KOOTENAY LAKE, BRITISH COLUMBIA

II

GEOGRAPHIC AND GEOLOGICAL SETTING

by

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Kootenay Lake, British Columbia: II, geographic and geological setting.

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ABSTRACT

This report presents descriptions of the location and physical geography of Kootenay Lake, including its bathymetry, morphometry, and morphology, its geological setting and history. A brief summary of the thickness and nature of the post-bedrock deposits is also provided.

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INTRODUCTION

This is the first in a series of four data reports which describe the geological aspects of the limnology of Kootenay Lake, British Columbia. The geological program, primarily concerned with the sedimentology and geochemistry of the bottom sediments, was part of a broad interdisciplinary, limnological research study of Kootenay Lake carried out between 1974 and 1978. Other reports deal with specific physical, chemical and biological programs. The philosophy behind the programme, and the rationale for its existance, are discussed in a major report of the entire study (Daley et al. 1980).

GEOGRAPHIC SETTING

Kootenay Lake lies in the central part of the Purcell Trench, a spectacular valley between the Selkirk and Purcell Mountains in southeastern British Columbia (Figure 1). It is a long, narrow, deep, fjord-type lake, with its axis aligned a few degrees west of north and its surface at an elevation of 529.7 metres above mean sea level (lowest recorded level of Kootenay Lake at Kuskanook and Kaslo until 1964: Canadian Hydrographic Service Chart 3050). Lake level fluctuates, however, by as much as 4 metres due to the seasonal nature of the hydrograph (see Wiegand et al. 1979). From both shorelines the mountains of the Purcell (east) and Selkirk (west) ranges rise steeply to summit elevations of between 2100 m and 2700 m above mean sea level.

The climate around Kootenay Lake is typically continental with moderately cold winters and warm summers. The mountains strongly influence the regional climate, causing the easterly flowing Pacific air masses to rise and release their moisture. Precipitation over the lake is typically 40-80 cm. yr^{-1}; snowfall varies in the range 1-2 m. yr^{-1} (see Morse, 1974).

The lake drains a large area (Figure 2) from the western slopes of the Rocky Mountains to the Selkirk Mountains. In the immediate vicinity of the lake the basin is drained by numerous small-volume, steep, mountain streams which only flow during snowmelt or immediately after heavy rain, and a few larger streams and small rivers that flow continously. Three major rivers enter Kootenay Lake (Figure 2). Kootenay River, the largest, originates in the Rocky Mountains and enters the south end of the lake near Kuskanook. The Duncan and Lardeau Rivers unite a few kilometres north of the lake and enter near Lardeau. These three rivers provide approximately 75% of the annual lake discharge. The single outlet of Kootenay Lake is the West Arm, which exits the lake near Balfour, forms the Lower Kootenay River below Nelson, and joins the Columbia River at Castlegar.

There are presently eight major dams or control structures in the Kootenay Basin. The first hydro-electric dam on the Kootenay River was completed in 1898 at Lower Bonnington Falls, about 16 kilometres west of Nelson. Corra Linn Dam, 12 kilometres below Nelson, was built in 1931 but operated on a free-flow basis until 1939. Other dams on the Lower Kootenay River include the Upper Bonnington Dam, the South Slocan Dam and the Brilliant Dam. After ratification of the Columbia River Treaty in 1961, the Kootenay Canal and Power Plant was started on the lower Kootenay River to utilize the controlled water releases of the Duncan and Libby Dams. Duncan Dam, a flood control and storage dam on the Duncan River, became operational in 1968. Libby Dam, a hydro-electric dam on the Kootenai River at Libby, Idaho, became operational in 1975.

Throughout the recorded history of European exploration and settlement in the Kootenay area, and undoubtably before, the lake has been a means of access to the hinterland and a transportation route; from early exploration by canoe through paddle-wheelers which carried settlers, their provisions and produce, and especially ore from the many mines located around the watershed, to modern diesel-powered tugboats hauling log booms up and down the lake. Currently there is also intensive use of the lake for recreation; primarily boating and fishing. The recreation-based portion of the local economy is steadily increasing, and this growth relies almost exclusively on the various attractions of Kootenay Lake.

Kootenay Lake is readily accessible from east and west via paved highways, one of which connects across the lake by ferry. Paved highways follow the southeast and northwest shorelines, the latter connecting to the Trans Canada Highway at Revelstoke, B. C. 200 km to the north. There are daily scheduled air services from Calgary and Vancouver to Castlegar, 47 km west of Nelson, B. C. A CP Rail branch line, primarily to carry ore from Kimberley to Trail, B. C., follows the southwest shore of the lake.

BATHYMETRY AND MORPHOMETRY

The bathymetry of Kootenay Lake is shown in Figure 3. Larger scale charts are kept in the files at the N.W.R.I. laboratory in West Vancouver. Table I provides the basic morphometric data for Kootenay Lake, and Table II summarizes the lake's watershed areas. Data for the compilation of the bathymetric chart was obtained using an ATLAS DESO-10 dual-frequency echo-sounder. Sounder motor speed was set to a sound velocity of 1490 metres per second, but subsequent recalculation of sound velocities averaged over the water column and compensating for the temperature profile suggested an error in the measured depth of between 3 and 5% greater than the true depth. Sounding lines were spaced approximately 0.5 to 0.8 km apart, oriented perpendicular to the long axis of the lake, and run using the "point-to-point at constant speed" method of naviagation. Depths were correlated to a chart datum of 532 m above mean sea level. While this chart is satisfactory for the purpose of this study, it is not considered sufficiently well controlled or detailed enough to be used for navigation in near-shore or shallow areas. No sounding lines were run in the West Arm. Detailed data for the nearshore zones and the West Arm are available on Chart 3050 (Canadian Hydrographic Service, 1964).

The general morphometry and geomorphic setting of Kootenay Lake fit closely with the description of a fjord lake (Type 28b, Hutchinson, 1957). It is a long, narrow, deep lake with steep sides and a relatively flat bottom. The north end is narrower than the south and has a more irregular bottom topography of gentle slopes and low hummocks (most less than 10 m elevation).

At the ends of the lake the bottom shallows gradually up the deltas of the Kootenay and Duncan Rivers. Relatively gentle slopes are associated with deltas of the larger streams that flow into the lake laterally. These latter are, however, usually of limited areal extent.

GEOLOGICAL SETTING

Reports on the geology of Kootenay Lake and its 'immediate' sub-basin are numerous, reflecting the importance the area has had as a mineral resource for British Columbia. The brief description which follows has been condensed from more detailed geological investigations by Rice (1941), Little (1960), Crosby (1960, 1968), Fyles (1967), Reesor (1973) and Höy (1977). Figure 4 is a simplified geological map of the lake basin.

Kootenay Lake is situated in an arcuate belt of complexly folded sedimentary, volcanic, and metamorphic rocks of Precambrian to early Mesozoic age, that have been intruded by fine-grained granodiorites and pegmatites of the Late Mesozoic Nelson Batholith. Local zones of high grade metamorphism, and mineralisation of economic grade, occur near intrusive contacts. Ore bodies are generally small, of the vein or replacement type, and occur in a variety of rocks. Replacement deposits in limestones produce the largest ore bodies. Ore minerals of most economic importance are galena (PbS), and sphalerite (ZnS), as well as chalcopyrite ($CuFeS_2$) and some native silver. Gangue minerals include quartz, calcite, pyrrhotite ($Fe_{n-1}S_n$), pyrite (FeS) and arsenopyrite ($FeAsS$). The importance of mining to the area, and a summary of mining history around the lake have been described in Pharo (1978).

