CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Geological Survey of Canada

GEOLOGY AND LIMNOLOGY OF KLUANE LAKE, YUKON TERRITORY I PRELIMINARY ASSESSMENT

Prepared for

TERRAIN SCIENCES DIVISION
GEOLOGICAL SURVEY OF CANADA
OTTAWA, CANADA

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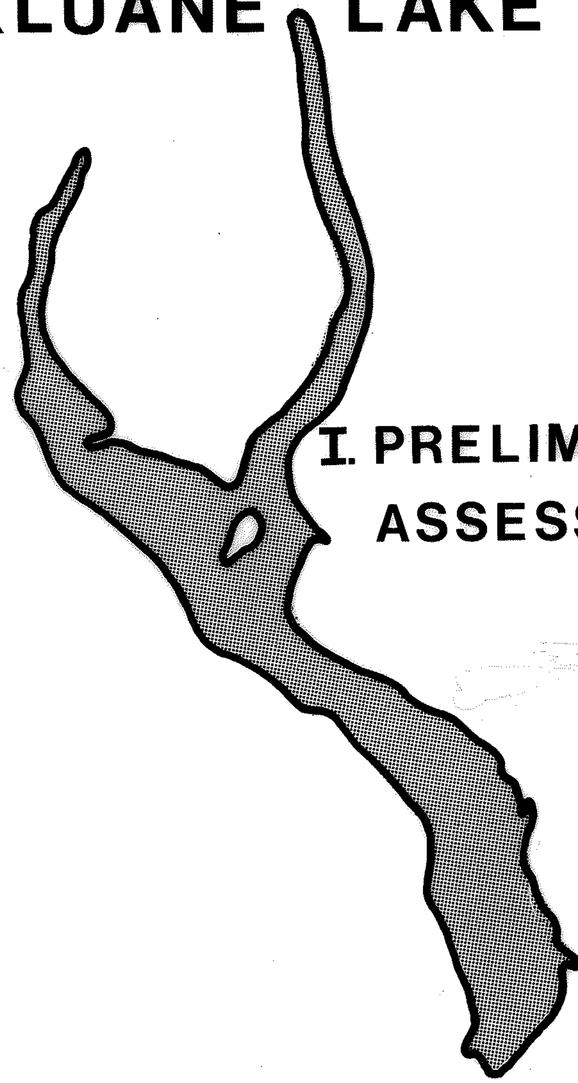
1.0 INTRODUCTION

1.1 Setting

Kluane Lake is the largest lake in the Yukon Territory and lies adjacent to the Alaska Highway between mile post 1055 and mile post 1095. The main body of the lake has a length of 56 km. (35 miles) and averages about 4.8 km. (3 miles) in width. Two arms, Brooks Arm and Talbot Arm, extend north of the main lake away from the Alaska Highway (Fig. 1); the former is 14.5 km (9 miles) in length and the latter 32.2 km. (20 miles) in length. The lake waters are clear except near the southern end where the Slims River discharges its sediment-laden water; the Slims River is the major source of water for Kluane Lake. Numerous high-gradient small creeks, e.g. Congdon Creek, Nines Creek, Bock's Creek, Lewis Creek and Halfbreed Creek, flow directly out of the Kluane Ranges across alluvial-fans into the southern edge of Kluane Lake (Fig. 2). The major creeks flowing into the northern edge of Kluane Lake, e.g. Brooks Creek, Talbot Creek, Raft Creek, Gladstone Creek, Cultus Creek and Christmas Creek, are all incised in drift-filled valleys. Much of the northwestern end of the lake is shallow, but the eastern end deepens to at least 82 m. (270 ft.). Kluane Lake discharges through the Kluane River past the toe of the Duke River alluvial-fan at its northern end into the Yukon River drainage system.

GEOLOGY AND LIMNOLOGY OF KLUANE LAKE



I. PRELIMINARY ASSESSMENT

TERRAIN SCIENCES DIVISION
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OTTAWA CANADA

TERRAIN ANALYSIS
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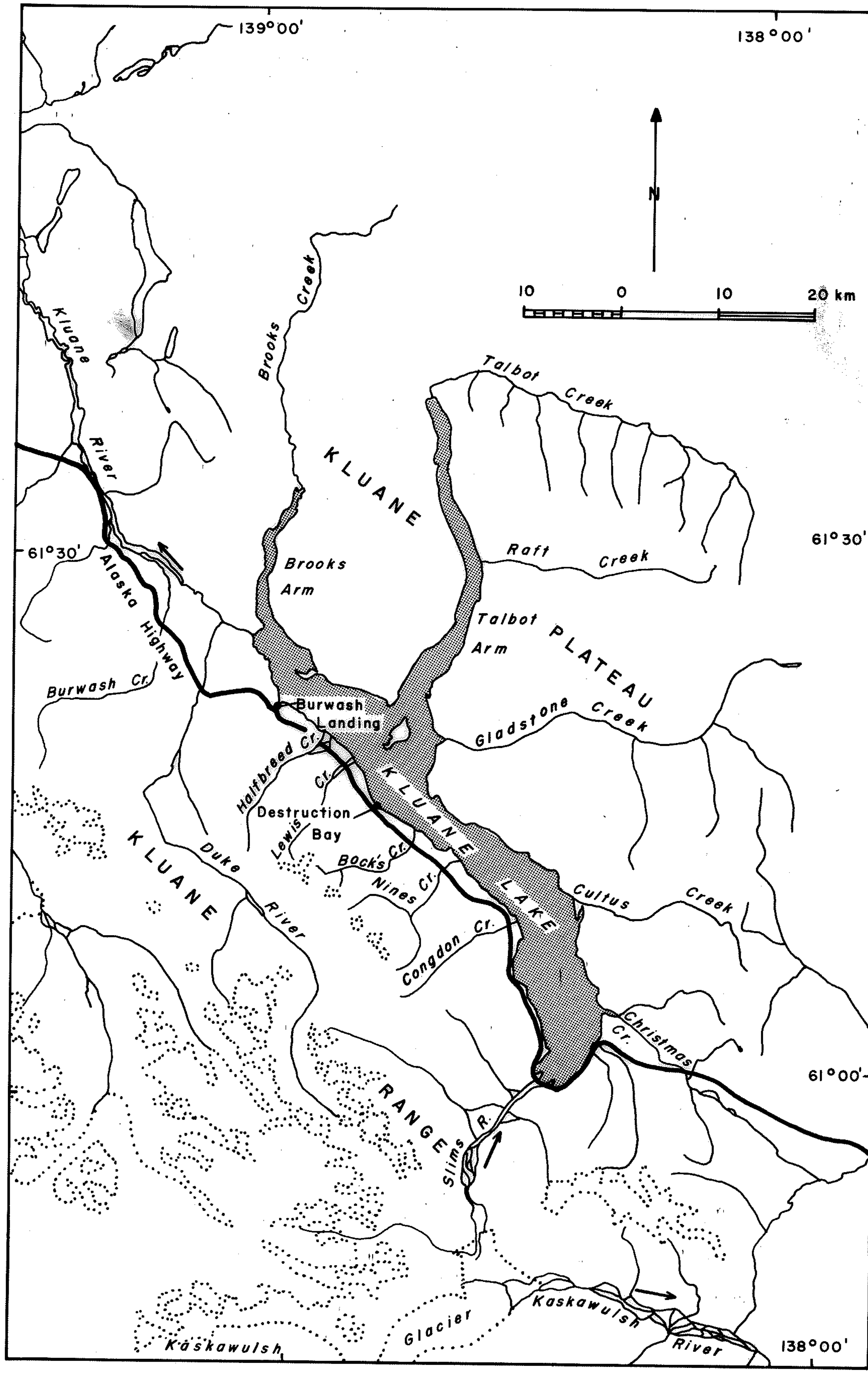

Figure 1. Location Map

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Figure 2. Southern end of Kluane Lake. Congdon Creek alluvial-fan on right, Slims River delta in far left, and Cultus Bay in foreground.

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Figure 3. Cabin cruiser being launched at Bayshore, November, 1977.

Recently, Foothills Pipe Lines (Yukon) Ltd. has proposed to construct a large-diameter gas pipeline through the Yukon Territory paralleling the Alaska Highway. The present proposed alignment parallels the southwestern edge of Kluane Lake skirting its southern end at the Slims River bridge: in doing so, it crosses slopes vulnerable to landslides, a delta having unknown liquification potential and Kluane National Park. To avoid the above phenomena, a possible crossing of Kluane Lake has been proposed, approximately 14.5 km. (9 miles) north of its southern tip from near the mouth of Congdon Creek to south of Cultus Creek. Further serious consideration of a Kluane Lake crossing will require knowledge of the bottom roughness, sediment composition and characteristics, sedimentation patterns and roughness of the underlying basement in the area of the potential pipeline crossing.

Because of Kluane Lake's potential recreational value, both as a scenic attraction and as a source of game fish (mainly lake trout), and because of Kluane Lake's importance to the total ecology of the region, it is believed that some basic knowledge of the lake's main sources of water and sediment, sedimentation patterns, water quality, water circulation, configuration and composition of shorelines, and the nature of its bottom material is necessary to assess any impact that pipeline construction or other developmental activities may have on the Kluane Lake ecosystem. This includes effects of construction and possible introduction of pollutants to (1) the creeks flowing into the southern edge of Kluane Lake, (2) the Slims River if the pipeline skirts Kluane Lake, and (3) Kluane Lake directly if the pipeline crosses Kluane Lake.

1.2 Objectives

The first objective of this study is to obtain an approximation of bottom roughness, sediment composition, sedimentation patterns and roughness of the underlying basement in the southern part of Kluane Lake near the potential pipeline crossing through shallow seismic investigations, review of existing data, and interpretation of these shallow seismic results. The requirements for further seismic investigations and locations for coring in the southern part of Kluane Lake will be determined from the results of the initial investigation.

The second objective of this study is to design a program that would establish the main sources of water and sediment, sedimentation patterns, water circulation, configuration and composition of shorelines, and the nature of bottom material of Kluane Lake. Existing data is to be assembled and used as a guide for the proposed program. This program is designed in order that those physical parts of the Kluane Lake ecosystem that would be most severely affected by developmental activities will be most closely scrutinized.

Finally, an estimate of the cost of the above programs will be computed and produced as a second report.

2.0 APPROACH AND METHODOLOGY

2.1 Preparation for Field Work

Shoreline geology and available bathymetric data was reviewed prior to field operations and used as a guide to the positioning of lines for shallow seismic. The geology was interpreted through air photos where the present data was inadequate.

2.2 Field Work

Shallow seismic geophysics was run in the southern part of Kluane Lake in early November of 1977. In spite of inclimate weather conditions consisting of -15°C temperatures and high gusty winds (Appendix A), 70 km. (43.5 miles) of surveying was completed. Only during periods of relative calm was it possible to operate, as capsizing was a consistant hazard with freezing wave splash. Nearshore navigation was prevented in some areas because of ice formation adjacent to the shore and because of low water levels.

Survey work was carried out from a 7.3 m. (24 ft.) cabin cruiser (leased from Kluane Lake Cruises, Destruction Bay) (Fig. 3). Two units, a Raytheon Model RTT 1000 (7 Khz) Sub-Bottom Profiling System (leased from Kenting Exploration

Services Limited, Calgary), and an Atlas-Deso 10 (33 Khz and 200 Khz) Sub-Bottom Profiling System (leased from Marinav Corporation, Ottawa) were used. A transducer from each unit was hung over the side of the boat with the signal processors and recorders spaced around the perimeter of an unheated open rear cabin. A Motorola Mini-Ranger Navigation System (leased from Kenting Exploration Services Limited, Calgary) consisting of shoreline transponders at three locations (Fig. 4) and a transmitter-receiver and console on the boat was used for fixing field positions. Fixes were taken every 5 minutes. Of the 70 km. (43.5 miles) of surveying, 65 km. (40 miles) was completed with proper navigational control, and 5 km. (3 miles) was run without navigation as a shakedown for the equipment.

2.3 Office Studies

Shoreline geology, bathymetric data and limnologic data from Kluane Lake, and hydrologic data from Slims and Kluane Rivers was collected and assembled from government libraries, company files and air photo interpretation. All seismic records were interpreted, and based on these interpretation maps were produced showing bathymetry, basement relief, and thicknesses of various sediment units. An outline of further investigations required to completely detail bottom roughness, sediment composition and characteristics, rates of sedimentation, sedimentation patterns and the nature and roughness of the basement in southern Kluane Lake and the cost of these investigations was completed, based on rates given by reputable geophysical sub-contractors.

A study strategy was developed for the delineating of the basic physical elements of the Kluane Lake ecosystem, mainly sources of water and sediment, a water budget, turbidity patterns, water chemistry, temperature profiles, water circulation, sedimentation patterns, configuration and composition of shorelines, and the nature of bottom materials. Proposed investigations leading to completing of the above objectives were focused at the Slims River delta, mouth of Congdon Creek, the outlet at Kluane River, and key localities within the lake.

A second study strategy was developed for determining the hydrological, sedimentological and chemical properties of a typical high-gradient arctic stream, namely Congdon Creek, crossing the proposed pipeline route and flowing into Kluane Lake. The parameters required for a complete empirical model of watershed discharge and the effects that any high turbidity and suspended sediments loadings might have on high-gradient streams such as Congdon Creek were determined.

A list of required equipment and cost to carry out the above investigation during one summer field season was established.

3.0 RESULTS AND INTERPRETATIONS

3.1 Southern Kluane Lake Bottom and Sub-bottom

3.1.1 Locations

The locations of all fixes are shown on Fig. 4. The accuracy of offshore locations is in the range of 30 to 70 m. (100 to 230 ft.). This is composed of a calibration error of between 10 m. (33 ft.) and 20 m. (66 ft.) and the location error of shoreline transponders on the topographic basemap of between 20 m. (66 ft.) and 50 m. (165 ft.). With accurately surveyed measurements between shoreline stations, fixing for existing offshore locations within 10 to 20 m. (33 to 66 ft.) is possible. The accuracy is verified by near identical bathymetry and sub-bottom data where different lines cross at Fix 15 and 52 and at Fix 4.3 and 59. Appendix B gives the actual field measurements between fix stations and the three shoreline transponders, and corrected measurements based on baseline crossing distances.

