The Earthquake-Induced Slide on the Sherman Glacier, South-Central Alaska, and Its Glaciological Effects*#

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Abstract

The March 27, 1964 earthquake dislodged about 10^7 m^3 of rock from the east wall of a tributary glacier on the south side of the Sherman Glacier, 25 km northeast of Cordova, south-central Alaska. The debris moved as much as 4.3 km across gently-sloping surfaces to cover about 8 km^2 of the ablation zones of the two glacicrs with a layer 1 to 3 m thick; debris is also found up to 150 m high on the west wall of the tributary. In summer 1965 the debris overlay undisturbed winter 1963–64 snow. This and other evidence indicate that over most of the distance, the debris sheet was supported on an aircushion. The generation of the slide was favored by the presence of weak slightly metamorphosed and fractured strata (slates and phyllites) overlain by massive quartzites. The bedding was steeply dipping and nearly parallel to the original surface of the ridge. The main scar is about 600 m wide and over 700 m long in the direction of the slip. It follows the bedding and various fault planes that are almost perpendicular to the bedding.

The debris layer has reduced the annual ablation from between 3 and 5 m of ice to almost zero over more than half of the ablation zone, and the mass balance of the Sherman Glacier and its main tributaries has been changed from a slightly negative value to a positive one.

Some of the measurements of surface ice velocity and strain, made in 1965, appear to be anomalous and may indicate that the glacier was already responding by then to the change in regime that had started only seventeen months earlier. Small push moraines may also indicate that the glacier is beginning to advance.

I. Introduction

The Sherman Glacier (Fig. 1) is a relatively simple valley glacier, about 12 km long and 2 km wide, in the Chugach Mountains of south central Alaska, about 35 km northeast of Cordova. The glacier flows westward, falling in surface elevation steadily from about 1 000 m (3 300 ft) at the col leading to the Copper River valley, to about 160 m (525 ft) at the snout. The longitudinal surface slope is about 3° over most of the glacier, increasing near the snout to 6° or more. The surface is relatively uncrevassed, and travel on foot is easy.

The main glacier is fed by three major and two minor tributary glaciers from the north and by two major and three minor tributaries flowing from névé fields at altitudes up to 1 600 m in the mountains south of the glacier. These tributaries cause local disturbances in the pattern of surface ice velocities where they join the main ice mass, and produce small medial moraines, but until 1964, the glacier could be considered as a clean one, and only minor parts of the ablation zone were covered by rock debris.

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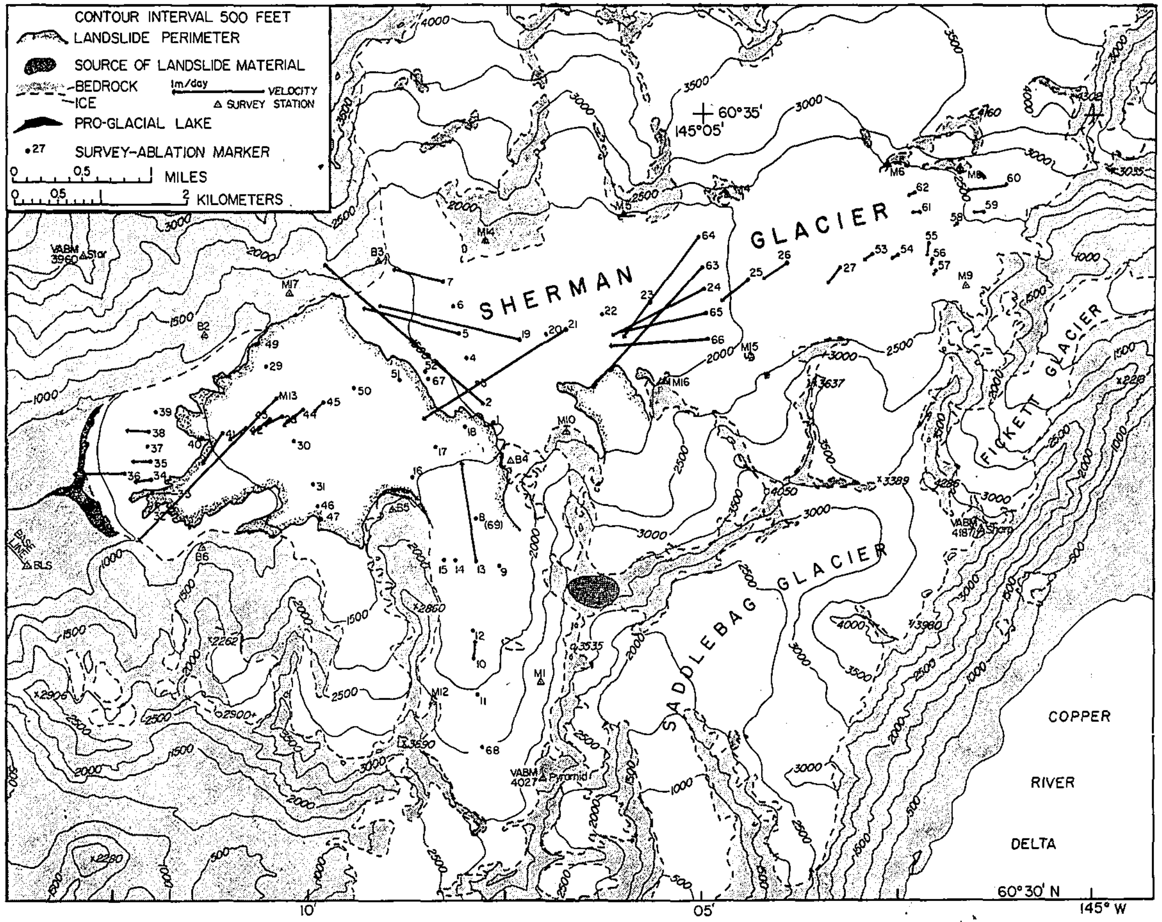

