crevasses although later in the season many crevasses were seen. Except in local areas, travel by sled was not hindered and it was possible to place the seismic stations in a straight line. The soft snow on the surface caused considerable difficulty and the movement of the heavily-laden sledges at times was quite slow.

Summary and Discussion of Results

The seismic equipment was first set up on Lower Taku Glacier so that it could be operated and checked in an area where the structure and thickness of the ice was known. Figure 2 shows the location of the stations occupied on lower Taku Glacier and the location of determinations of the depth of the bay as reported on the Bathymetric Chart of the U.S. Coast and Geodetic Survey, 1890. The depth determinations made on lower Taku Glacier during July of 1949 and the corresponding depths as measured before the glacier covered the area are listed in Table I. From these data it will be seen that the thickness of the ice as determined by means of the seismograph compared to the values obtained from the bathymetric chart and elevations of the surface determined from an aneroid altimeter checked very well. This provides an excellent check on the reliability of the Poulter Seismic Method for the determination of glacier ice thicknesses.

The quality of the records that it was possible to obtain even in the névé zone are shown in Figure 1, and Table II lists all of the records which were taken primarily for the purpose of determining the thickness of the ice or from which reflections permitted such determinations.

The location of all of the stations occupied during the summer are shown on the mosaic map (Fig. 3) which was made up from vertical photographs. Four lines of stations were occupied from which it was possible to construct vertical cross sections of the glacier and these are shown in Figure 4.

Although much work remains to be done on the seismic records obtained during the time that the Juneau Icefield Research Project was in the field, this analysis has progressed far enough to provide a great deal of useful information.

Types of Wave Motion

The presence of at least three types of wave motion have been shown to be present in glacier ice, and methods of generating and identifying them has been worked out. The different types of wave motion are longitudinal or compression waves, transverse or shear waves, and Rayleigh waves which are a combination of transverse and longitudinal waves that travel only along the surface of the ice with the ice particles traveling in an elliptical path. The Rayleigh waves were detected and studied by two component geophones.

It was found that charges suspended above the surface produce only compressional waves directed downward and shear waves traveling primarily along the surface. Thus, if a charge is placed above the surface of the ice with a crevasse crossing between the geophone and the shot point, no Rayleigh wave will be produced, the shear wave will not cross the crevasse, and the compression waves which are directed downward are free to produce reflections with but a very minimum of background noise. In fact, several very good reflections were obtained without the use of explosives but merely by tapping with a hammer a stake driven into the ice.

Velocities

Unusually favorable conditions were obtained for making velocity determinations, and essentially theoretical values were obtained.

Solid Blue Ice

Longitudinal Wave	-	12,900 feet per second
Shear Wave	-	6,620 feet per second
Rayleigh Wave	-	5,800 feet per second.

Névé

Longitudinal Wave - 3,600 to >5,000 feet per second

Ice Thicknesses

Reflections were obtained on more than one hundred records from which ice thicknesses were determined.

Depth of Crevasses

A convenient seismic method was devised for readily determining the depth of crevasses. It consists of placing geophones on both sides of the crevasse and then making a seismic record while striking the top of a metal stake which has been driven into the ice near the geophones on one side of the crevasse. From the travel time of the compressional wave down one side of the crevasse and up the other side the depth of the crevasse can very readily be determined. This is particularly useful in measuring the depth of very narrow crevasses but cannot be used if there are connecting ice bridges or large stringers between the two opposite faces of the crevasse.

Depth and Density of Névé

The depth and variation in density of the névé can readily be approximated from the average velocity to various depths as determined from the first arrival times on the seismic records. From such data it has been determined that the average velocities for the first fifty feet in depth of the glacier on the upper ice field varies from 6,700 feet per second to more than 11,000 feet per second, thus giving a depth of unconsolidated névé of from 14 to 25 feet.

This seismic equipment and method have proven to be the most effective combination that has thus far been used in the study of the thickness of glacier ice and it is believed that from the information gained on this expedition techniques can be developed which will give even greater portability and flexibility.

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ILLUSTRATIONS

1. Records Nos. 24-117, 25-119 and 27-130
2. Enlarged section of lower glacier with the location and value of all depth determinations as determined before the area was covered by the glacier. Also the location of all seismic stations.
3. Mosaic map of Taku Glacier and upper ice field with location of all stations marked on it and including names of as many different portions of glacier and ice field as are available, camp locations, and so forth.
4. Four cross-section profiles of Taku Glacier.