3.1.2 Bathymetry and Bottom Roughness

Bathymetric data from the Atlas-Deso 10 records are tabulated in Appendix C and plotted on Fig. 5. Little error is probably inherent in the data as a velocity of 1420 m/sec. for sound was used, which is the correct speed of sound in water with a salinity of zero and temperature around 4°C. Because the survey was done during a period of low water, it should be realized that depths obtained during this survey

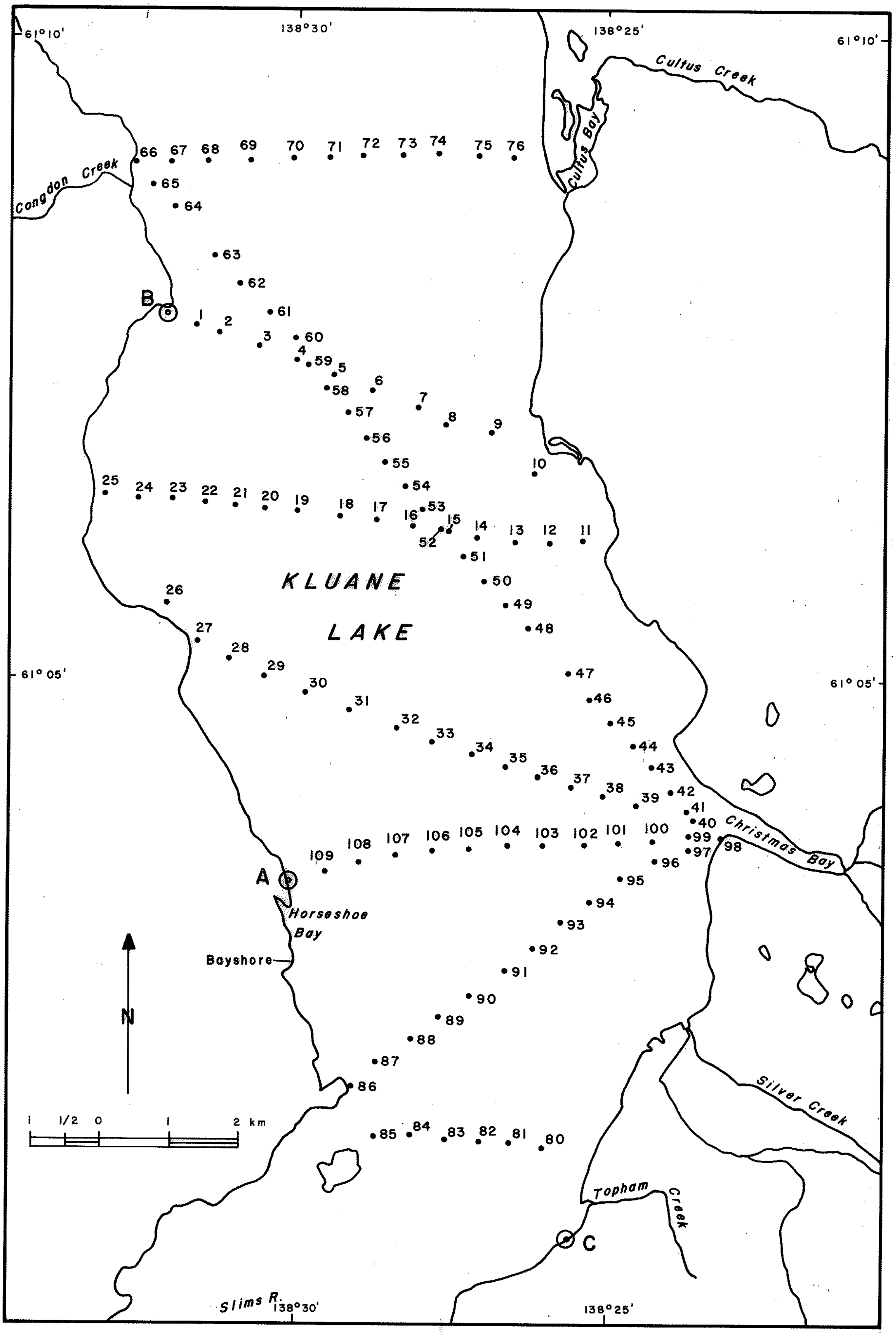

Figure 4. Fix positions. Shore transponders were located at stations A, B and C.

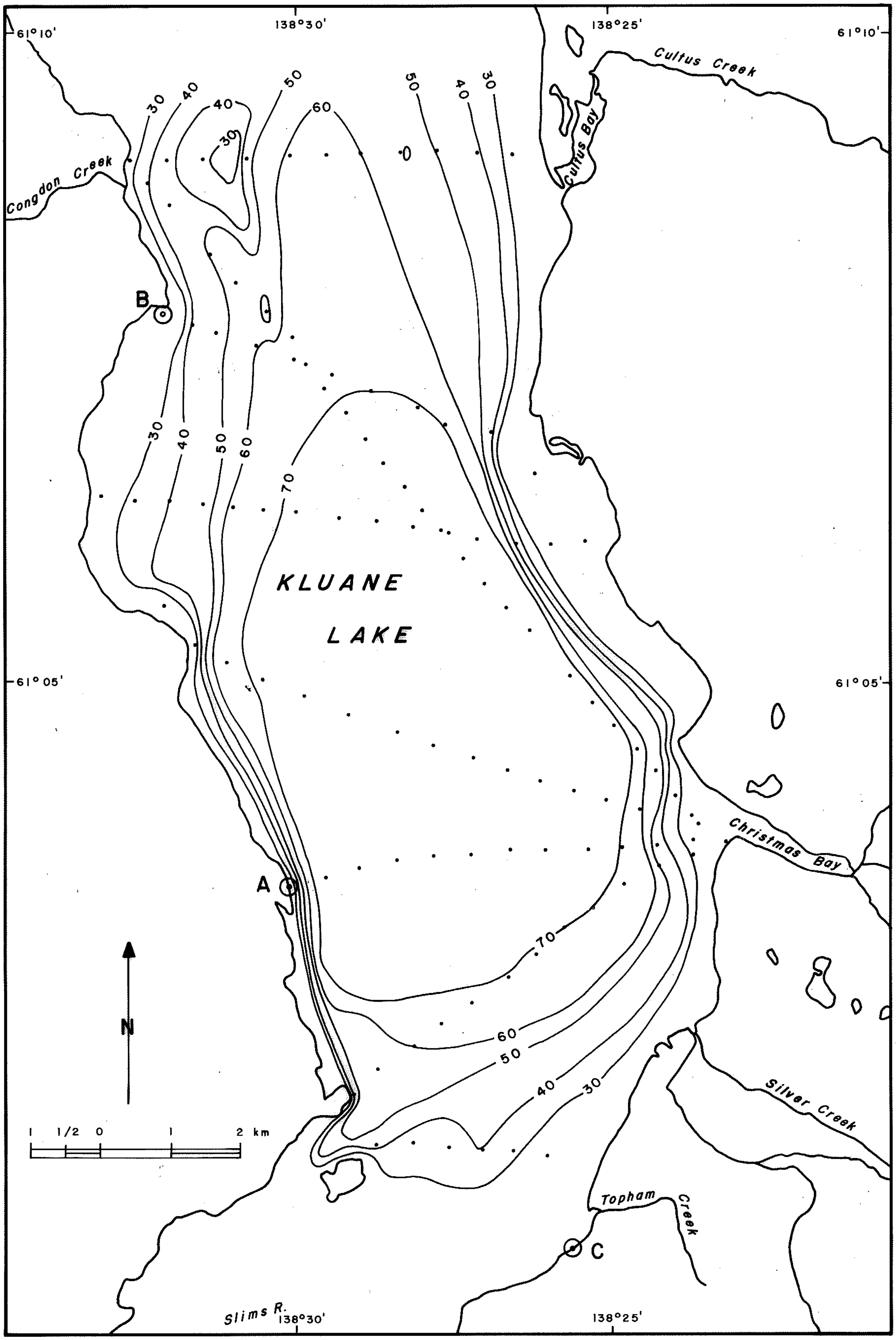

Figure 5. Bathymetry of southern Kluane Lake with contours in meters. Note the SSE trending ridge east of Congdon Creek.

are approximately 2 m. (6ft.) shallower than what might be realized during typical summer water levels.

In general, the bottom of the southern end of Kluane Lake is flat to gently sloping with slopes increasing towards the shorelines in the manner of a saucer. Relatively steep slopes, e.g. 10-15 degrees, are present adjacent to the Bayshore and Christmas Bay shorelines; whereas relatively gentle slopes, e.g. less than 5 degrees, are present adjacent to the mouths of Congdon Creek and Cultus Creek and the Slims River delta. Nevertheless, distinctively steeper slopes are present near the front of the subaerial Slims River delta where its foreset beds are presently being deposited.

The broad, flat bottom of southern Kluane Lake is interrupted by a complex ridge running about 3 km. (1.9 miles) in a SSE direction, beginning about 1.5 km. (1 mile) directly opposite the mouth of Congdon Creek. In general, the width and relief decrease toward its south-eastern end (Fig. 6).

A number of step-like features were found near Christmas Bay (Fix 96-100) at depths of between 21 m. (70 ft.) and 45 m. (150 ft.). Such features may be typical along shorelines where thick glacial drift is known to be present. The features near Christmas Bay are not to be confused with previously reported similar features, which appear to have been the result of instrument malfunction, rather than bottom morphology.

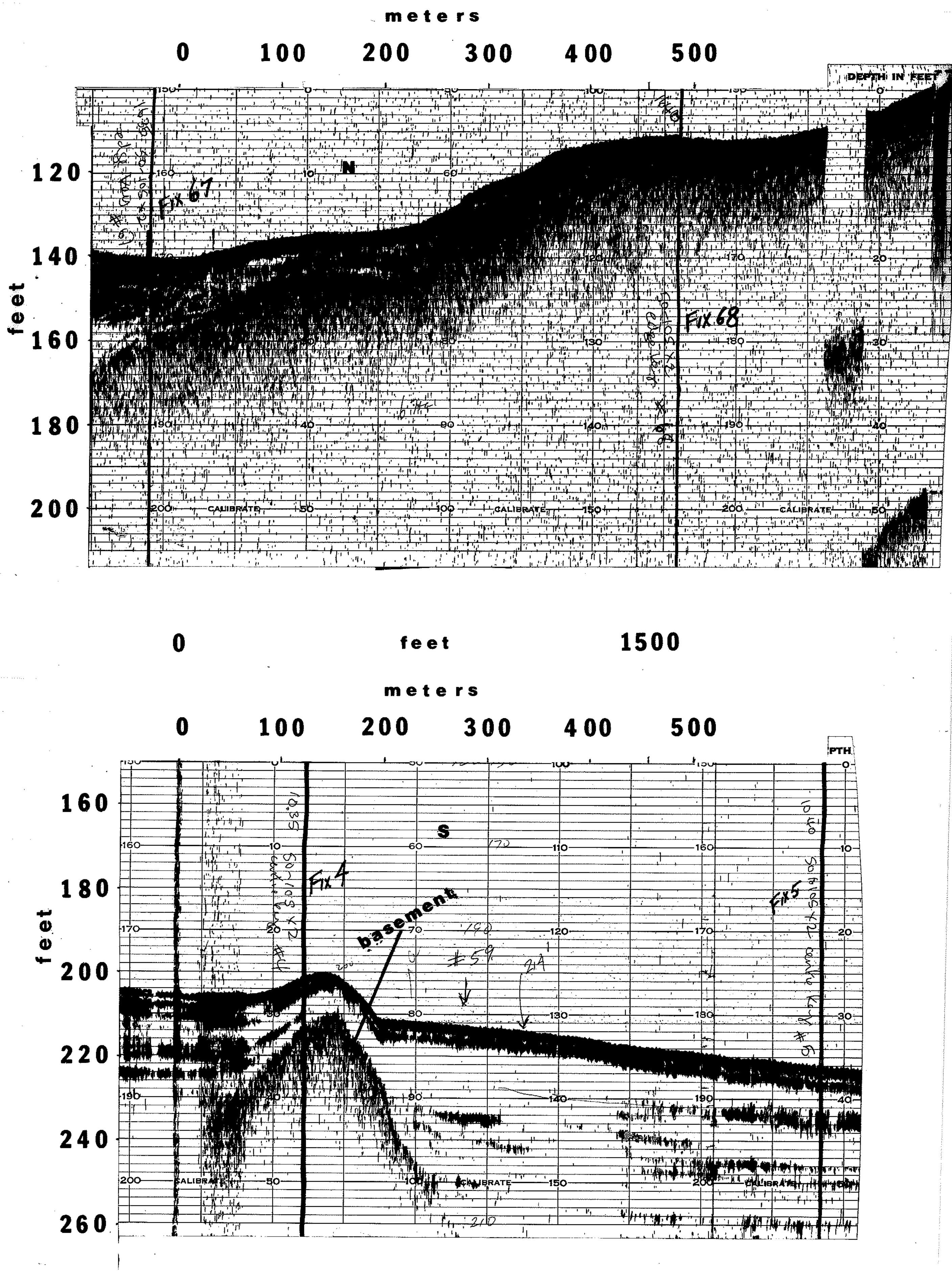

Figure 6. Basement-like ridge off Congdon Creek. Note that its width decreases and its sediment cover increases to the south (Fix 4).

3.1.3 Basement

Except near shorelines where bedrock outcrops or is covered by a thin veneer or blanket of colluvium or drift, bedrock can rarely be identified in the seismic records. The island located off the Slims River delta in Kluane Lake would appear to be unique in that it is probably one of the few places within the southern Kluane Lake basin that bedrock rises so high above the base level of the basin. Another possibility is the basement-like reflector forming the ridge that runs SSE off the mouth of Congdon Creek (Figures 6 & 7). The thickness of less competent sediments overlying this feature decreases toward the north (Figure 6). It is possible that this basement-like reflector may be glacial drift as is suggested by the presence of till and outwash near the toe of the Congdon Creek alluvial-fan. Final identification of the various units making up the ridge requires a lower frequency seismic survey and coring. Figure 8 shows the depth to basement (Appendix D) around this ridge and it indicates considerable relief. The surface of the basement on this ridge appears to be relatively smooth in the seismic records.