Fig. 1. Map of Sherman Glacier showing location of survey stations, movement markers and surface ice velocities at representative points. Extent of the debris slide is shown. (From U. S. Geological Survey Topographical Maps 1 : 63 360, Cordova C-3 and Cordova C-4 sheets, 1954)

On March 27, 1964 an earthquake of magnitude about 8.5 on the Richter scale occurred with its epicenter in the Prince William Sound area of south-central Alaska, within 100 km of the Sherman Glacier (Grantz and others, 1964). General accounts of the effects of the earthquake on the glaciers of the area have been given by Sater (1964), Post (1964), Field (1964), Ragle and others (1965), Tuthill (1966 a), and others. Snow avalanches were widespread in the area, but the total volume of material added to the glaciers was small and its effect on their regime is probably insignificant (Kachadoorian, 1964), and is not likely to be the cause of large glacier advances, as Tarr and Martin (1914) had suggested from their studies following the Alaska earthquake of 1899.

On the Sherman Glacier, however, (and to a lesser extent on the "Sioux" and other glaciers) (Tuthill, 1966) the earthquake released substantial rock slides and avalanches, which are having significant effects on the glacier regime. Glaciological studies on the Sherman Glacier were started in 1965 and are being continued now (summer 1966). From the results gained in these preliminary studies, a program will be formulated for the continued investigation of the glacier during the next decade.

The 1965 field work was undertaken with the support of the National Science Foundation (Grant GP-4396) and The Ohio State University. The field party comprised Mr. Cedomir Marangunic (Principal Investigator), and George Markarian and James Westwater (Field Assistants). Dr. Colin Bull (Supervisor) spent part of the season with the field team. A tent camp was established by helicopter at the eastern end of the debris slide, near the centerline of the glacier, at an elevation of 460 m (1 500 ft). The field work continued from July 3 to August 28, 1965. The 1966 work is again supported by the National Science Foundation (Grant GA-409) and The Ohio State University. The field party consists of Mr. Cedomir Marangunic (Principal Investigator), and James Westwater and Leslie Morris (Field Assistants). Most of the data reduction is being undertaken by Mr. Marangunic, under the supervision of Dr. Bull.

During 1965 some of the field work was done in cooperation with a party from Muskingum College, New Concord, Ohio, led by Mr. Samuel J. Tuthill, who was studying the glacial geology and some aspects of the animal ecology in the area between the Sherman and Sheridan Glaciers.

II. The Debris Slide

Most of the rock debris, which now covers a large part of the ablation zone of the Sherman Glacier, originated on the west face of a north-south ridge separating two of the tributary glaciers flowing from the south. The earthquake caused the collapse of a peak, initially with an elevation of 1 320 m (4 330 ft) at a time when there was a thick snow cover (Fig. 2). Most of the displaced rock fell to the west, and subsequently covered a large part of the tributary glacier on that side and a part of the ablation zone of the Sherman Glacier, as discussed below. Only minor amounts of the rock debris and the overlying snow fell toward the glacier east of the peak, and only small rock falls occurred elsewhere on the peaks surrounding the glacier.