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TABLE I

TABULATION OF ALL RECORDS TAKEN FROM WHICH ICE THICKNESSES CAN BE DETERMINED ON THE LOWER GLACIER

Profile No.	Station No.	Record No.	Ice Surface Elevation (feet)	Ice Thickness (feet)	Depth of Ice (feet(	Depth from Bathymetric Chart (feet)	Per Cent of Ice Thickness
	1 1 1 1	9c 9d 9e 9f	240	358	118	120	0.6
	3 3	50 54	500	825	325	290	4.1
	4	56	650	852	202	290	9.4
	5	57	700	1034	324	295	2.8
	6 6	65 66	800	1020	220	275	5.4
I	7	68	1000	1086	86	?	-
I	8	69	1000	1300	310	290	0.1
I	9	71	1000	1300	300	302	0.01
I I	10 10	72 75	1000	1378	378	325	0.38
I I	11 11	77 80	1000	1048	48	310	25.0
I	12	83	1040	1177	137	300	15.0
I I	13 13	85 86	1000	1086	86	230	13.0
I I	14 14	87 88	1020	1203	183	180	0.3
I I	15 15	89 90	1000	1047	47	shallow	-

TABLE II

Profile No.	Station No.	Record No.	Surface Elevation (feet)	Ice Thickness (feet)
I	7	68	1000	1086
I	8	66	1000	1300
I	9	71	1000	1300
I	10	72	1000	1378
I	10	75		
I	11	77	1000	1048
I	11	80		
I	12	83	1040	1177
I	13	85	1000	1086
I	13	86		
I	14	87	1020	1203
I	14	88		
I	15	89	1000	1047
I	15	90		
II	16	92	2520	1033
II	16	94		
II	17	95	2540	800
II	17	96		
II	19	102	2505	786
II	19	125		
II	20	123	2490	801
II	20	124		
II	21	108	2500	708
II	21A	120	2500	732
II	22	109	2510	598
II	22	110		

TABLE II (Continued)

Profile No.	Station No.	Record No.	Surface Elevation (feet)	Ice Thickness (feet)
III	23	111	2760	826
III	24	117	2800	1217
III	25	119	2820	1534
III	26	127	2760	1303
III	27	130	2830	1030
III	28	131	2930	904
III	28	132		
III	29	134	2905	946
III	29	136		
III	30	137	2960	767
III	31	138	2940	728
IV	32	139	3415	800
IV	33	142	3405	1020
IV	34	143	3395	1051
IV	34	144		
IV	35	145	3395	1132
IV	35	147		
IV	36	148	3415	1144
IV	36	149		
IV	37	150	3455	1138
IV	37	151		
IV	37	152		
IV	38	153	3455	1092
IV	39	154	3495	923
IV	39	155		
IV	40	157	3445	734
IV	40	158		
IV	41	159	3440	559