3.1.4 Sediment Composition and Characteristics

Most of the surface of the bottom of southern Kluane Lake is underlain by clay and fine silt with a general decrease in grain size from south to north irregardless of lake depth. Coarser materials are present only close to

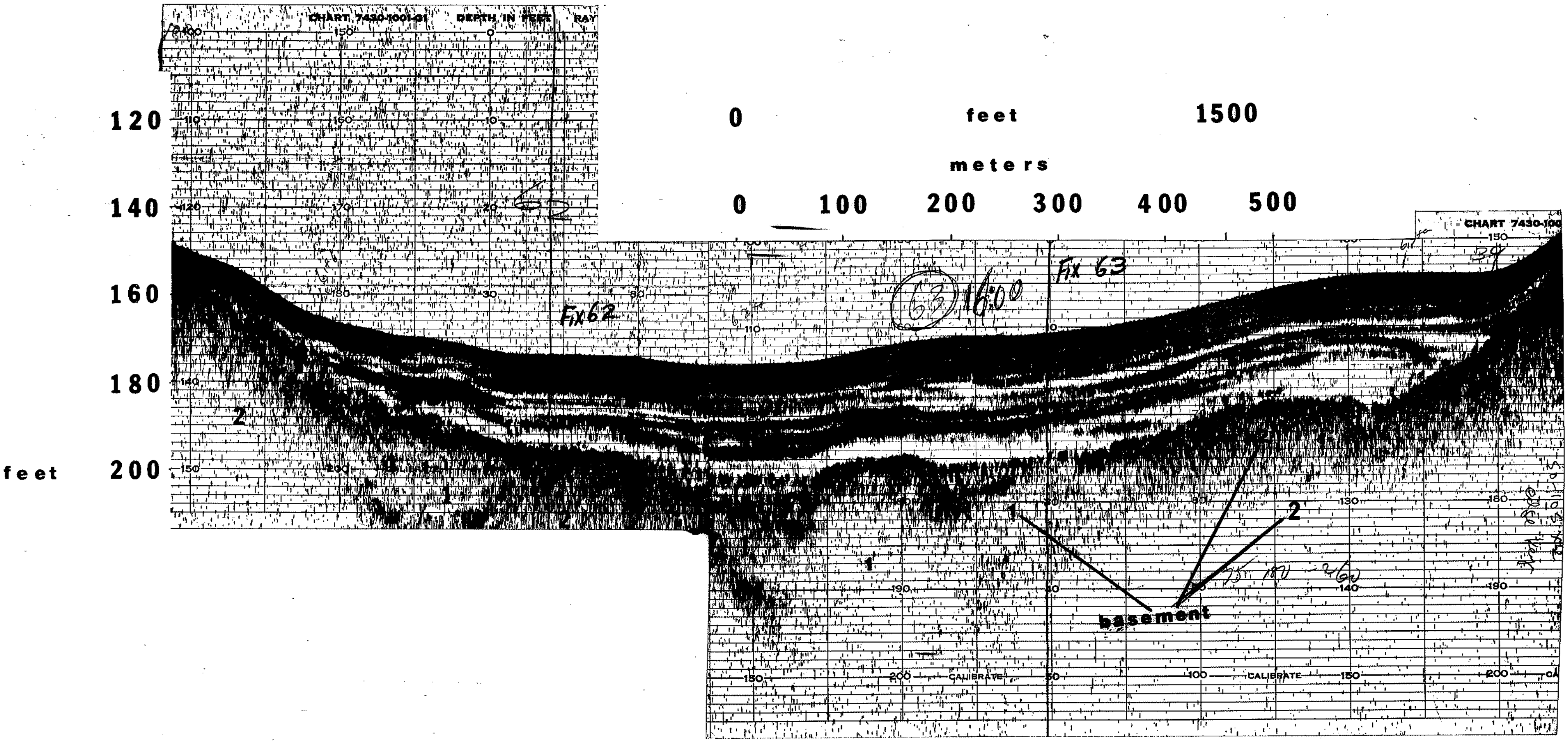

Figure 7. Seismic record showing the presence of two different types of basement. Note that type 1 overlies type 2.

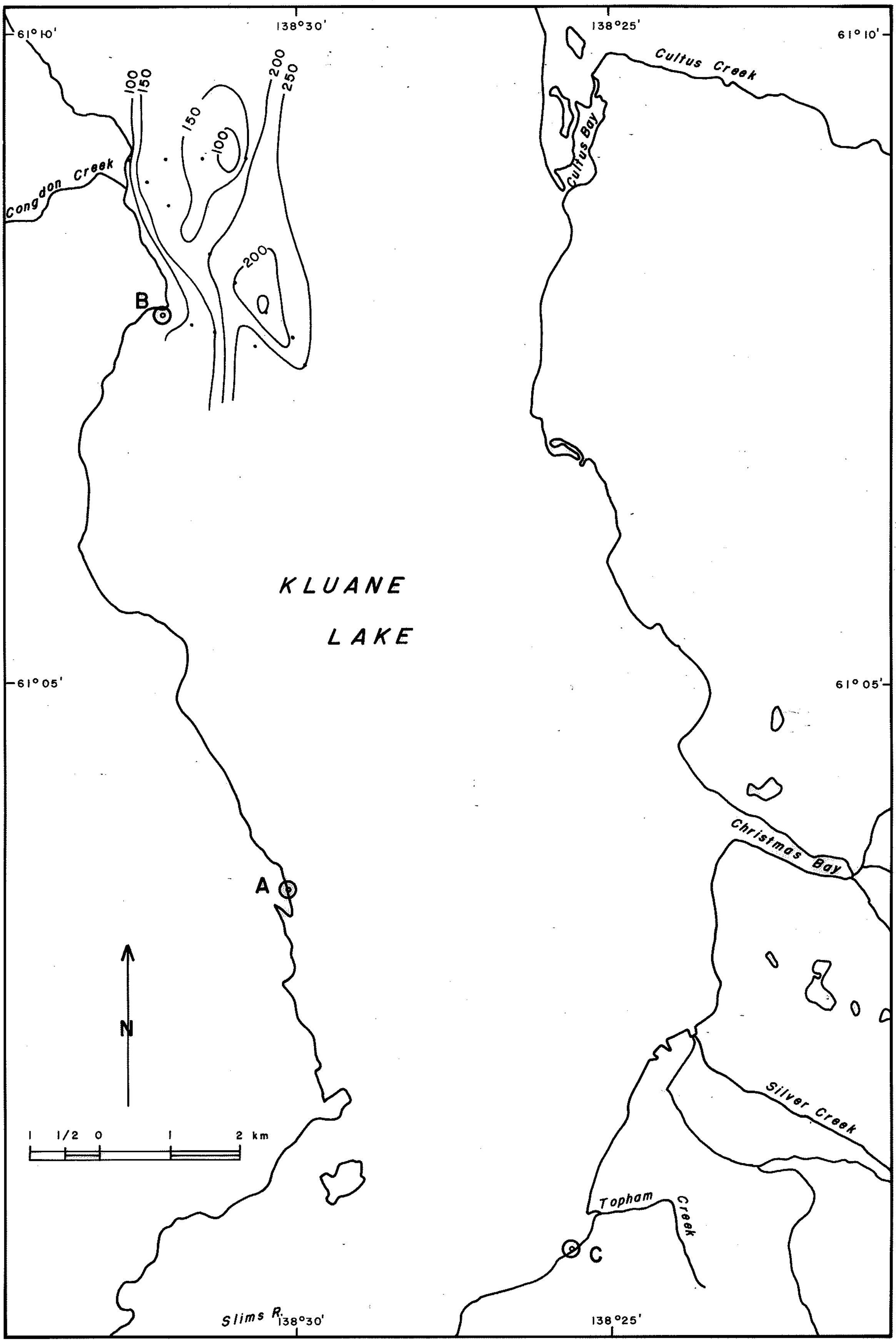

Figure 8. Depth to basement in feet around ridge off Congdon Creek. Relief of basement is considerably greater than the relief of the lake bottom in that area.

shorelines. The transition from sand to finer sediments is often quite abrupt. Seismic records indicate that most of the lake bottom of southern Kluane Lake is underlain by 25 m. (80 ft.) or more of lacustrine sediments (Fig. 9).

Examination of the records shows that a striking unconformity exists within the lacustrine sediments. The unit above the unconformity is extremely thick near the Slims River delta, in general thinning exponentially to the north. This upper unit is less than 1 m. (3 ft.) thick along the Congdon Creek/Cultus Creek axis. Local anomalies do occur however: for example at one locality near fix 109 the upper unit appears to be absent (Figure 10). Also, the upper unit to the east of fix 109 seems to be represented by lens-like sand or silt bodies, as indicated by the nature of the 7 khz reflections and lack of penetration of the 33 khz frequency of the Atlas-Deso 10 unit. The sand or silt body is overlain by a thin layer of silt or clay.

The distribution of the upper unit (Fig. 11) indicates that it probably has a Slims River source. The Slims River has drained into Kluane Lake for only the last 300 to 500 years (previous to this time the Slims River valley acted as an outlet for Kluane Lake: the present drainage patterns being the result of blockage of the valley by a Neoglacial advance of the Kaskawulsh glacier). Thus the upper unit has been deposited in a short period of time. Because of

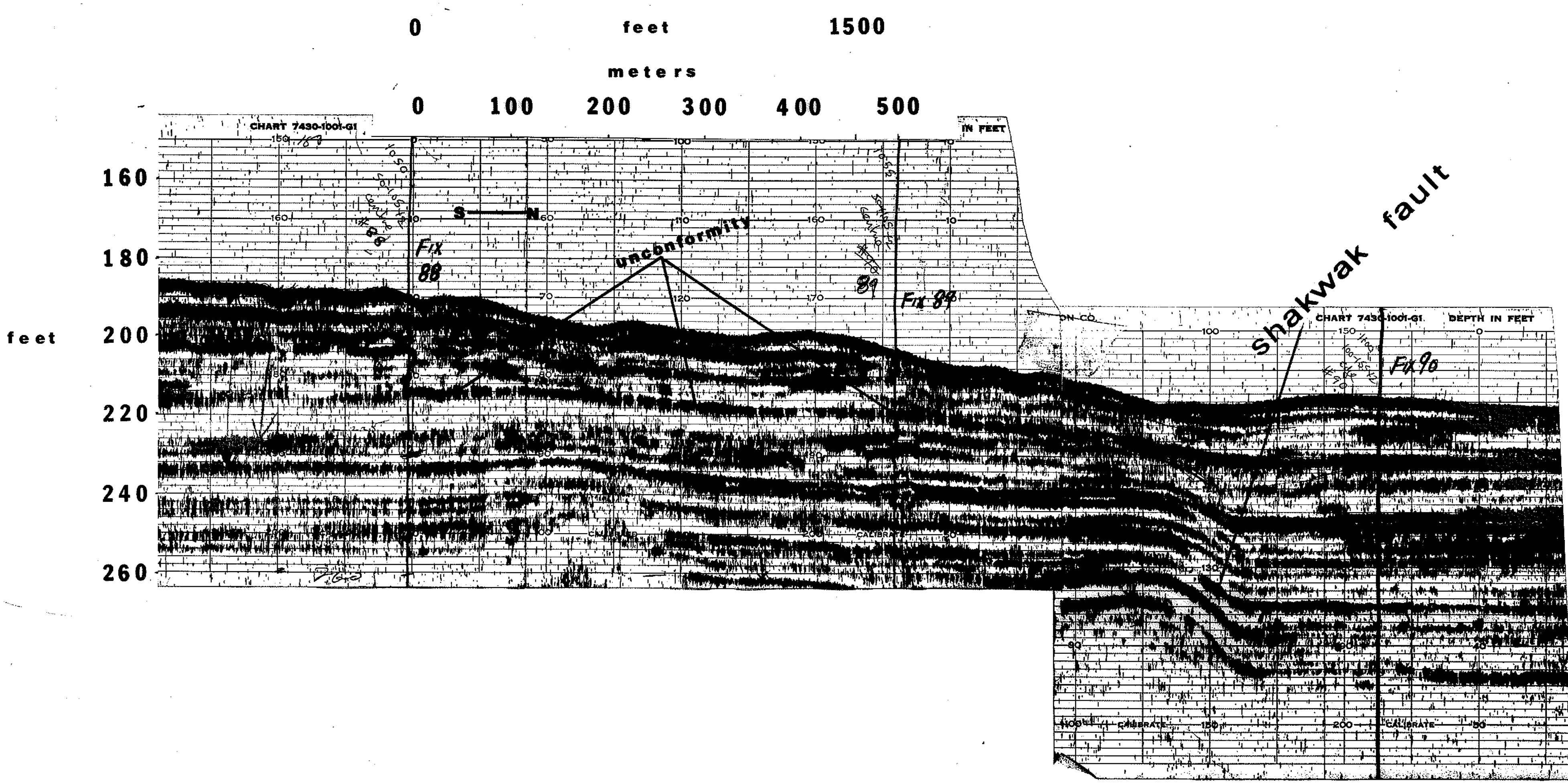

Figure 9. Lacustrine sediment in southern Kluane Lake. Note thickening of upper unit from north (fix 90) to south (fix 88). A unit underlying the unconformity at fix 88 is similar to the sand body illustrated in figure 10.