Geologic setting

Most of the outcrops in the area are of metamorphic rocks. Typically hard, dark

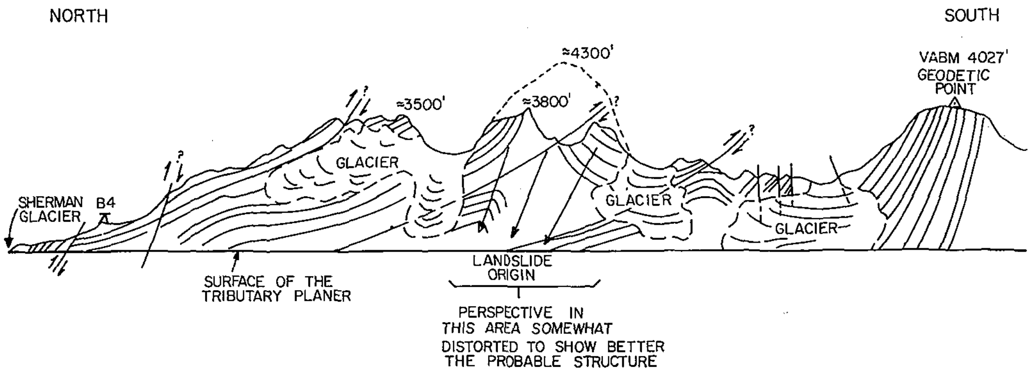

Fig. 2. *Sketch of ridge from which slide material originated, seen from* west side of tributary glacier. Scale is distorted to allow geological structure to be shown more clearly

gray fine-grained quartzite, with some feldspathic and micaceous constituents, occurring in layers up to about 1 m thick, is intercalated with thin layers of a dense, homogeneous black slate, that grades in places to a phyllite. In the ridge from which the rock fall originated, the total thickness of the slate is very small, but in the hillside north of the snout of the glacier, the total thickness exceeds 100 m, most of it lying at the base of a quartzitic series, which has a total thickness exceeding 700 m.

South of the snout of the Sherman Glacier a granitic pluton over 2 km in diameter crops out.

In the northern half of the ridge containing the collapsed peak, the bedding strikes approximately east-west. The dip is to the north (Fig. 2), being gentle at the northern extreme of the ridge and becoming increasingly steep southward toward the collapsed peak. The structure of the collasped peak itself was almost certainly a single asymmetrical fold, but highly unstable surfaces and thick snow cover precluded a satisfactory field examination during summer 1965. Farther south, near Pyramid Peak, overlooking the head of the tributary glacier, the dip of the bedding is almost vertical.

Near the northern end of the ridge a fault plane strikes east-southeast and dips about 80° to the north. Farther south along the ridge are several other faults, probably closely parallel to the first mentioned.

The height of the peak was reduced by the rock fall from approximately 1 320 m (4 330 ft) to about 1 160 m (3 800 ft). The main scar is concave and is about 600 m wide and over 700 m in the direction of the slip, which is dominantly toward the northwest. Near the bottom of the scar the slope is about 45°, increasing to nearly vertical at the top. The scar plane was not visited by the 1965 field party because it appeared to be dangerously unstable, several minor rock falls from it having occurred since the March 1964 earthquake.

Another and much smaller rock fall occurred from the same ridge but south of the collapsed peak. Material from this moved down the tributary glacier to join with that from the main source. An examination of this area of the tributary glacier should give information on the time relationship of the two slides, but so far a thick snow cover on the debris has prevented this work.

Distribution and composition

The debris from the rock falls now covers part of the tributary glacier and approximately half of the area below the balance (firn) line at about 500 m (1 640 ft) on the Sherman Glacier, a total area of more than 8 km^2 (Fig. 1).

Debris from the fall also is found on the ridge west of the tributary glacier, at altitudes up to 643 m (2 110 ft), approximately 150 m (490 ft) above the level of the tributary glacier on the line between this western ridge and the collapsed peak. It is noticeable that in most places the debris on this ridge had been deposited without significantly disturbing the original vegetation, but that on the eastern slope of this western ridge, just above the level of the tributary glacier, the surface had been extensively fractured by a very strong impact.

The slide material consists mainly of quartzite, slate, phyllite and some greywacke, along with minor quantities of soil and vegetation. Initially, the rock debris was probably mixed with at least an equal volume of snow, but this had largely ablated by July 1965.

The particles in the slide material range from clay size to boulders 30 m in diameter; the average diameter is probably about 30 cm.

During the 1965 field season only a short time could be devoted to studies of grain size and compositional variations in various parts of the debris sheet. Some of these studies, and detailed examinations of the geology of the ridge from which the material originated, are being undertaken this year (1966).

