27th EWG-IE MEETING:

University of British Columbia, Vancouver, Canada

FIELD-TRIP NOTES:

Cleveland Dam, 19 June 2019

Compiled by:

Jonathan Fannin, Ph.D., P.Eng.

Reference:

<u>REPORT</u> ON STABILITY CONDITIONS AT EAST ABUTMENT OF CLEVELAND DAM, G.V.W.D., BRITISH COLUMBIA

by Karl Terzaghi, M.I.C.E, Consulting Engineer

Winchester, Mass.

June 30, 1961

Archives retrievals:

University of British Columbia Archives (Terzaghi fond 5.39),

accessed February 1, 2019.

City of Vancouver Archives (066-A-06 fld04, Ref. Code AM1257-515),

accessed February 22, 2019.

Cleveland Dam, Vancouver: Terzaghi's Recommendations on Seepage Control and Mitigation of Internal Erosion

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INTRODUCTION

The Cleveland Dam is a 91 m high concrete gravity dam, on the Capilano River, North Vancouver. It impounds the Capilano Reservoir (Fig. 1), a source of drinking water for the City of Vancouver. The left (east) abutment of Cleveland Dam comprises a thick sequence of interbedded glacial deposits. In 1957, Karl Terzaghi was retained by the Commissioner of the Greater Vancouver Water District, "*to investigate the complex drainage conditions extant at the left abutment… and make recommendations as to what additional measures seem appropriate*". In the years 1958 to 1961, Vancouver-based geotechnical consultants C.F. Ripley and Associates prepared a "*Compilation of data re. downstream slope of east abutment, Cleveland Dam, for Dr. Terzaghi*". To inform his understanding of the stability of the east abutment, Terzaghi drew upon extensive observations by Dr. Victor Dolmage, a Vancouver-based consulting geologist working on the subsoil exploration of the damsite. In 1961, Terzaghi reported on his conclusions and recommendations.

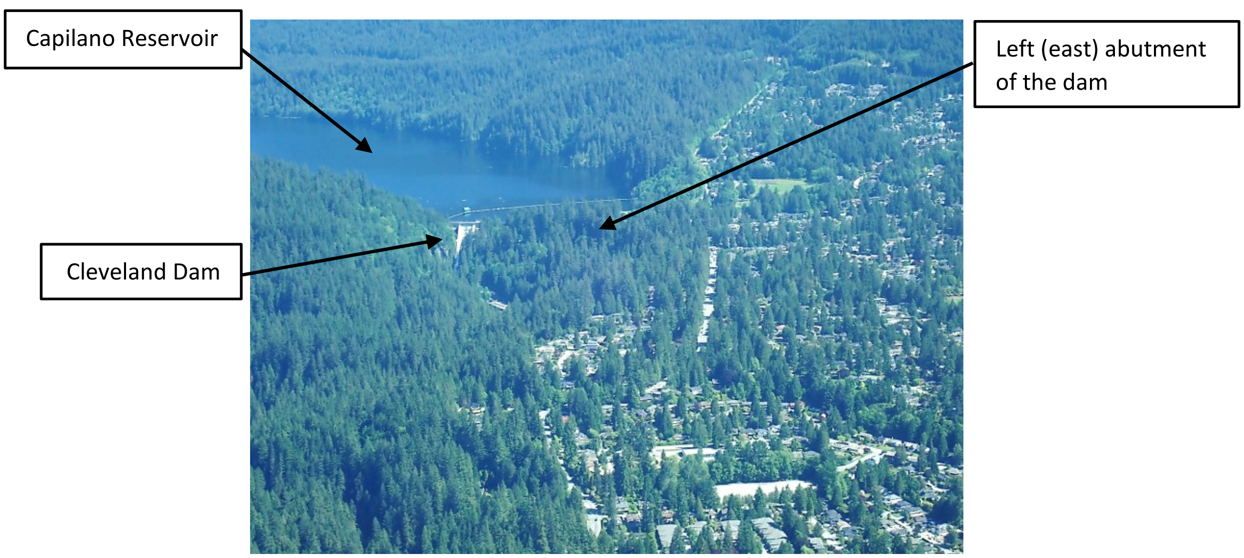

Figure 1. Cleveland Dam and left (east) abutment [Photo. J.Fannin]