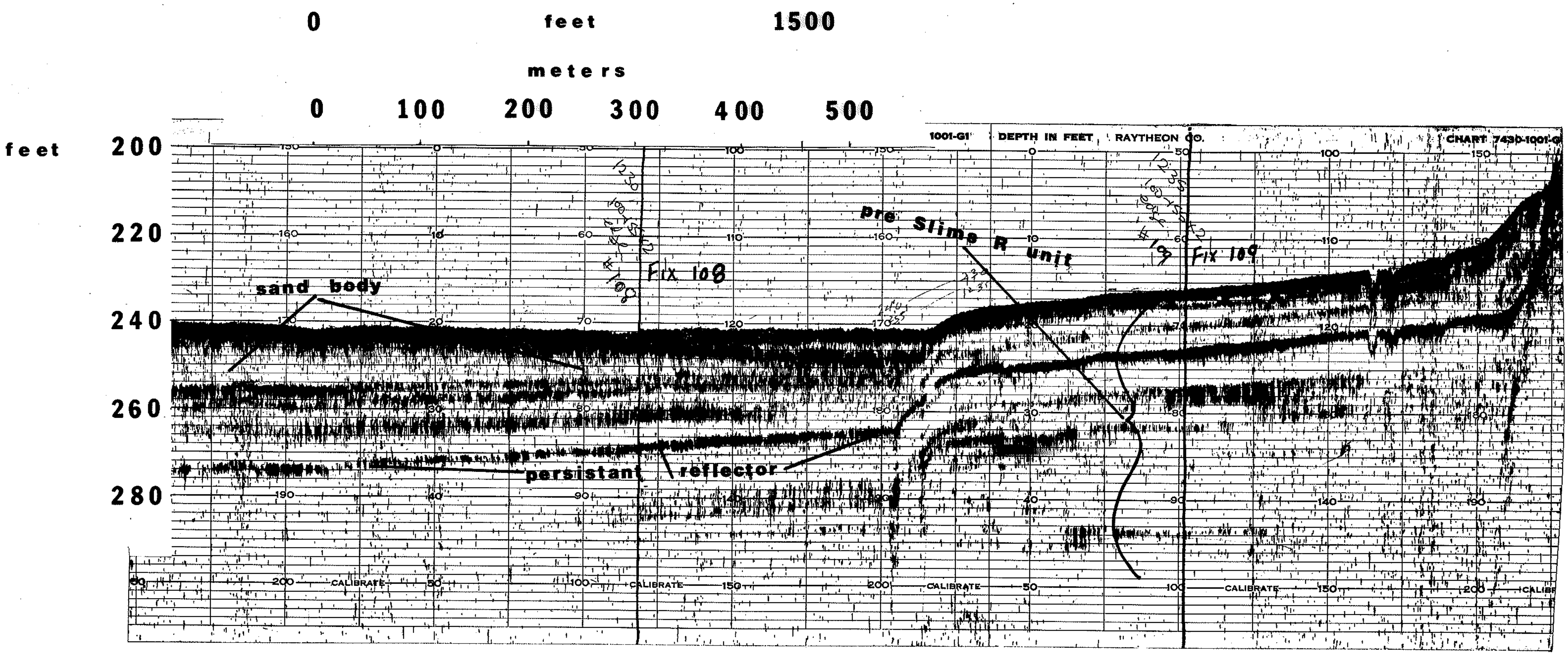

Figure 10. Area where upper unit appears to be absent (fix 109). Note sand body in vicinity of fix 108, persistant reflector, and thick lacustrine sediment under this reflector.

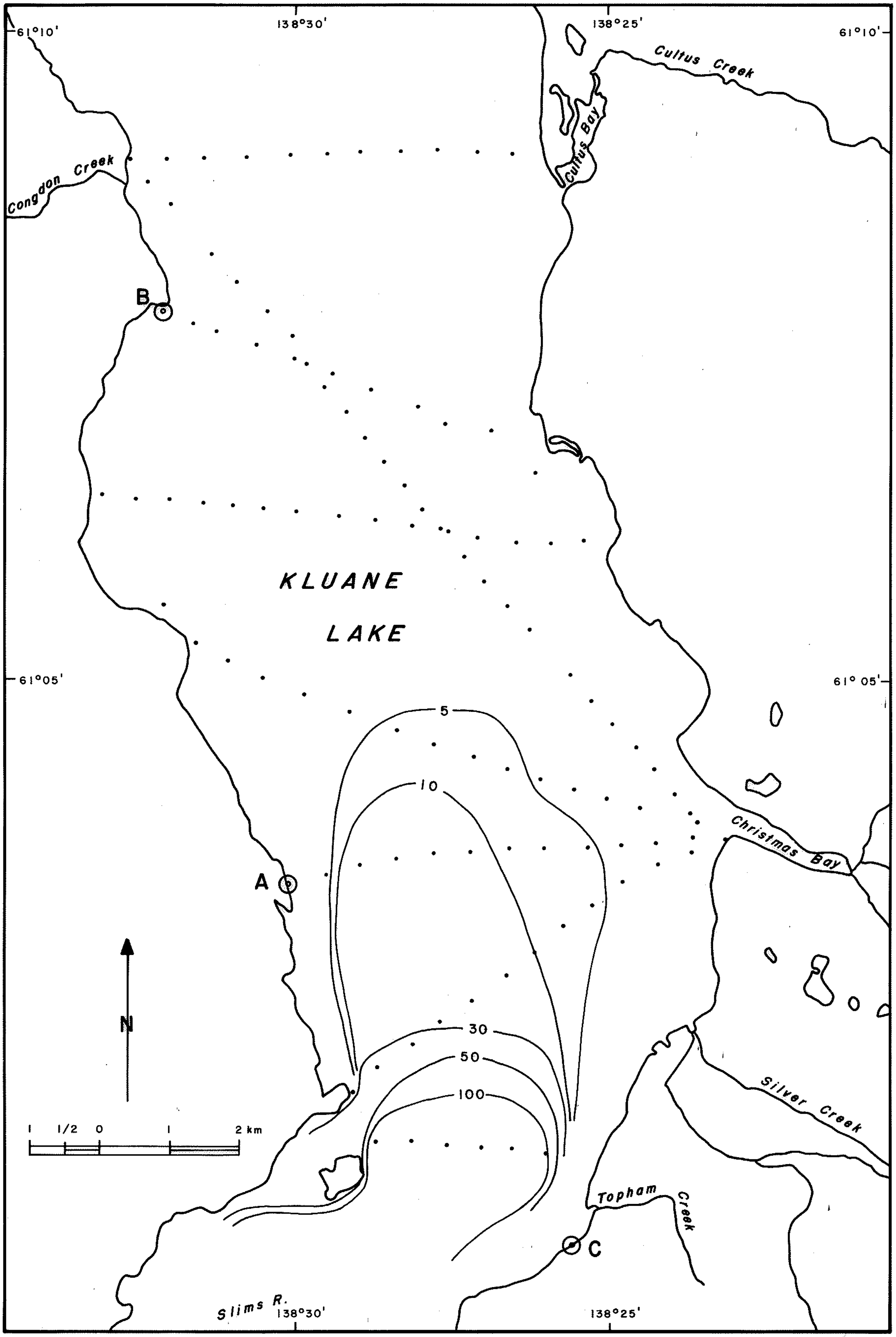

Figure 11. Isopach map of upper unit in feet. It shows a Slims River source for this unit.

the rapid deposition, the upper unit may not be particularly competent. It is interesting to note that given the presently published suspended sediment concentrations and flow rates at the Slims River bridge, the total calculated sediment volume for a 400 year period is only twice the calculated volume of the upper unit in the southern end of Kluane Lake. However a major part of this excess volume would have in-filled the Slims River valley from the Kaskawulsh Glacier to the present delta front.

Some discontinuities observed in the upper unit (Figures 12 and 13) are thought to be from gas seeping upward through the sediments; the gas presumably from the decomposition of organic material. As well, where this unit is thick, such as near the Slims River delta front (Figure 12) unconformities are present that suggest erosion by sediment-laden bottom currents.

A lower unit has been identified whose upper boundary is the unconformity described above and whose lower boundary is a distinctive and persistent reflector (Figures 10, 14 and 15). Isopachs of the lower unit are plotted on Figure 16. The thickness of the lower unit increases from near the central part of the southern lake basin in a number of directions. Its thickness increases very prominently toward the toe of the Silver Creek alluvial-fan; it also thickens toward the northern edge of the surveyed area being

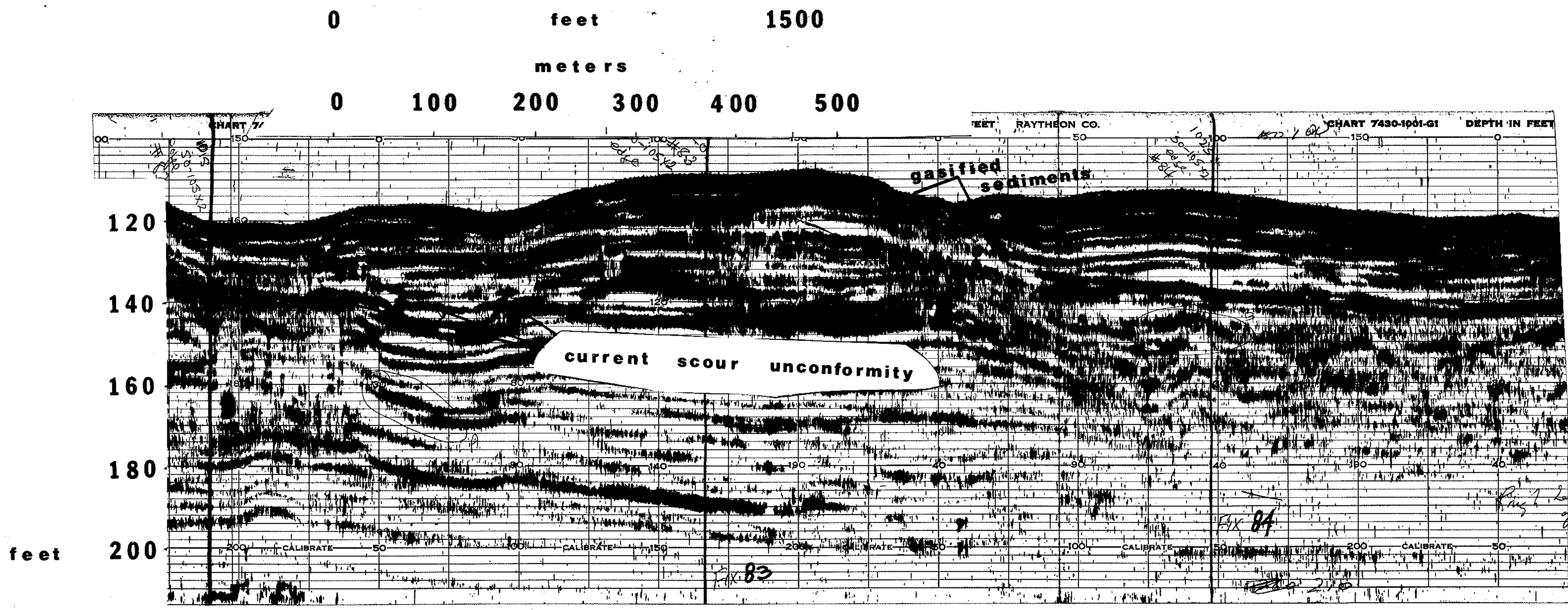

Figure 12. Seismic record of upper unit, which is so thick that the base of the unit is beyond the maximum depth of penetration of the Raytheon RTT-1000. Gasified sediments are more clearly shown in figure 13.

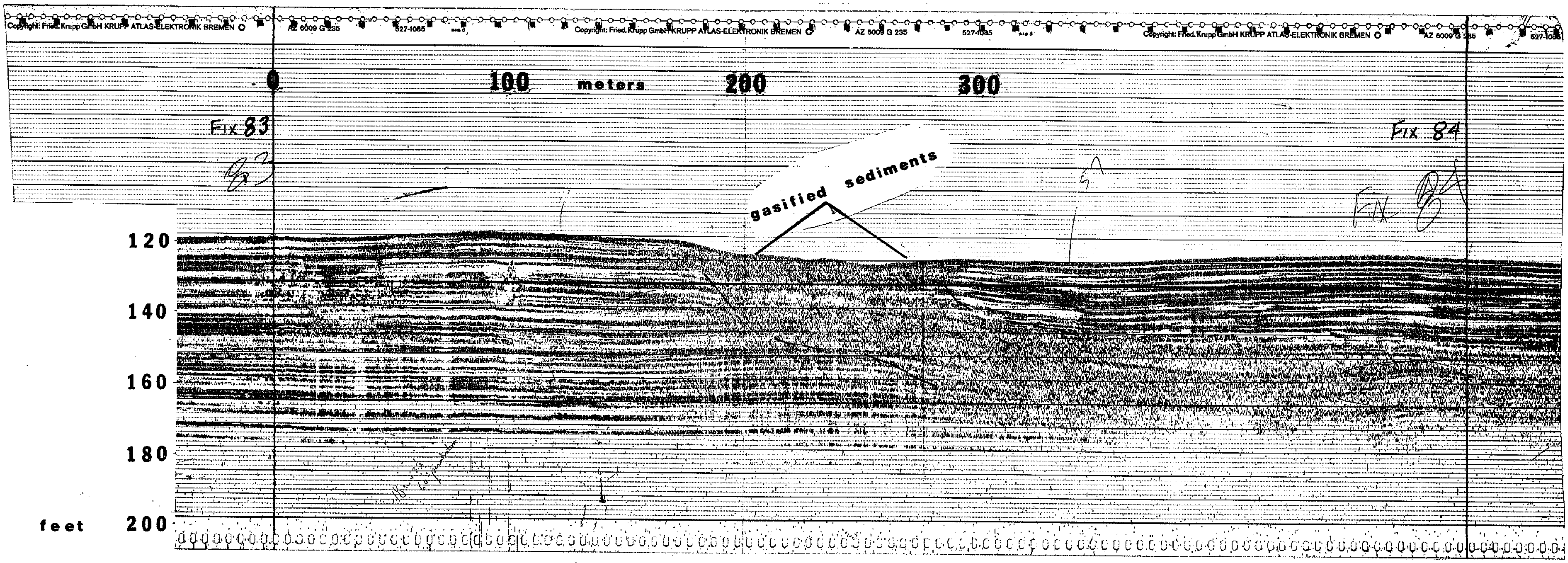

Figure 13. Gasified sediments in upper unit. Note better resolution of this phenomena in the Atlas-Deso 10 records here as compared to the Raytheon RTT-1000 records shown on Figure 12.