Over most of the debris sheet on the glacier there are obvious changes in the average particle size of the debris from one place to another. Along the direction of flow are stripes, up to 20 m wide and several hundred meters long, in which the maximum diameter of particle is 10 or 15 cm. In other stripes nearly all of the rock volume is in boulders more than 70 cm across. To some extent the particle size reflects the composition of the material in the stripes; slate and phyllite are usually broken into small pieces, whereas quartzitic rocks occur as large boulders, but in the separate stripes the compositional differentiation is not as complete as is the particle size.

The thickness of the debris cover is about one meter on the western and northwestern margins and probably averages a little more than one meter over most of the area of the slide; the greatest measured thickness was in a section exposed in a newly-opened crevasse near the center of the tributary glacier west of the collapsed peak. Here the debris was 3 to 3.5 m thick, but it may be thicker nearer the source of the rock fall. The total volume of the rock in the slide has been estimated previously as 2×10^9 ft^3 (6×10^7 m^3) (Shreve, 1965) and 1×10^7 m^3 (Field, 1964). Our measurements give a volume close to Field's estimate.

The material of the slide is extremely angular and the "striking three-dimensional jig-saw effect" (Shreve, 1965) in the medium and large boulders indicates that there was little change in relative position of the boulders during the movement from their initial positions on the ridge to their final resting place on the glacier, up to 5 km away. In the slate and phyllite cobbles and boulders most of the surfaces are cleavage and bedding planes that usually show some weathering. With the quartzites and other rocks a larger proportion of the surfaces are completely fresh, but with all rock types the number of marks indicating impact between boulders during transit is quite negligible, except in some areas near the distal edges of the slide.

Mechanism of emplacement of the slide

In crossing the Sherman Glacier some of the rock debris traversed distances greater than 3 km, down slopes as small as 1.5°. To account for the low coefficient of friction, Field (1964) suggested that the rock debris "joined with snow as it fell to form a mixture which then behaved somewhat like a mudflow. Friction presumably caused melting, which further lubricated the mass and reduced the internal and basal friction."

Shreve (1965 and in preparation) on the other hand considers that a layer of compressed air constituted the lubricating layer, and this hypothesis is supported by nearly all of our field observations. The absence of impact marks and the jig-saw puzzle effect have been mentioned above. In addition, it is most noticeable that the ridges and depressions in the surface of the slide are aligned in the direction of movement of the debris, and are not transverse to it as they would probably be with a mudflow type of mechanism.

The fan shape of these surface corrugations is clearly shown in the oblique aerial

Fig. 3. The debris slide on the Sherman Glacier, from above north wall of the glacier. Aerial photography by Austin S. Post, U. S. Geological Survey

photograph (Fig. 3) in which it can also be seen that the debris sheet conformed to the surface features of the glacier at the time of the earthquake. The longitudinal ridges and troughs of the glacier surface and its medial moraines produce similar features on the surface of the debris slide, and even small depressions (of the order of 100 m^2) in the glacier surface remained unfilled.

Only at the edges of the slide are these flow lines disrupted. At the northeastern edge of the slide is an area about 200 m wide in which debris has accumulated in small irregular piles up to 10 m high. All of the sections dug into these hills showed a snow core, covered by a thin layer of debris material. Evidently in these distal parts of the debris sheet the lubricating air layer had escaped but the horizontal momentum of the debris was still sufficient to bulldoze into piles the snow on the glacier surface. A similar bulldozed zone exists in nearly all the other parts of the edge of the debris sheet, but elsewhere the bulldozed zone is narrower than at the northeastern margin.

In 1965 eight sections were dug through the debris sheet at points distributed over the width of the glacier, but well away from the edges of the slide. In all of the sections except one, the rock debris overlay a firnified snow layer between 30 cm and 1 m thick and this, in turn, overlay the ablation surface of the glacier ice. In at least four of the sections dirty layers and wind crust surfaces in the firnified snow were almost horizontal and undistorted, and had not been disturbed during the passage over them of the rock debris now lying farther down the appropriate flow line, or during the deposition of the rock material now lying over the snow. One such section is shown in Fig. 4. The ice surface is the level of the glacier at the end of the 1963 ablation season; the overlying snow with its wind crusts and dust layers were deposited on the glacier between September or October 1963 and the time of the earthquake, March 1964. During the sixteen months of burial normal diagenetic processes have been reinforced by compression from the overburden to increase the density and grain size of the snow, and some of the snow has disappeared by melting.

Because this firnified snow layer underlying the debris remained undisturbed, even along the flowlines behind large boulders, it is difficult to envision any transport mechanism for the sheet other than one of flotation on a layer of compressed air. For the main part of the debris sheet the layer of air was probably trapped beneath the sheet of material as it shot over the low ridge on the west side of the valley containing the tributary glacier.