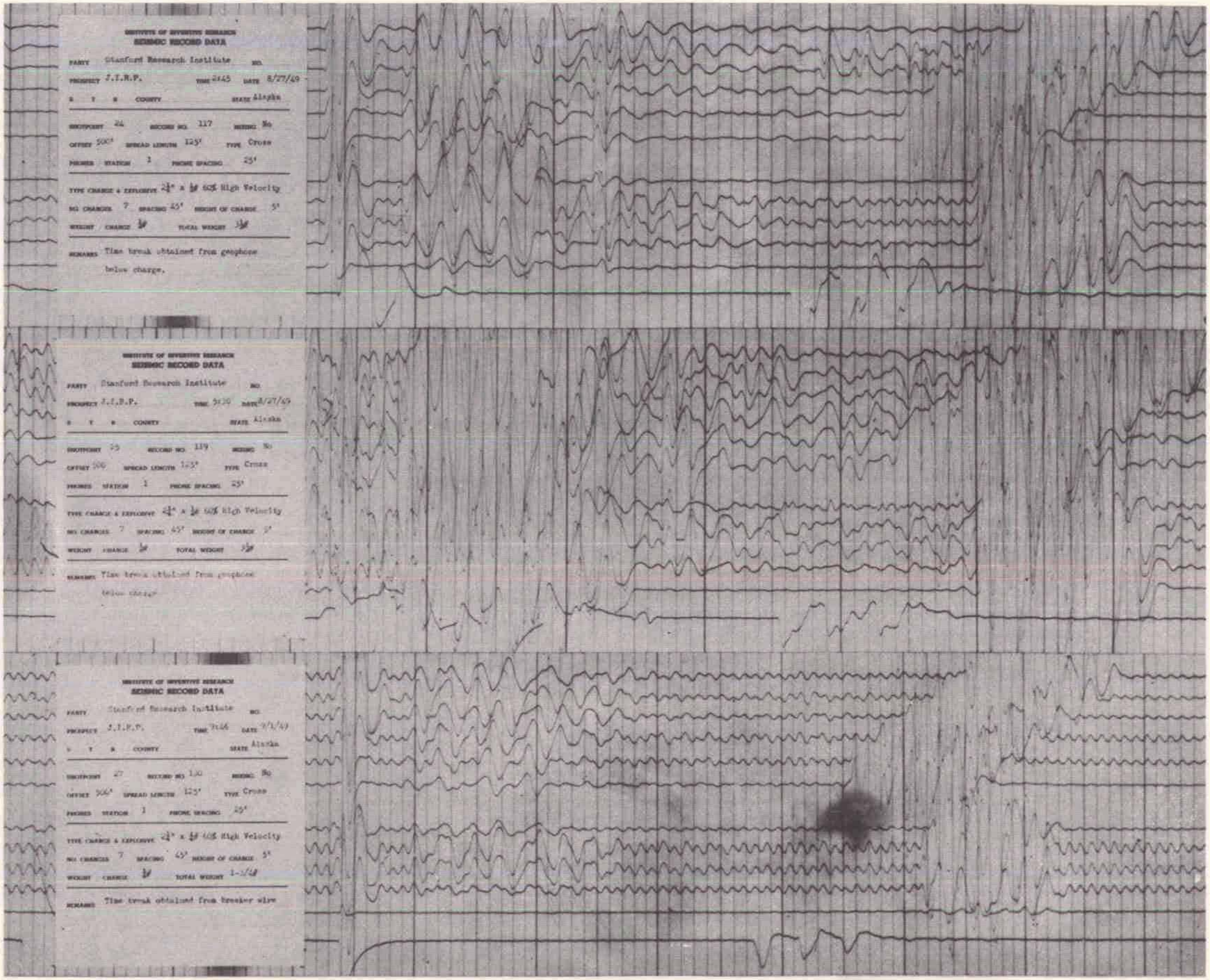

SEISMIC RECORD DATA
PARTY Stanford Research Institute
PROJECT J.I.R.P.
DATE 8/27/49
STATE Alaska
SHOTPOINT 24
RECORD NO. 117
OFFSET 500'
SPREAD LENGTH 125'
TYPE Cross
STATION 1
PHONE SPACING 25'
TYPE CHARGE & EXPLOSIVE
High Velocity
NO CHARGES 7
SPACING 45'
HEIGHT OF CHARGE 5'
TOTAL WEIGHT
REMARKS Time break obtained from geophone below charge.
SEISMIC RECORD DATA
PARTY Stanford Research Institute
STATE Alaska
RECORD NO. 119
TYPE Cross
STATION 1
PHONE SPACING 25'
High Velocity
NO CHARGES 7
SPACING 45'
TOTAL WEIGHT
SEISMIC RECORD DATA
STATE Alaska
TYPE Cross
STATION 1
High Velocity
NO CHARGES 7
TOTAL WEIGHT
REMARKS Time break obtained from breaker wire