As evident in Figure 4, and more clearly demonstrated in maps accompanying Rice (1941), Little (1960), Crosby (1960) and

Reesor (1973), the general geological structure of the area produces a bedrock outcrop pattern grading from oldest rocks in the east to youngest in the west on the inner side of the arc. Dip is generally toward the west. Specific formations, even horizons, are continuous across the lake without offset suggesting that large scale faulting is not responsible for the formation of the lake valley. In the middle and southern parts of the lake, structures and formations cross the lake nearly at right angles suggesting that the location of the lake valley is neither structurally nor stratigraphically controlled.

The geological origin of Kootenay Lake is described by Schofield (1916) as the result of river erosion which commenced in the late Cretaceous and continued through the Tertiary, keeping pace with the growing mountain ranges, until ice filled the valley in the Pleistocene. Valley glaciers originating in the Purcell and Selkirk Mountains fed the main ice mass laterally. During this time the large valley glacier that occupied what is now the West Arm (outlet) of Kootenay Lake flowed into the Kootenay ice mass from the west. A large terminal moraine was constructed near what is now the big bend in the Kootenay River near Libby, Montana. As ice melted, a lake formed behind the moraine and drained southward over it. However, as ice melted in the West Arm, drainage was established over a lower divide near Nelson causing the West Arm to drain toward the west, the southerly drainage over the moraine to dry up, and the Kootenay River to follow its present arcuate path. The present form of the lake, with deltas prograding from both ends and drainage to the west from an outlet in the middle, was also established.

THICKNESS OF POST-BEDROCK SEDIMENTS

The thickness of the post-bedrock (and probably post-Pleistocene) sediment pile on the lake floor, its degree of homogeneity, the attitude of the sediments and the pre-sediment bedrock topography have been interpreted from two sources of information. In 1960, 1967 and 1970 COMINCO LTD. contracted a series of geophysical surveys to HUNTING SURVEY CORP. (1960), HUNTEC LTD. (1967) and KENTING EARTH SCIENCES (1970). The aims of the survey ranged from establishing the extent of the ore-bearing structure at Riondel (Bluebell Mine) to determining the shape, extent and volume of the old tailings pile in Bluebell Bay. COMINCO LTD. kindly released copies of the reports and geophysical maps to augment data N.W.R.I. collected in 1975. The 1960 survey used a Sparker as power source, but no other data on the power or configuration of the array was given. In 1967 HUNTEC used a Hydrosonde Mark 2A recording and triggering system (the latest at that time of their own family of continuous seismic profiling systems) and a Bolt Associates Model 600 air gun with 10 in^3. (154 cm^3) chamber as signal source. The hydrophone array consisted of an eel of 20 MP-7 hydrophones towed in a plastic tube. The frequency range used for most of the survey was 101-628 Hz. Further details are available in COMINCO's report. The same system was used in the 1970 survey by KENTING.

In 1975, N.W.R.I. let a contract to THALASSIC DATA for continuous seismic profiling of Kootenay Lake to provide information on the history of Kootenay Lake beyond the depths to which N.W.R.I. equipment (echo-sounding and coring) could reach. THALASSIC DATA LTD. mounted their equipment on the N.W.R.I. Sea Truck, a 9 X 3 metre flat-bottomed vessel powered by a 255 HP Mercruiser inboard-outboard motor. Their equipment included a 200 Joule E.G. & G. Boomer as signal source, a 25-element hydrophone array designed and built by THALASSIC DATA, and a E.P.C. dry paper recorder. The preamplifier, also of THALASSIC's design and construction, was set for a band width of 400-5,000 Hz. Some noise due to the boat's engine being exhausted into the water was evident on the records. Positioning was accomplished using radar fixes during point-to-point cruising.

Figure 5 shows the seismic profiling lines run by N.W.R.I., and Figures 6 to 10 are photo-reduced copies of some of the origninal records (on file at N.W.R.I., Pacific and Yukon Region, I.W.D., West Vancouver, B. C.). The N.W.R.I. data has not been reduced (migrated) to eleminate the effects of steeply dipping bedrock (cf. HUNTEC, 1967). The signal source and hydrophones were omnidirectional in character although made to function hemispherically directional by towing near the surface. Hence when 'close' to shore the outgoing (spherical) pulse may be reflected back by a side wall before the wave front reaches the bottom directly beneath the boat. The effect is to overlap echoes and produce parabolic reflections. It is possible to apply corrections to the data to compensate for, or eliminate, the effect of early side-echo return. However, the N.W.R.I. seismic survey was neither intended nor designed to be utilised in a more sophisticated manner than as a guide to the sedimentary sequence in the lake basin.

Thickness of sediments have been estimated from the N.W.R.I. records using the assumption that sound velocity in lake water is 4800 ft. sec.$^{-1}$ (1463 m. sec.$^{-1}$) and in the sediment is constant at 7000 ft. sec.$^{-1}$ (2134 m. sec.$^{-1}$). Normally, sound velocity increases with depth in sediments (barring the presence of low velocity layers due to organic matter, particularly hydrocarbons), but in the absence of definite, measured, velocity data the averaged value calculated by HUNTEC LTD. (1967) has been taken as a reasonable one for these sediments. In this section, the term "bedrock" is used as a 'catch-all' designation for consolidated rock upon which unconsolidated or superficial sediments rest. In Figures 6 to 10 it is defined by the portion of the record that can be seen to dip steeply down under the water (clear part of record) and lake bottom muds (generally horizontally stratified) from each shore, and gives a sequence characterised by relatively low (sound) penetration and strong, parabolic reflections (cf. Figure 6A).

From their survey in 1960 HUNTING could show only that the sediments in Kootenay Lake near Riondel are more than 400 feet (122 m) thick, and the bedrock surface plunged steeply beneath the sediments, until its signal was lost in electronic noise. They traced bedrock for more than 1100 feet (335 m) below lake surface. In 1967, however, HUNTEC obtained clearer records and could show bedrock at elevation of 1400 ft. (427 m) - 1700 ft. (518 m) below mean sea level (Kootenay Lake surface was regarded as 1752 feet (534 m) above mean sea level; water depth near Riodel 460 feet (140 m). A map presented with the 1967 report showed an interpolation of bedrock contours which provided a valley cross-section whose bedrock floor now reaches more than 1600 feet (488 m) below mean sea level (1016 m below present lake surface, 876 m beneath the top of the sediment pile). Their map also shows that the direction of increasing depth to bedrock is toward the north from Riondel.

N.W.R.I. records rarely managed to trace bedrock from one side of the lake to the other. In the few records which do, however, depth to bedrock in centre lake is variable, indicating some topographic relief existed on the bedrock surface. It is not possible to clearly define sediment types within the post-bedrock sequence. Some profiles have zones of reflections that could be interpreted as gravel or glacial till. Most sections show parallel reflections in the upper portions suggesting even, continuous, indeed monotonous, sedimentation over the last few hundreds or even thousands of years.

Close to the mouths of major creeks the seismic record is masked by reflections from the creek outwash fans. Sediments close to the creek mouths are sandier than the main lake sediments and the signal source was not powerful enough to profile through the sands. Similarly, the records from the Kootenay and Duncan River deltas show very little pentration.

Cross-lake bedrock profiles were not obtained from the South Arm, making interpretation of average sediment thickness impossible. If, however, the figure obtained from Huntec (1967) of 880 m is accepted, and if ice left the basin about 9,000 years ago having scoured the valley clear to bedrock, the average sedimentation rate is 0.1 m. yr^{-1}. Present sedimentation rates near Riondel are closer to 0.18 cm. yr^{-1}, two orders of magnitude less. While the assumption may not be correct, it is likely that the discrepancy is explained by very much more rapid sedimentation rates during and immediately after ice retreat from the area.