It is not certain whether the movement of the debris across the tributary glacier was assisted by the presence of a trapped lubricating air layer, but the movement was certainly a rapid one. A most interesting feature is the existence of an isolated area about 200 m wide and 500 m long on the east side of the tributary glacier, north of the point at which the landslide met the glacier, that is completely clear of rock debris (Fig. 1). No worthwhile explanation can be given yet.

Near the edges of the debris sheet on the Sherman Glacier there is evidence of other kinds of flow of the material, but these are local and did not contribute significantly to the total amount of transport. The bulldozing effect seen at many parts of the edge of the slide was almost certainly the last part of the main forward movement. On the tongue of material that extends farthest westward toward the snout of the glacier, and

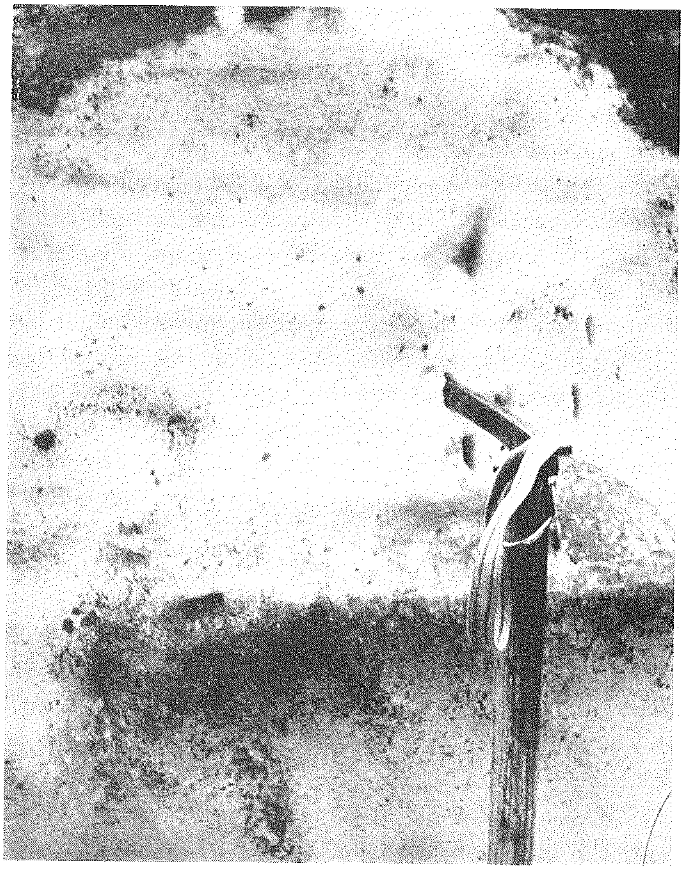

Fig. 4. Section through the debris slide, near centerline of glacier, July 25, 1965, showing rock debris oberlying undisturbed winter 1963-64 snow, lying on glacier ice

elsewhere at the margins of the slide, a series of crescentic steps and fractures occur, which indicate that some flowage, of a more normal solifluction or downslope-creep type, took place after the main emplacement.

Causes of the slide

An authoritative statement of the causes and mechanism of emplacement of the landslide must await a great deal more field work, but some points are obvious. On the west side of the collapsed peak, lithologic, structural and topographic factors were all favorable for a massive slide. Thin beds of weak and fractured slate and phyllite were overlain by beds of unfractured quartzite. The bedding planes were almost parallel to the steep western surface of the peak, and various fault planes are almost perpendicular to the bedding. At the time of the earthquake, the rock surface was heavily loaded with the winter's accumulation of ice and snow, and this may have helped in a minor way to initiate the slide.

Glaciological effects of the debris slide

Thin layers of dust and small-size rock debris on the surface of a glacier increase the absorption of solar radiation and the quantity of heat energy transferred to the surface. With temperate glaciers this results in increased melting. The main effect of a thick layer of rock debris is to insulate the glacier surface from the main sources of heat energy, solar radiation and convective transfer from the air above the surface, so that ablation is greatly reduced. Nearly everywhere on the part of the Sherman Glacier and its tributary affected by the slide, the cover is thick enough so that the insulating effect is much more important than that of the additional absorption. As the slide covers more than 40 % of the ablation zone of the glacier, and the regime is a vigorous one, with high values of gross accumulation and ablation, it is apparent that significant changes in the glacier will occur in the next few years. Thus, the situation offers an unusually good opportunity to examine the changes produced over the whole of a glacier system by a large change in the regimen of a part of it.

Unfortunately, no work at all had been done on the glacier before the 1964 earthquake, so that none of the parameters are known for assessing the regime at that time. It was not possible to start these glaciological measurements in summer 1964 but we believe that the response of the glacier to the changes between March 1964 and July 1965 was small, so that the summer 1965 data (especially of surface velocity) may be used as base values for comparison with values obtained in subsequent years.