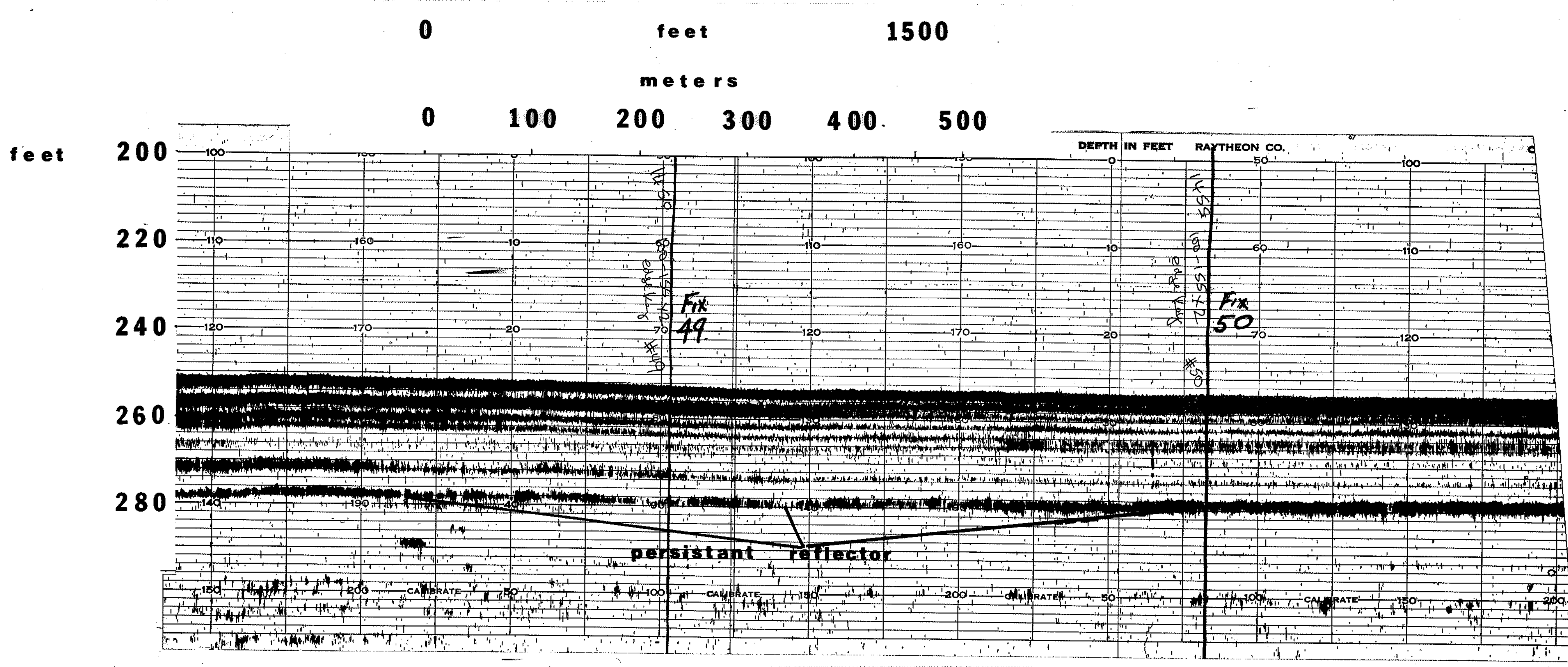

Figure 14. Seismic record of lower unit in middle part of southern Kluane Lake. Upper unit has not been identified, no unconformity exists because sedimentation rates of material from Slims River is similar to sedimentation rates of material from other sources.

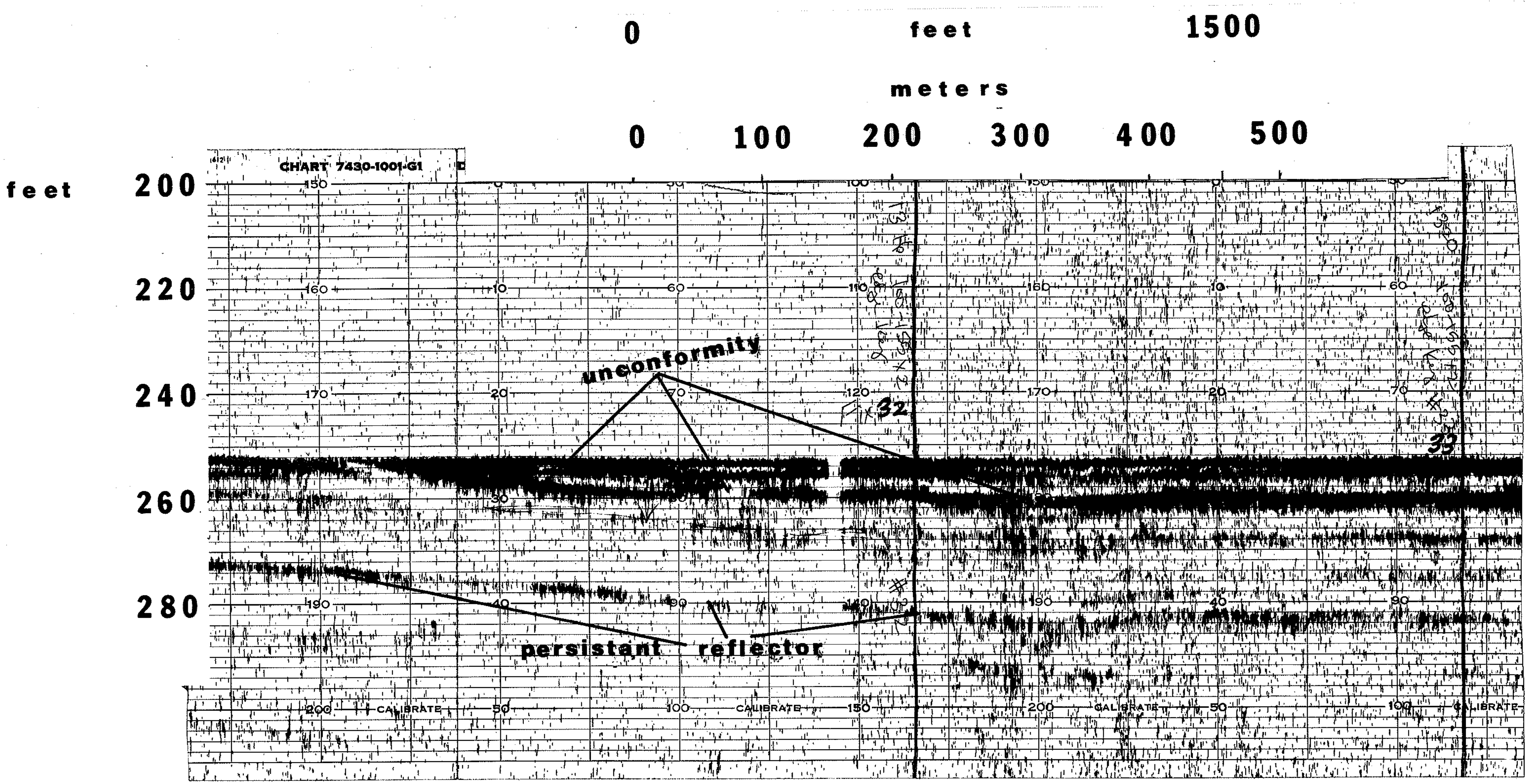

Figure 15. Persistant reflector and unconformity that mark boundaries of lower unit.

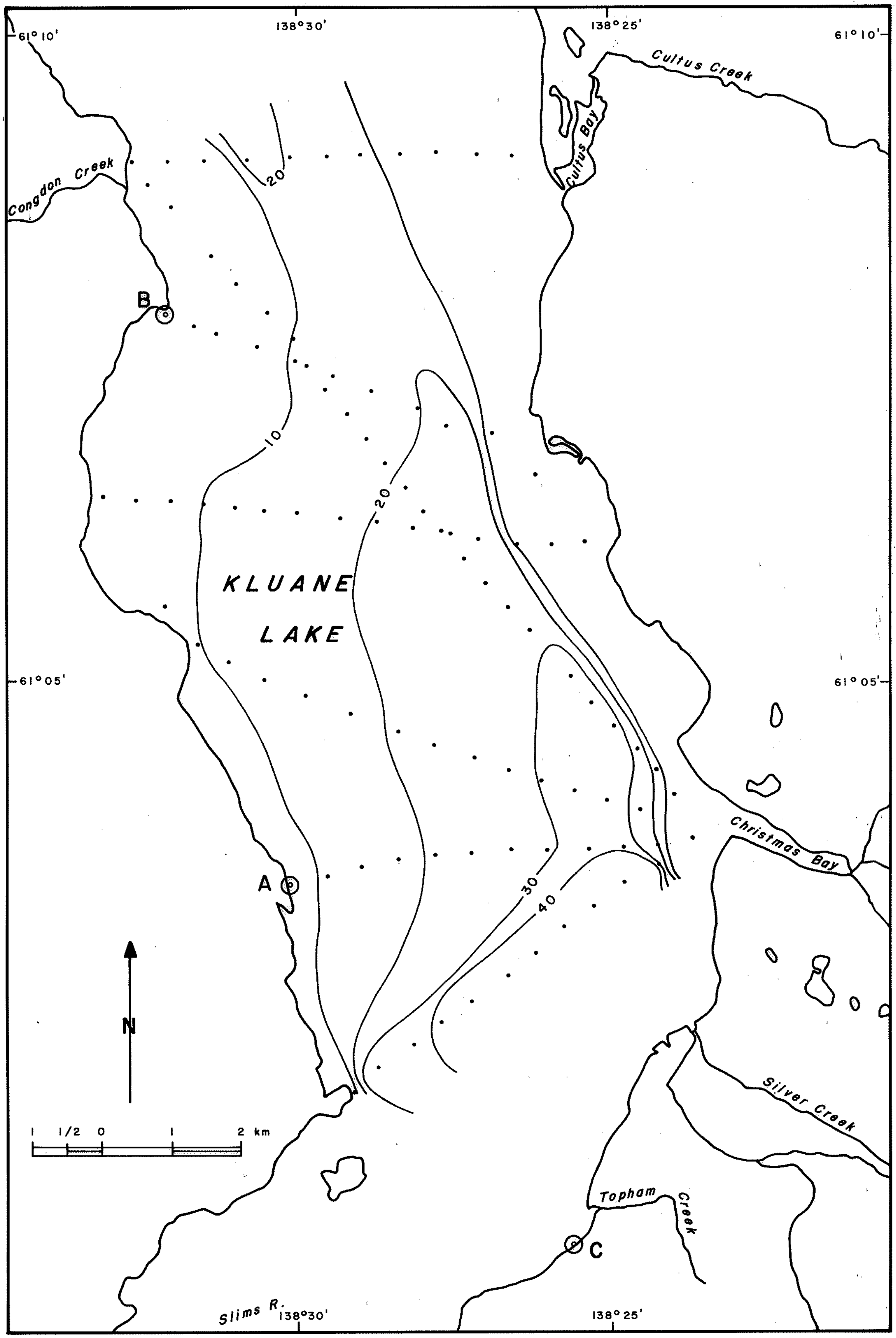

Figure 16. Isopach map of lower unit in feet.

3 to 6 m. (10 to 20 ft.) thick at its thinnest point. Major sediment sources for this unit were probably the numerous creeks flowing into Kluane Lake; for example, local thickening is present near Congdon Creek (Fig. 17) because of the influx of material from this alluvial-fan. Because the isopachs do not point to a Slims River source of sediment, it is thought that the lower unit was deposited during the time when Kluane Lake drained south through the Slims River valley to the Kaskawulsh River (from about 10,000 B.P. to about 400 B.P.).

Deposition from the small creeks flowing into Kluane Lake has not decreased during the last 400 years, but their contribution has been masked by rapid sedimentation from the Slims River in the southern part of the lake. This change in the sedimentation regime produced the apparent unconformity that marks the boundary between the upper and lower units. This unconformity becomes indistinct in the northern part of the study area where the sedimentation rate of material from the Slims River is similar to that from other sources.

The sediment comprising the lower unit is probably fairly compact and thus relatively competent because it has been deposited from small amounts in suspension over a long period of time. Slow depositional rates of the upper unit in the northern part of the study area probably also increases its competence in that area.

The material under the lower unit over much of the southern Kluane Lake basin was probably deposited under

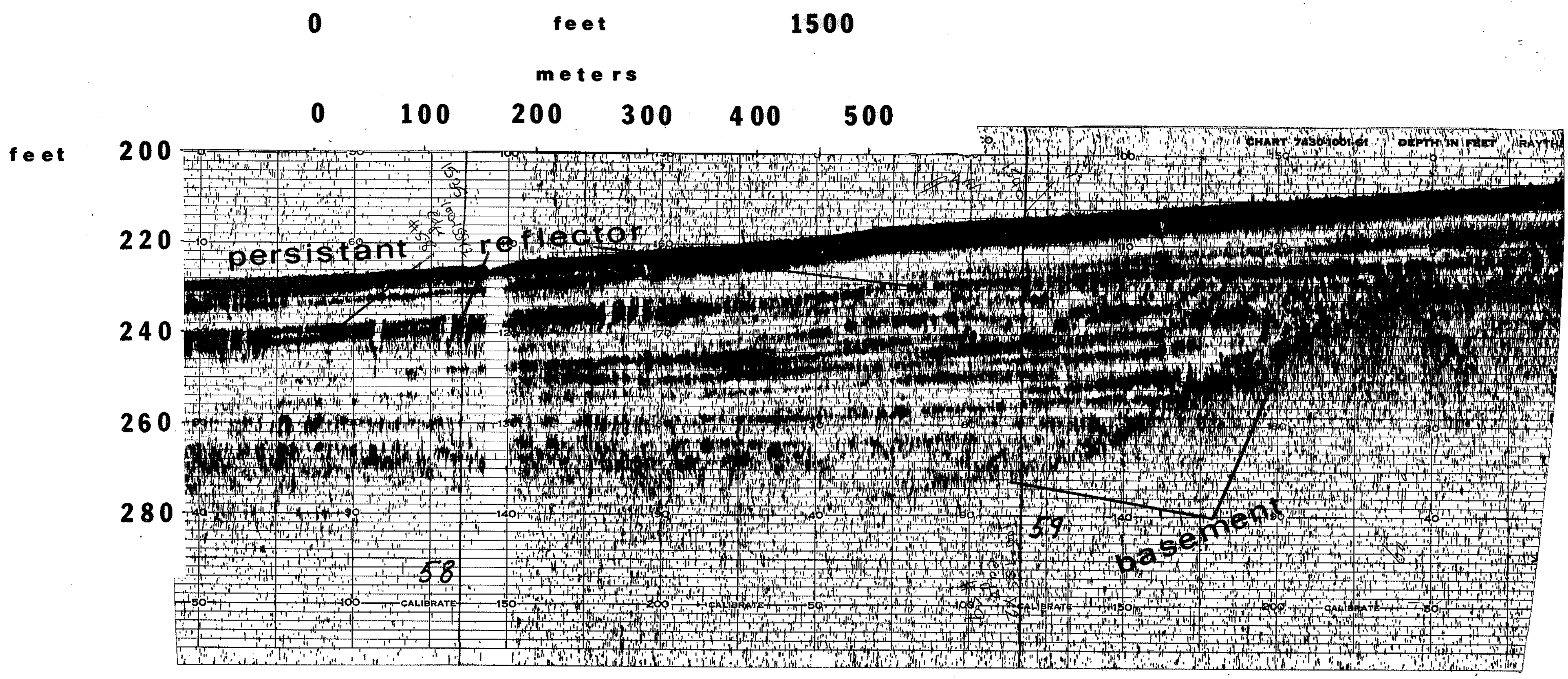

Figure 17. Local thickening of the lower unit and similar units underlying the lower unit. Lowest units interrupted by basement. Sediment wedge probably has Congdon Creek origin.

a sedimentologic regime similar to that which formed the lower unit. The whole unit underlying the unconformity was not measurable because it was too thick to find its base with the seismic equipment used.