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LIST OF TABLES

TABLE I

Morphometric parameters, Kootenay Lake
(excluding the West Arm)

Area (A)		389	km^2
Volume (V)		43.3	km^3
Length (L)		107	km
Breadth:	maximum (b_{max})	6.1	km
	minimum (b_{min})	2.2	km
	mean ($\bar{b}$)	3.8	km
Depth:	maximum (Z_{max})	154	m
	mean ($\bar{Z}$)	107	m
Shoreline (S)		286	km
Shoreline development ($D = S/2 \sqrt{\pi A}$)		4	

TABLE II

Kootenay Lake, Watershed Areas

Duncan/Lardeau Watershed, including Duncan Lake	4,587 km^2
Duncan Lake	79 km^2
Duncan/Lardeau watershed	4,508 km^2
Kootenay Lake, excluding West Arm	389 km^2
Kootenay Lake, watershed:	
NW (Kaslo) 900 km^2	
NE (Argenta) 1,178 km^2	
SE (Kuskanook) 651 km^2	
Sw (Midge) 870 km^2	
Total:	3,599 km^2
Kootenay River drainage basin,	
- total (including Libby Reservoir)	36,308 km^2
- in U.S.	12,104 km^2
- % in U.S.	33%
- downstream of Libby Reservoir	
- west side	3,440 km^2
- east side	7,445 km^2
- Total	10,885 km^2
- in U.S.	6,359 km^2
- % in U.S.	58%
- upstream of Libby Reservior	
(including Libby Reservoir)	25,452 km^2