Surface ice velocities

At the beginning of the field season a series of 17 survey stations was erected along the margins of the Sherman Glacier and the debris-covered tributary glacier on the south side (Fig. 1). In addition, Dr. W. O. Field, of the American Geographical Society, working with Mr. Tuthill's party, erected two other survey stations overlooking the snout of the glacier, laid out and measured a baseline on the outwash plain west of the glacier, and established a number of photo-observation points from which the appearance and position of the snout of the glacier can be recorded regularly in the years ahead. All of the survey stations are marked with guyed and flagged 10 cm × 10 cm posts about 1.5 m long, painted red, and inscribed with the station number. Locations of the stations are shown in Fig. 1.

About 70 aluminum stakes, 3 m long, were implanted in a central longitudinal line and four transverse lines on the Sherman Glacier, and on one longitudinal and two transverse lines on the debris-covered tributary glacier. One survey of the markers was made in the period July 23 to August 10, being often interrupted by bad weather. A second survey was made between August 23 and August 28. From each of the survey stations the rounds of angles included at least two of the clearly distinguishable peaks marked on the existing U. S. Geological Survey maps (Cordova C-3 and C-4 sheets; 1 : 63 360). At most of the survey stations, black and white photographs, covering an 180° panorama, were taken with a 135 mm focal length camera mounted on the theodolite tripod.

Because the period between the two surveys varied so much from marker to marker, and the velocity during this period may not be the same as the average for the whole year (Lliboutry, 1965, p. 624), the results have been expressed in terms of movement per day. A representative set of values is shown vectorially in Fig. 1.

The velocities recorded over this short period vary from a few centimeters per day on the transverse line near the head of the glacier, to about 2 m per day near the center of the glacier at the elevation of the firn line. Along the lowest transverse line the velocities average 25 cm per day, compared with an average of about 20 cm per day at markers 41, 43, 44, and 45, 1 to 2 km farther up-glacier and near the middle of the debris slide. The possibility cannot be discounted that these markers on the debris slide have been affected by settling of the debris and by anomalous lateral movement of individual boulders (as is almost certainly the case with M–13), but if these velocities are confirmed by the resurvey in July 1966, it will indicate that already by summer 1965 the snout was responding to the increased load farther up-glacier. Such an increase in velocity toward the snout would produce a forward movement of the snout. Dr. W. O. Field and Mr. Lee Clayton, working with the Muskingum College party, examined a ridge of material 0.5 to 1 m high in the outwash in contact with a gently sloping part of the terminus of the glacier, and considered it probably to be a small push moraine, of the kind that could be produced in such wet and unconsolidated material by the forward movement of the snout.

A few other markers in Fig. 1 show apparently anomalous velocities (for example, numbers 2 and 55), but these may be due entirely to errors in the survey, carried out sometimes in appalling weather conditions and over too short a time base for very reliable measurements.

Strain nets

Markers for the measurement of surface strain were erected in groups of five at three places on the glacier: near the middle of the landslide, near the balance line up-glacier from the slide, and near the head of the glacier. Each network was surveyed twice during the 1965 field season; the interval between measurements was considered too short to obtain very reliable values for strain rate, although the results obtained are acceptable by normal tests of consistency.

For the strain net in the slide, taping of distances between markers was very difficult, so one length only was measured and the survey was completed by theodolite triangulation. With the other two nets, distances were measured by flat-taping at a fixed tension with a 100 m steel tape.

At the head of the glacier the longitudinal strain rate was an extension of 0.000396 per day, and near the firn line it was 0.000180. In the slide the strain rate was still an extension of about 0.0001 per day, although this location is well within what was the ablation zone of the glacier before the debris slide was deposited and would therefore be a zone of longitudinal compression. If the 1966 measurements confirm this strain rate, this will also indicate that by summer 1965 the glacier was already responding to the changed regime produced by the slide.