3.1.5 Present Sedimentation Patterns

The present sedimentation regime in southern Kluane Lake has two components: (1) a major source of sediment from the Slims River; and (2) minor sources from the numerous creeks flowing into the lake. Maximum rates of sedimentation are occurring near the front of the Slims River delta. In the vicinity of the Congdon Creek/Cultus Creek axis, the present calculated rate of sedimentation is in the order of 2-3 mm/year.

Although much of the sediment being deposited in Kluane Lake is coming out of suspension, the bottom morphology and seismic records near the front of the Slims River delta indicate that lake bottom sediment-flows occur in this area; such flows would produce some erosion and sediment redistribution.

Recorded water turbidities and observations on turbid plumes indicate that much of the water and sediment being introduced by the Slims River is presently being deflected northwest toward the bedrock island opposite the mouth of the river.

Some contribution to the lake sediments at the very southern end of the lake is being made by wind blowing out of the Slims River valley during some seasons (Figure 18).

Some evidence of slumping in the steeper transition zones is indicated in some seismic records, although more work is required to confirm this. Small areas of sediment may be presently being distrubed by gas from the decomposition of organic sediments seeping upward through them, as can be observed on seismic records (Fig. 13).

It is interesting to note that although the Shakwak Fault can be easily traced along the lake bottom (e.g. Fig. 9) that no indication of recent fault activity is evident. Deposition has gradually reduced the relief along the fault trace, especially deposition during the last 300 to 500 years. The records suggest that the last movement on the Shakwak fault in this area occurred just prior or during the early part of the time during which sediments of the lower unit were deposited.

3.2 Shoreline Geology

Most of Kluane Lake lies in the Shakwak Trench, a major fault system along which late Tertiary and Pleistocene faulting has occurred. Physical evidence of Late Wisconsin faulting is evident along parts of the fault. South of the Shakwak Trench in the Kluane Ranges, the rocks are primarily argillites, volcanics, and greenstones of Permo-Triassic age. These rocks outcrop along the lakeshore at the south end of the lake. North of the Shakwak Trench in

Colour Photo Omitted

Figure 18. Loess blowing out of Slims River Valley by strong south winds, November, 1977. Note rough water.

the Kluane Plateau, the rocks are primarily metamorphic rocks of Precambrian or Paleozoic age that have been intruded by granitic rocks of Mesozoic age. These rocks outcrop along the lakeshore along Talbot Arm.

Many of the unconsolidated deposits that form the shoreline of Kluane Lake (Fig. 19) were deposited during the waning stages of the Kluane glaciation of Late Wisconsin age. As the glaciers retreated to the south and east, much of the meltwater flowed along the northeastern flank of the glacier and deposited outwash, some of it on glacier ice: the kame-and-kettle complex between Christmas Creek and Cultus Creek resulted when the ice subsequently melted. Some perched lakes must have existed in this same area as evidenced by the patches of glaciolacustrine material along the shore. The glacial deposits are often covered by a veneer of loess (silt), which contains at least one thin volcanic ash layer deposited about 1220 B.P. Tills in this area have high sand contents and low clay contents. The Kluane glacial sediments are probably underlain by older glacial sediments throughout much of the Shakwak Trench.

Postglacial time has been marked by continued active formation of large alluvial-fans by high-gradient creeks flowing out of the Kluane Ranges into the broad flat Shakwak Trench. Although the material within the fans is primarily gravel, some of the older, abandoned alluvial-fan surfaces have a shall cover (less than one meter) of highly-shallow

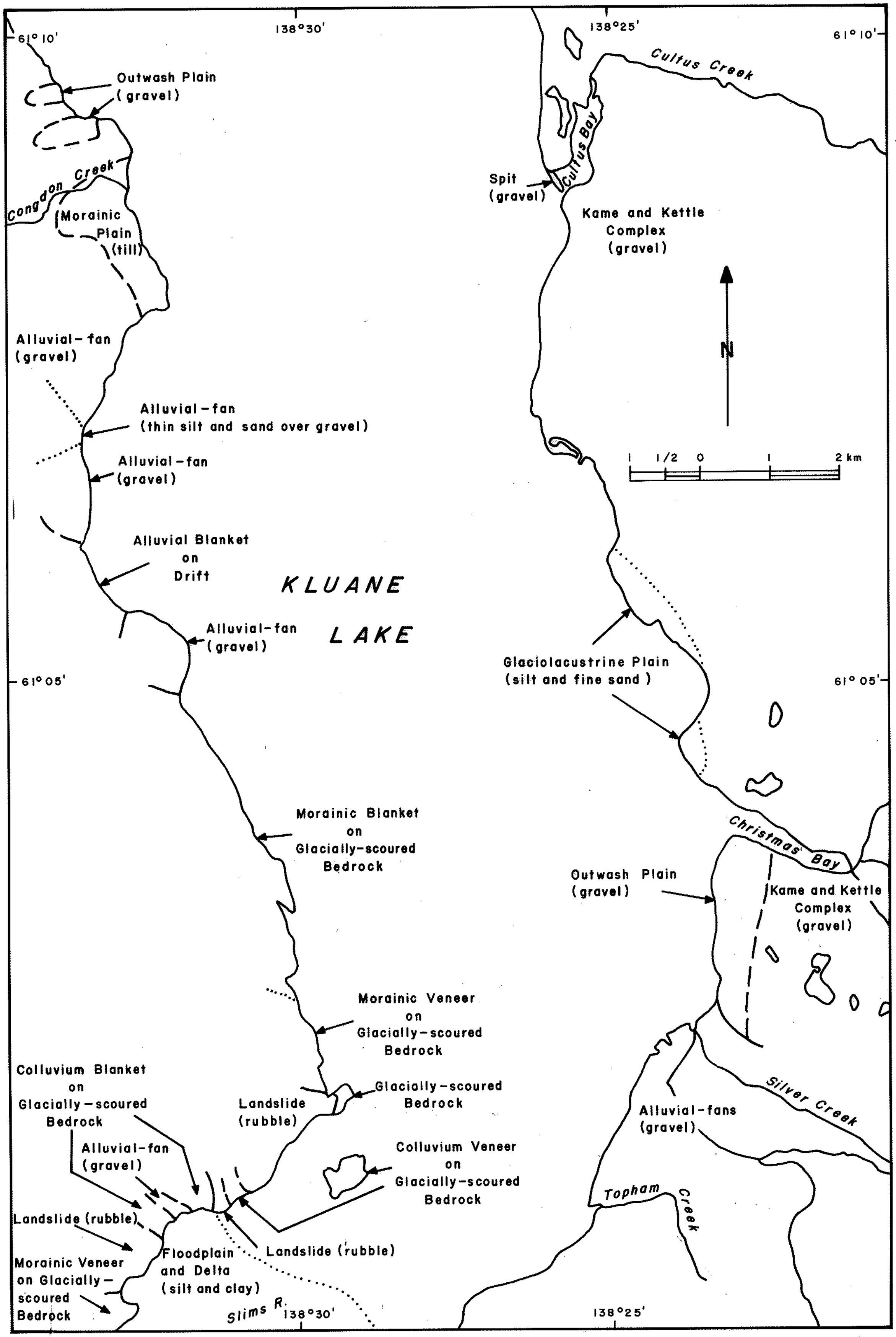

Figure 19. Shoreline geology.

organic sand and silt. The smaller, steeper alluvial-fans contain a significant portion of debris-flow material. Presently, the channel courses on many alluvial-fans have been restricted because of highway maintenance.

Because of oversteepening of the Slims River and Shakwak Trench valley walls, a number of landslides have occurred periodically in Postglacial time until present near the southern end of Kluane Lake. The landslide debris is generally blocky weathered bedrock. However, some landslides have incorporated drift and alluvial gravels.

Colluvium on slopes around the southern end of Kluane Lake is generally a mixture of bedrock rubble, silt (loessial origin?), alluvium, and drift that has been subjected to mass wastage due to the steep slopes. Generally the colluvium is less than 3 m. (10 ft.) in thickness.

Narrow, modern beaches are infrequently present along the shoreline; they are most prominent along the fronts of the alluvial-fans. The beach material is generally well sorted and pebbly or cobbly. Equally as evident are the beaches and strandlines marked by driftwood that stand 3.7 m. (12 ft.) and 13 m. (43 ft.) above the present mean high water level of Kluane Lake; these strandlines probably were occupied about 300 year ago near the time that the Slims River drainage reversal occurred.

3.3 Slims River Hydrology

Reconnaissance studies of the Slims River and its watershed indicate a river valley having a complex late Pleistocene history, a prograding river delta, a river with a complex source of its water and extreme and erratic variations in discharge volume and water quality.

Geologic studies suggest that Kluane Lake drained south through the Slims River valley into the Alsek River drainage system between sometime following 12,500 B.P. and previous to 500 B.P. Between 300 B.P. and 500 B.P. the valley was blocked by a Neoglacial advance of the Kaskawulsh Glacier and sediment-laden water flowed north toward Kluane Lake from the glacier's present terminus, as does the modern-day Slims River.

Maps of Kluane Lake from 1899 to the present and recent air photos indicate that the subaerial front of the Slims River delta is advancing rapidly into Kluane Lake. The following rates have been published: 74.1 m./yr (243 ft./yr.) for 1899-1914; 48.2 m./yr. (158 ft./yr) for 1914-1947; 17.7 m./yr. (58 ft./yr.) for 1944-1970. A general decrease in the rate that the delta front is advancing into Kluane Lake is suggested by the published data. This has been attributed to either (1) a widening of the Slims River valley near the present front of the Slims River delta that would slow the rate of growth, given a constant volume of introduced material or (2) a change in the rate that material has been introduced to the Slims River delta. The most probable cause of the latter would be a total diversion of meltwater from the Kaskawulsh Glacier away from the Slims River to the Kaskawulsh River (see Fig. 1).

The Slims River receives water from the Kaskawulsh Glacier and from tributary streams between the Kaskawulsh Glacier and Kluane Lake. The tributary streams receive glacier melt, snow melt, and storm water; much of the water percolates through the alluvial-fans at the mouths of the tributary streams. During the melt season, the suspended load is high because the major source of water is from the Kaskawulsh Glacier. During periods of low flow, suspended load is relatively low and dissolved material is high because the major source of water is from tributary streams. Published values for Slims River discharge varies from negligible to 425 m.3/sec. (15,000 ft.3/sec.). Although Slims River shows both diurnal and seasonal variations characteristic of a glacier-fed stream, abnormally low discharges occur during some seasons. These low discharges are the result of diversion of the Kaskawulsh meltwater from the Slims River to the Kaskawulsh River. When this occurs, suspended sediment load decreases and dissolved load increases.

3.4 Kluane River Hydrology

The present Kluane River channel near Kluane River, which serves an outlet to Kluane Lake, is relatively youthful having been established between 300 and 500 years ago. The base level of this channel appears to be governed by bedrock just west of the mouth of the Duke River or by coarse sediment being introduced to it at the toe of the Duke River alluvial-fan.

Flow data from the gauging station at the outlet of Kluane Lake shows high seasonal variations from less than 6m.^{3}/sec (200 ft.^{3}/sec) to more than 310 m.^{3}/sec (11,000 ft.^{3}/sec). High water levels appear to roughly correlate with recorded Kluane Lake high water levels.

4.0 FUTURE STUDIES

4.1 General Objectives

Future studies should be oriented toward obtaining a full understanding of (1) the bottom and sub-bottom materials and processes in the southern part of Kluane Lake where a pipeline crossing is possible; (2) the characteristics of high-gradient watershed flowing into Kluane Lake and the dispersion of water and introduced materials from such a watershed in Kluane Lake; and (3) the basic physical elements of the Kluane Lake ecosystem, namely sources of water and sediment, the water budget, turbidity patterns, water chemistry, temperature profiles, water circulation, sedimentation patterns, configuration and composition of shorelines, and the nature of bottom materials.

4.2 Southern Kluane Lake

The field work and resulting seismic records have allowed for the conceptual delineation of the main physical characteristics of the bottom and sub-bottom of southern Kluane Lake. However the interpretations require confirmation, certain elements need to be quantified, and some gaps in data need to be eliminated.

For a more accurate delineation of the upper unit in the southern basin further survey lines with the Raytheon RTT-1000 (7Khz) and the Atlas-Deso 10 (33Khz.) need to be run from the centre of the lake toward the Slims River delta. More lines would also allow a more exact determination of where the unconformity between the upper and lower units disappears; of recent sedimentation rates throughout the southern basin; and of the distribution of the sand or silt body identified within the upper unit. To ensure proper resolution of the basement, i.e. determine whether it is drift or bedrock, opposite Congdon Creek lower frequency seismic profiling is required (e.g. a uniboom operating in the 500 hz. range).