FIG. 1

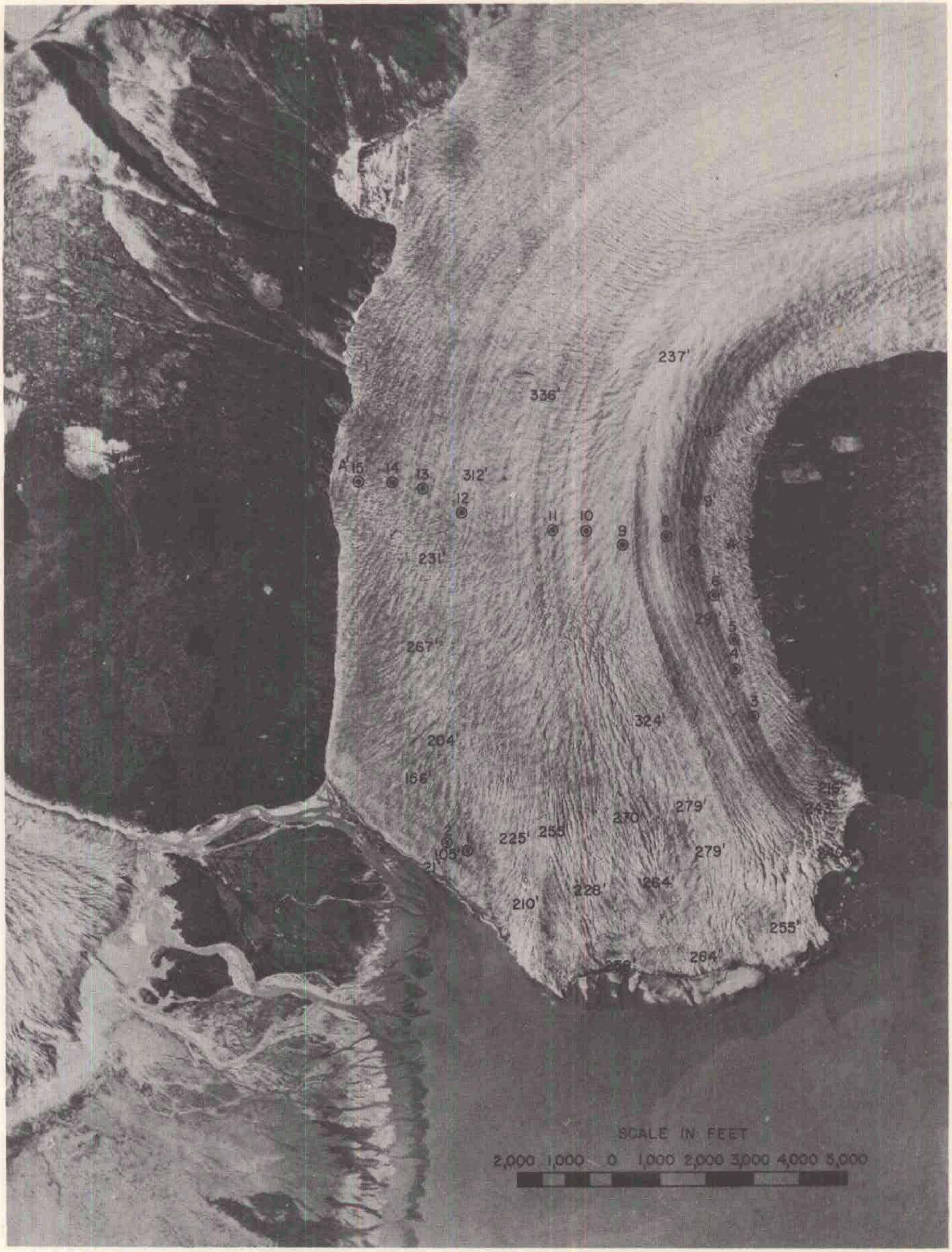


FIG. 2

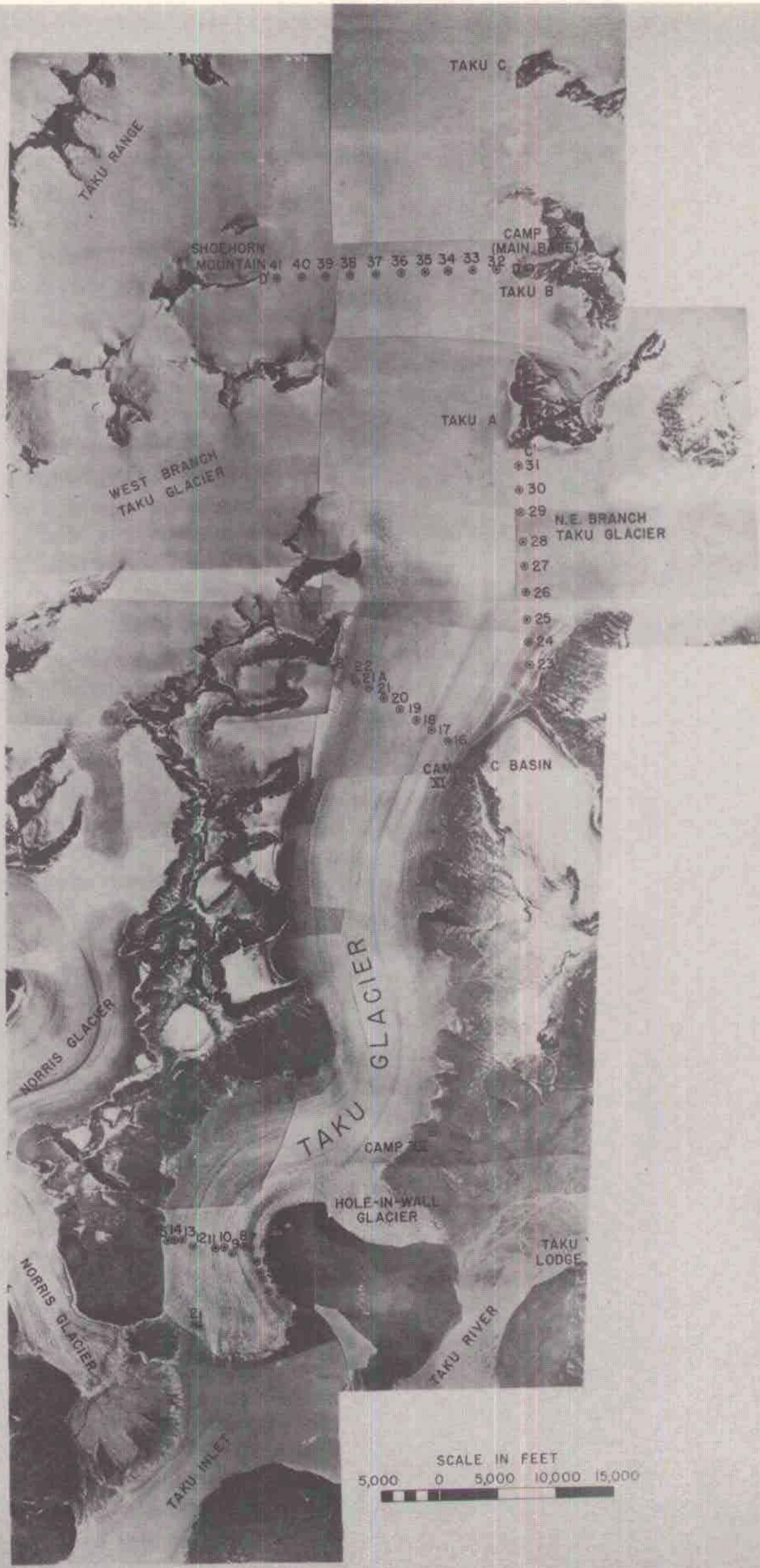

TAKU C
TAKU RANGE
CAMP
(MAIN BASE)
SHOEHORN
MOUNTAIN
41 40 39 38 37 36 35 34 33 32
TAKU B
TAKU A
WEST BRANCH
TAKU GLACIER
31
30
29
28
27
26
25
24
23
N.E. BRANCH
TAKU GLACIER
22
21A
21
20
19
18
17
16
C BASIN
NORRIS GLACIER
TAKU GLACIER
CAMP
HOLE-IN-WALL
GLACIER
TAKU
LODGE
NORRIS GLACIER
TAKU RIVER
TAKU INLET
SCALE IN FEET
5,000 0 5,000 10,000 15,000