TABLE II Cont'd

Libby Reservoir-upstream to Bull River approximately	337 km^2

Discrepancy: Kootenay River basin

- total measured 36,308 km^2
- by addition 36,337 km^2
- error: 0.08%

LIST OF FIGURES

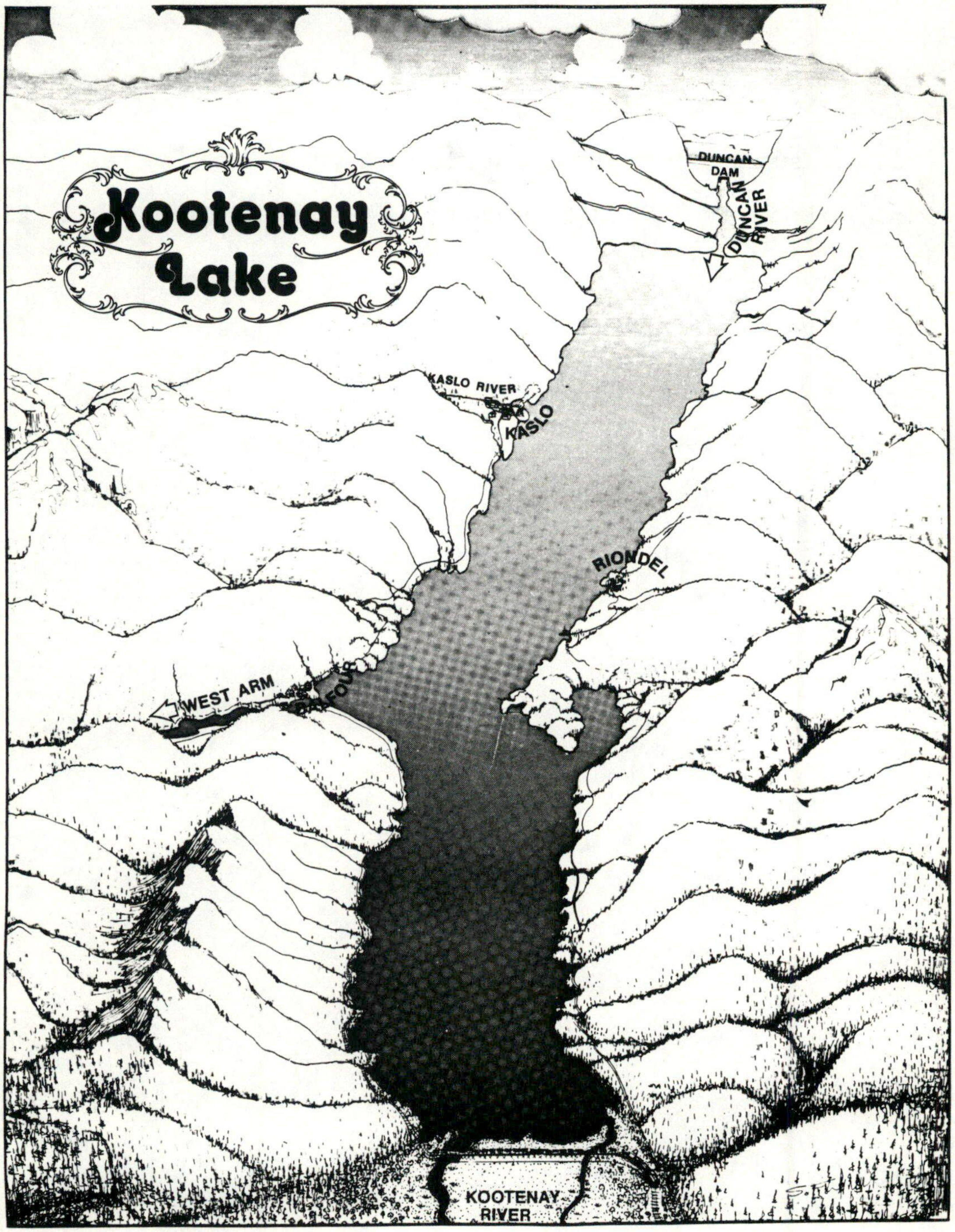


Figure 1. Frontispiece

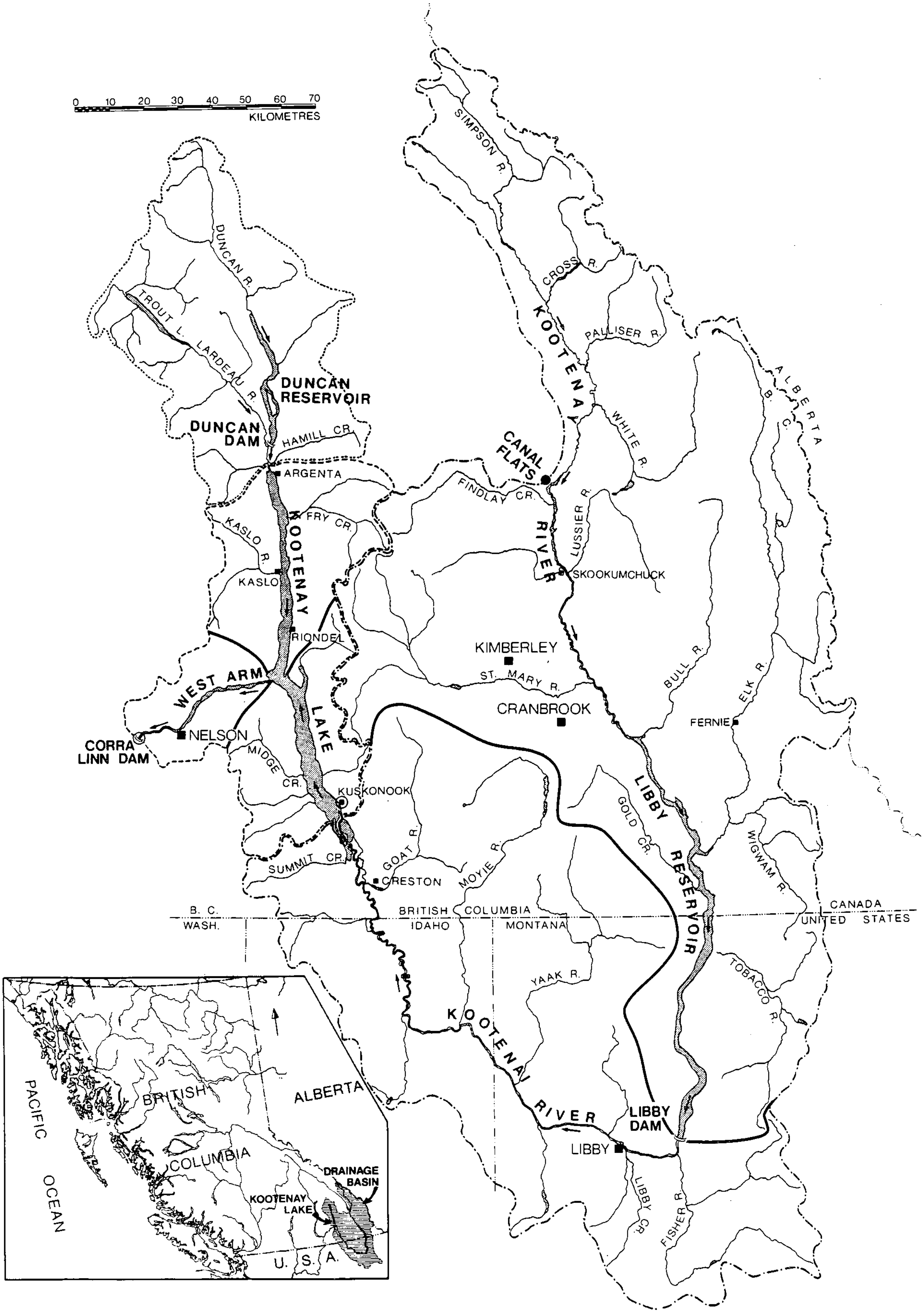

0 10 20 30 40 50 60 70
KILOMETRES
SIMPSON R.
DUNCAN R.
TROUT L.
LARDEAU R.
CROSS R.
KOOTENAY
PALLISER R.
DUNCAN RESERVOIR
DUNCAN DAM
HAMILL CR.
ARGENTA
ALBERTA
B.C.
WHITE R.
CANAL FLATS
FINDLAY CR.
LUSSIER R.
RIVER
FRY CR.
KASLO R.
KASLO
KOOTENAY
SKOOKUMCHUCK
RIONDEL
KIMBERLEY
BULL R.
ELK R.
WEST ARM
LAKE
ST. MARY R.
CRANBROOK
FERNIE
NELSON
CORRA LINN DAM
MIDGE CR.
KUSKONOOK
GOLD CR.
LIBBY RESERVOIR
WIGWAM R.
GOAT R.
MOYIE R.
SUMMIT CR.
CRESTON
B. C.
WASH.
BRITISH COLUMBIA
IDAHO
MONTANA
CANADA
UNITED STATES
YAAK R.
TOBACCO R.
KOOTENAI
RIVER
LIBBY DAM
LIBBY
LIBBY CR.
FISHER R.
PACIFIC OCEAN
BRITISH COLUMBIA
ALBERTA
DRAINAGE BASIN
KOOTENAY LAKE
U. S. A.

Figure 2

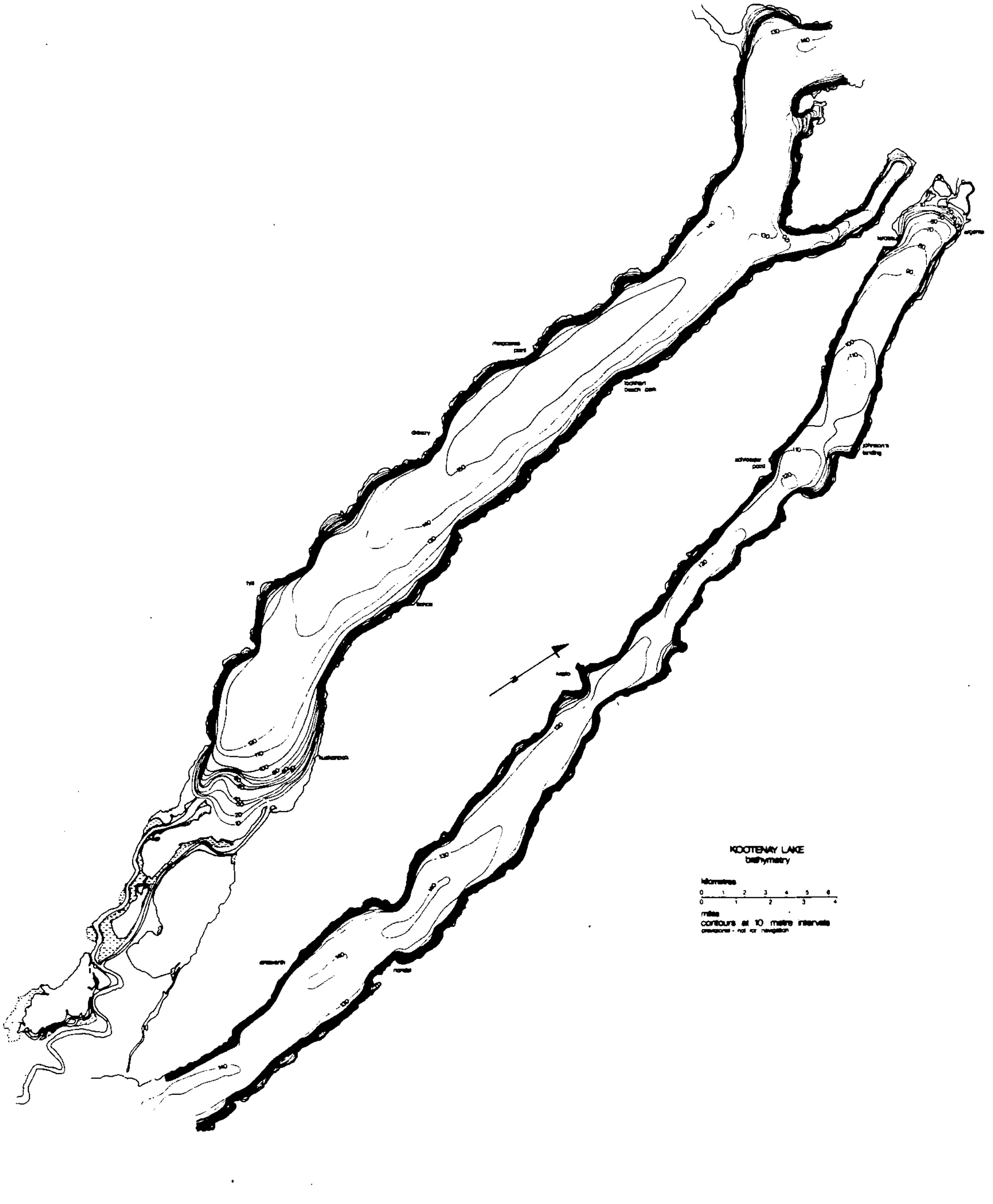

lockhart
beach park
schroeder
point
johnson's
landing
100
110
120
KOOTENAY LAKE
bathymetry
kilometres
0 1 2 3 4 5 6
0 1 2 3 4
miles
contours at 10 metre intervals
provisional - not for navigation

Figure 3

SIMPLIFIED GEOLOGICAL MAP OF:

KOOTENAY LAKE AREA

modified from:
GEOLOGICAL SURVEY OF CANADA MAPS
1326A LARDEAU
603A NELSON (east half)
1090A NELSON (west half)
lithology only shown, structural details omitted

LEGEND

Formational legend derived from source maps and simplified. Quarternary deposits (glacial tills, periglacial outwash and recent alluvium) omitted.