A bottom sampling and coring program should be undertaken to determine the geotechnical properties of the bottom materials, both the upper and lower units; possible lateral and vertical variations in the geotechnical properties of the bottom materials; and sedimentation rates.

Accurate rates of sedimentation for various areas of the lake are important and can probably be achieved by C^{14} dating of organic materials and locating the White River ashes (deposited at 1220 B.P. and 1850 B.P.) within sediment cores. In the central southern lake area, if sedimentation rates are in the order of 2-3 m./yr. these deposits should be at depths of 2 to 6 meters (6 to 20 ft.). A piston core unit with a 6 m. core barrel is required for the job.

Areas between the shoreline and the basin are least well known from our present survey as they cover a small area and have not been surveyed to the same degree as the remainder of the basin. To increase detail in the shore areas, slower surveying must be achieved and a greater number of lines run. Information on the step-like features off Christmas Bay and the transition zones between the shorelines and the basin could be enhanced in this manner. In addition, closely spaced grab sampling from the shoreline to the basin in selected areas (i.e. areas of sedimentation such as Christmas Bay, Congdon Creek, Slims River and areas of bedrock near Bayshore) would be necessary to provide control for the recommended detailed seismic work. To achieve the above objectives, 160 km. (100 miles) of seismic profiling with 100 km. (60 miles) in the nearshore areas of Congdon Creek, Slims River, Christmas Bay and Bayshore are needed. A surface sampling program of some 100 grab samples with

60 to 80 collected from the near-shore areas mentioned should sufficiently compliment the seismic work. A coring program of some 10-20 cores, mainly in the central basin, and the Slims River and Congdon Creek depositional areas is necessary to achieve the above objectives.

4.3 Congdon Creek

Evidence given by a number of hydrologists, engineers and fisheries biologists at hearings regarding the problems of constructing the Alcan gas pipeline revealed that little or nothing is known about the characteristics of small high gradient arctic watersheds. Accordingly, the following research study is required to provide essential background data on the hydrological, sedimentalogical, and chemical properties and hence the environmental sensitivity of small streams that will be crossed by a gas pipeline. The Congdon Creek watershed is considered to be an excellent study drainage basin in that its catchment area is similar to numerous fluvial systems along Kluane Lake, and in the southern Yukon and northern British Columbia.

This study would establish:

1) the hydrological regime of the Congdon Creek watershed. All available meteorological data on temperatures and precipitation would be analyzed. A continuously recording portable Leopold-Stevens gauge should be installed from May 15,

to October 31, 1978 to calculate low flow and peak flow data and accurately record the response of the watershed to individual storm events. Current measurements would be made with a hand held current meter to calibrate the gauge. The geology and vegetative cover would be mapped to permit an empirical model for watershed discharge to be developed;

2) the total dissolved chemical load. This would be established by field measurements of conductivity, pH, Alkalinity, major cations (calcium, magnesium, sodium, potassium) and major anions (sulphate and chloride). Analyses would be cross-checked by sending samples to the Bondar-Clegg Water Chemistry Laboratory in Whitehorse. Trace element concentrations would be measured in approximately 20 samples to relate concentrations to seasonal and diurnal flow variations.

3) the suspended sediment load carried by Congdon Creek. This would be measured at regular intervals using a small depth-integrating suspended sediment sampler. These measurements will permit calculation of the overall sediment input to Kluane Lake from the numerous small tributary watersheds. In addition, the length of a small watershed that will be affected by high turbidity and suspended sediment loadings will be measured in the field. Knowledge of this "sediment effect length" is essential to understanding how salmon and trout fisheries will be affected by pipeline construction across small streams.

4) the dispersion of water and suspended sediment introduced by Congdon Creek in Kluane Lake. Measurements of longshore current directions and velocities would be combined with a water chemistry, conductivity, suspended sediment and turbidity survey to establish the dispersion plume from the mouth of Congdon Creek into Kluane Lake. Areas of sediment deposition would be mapped in detail to verify these results by increasing the density of grab sampling, coring and seismic profiling in this area. Small-scale geological mapping of surficial deposits within the watershed and of beach lithologies should be conducted to provide a basis for data interpretations.

4.4 Kluane Lake System

Because of Kluane Lake's recreational value as a scenic attraction and as a fishery and because of its importance to the total ecology of the area, an understanding of the physical elements of its ecosystem are required to assess any impact that pipeline construction or other developmental activities may have on the system. Both the short-term and long-term effect of introduced sediment and pollutants that might result from construction activity could be projected if the physical elements of the Kluane Lake ecosystem are understood. This would further allow a determination of the type and degree of preventative and containment measures required to protect the Kluane Lake ecosystem.

4.4.1 Bathymetry, Bottom Materials and Sedimentation Patterns

The bathymetry and nature of bottom materials can best be determined by shallow seismic sub-bottom profiling supplemented by spot bottom sampling and coring. Results from the southern end of Kluane Lake obtained to determine the feasibility of a pipeline crossing will aid in interpretations. Approximately 240 to 320 km. (150 to 200 miles) of profiling with Raytheon Model RTT 1000 (7 Khz), Atlas-Deso 10 (33 Khz and 200 Khz), and Uniboom (500 hz) sub-bottom seismic systems, about 20 grab samples (Shipek sampler) and 10 cores (piston) should be adequate to outline the major bathymetric and sub-bottom elements, including bottom roughness, sediment composition, stratigraphy, and basement roughness of northern Kluane Lake. If abundant organic materials are present in any cores, a number of C^{14} dates (2 to 4) may be obtained to determine sedimentation rates and patterns; otherwise it will be necessary to rely on dated volcanic ash layers to determine sedimentation rates.

4.4.2 Shoreline Configuration and Composition

To determine sediment input and dispersion along the shoreline a detailed inventory of shoreline types and processes, and the nature of shoreline materials should be carried out through air photo interpretation, walking and boat traverses. Possibly detailed sampling and profiling of a few selected beaches would be required.

4.4.3 Sediment Dispersion and Deposition

Sediment dispersion in Kluane Lake is to be determined mainly through analysis of previously obtained data near the Slims River delta, through the interpretation of seismic records, which indicate patterns of sedimentation, and data obtained in the Congdon Creek study. The above data needs be supplemented by suspended sediment samples, and turbidity measurements near the Slims River delta and at certain key localities in the lake to provide a complete and factual picture of sediment input, dispersion and sedimentation. A complete analysis of the combined data should result in a general model for sediment dispersion and deposition patterns throughout the lake. Some knowledge of lake water properties and currents, which will also be obtained during this study, is required to complete the model.

4.4.4 Lake Water Properties

Temperature, conductivity and PH should be measured using remote sensors at selected stations on Kluane Lake to determine whether the lakes are physically or chemically stratified. Water samples should be taken at various depths at several stations using Nansen bottles and should be chemically analysed to determine major and minor ion and trace metal concentrations. Similarly, a representative number of samples should be taken and analysed from the Slims River, Congdon Creek, and other selected creeks to determine the loading of total dissolved solids to Kluane Lake.

This survey will establish the background chemistry of the Kluane Lake system so that any future water quality degradation due to mans activities can be properly evaluated.

4.4.5 Kluane Lake Water Circulation and Budget

The hydrological budget of the Kluane Lake system would be analysed by:

1) measuring the flow from the Slims River into Kluane Lake from before breakup (May 15, 1978) to late Fall (Oct. 31, 1978) by installing a Leopold-Stevens portable gauge on the Slims River bridge. The channel morphology would be mapped (width + depth = wetted perimeter) and a discharge rating curve established. The diurnal discharge fluctuation from the Kaskawulsh Glacier would be accurately measured.

2) measuring the input from the Congdon Creek watershed to Kluane Lake by similar portable gauging techniques. The total input to Kluane Lake from all its small tributary watersheds could then be computed with good accuracy by mathematical extrapolation.

3) obtaining the existing gauge hydrographs and

flow from the Kluane River gauge station (1953 to present are available). A rating curve should have already been prepared for this station.

4) mapping the channel morphology of the Kluane River and the probable critical cross-section of the Kluane River channel at the mouth of the Duke River over the season. This data would be compared with flow data from the Kluane River gauge station, and with Kluane Lake water levels as measured at Burwash Landing; this comparison would determine any possible annual water level change in Kluane Lake that might be attributed to Duke River aggradation at the toe of its alluvial-fan.

5) obtaining all meterological data from the Burwash Landing station. This data combined with assembled outflow and inflow data will allow a total water budget for the Kluane Lake system to be established. This is essential to the understanding of Slims River deltaic processes, fluctuations of Kluane Lake levels, sediment loadings and water circulation in the Kluane Lake system.

6) measuring currents at 10 to 15 fixed stations throughout Kluane Lake. The measurements will include direction and velocity and will be taken at different depths. Stations will be reoccupied at least three times during the year. These measurements are critical to the understanding of the movement of water through Kluane Lake and of circulation

of water between Talbot Arm, Brooks Arm and the main body of Kluane Lake.

5.0 SUMMARY

Our reconnaissance indicates that a pipeline crossing of southern Kluane Lake is feasible. Seismic records indicate that the bottom is smooth and that bedrock is generally covered by great thicknesses of unconsolidated sediments except near steep shorelines where bedrock presently outcrops. A ridge opposite the mouth of Congdon Creek reflects a basement structure composed of bedrock or drift. Although the thickness of softer unconsolidated sediments thin over the ridge, both the ridge and basement show a smooth profile. Most of the southern basin of Kluane Lake is filled with thick silt and clay; sand is present near the shorelines. Present sedimentation rates are high near the Slims River delta, but decrease to 2-3 mm along the Congdon Creek/Cultus Creek axis. Sediment compaction and competence is probably relatively high in areas of slow sedimentation. Some slumping along steeper shorelines; sporadic sediment degasification at isolated localities; and sediment erosion by lake bottom sediment-flows near the front of the Slims River delta may be occurring: otherwise, the basin is generally quiescent. No evidence of recent fault activity was found. About 160 km. of seismic profiling with units having 500 hz, 7 Khz, 33 Khz and 200 Khz frequencies; 100 grab-samples; and 15 cores are

required to confirm interpretations, quantify certain elements, and complete the data base.

To assess any impact that pipeline construction or other developmental activities may have on the Kluane Lake system a program is needed to establish its main sources of water and sediment, sedimentation patterns, water circulation, configuration and composition of shorelines, and the nature of bottom material of Kluane Lake. To successfully attain this objective the following work is required; about 300 km. of seismic profiling, bottom sampling (20 grab samples), and coring (20 cores) within Kluane Lake; obtaining numerous current measurements and gauging, suspended sediment samples, temperature measurements, conductivity measurements, pH measurements, and chemical analysis of Slims River, Congdon Creek, and Kluane Lake waters; mapping of shoreline types and geology of Kluane Lake and of surficial geology of Congdon Creek watershed; analysis of meteorological data, flow data for Kluane River and water levels for Kluane Lake as published by government agencies. From the data obtained, models of the Kluane Lake system and of a small high-gradient watershed, such as Congdon Creek, could be constructed.

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Respectfully submitted,

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REGISTERED PROFESSIONAL ENGINEER
V. N. RAMPTON
PROVINCE OF ONTARIO

Stittsville, Ontario
January, 1978

A P P E N D I C E S

CHECKED, CERTIFIED COMPLETE AND CORRECT BY [signature]

I OBSERVED DATA AND COMPUTATIONS

NOTES AND INSTRUMENT DEFECTS AND CHANGES

II HOURLY OBSERVATIONS

SUBTRACT 8 HOURS FOR LOCAL TIME. SKY CONDITIONS FOR YOUR INFO

WIND: DIRECTION IN TENS OF DEGREES; SPEED IN KNOTS; GUSTS (IF OVER 18 KTS). WEATHER: S – SNOW, S- – LIGHT SNOW, S-- – VERY LIGHT SNOW, F – FOG. TEMPERATURES IN °CELSIUS.