FIG. 3

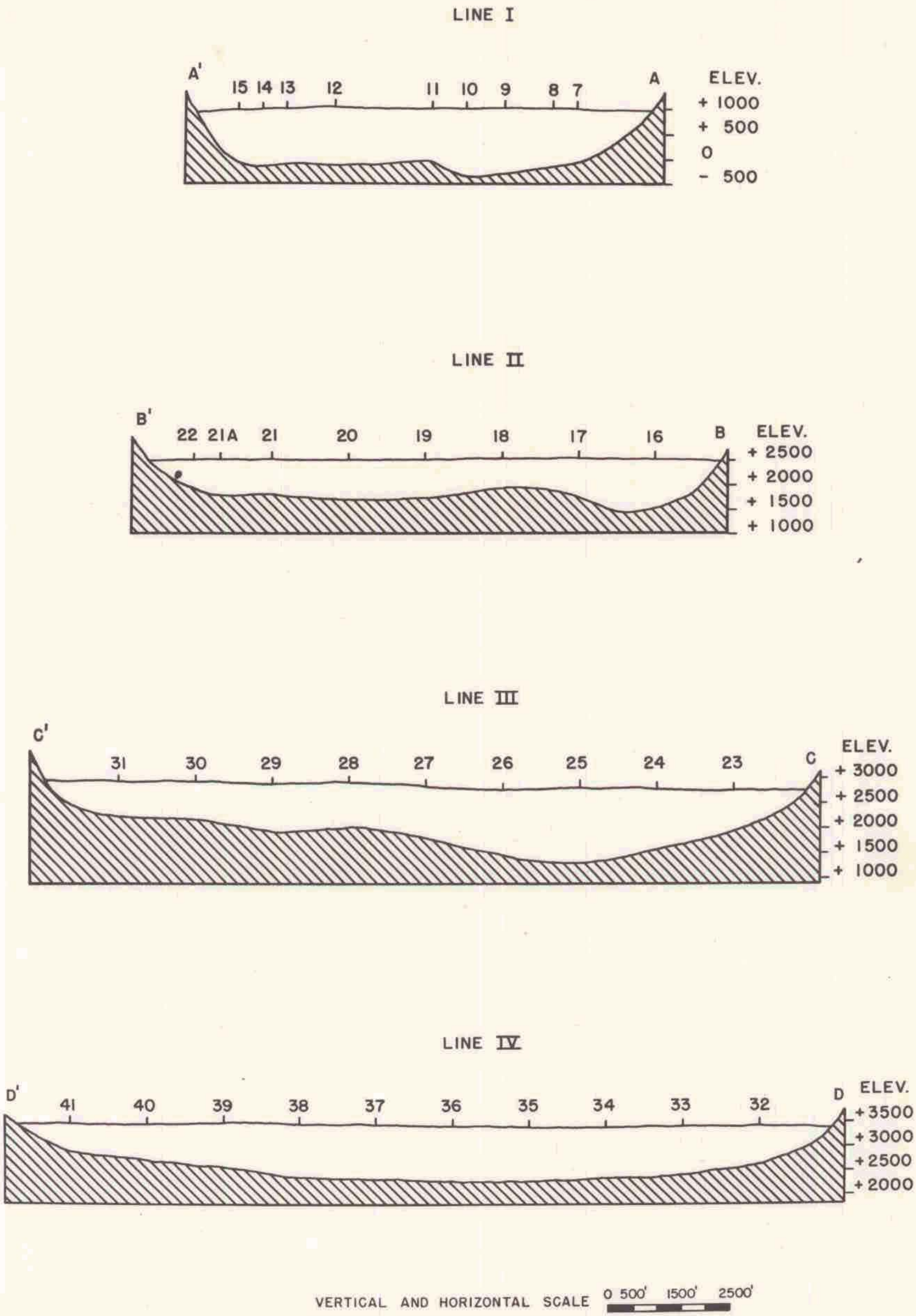