Glacial Geology of the Damsite

Cleveland Dam was built in a narrow rock canyon (Fig. 2), believed incised after the last glaciation. The deposits of the east abutment, which Dolmage had identified to contain "*at least three till sheets separated from each other by glacial river and lake sediments*", are attributed to infill of an ancestral pre-glacial channel of the Capilano River. In the vicinity of the east abutment, the bedrock surface is "*locally covered with a layer of very hard till T_s, and till sheet T_3 rests directly on the till T_s or on bedrock*". Terzaghi believed the "*extremely uneven character of its upper surface suggests that much of the sheet has been removed by erosion*", before a silt stratum S_1 was "*probably deposited in an inter-glacial lake*". The overlying T_1 stratum, an "*ill-defined and locally composite layer*", was identified as "*a till, or till-like material*". The formation of the G_1 stratum found above it, "*a fluvio-glacial deposit with a lenticular pattern of stratification*", was attributed to repeated advance-retreat movements of ice. Terzaghi believed that "*whenever the ice front retreated the till sheet formed during the preceding advance was partly removed by erosion and replaced by fluvio-glacial sediments or* *glacial lake deposits*", yielding a discontinuous pattern of stratification that is characterised by "*steep and sharp boundaries between undisturbed silt and adjacent sand and gravel*". The G_1 stratum, termed the upper aquifer, was found to extend without discontinuity from the left abutment of the dam to exposures on the east slope of the present valley downstream from the left abutment. It is overlain by a very dense and hard till stratum T_o. The formation of the uppermost G_o blanket of clean sand, gravel, cobble and boulders "*may have been glacio-fluvial initially, with later re-sorting as a marine beach*".

Cleveland Dam: Provisions for Seepage Control

The dam rests on bedrock that was cleared of river sediments, prior to the start of construction in 1952. On both ends of the gravity section, abutment core walls increase the seepage path length in the glacial sediments above bedrock surface. Bedrock beneath the gravity section and core walls was grouted. The design also incorporated a grout curtain extending into the east abutment, and an impervious blanket on the east slope of the reservoir, both of which were constructed in 1953-54.

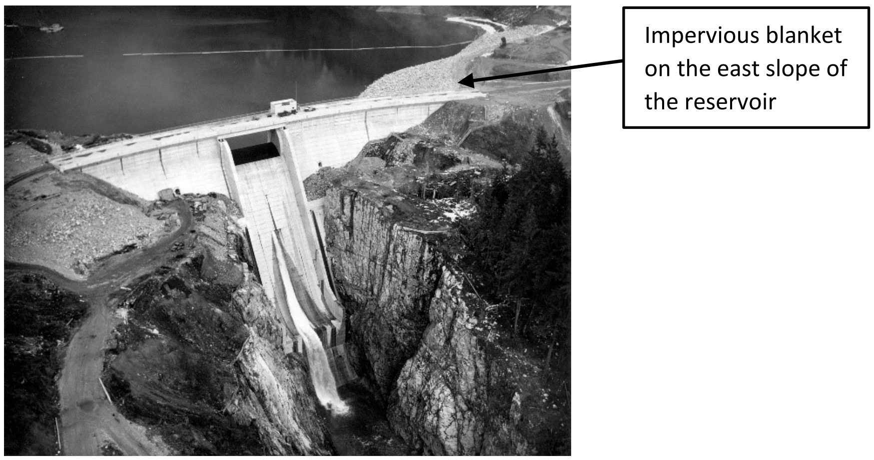

Figure 2. Vancouver City Archives CVA 275-20: Cleveland Dam [Photo. W. Draycott]

First-filling of the reservoir commenced in December 1954. It was recognised that impounding the reservoir might compromise the stability of the east slope of the valley downstream from the dam. Given the complex pattern of stratification in the east abutment, as a precautionary measure, three drainage tunnels were excavated into the slope (in 1954-55). Supplemental drainage provisions on the slope downstream of the dam included weighted filter blankets (in 1955) over groundwater seeps exhibiting discharge of eroded silt, bleeder wells (in 1955), and a drainage shaft (in 1957). The concept of a weighted granular filter had first been proposed and patented by Terzaghi in 1922-24 (see Fannin, 2008): the empirical (D_{15}) design criteria for soil retention and permeability were first published by Terzaghi himself in 1939 (and subsequently extended for application to widely-graded base soils in a 1955 USBR publication).