Day	Local time	Type (27)	Date (GMT) (28)	Hour (GMT) (29)	Sky Condition (30)	Visibility (31)	Weather and Obstructions to Vision (32)	Sea-level Pressure (33)	Dry-Bulb Temperature °C (34)	Dew-Point Temperature °C (35)	Wind Direction (36)	Wind Speed (37)	Wind Character (38)	Remarks
DAY 1	8Am	R	03	1600	20SCT 100-BKN	50		1021	-12	-14	25	06		This day poor for boating due to S.E. winds Kluane Lake. BLOWING DUST SLIMS RIVER OBSERVED. Boat prep.
		R	03	1800	18SCT 25SCT 100-SCT 220-BKN	50		1033	-14	-17	31	07		
		R	03	2000	25SCT 100SCT E120BKN 220 BKN	50		1032	-11	-13	34	02		
		R	03	2200	25SCT 100SCT E120BKN 220 OVC	40		1012	-6	-10	05	06		
		S	03	2235	SPECIAL WEATHER OBSERVATION						12	20	G33	WIND SHIFT
		R	04	0000	25SCT 100SCT E120BKN 200OVC	50		982	-3	-8	12	15	G23	
	6 PM	R	04	0200	25SCT 80SCT E120BKN 200 OVC	50		973	-4	-10	12	14	G22	~~PCPN DSTNT SE 040100~~
DAY 2	8Am	R	04	1600	1SCT 18SCT 30SCT 100-OVC	50		962	-14	-16	28	10		This day poor due N.W. winds. Cool Temperatures.
		RS	04	1800	2SCT 20SCT 100SCT 230-BKN	50		975	-14	-17	29	09		
		R	04	2000	2SCT 25SCT 100SCT 230-SCT	50		972	-11	-15	28	06		O.K. working Day – Boat ramp buckets
		R	04	2200	2SCT 25SCT 100SCT 230-SCT	50		964	-8	-13	29	14		full of Gravel – Had to Hire Grader
		R	05	0000	25SCT 220 SCT	50		974	-8	-12	28	07		
	6Pm	R	05	0200	25SCT 230SCT	50		977	-10	-11	00	00		
DAY 3	8Am	R	05	1600	90-SCT	50		1023	-19	-22	00	00		Very cold chill factor.
		R	05	1800	35-SCT 90-SCT	50		1011	-5	-11	14	15	G33	
		R	05	2000	35-SCT 90-SCT 220-SCT	50		1013	-3	-7	11	21	G39	work. This day Poor due
		R	05	2200	35SCT 90SCT 220-SCT	50		1021	-2	-6	14	17	G37	Strong SE winds.
		R	06	0000	35-SCT 220-SCT	50		990	-3	-8	12	15	G26	Suggest: No boating Kluane.
	6Pm	R	06	0200	220-SCT	50		981	-4	-9	11	12	G21	
DAY 4	8Am	RS	06	1600	E25 OVC	30	S--	963	-15	-17	29	11		Cold NW winds
		R	06	1800	E25 OVC	30	S--	971	-14	-17	30	10		and fog conditions
		R	06	2000	15SCT E25 OVC	30	S--	977	-13	-16	30	12		FOG SE-VSBS.
		RS	06	2200	-XE25OVC	1½	S-F	985	-12	-14	29	13		Making Poor Day
		R	07	0000	-XE25 BKN 220 OVC	4	S-	1000	-12	-14	29	05		for Boating Kluane
	6 Pm	R	07	0200	-XE25OVC	6	S-	1013	-12	-14	28	08		
DAY 5 NOV 7	8Am	R	07	1600	30-OVC	40		1088	-18	-20	32	06		
		R	07	1800	15SCT E30OVC	40	S--	1092	-14	-17	29	04		work. This Day Poor due
		R	07	2000	15SCT E25OVC	40	S--	1102	-12	-15	28	03		temperature and N.W.
		R	07	2200	15SCT E25BKN	40		1108	-11	-14	30	10		winds Kluane Lk.
		R	08	0000	15SCT 25-BKN 220-BKN	30		1115	-12	-15	29	07		
	6 PM	R	08	0200	25SCT E80OVC	30		1120	-14	-16	27	07		
DAY 6	8Am	R	08	1600	M27 OVC	20	S--	1139	-16	-18	28	10		
		R	08	1800	E27 OVC	20	S--	1144	-16	-18	30	11		This day poor due N.W.
		R	08	2000	E27 BKN 50 OVC	20	S-	1147	-15	-18	28	10		winds and cool temperatures
		R	08	2200	E27 BKN 40 OVC	15	S-	1147	-14	-17	30	09		Kluane Lake.
		R	09	0000	E25OVC	10	S-	1147	-15	-17	30	10		
	6Pm	R	09	0200	E25OVC	20		1147	-16	-20	29	11		
DAY 7 NOV 9	8Am	R	09	1600	1A1F OVC	20	S--	1164	-17	-20	29	05		work. Light NW winds
	Noon	R	09	2000	A8 OVC	20	S-	1159	-16	-18	30	04		Cool temperatures.
	3Pm	R	09	2300	18SCT 30-BKN	50	S--	1166	-12	-15	10	08		

Handwritten remarks my own summation of Boating Weather [signature]

HOUR (GMT)	Corrected Maximum	T_xT_x	Corrected Minimum	T_nT_n	Snowfall	Water equivalent	Rainfall	Total Precipitation	24 hour Precipitation	Depth Snow on Ground
12		(24)		12						
18		12		24						
00		12		18						
06		24		24						
24-HR.										

TIME (GMT): 0900 | 1200 | 1500 | 1800 | 2100 | 0000 | 0300 | 0600

III CODED SYNOPTIC REPORTS

Hour	$6P_oP_oP_oP_o$	$7RRR_ts$	$8N_sC h_sh_s$	$8N_sC h_sh_s$	$8N_sC h_sh_s$	$9S_pS_ps_ps_p$		
09			8	8	8	9		(24) 12
12	6	7	8	8	8	9	2	4
15			8	8	8	9		12 24
18	6	7	8	8	8	9	2	4
21			8	8	8	9		12 18
00	6	7	8	8	8	9	2	4
03			8	8	8	9		24 24
06	6	7	8	8	8	9	2	4

The above weather sequences transcribed from BURWASH AIRPORT weather sheets. 15/11/77 [signature]

IV. SUMMARY FOR THE CLIMATOLOGICAL DAY ENDING AT 0600 GMT

APPENDIX A: WEATHER CONDITIONS DURING SURVEY PERIOD

APPENDIX B: FIX LOCATIONS

FIX #	TIME	Distance to Station A (meters)	Distance to Station A Corrected (meters)	Distance to Station B (meters)	Distance to Station B Corrected (meters)
1	10:22	8236	8166	526	456
2	10:25	8076	8006	873	803
3	10:30	7812	7742	1482	1412
4	10:35	7593	7523	2068	1998
5	10:40	7400	7330	2663	2593
6	10:45	7262	7192	3261	3191
7	10:51	7150	7080	3982	3912
8	10:55	7009	6939	4455	4385
9	11:00	7169	7099	5114	5044
10	11:10	6957	6887	5912	5842
11	11:20	6574	6504	6973	6903
12	11:25	6251	6181	6572	6502
13	11:30	5975	5905	6133	6063
14	11:37	5719	5649	5612	5542
15	11:40	5605	5535	5243	5173
16	11:45	5489	5419	4791	4721
17	11:50	5430	5360	4350	4280
18	11:55	5395	5325	3942	3872
19	12:01	5403	5333	3514	3444
20	12:05	5457	5387	3257	3187
21	12:10	5554	5484	3025	2955
22	12:15	5688	5618	2849	2779
23	12:20	5848	5778	2749	2679
24	12:25	6009	5939	2759	2689
25	12:30	-	-	2915	2845
26	12:45	4452	4382	4258	4188
27	12:50	3782	3712	4863	4793
28	12:55	3373	3303	5175	5105
29	13:00	3027	2957	5550	5480
30	13:05	2796	2726	5952	5882
31	13:10	2687	2617	6429	6359
32	13:16	2780	2710	6977	6907
33	13:20	2969	2899	7414	7344
34	13:25	3288	3218	7886	7816
35	13:30	3611	3541	8302	8232
36	13:35	3983	3913	8702	8632
37	13:40	4395	4325	9106	9036
38	13:45	4818	4748	9518	9448
39	13:50	5244	5174	9951	9881
40	13:56	-	-	10691	10621
41	14:01	-	-	10540	10470
42	14:10	-	-	10181	10111
43	14:17	5604	5534	9694	9624

FIX #	TIME	Distance to Station A (meters)	Distance to Station A Corrected (meters)	Distance to Station B (meters)	Distance to Station B Corrected (meters)
44	14:20	5447	5377	9333	9263
45	14:25	5261	5191	8874	8804
46	14:30	5140	5070	8402	8332
47	14:35	5099	5029	7915	7845
48	14:45	5087	5017	7032	6962
49	14:50	5138	5068	6587	6517
50	14:55	5228	5158	6142	6072
51	15:00	5376	5306	5700	5630
52	15:07	5584	5514	5187	5117
53	15:10	5777	5707	4815	4745
54	15:15	6000	5930	4392	4322
55	15:20	6269	6199	3959	3889
56	15:25	6567	6497	3530	3460
57	15:30	6885	6815	3111	3041
58	15:35	7213	7143	2697	2627
59	15:40	7553	7483	2298	2228
60	15:45	7914	7844	1917	1947
61	15:50	8301	8231	1587	1517
62 & 63	-	-	-	-	-
64	16:20	9961	9891	1604	1534
65	16:25	10343	10273	1895	1825
66	16:30	10726	10656	2230	2160
67	16:35	10625	10555	2237	2167
68	16:40	10541	10471	2356	2286
69	16:45	10505	10435	2605	2535
70	16:51	10495	10425	2979	2909
71	16:55	10516	10446	3321	3251
72	17:00	10575	10505	3744	3674
73	17:05	10668	10598	4220	4150
74	17:10	10779	10709	4678	4608
75	17:15	10885	10815	5144	5074
76	17:20	10995	10925	5611	5541

Fix #	TIME	Distance to Station A (meters)	Distance to Station A Corrected (meters)	Distance to Station C (meters)	Distance to Station C Corrected (meters)
80	10:05	5456	5386	1384	1314
81	10:11	5053	4983	1656	1586
82	10:15	4782	4712	1932	1862
83	10:20	4472	4402	2327	2257
84	10:25	4199	4129	2760	2690
85	10:30	3984	3914	3201	3131
86	10:40	3228	3158	3875	3805
87	10:45	3018	2948	3815	3745
88	10:50	2968	2898	3737	3667
89	10:55	3030	2960	3749	3679
90	11:00	3201	3131	3843	3773
91	11:05	3474	3404	4030	3960
92	11:10	3753	3683	4296	4226
93	11:15	4080	4010	4622	4552
94	11:20	4468	4398	4975	4905
95	11:25	4899	4829	5344	5274
96	11:30	5378	5308	5700	5630
97	11:35	5890	5820	5979	5909
98	11:40	6419	6349	6283	6213
99	11:45	5958	5888	6153	6083
100	11:50	5429	5359	5952	5882
101	11:55	4895	4825	5832	5762
102	12:00	4426	4356	5774	5704
103	12:05	3816	3746	5778	5708
104	12:10	3281	3211	-	-
105	12:15	2757	2687	5899	5829
106	12:20	2216	2146	6009	5939
107	12:25	1671	1601	6173	6103
108	12:30	1143	1073	6306	6236
109	12:35	620	550	6452	6382

APPENDIX C: BATHYMETRY

Fix #	Depth in meters	Fix #	Depth in meters	Fix #	Depth in meters
.5	11	21	61	52	74 1/2
.75	16	21.7	50	53	74
.80	18	22	48	54	73 1/2
.90	22	23	40	55	73
.96	32	24	33	56	72
1	35	25	12	57	70
1.2	39	25.8	37	58	68
2	43	26	11	59	64 1/2
2.15	46	27	12	60	62
2.3	59	27.05	20	61	45
3	59	27.1	24	62	53
3.9	62.5	27.15	40	63	52
4	61	27.25	47	64	41 1/2
4.1	64	27.6	64	65	40
5	68	28	67 1/2	66	28
6	70	29	71 1/2	67	41 1/2
7	70.5	30	76	68	32
7.5	70.5	31	77	68.65	28
8	70	33	77 1/2	69	45
8.4	67	34	77	69.3	57
9	42	35	77	70	60.5
9.13	30	36	77	71	61
9.23	17	37	75	72	60
9.3	2	38	73	72.85	57
9.7	2	39	63	73	52
9.75	13	39.1	52	73.15	49
9.9	12	40	34	73.3	52
10	17	40.25	27	74	50
10.3	18	40.28	23	75	41
11	10	40.6	17	75.4	38
11.35	14	41	21	75.7	33
11.6	14	41.5	24	75.75	30
12	20	41.52	25	75.8	25
12.5	29	42	32	75.95	23
12.55	32	42.5	40	76	20
13	47	43	55	80	16
13.5	72	44	65	80.55	18
14	74	45	73	80.7	22
15	75	46	74	80.8	30
16	75	47	74 1/2	81	35
17	75.5	48	75	81.85	38
18	74	49	75	82	40
19	72	50	75 1/2	82.5	39
20	68	51	75 1/2	83	36

Fix #	Depth in meters
83.65	38
84	37 1/2
85	41
85.1	44
85.8	52
86	30
86.1	8
86.4	56
87	57 1/2
88	60
89	64
89.55	68 1/2
90	68
91	69
92	69 1/2
93	70
94	70
95	68
95.9	61
96	54
96.1	46
96.25	44
96.30	40.5
96.35	40
96.40	37
96.85	35
96.95	33
97	27
97.05	26
97.1	22 1/2
97.5	20
98	5
98.4	16
99	23
99.05	27
99.1	27 1/2
99.25	33
99.40	35
99.45	36
99.55	36
99.57	37
99.80	38
100	44
100.15	45
100.3	53
100.35	60
100.4	63

Fix #	Depth in meters
101	70
102	73
103	75
104	76 1/2
105	75 1/2
106	75
107	75
108	75
108.5	75
108.55	73
109	71 1/2

APPENDIX D: DEPTH TO BASEMENT

Fix #	Depth in ft.	Bottom depth (ft.)
3.6	260	206
3.8	230	206
4	210	200
4.2	250	210
4.4	> 260	215
59	270	215
59.55	230	208
60	229	205
60.3	200	190
60.6	195	185
61	153	150
61.2	147	145
61.5	180	165
62	195	174
62.5	210	178
63	200	172
63.2	190	158
63.4	170	158
63.5	145	135
64	160	131
65	190	128
65.8	180	110
66	93	93
66.2	180	113
67	160	140
67.5	144	134
68	112	112
68 1/2	93	93
69	170	146
69.3	220	183
69.5	> 250	190

APPENDIX E: SEDIMENT THICKNESSES

FIX #	Upper Unit (ft.)	Lower Unit (ft.)
42		< 5
43		13
44		25
45		37
46		35
47		32
48		27
49		26
50		25
51		24
52		23
53		22
54		20
55		18
56		17
57		16
58		14
59		14
60		16
61		< 5
28		12
29		16
30		17
31	3	17
32	7	22
33	7	23
34	7	25
35	6	28
36	2	32
37		33
38		39
39		25
40		< 10
109		14
108 1/2	10	13
108	12	14
107	15	13
106	14	26
105	13	25
104	8	26
103	7	29
102	7	32
101	10	32
100	10	< 20
99		< 8

FIX #	Upper Unit (ft.)	Lower Unit (ft.)
86		
87	47	33
88	35	35
89	19	46
89 1/2	12	38
89 1/2(F)	22	46
90	21	47
91	11	54
92	10	50
93	9	51
94	6	49
95	3	58
95 2/3	3	67
96		10
13		10
14		22
15		22
16		21
17		20
18		17
19		18
20		13
21		12
22		10
69		20
69 1/2		27
70		18
71		17
72		14
73		< 10
2		12
3		8
3 1/2		14
4		6
4 1/2		14
5		14
6		14
7		20
8		18
8 1/2		20
9		< 5