⊞ **NELSON INTRUSIVE**
Intrusive rocks: post-Triassic (lower Cretaceous) granite, granodiorite, quartzite

▒ **SLOCAN SERIES**
Triassic: slate argillite, quartzite, limestone, schists

▓ **KASLO SERIES**
Triassic: lavas, tuffs, breccias; allied intrusives, schists

░ **MILFORD GROUP**
Carboniferous and Permian: slate, argillite, chert, limestone, schist, some greenstone

▥ **LARDEAU SERIES**
Windermere (upper precambrian) micaceous and quartzitic schist, quartzite and limestone (incl. badshot, Fm); paragneiss

▨ **HAMIL SERIES**
Windermere: grey, green, and white siliceous quartzite

▥ **HORSETHIEF CREEK**
Windermere: (incl. irene volcanics, toby conglomerate); quartzite, limestone, arkose, conglomerate, andesite

▤ **UPPER PURCELL**
Mount Nelson (**4**) & Dutch Ck. (**5**) formations: laminated argillite, magnesium limestone, quartzite

▒ **LOWER PURCELL**
Kitchener-siyeh (**1**), Creston (**2**) & Aldridge (**3**) formations: limestone, argillite, quartzite

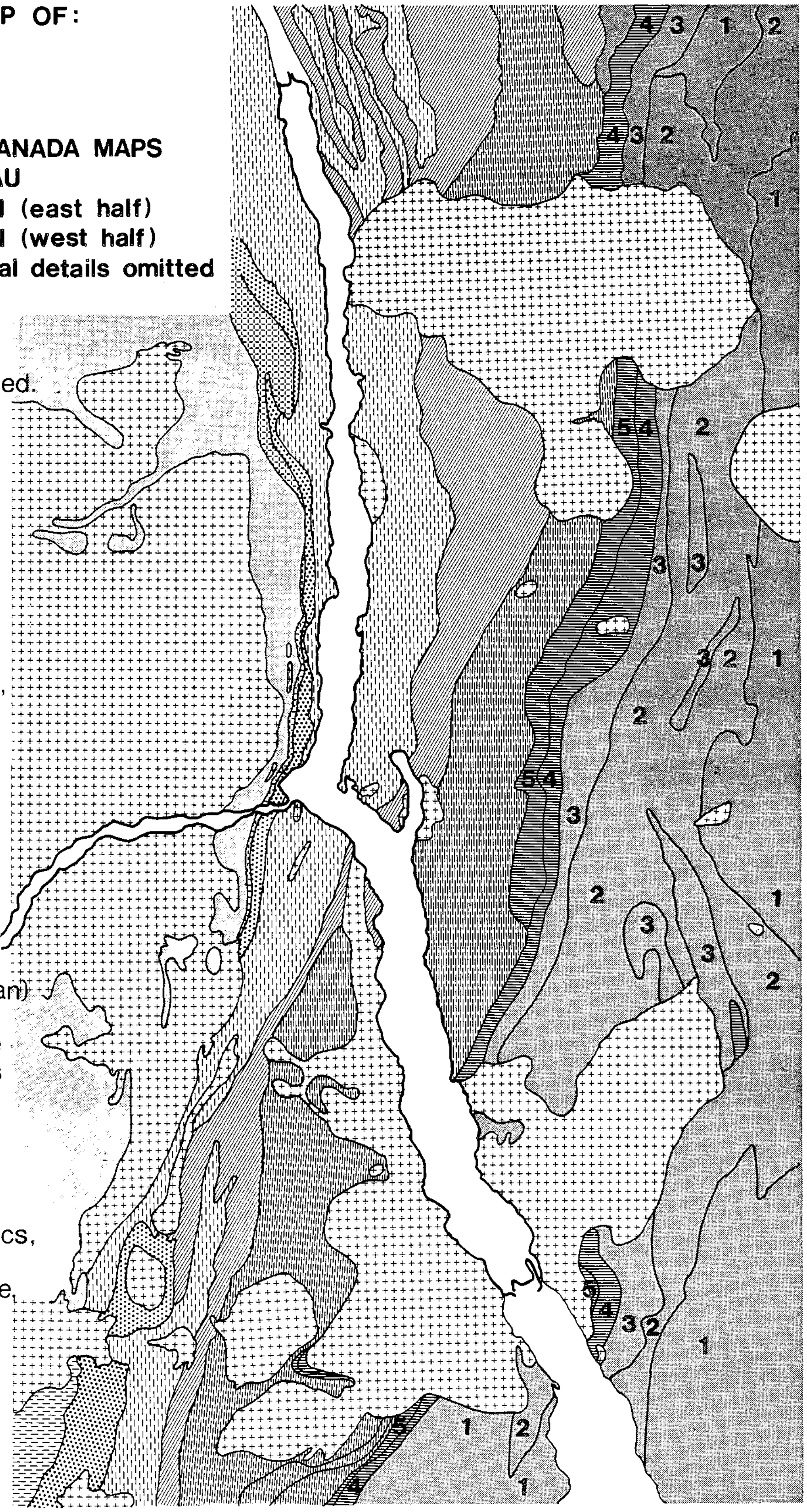


Figure 4

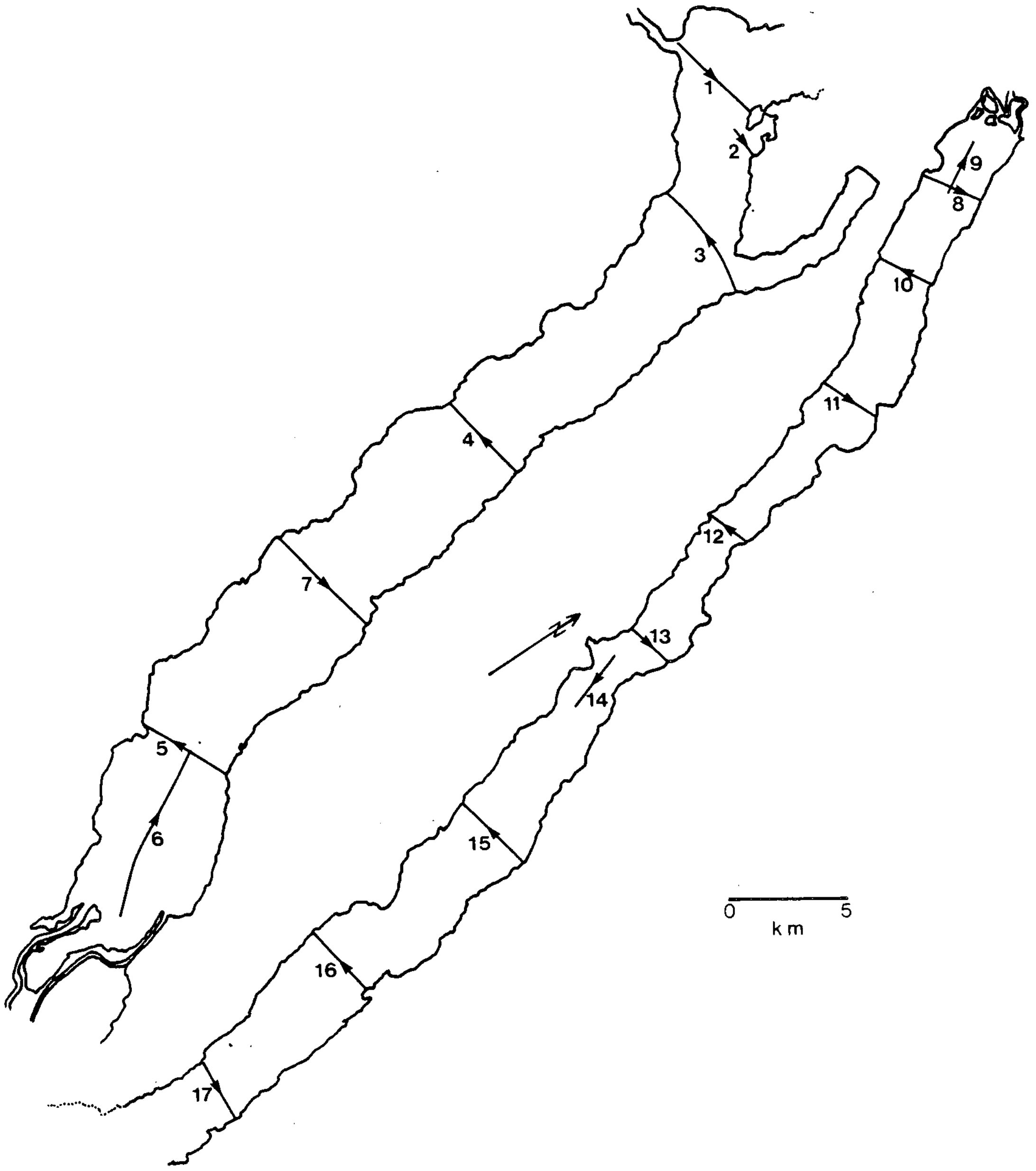


Figure 5

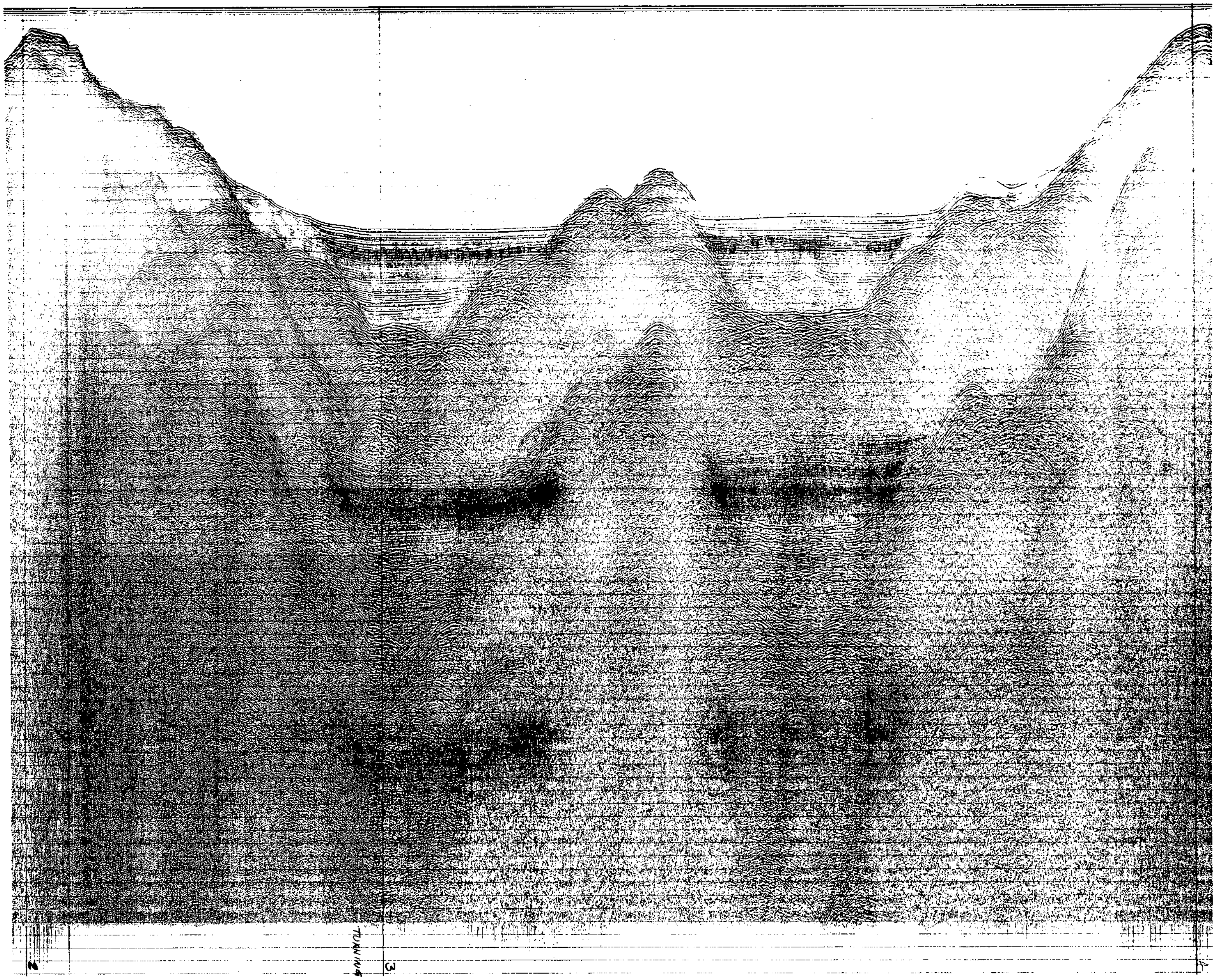


Figure 6

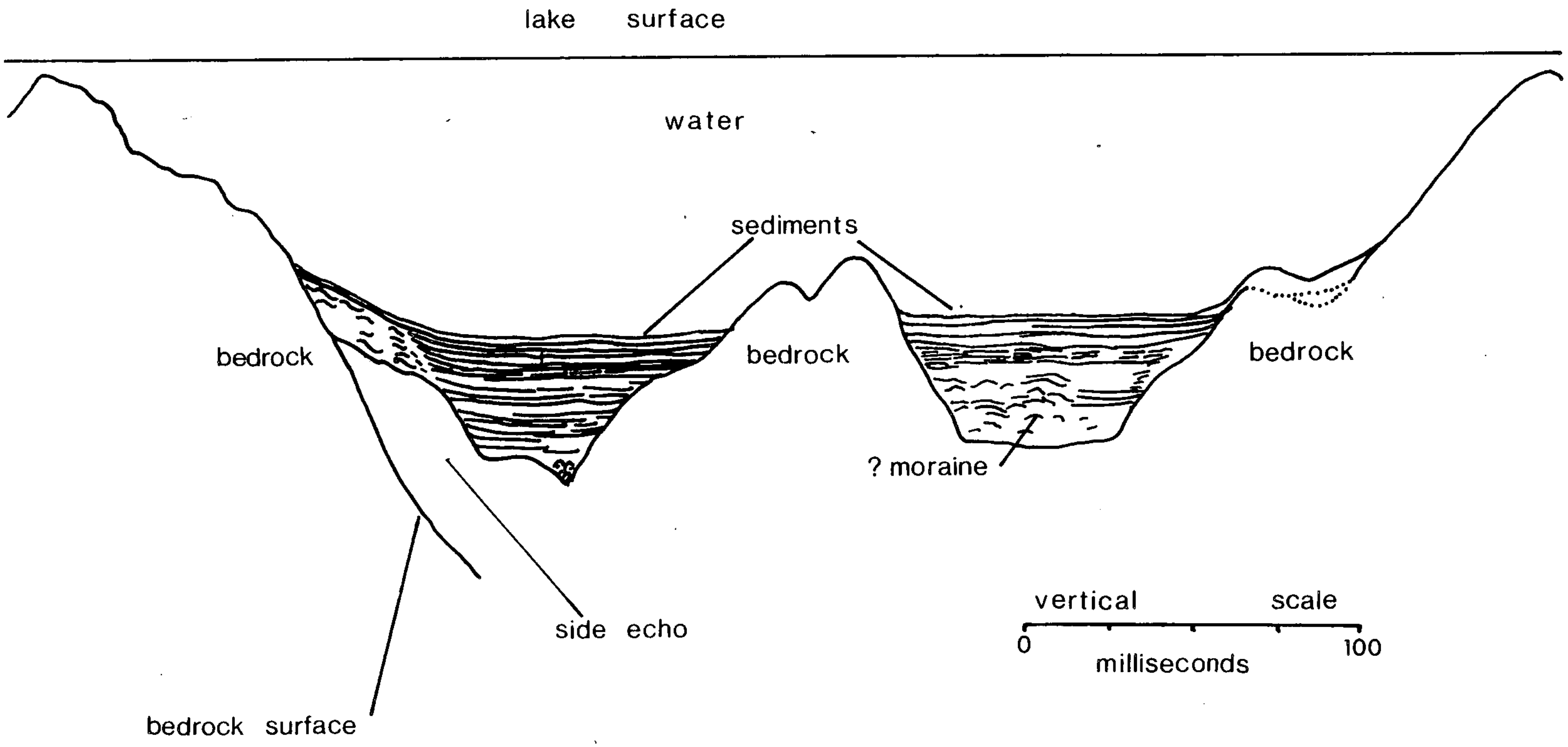
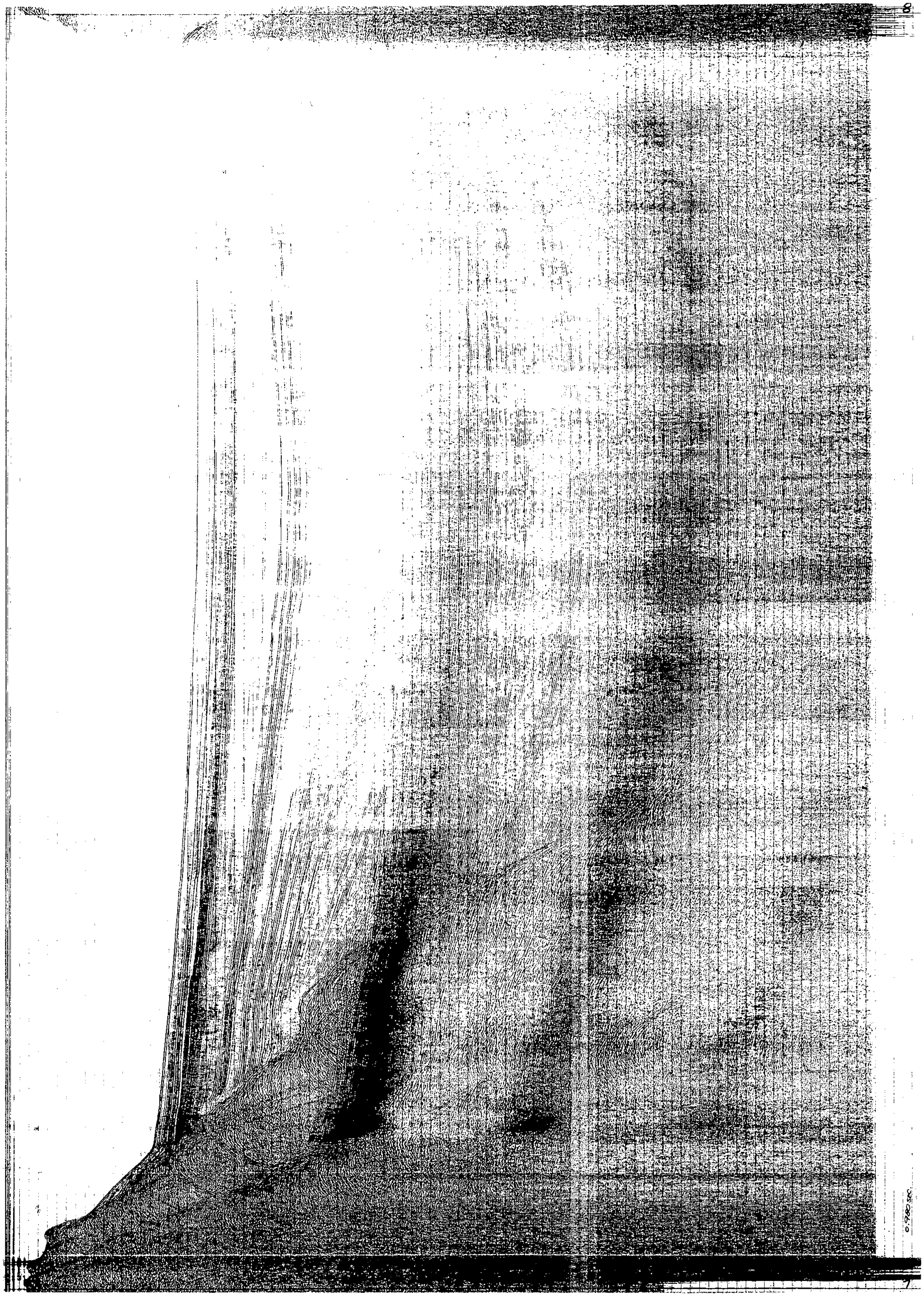


FIGURE 6A. Interpretation and simplification of seismic profile Figure 6.



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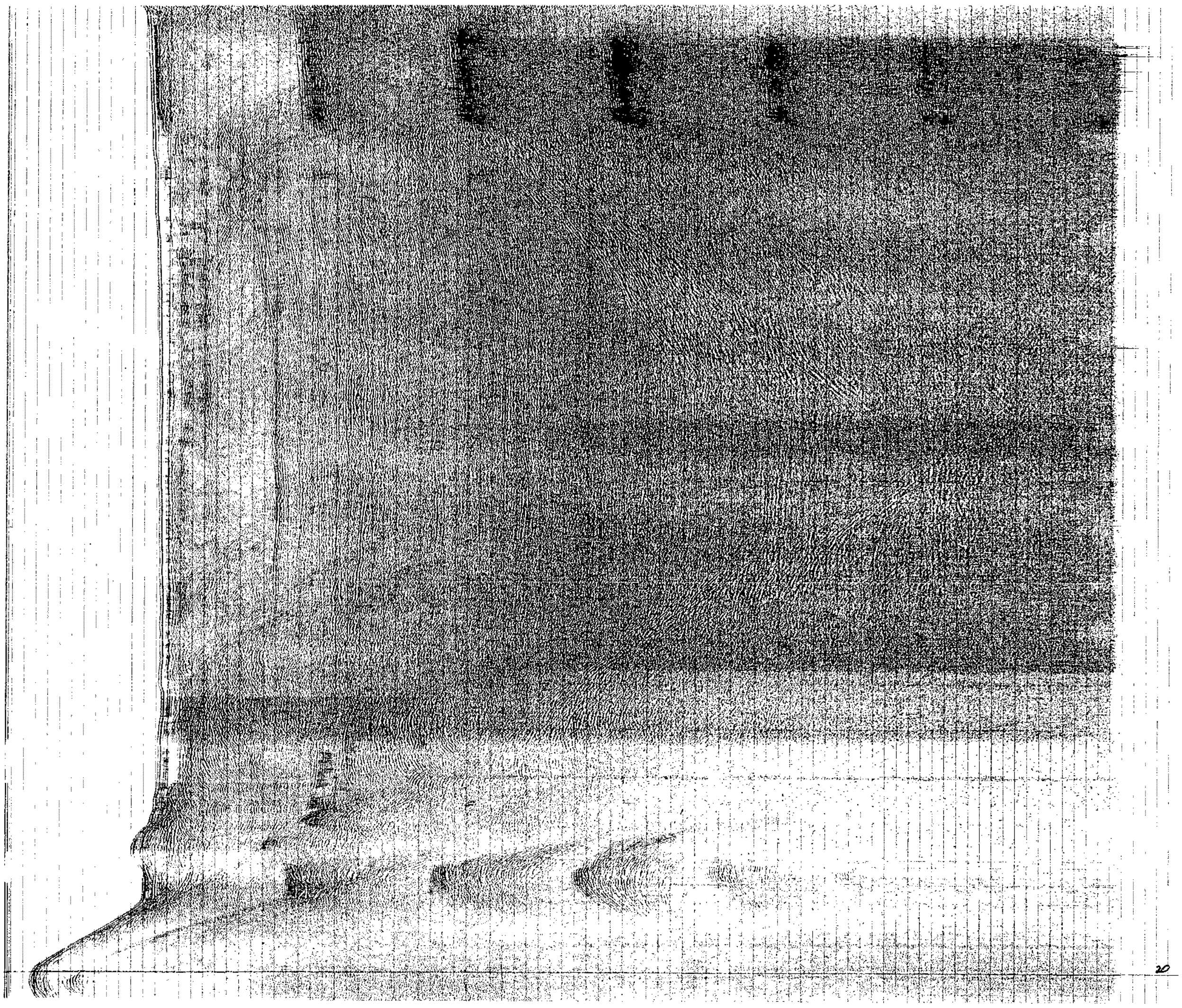