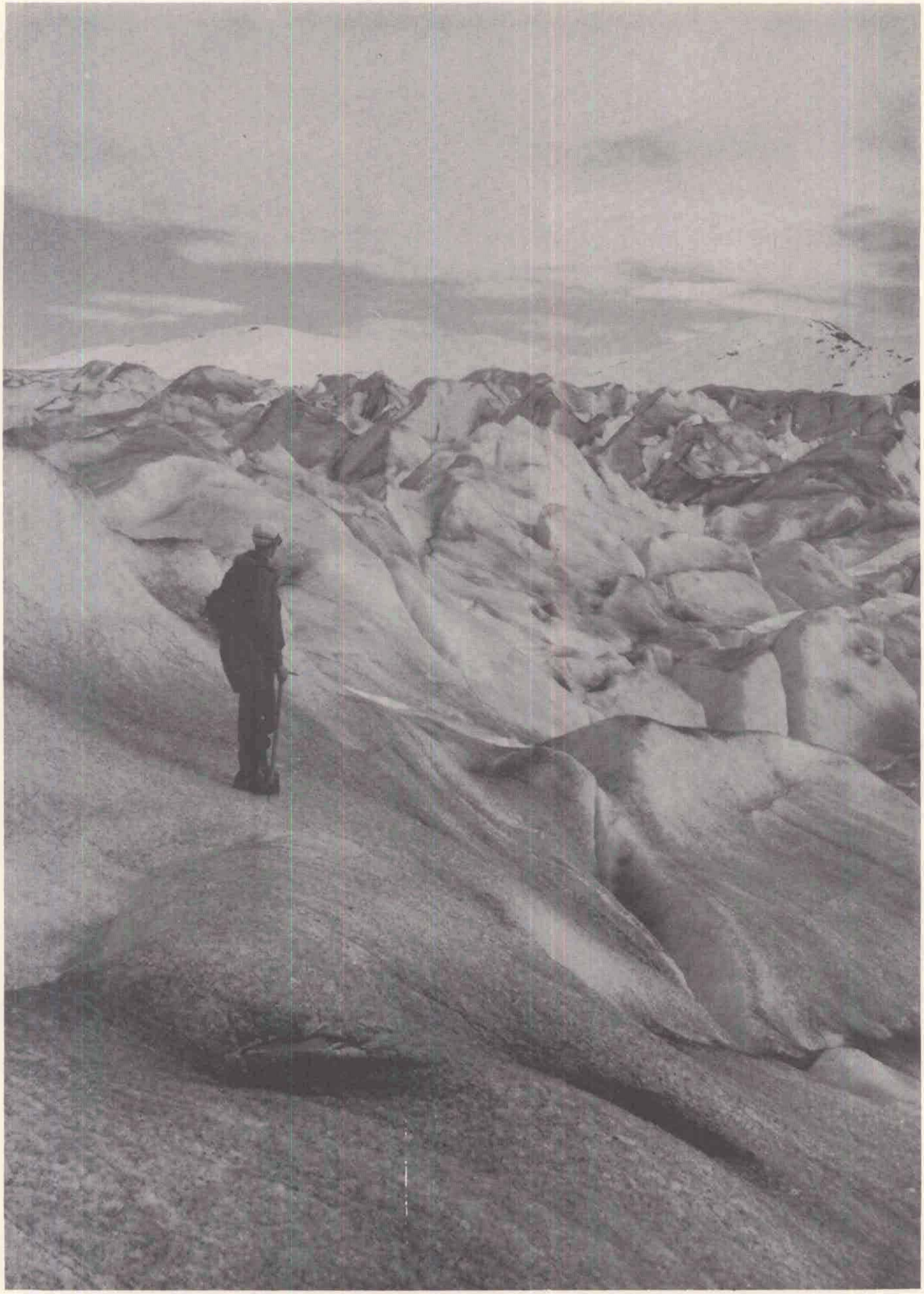
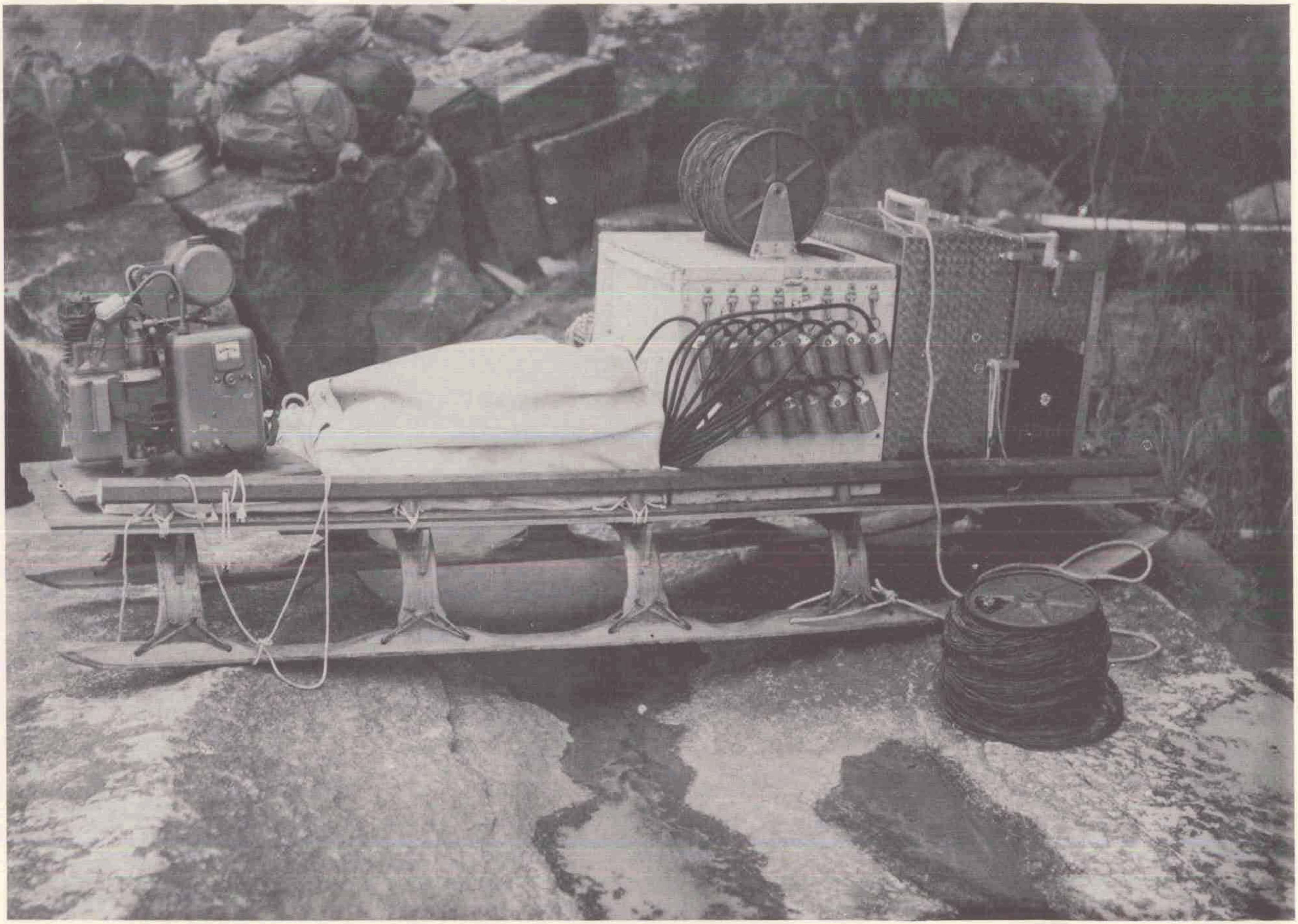