Terzaghi's Conclusions and Recommendations

The pattern of seepage through the east abutment was primarily established with reference to periodic readings of piezometric level at observation wells, and a comparison of these field data with a series of idealised flow net diagrams. Terzaghi's conclusions and recommendations addressed (i) the efficacy of the grout curtain, the impervious blanket, and the drainage tunnels, for purposes of seepage control, and (ii) the mitigation of internal erosion within the glacial deposits of the east abutment of the dam, believed induced by filling of the reservoir.

References

Terzaghi, K. (1961). On stability conditions at East Abument of Cleveland Dam, G.V.W.D., British Columbia. Report, 88p.

Fannin, R.J. (2001). Karl Terzaghi: from theory to practice in geotechnical filter design. ASCE J. Geotech. & Geoenv. Engng., 134: 267-276.

APPENDIX A

GLACIAL GEOLOGY OF THE DAMSITE

In order to understand the peculiar characteristics of the damsite it is necessary to start with a review of the glacial history of the entire region. The following review is based on the information contained in the paper "Surficial Geology of Vancouver Area, British Columbia," by J. E. Armstrong, Geological Survey of Canada, Paper 55-40, Ottawa, 1956. Supplementary data were derived from Map No. 4, B. C. Glacial Geology, B.C. Atlas of Resources published by the B.C. Natural Resources Conference, 1956.

The Capilano Valley has a length of about 16 miles. It descends in a southerly direction from the south slope of Capilano Mt. with a height of 5829 ft., to Burrard Inlet. At the damsite the mountains rise on both sides of the valley to elevations of about 4800 ft. At the beginning of the last glaciation the Capilano Valley was probably occupied by a valley glacier which joined a very much larger one flowing through the Burrard Inlet into the Straight of Georgia.

As the accumulation of ice on the continent continued, the ice level in the Vancouver area rose to about 5000 ft. above the present sea level whereby the high mountains on both sides of the damsite became completely flooded by the ice. The withdrawal of water from the sea and its accumulation on the continent in the form of ice was associated with a lowering of the sea level by an amount of several hundred feet, but it was followed by a gradual sinking of the land, due to the weight of the accumulated ice. As a result of the sinking of the land, areas with a present elevation of about 600 ft. or less were submerged. The surface of the glacial deposits at the damsite is located at about el. 600. Hence the lower portions of the glacial deposits encountered at the damsite were laid down in a marine environment, except for the oldest ones (basal tills) which were formed prior to the submergence.

These conclusions are in accordance with Armstrong's description of the glacial deposits of the lower Capilano Valley. Attached Fig. I was copied from Armstrong's geological map. The map shows that the damsite is located south of the apex of a large marine delta with its front at the shore line of Burrard Inlet. The glacial deposits east of the damsite, with surface elevation 600 to 650 are described as follows. The lower portion of the deposits (labeled "3" in Fig. I) consists of "glacial, marine and non-marine deposits: sand, gravel, silt, till and minor peat. These deposits normally underlie Surrey till (labeled "5"). May be up to 500 ft. or more thick." The Capilano variety of these sediments is assigned by Armstrong to the Seymour group. The Surrey till of the Capilano region ("5a") consists of "sandy to silty till and minor substratified drift up to 60 ft. thick but generally less than 20 ft., overlain in most places by glacio-marine stoney clayey silt and minor interbedded marine clayey silt, silty clay and sand, up to 25 ft. thick but generally less than 10 ft." Above about el. 600 the Surrey till and overlying clayey silt are buried beneath a layer of Capilano gravel. (Blank areas in Fig. I). Immediately east of the dam the gravel is about 12 to 15 ft. thick, but further east it is somewhat thicker, which can be seen in the road cuts. West of the dam the till is buried beneath a layer of coarse sand with a thickness up to 50 or more ft. Armstrong's description combined with his geological map, Fig. I, leave no doubt that Dolmage's "Upper Till" is part of Armstrong's "Surrey Till," and that the old valley floor, south of the damsite (el. 300±) is covered with Armstrong's "deposit related to glaciation, ... up to 500 ft. or more thick," belonging to the Seymour group.