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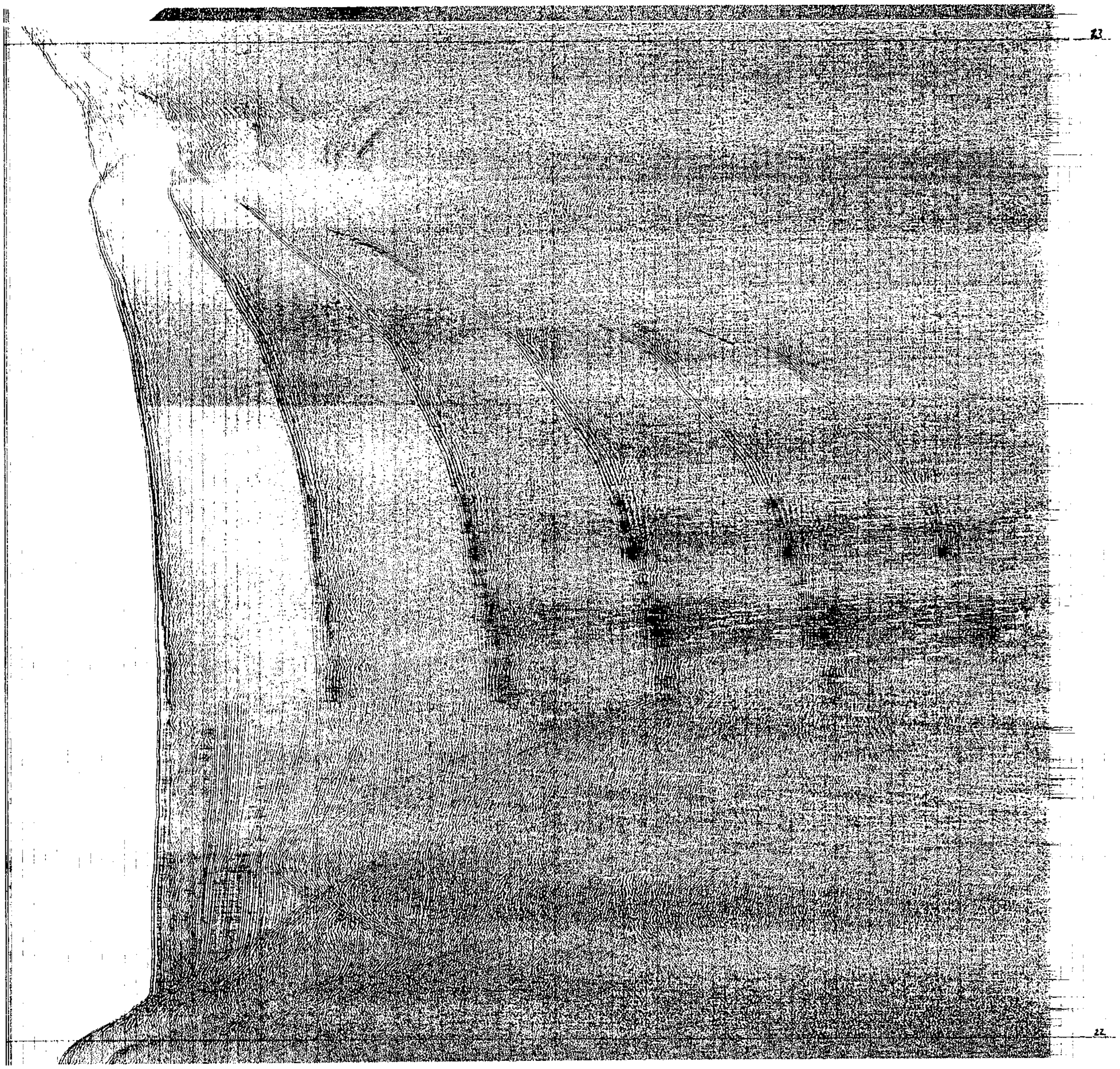

Figure 9

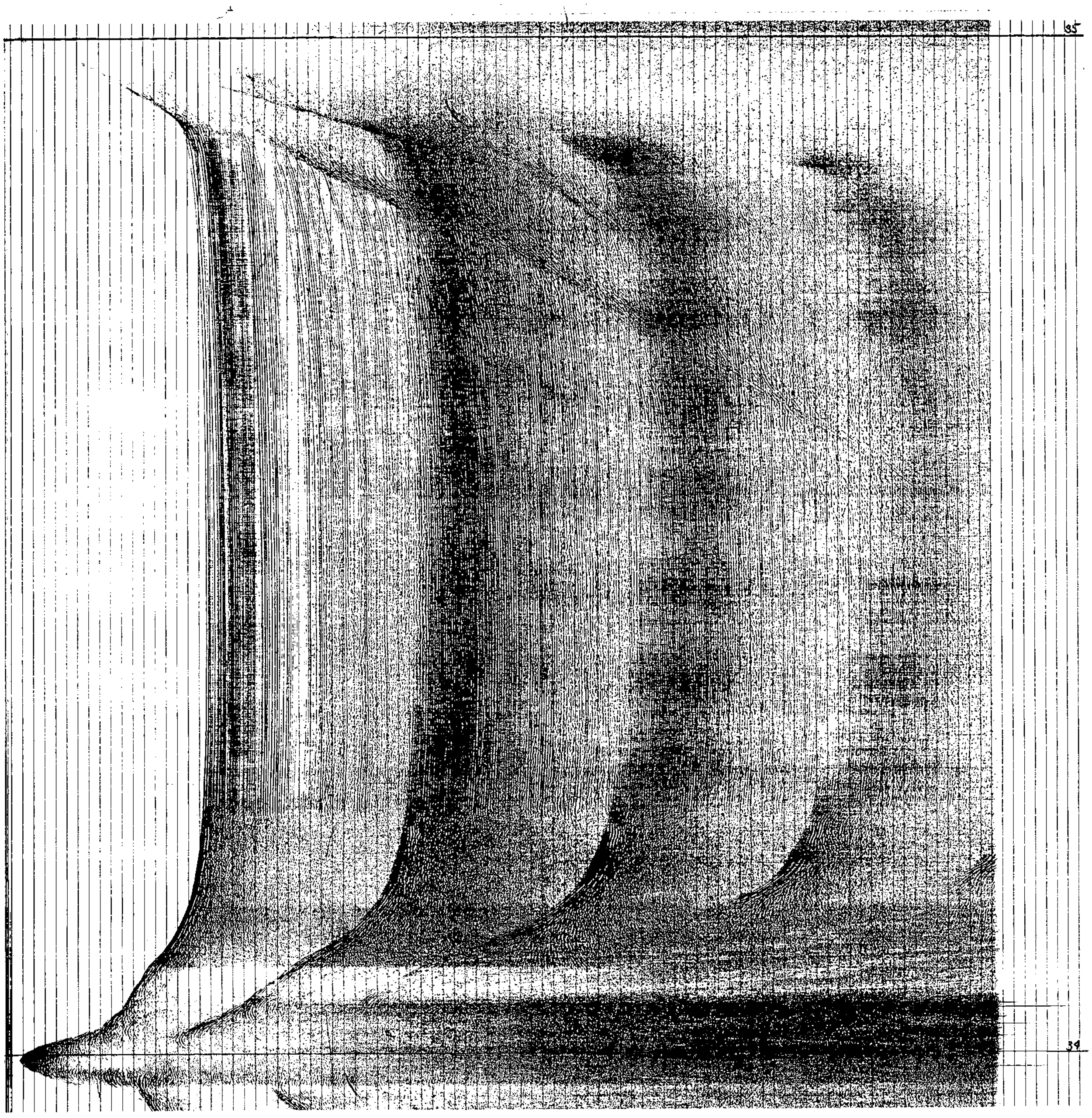

Figure 10