LINE I
A'
15 14 13 12 11 10 9 8 7
A
ELEV.
+ 1000
+ 500
0
- 500
LINE II
B'
22 21A 21 20 19 18 17 16
B
ELEV.
+ 2500
+ 2000
+ 1500
+ 1000
LINE III
C'
31 30 29 28 27 26 25 24 23
C
ELEV.
+ 3000
+ 2500
+ 2000
+ 1500
+ 1000
LINE IV
D'
41 40 39 38 37 36 35 34 33 32
D
ELEV.
+3500
+3000
+2500
+2000
VERTICAL AND HORIZONTAL SCALE
0 500' 1500' 2500'

FIG. 4

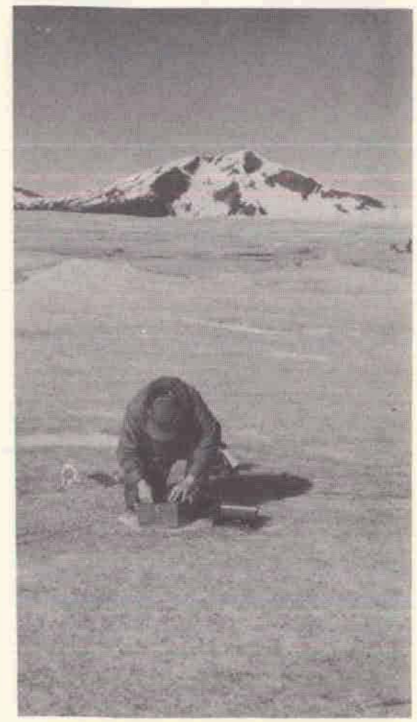


ROUGH ICE on LOWER TAKU GLACIER - A.W.HOLBEN in FOREGROUND.



SEISMIC EQUIPMENT NEAR FOOT of TAKU GLACIER

TERMINUS of TAKU GLACIER



Left: C.F.ALLEN and S.W.MILLER.

Middle: MAN-HAULING SEISMIC EQUIPMENT on TAKU GLACIER.

Right: SHOOTING STATION with RECORDING EQUIPMENT in BACKGROUND.

SEISMIC SET-UP BETWEEN CREVASSES on LOWER TAKU GLACIER.

S.W.MILLER and SEISMIC EQUIPMENT on LOWER TAKU GLACIER

EQUIPMENT NEAR CAMP XIA - NOTE SLEDGE-METER on REAR of SEISMIC SLED.