Accumulation and ablation measurements

The length of the markers used for surface velocity and strain measurements was recorded on erection and at least once subsequently during the 1965 field season. At all of the markers on the ice surface, the surface was ablating by an amount increasing from about 2 cm per day at the head of the glacier, to about 5.5 cm per day near the

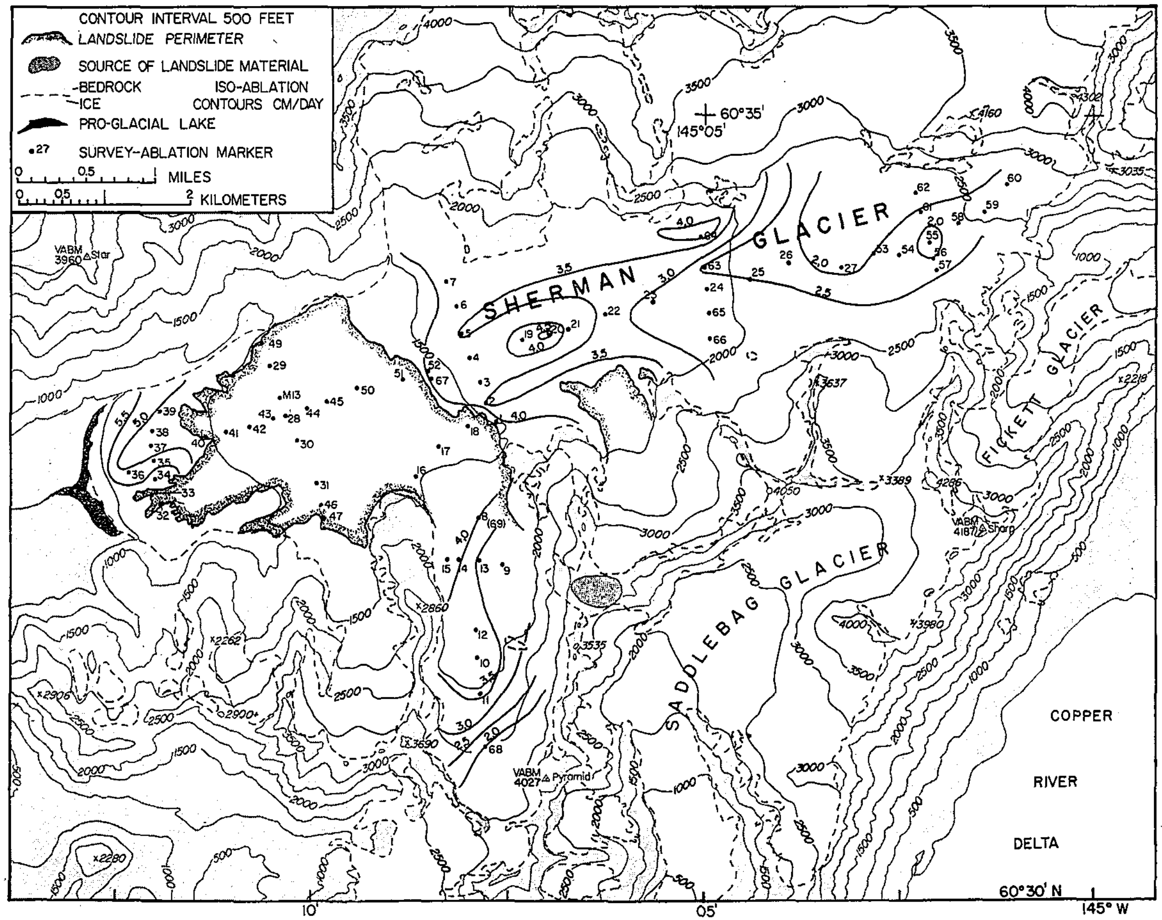

Fig. 5. Map of Sherman Glacier showing lines of equal ablation (in cm of ice per day) during summer 1965. (*From U. S. Geological Survey Topographical Maps* 1 : 63 360 Cordova C-3 and Cordova C-4 sheets, 1954)

snout (Fig. 5). In the accumulation zone of the glacier, above about 550 m (1 800 ft) elevation, some of this increase in length of the markers represents normal compaction in the upper layers of the snow. Not enough values were obtained for the change of the snow density during the season to allow a good assessment to be made of the net loss of material.

Around the debris slide the ablation of ice was about 4 cm per day near 460 m (1 500 ft) elevation and about 5 cm per day at 180 m (600 ft). Most of the markers set in the debris slide are supported by rocks and do not penetrate far into the glacier ice. Consequently the ablation of the ice does not alter the length of the markers above surface level and the ablation there may be obtained only from changes in the absolute elevation of the end of these markers. Vertical angles from several of the survey stations to each of the markers were measured twice during the season, but the estimates of the small rate of ablation are unreliable over such a short time, primarily because of the large and unknown changes in atmospheric refraction that can occur between one survey and the next.

By the end of the 1965 ablation season, the debris slide was on a pedestal about 10 m high. Measurements of the glacier thickness were deferred until the 1966 season, but the average over the width of the glacier in the debris slide region is likely to be about 200 m, so that the slide is producing an increase in thickness, and in shear stress at the glacier bed, exceeding 2 % per year. Repeated measurements of surface ice velocities and glacier surface elevations in 1966 and later years should give valuable direct data on the variation of strain rate with stress in glacier ice.

These preliminary ablation measurements (Fig. 5) show an anomalous area extending about 1.5 km up-glacier from the eastern margin of the slide. During the field season it was noticeable that with high-level westerly winds the cloud level was often closer to the surface in this area than elsewhere on the glacier. This may be related to the additional absorption of solar radiation in the area of the slide, and the consequent additional heating of the lower layers of the atmosphere. Valuable information could be obtained from measurements of temperature and humidity from low-level tethered balloons at a few localities on the glacier.

A study was made of the snow stratigraphy to a depth of 9.64 m as revealed in the wall of a crevasse in the accumulation zone, at 600 m elevation.

Based on profiles of density, grain size, and hardness, the depths of the 1964 and 1963 summer surfaces can be given with confidence, and those of earlier years with less certainty. At this elevation the net accumulations for 1964–65 and 1963–64 were respectively 196 and 160 g/cm^2.

Shallow pits dug at other points near the head of the glacier give similar values for the 1964–65 accumulation.

Values of the 1965–66 net accumulation at many points are being obtained directly from the stake measurements and surface density measurements.

III. Meteorological Observations

During the 1965 field season, two meteorological instrument shelters were maintained. One of these was near the camp site at about 480 m elevation and close to the eastern end of the debris slide. The second was at 510 m elevation on the hillside 1.5 km north of the camp. Both shelters were equipped with thermohygrographs, hygrometers and standard thermometers. A totalizing rain gauge, hand anemometers and psychrometers were also used at the slide station.

The instrumental observations between July 5 and August 22 are summarized as follows:

		Slide Station	*Hillside Station*
Maximum temperature	(°C)	13.9 (July 30)	20.0 (Aug. 7)
Minimum temperature	(°C)	2.8 (July 24, 25; Aug. 12, 13, 21)	4.2 (July 24, 25)
Mean maximum temp.	(°C)	9.0	12.8
Mean minimum temp.	(°C)	4.0	8.3
Overall mean temp.	(°C)	6.4	9.5
Mean relative humidity	(%)	87	78

At the camp site, the rainfall between July 5 and August 19 was 22.4 cm. The average wind speed during this period was 2.2 m/sec and the wind usually blew down-glacier from the east or northeast. The mean cloudiness was greater than 6/8, most of the cloud being stratus. Usually the cloud formed a complete cover, moving up-glacier from the west or southwest, but even when low cloud moved in this direction, the wind at the glacier surface was usually down-glacier. Because of its relatively simple topography, this might be a good area for detailed studies of valley and mountain winds in a glaciated area (see Buettner and Thyer, 1965).

During summer 1966 a third instrument shelter, at about the same elevation, is being maintained on the glacier well away from the slide. The data from the three stations should allow an assessment to be made of the effect of the slide on the summer climate in the ablation zone of the glacier.

IV. Conclusions

Using the somewhat sparse data gathered in the first field season (1965), it is calculated that the total accumulation over the Sherman Glacier and its tributaries in 1964–65 was about 1.7×10^8 m^3 of ice, while in the absence of the debris slide the total ablation would have been 1.8×10^8 m^3 of ice. The reduction in the annual ablation due to the presence of the slide was 0.4×10^8 m^3 or more, enough to change the mass balance from slightly negative to positive. If the debris sheet were to remain equally effective in preventing the ablation of the underlying ice in the years ahead, and other factors remained unchanged, the Sherman Glacier could expand by more than 1 km before the ablation zone is of sufficient area to allow equilibrium to be re-established. Such an advance would contrast with the slow retreat of the snout that has continued since about 1930. Then the glacier was about 500 m farther forward than in 1964; 375 m of the retreat has occurred since 1950 (Clayton and others, 1966).

The melting of the debris-free snout west of the slide will continue at more than 5 m of ice per year, so that even with an advance of the snout, pushed forward by the increased relative ice thickness up-glacier, the debris will soon start to fall from the increasingly-steep front. This will be an excellent opportunity to study the mode of formation of the terminal moraines (Field, 1964).

After an advance of the snout, the debris-covered part is likely to become separated from the rest of the glacier, largely because the ablation of the debris-free part east of the slide will continue at its present high rate. This stagnant mass of debris-covered ice will melt slowly in place. Again excellent opportunities are provided for both glacial geologists and biologists to study the development of knob and kettle topography and its colonization by flora and fauna (Tuthill, 1966 b).

The debris slide on the Sherman Glacier provides an unusually good laboratory for glaciological, glacial geological and ecological studies, and will be worth increased attention by these and other specialists in the coming decades.

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