The delta, with its apex upstream from the damsite, is a river deposit and it contains large quantities of sand and water-worn gravel. Therefore one cannot help asking "where is the source of the material and when and how was it deposited?" The bulk of the material which is excavated and transported by ice is deposited at the ice front or transported beyond it. Therefore we have to expect that most of the material which was transported by the ice during the growth of the continental ice cap now covers areas at and beyond the outer edge of the ice at the climax of glaciation and this edge was located more than one hundred miles south and west from the Capilano region.

During the peak of glaciation the quantity of material subject to ice transport was very small, because the gradient

of the ice surface was less than one per cent and the quantity of debris which descended onto the ice surface was negligible because practically all the rock slopes were located below the ice level. Hence the formation of the delta must have started during a late stage of recession.

At that stage the rise of the sea level due to melting of the ice cap was also well advanced whereas the rising of the land due to removal of weight from the surface of the continent had hardly started on account of the important time lags involved. At that stage the Capilano Valley was submerged to a distance of at least four miles upstream from the damsite except for the areas still occupied by stagnant ice. The upper reaches of the valley were occupied by mountain glaciers, and from the barren slopes located above the glaciers, the products of mechanical rock weathering descended onto the ice. Most of the debris was picked up by marginal or subglacial streams and reduced by attrition to sand and gravel with rounded fragments.

While the delta was growing the sea level went down on account of the slow isostatic rise of the land. Therefore the surface of the delta deposit upstream from the dam has a gradient of more than one hundred feet per mile in a downstream direction. Two miles upstream from the damsite the top surface of the sediments of the Seymour group are located at about el. 800 and at the damsite at about el. 450. According to Armstrong the deposition of these sediments was followed by an "Erosional interval. Relief development on underlying deposits." At that stage the surface of the Seymour sediments was already located above sea level and the rock ridge east of the damsite with crest elevation 400 was already completely buried by sediments. The erosion interval accounts for the numerous disconformities which were encountered at the damsite between about el. 410 and 510. The sand and sandy gravel deposits located within this zone were probably laid down by melt-water streams during this period, prior to the deposition of the "Upper Till." They are underlain by the sediments of Armstrong's Seymour group, which are delta deposits. The erosional interval was followed by a temporary but major advance of the ice front, to a distance of many miles to the south. This is shown by the location of the southern boundary of the areas covered by the Surrey Till 5a in Fig. I.

After this review of the glacial history of the Capilano region an explanation of the unusual features of the damsite can be attempted. These include the peculiarities of the rock surface topography of the damsite and the existence of the broad and almost horizontal berm at el. 470. Both are shown in Fig. 1 of the main report.

Upstream from the damsite the rock surface descends at an average slope of about 1:1 from el. 400 to an elevation of less than 128 and probably to an elevation below sea level. This slope is very much steeper than the rock slopes which are formed by rock-weathering and creep under temperate climatic conditions. Downstream from the damsite the present valley is located above a narrow rock valley descending from the crest across which the postglacial canyon of the present Capilano River has been cut. This buried valley will be called the western valley. The gradient of the east slope of the western valley is about 3:1. That is the gradient one would expect on the slopes of an erosion valley formed in a moist and temperate climate. However the shape of the head of the western valley is definitely abnormal. It is blunt as shown in Fig. 1 of the main report and the valley floor, which has a very gentle gradient, rises almost abruptly at a slope of 1.8:1 to the crest from which the valley descends.

These peculiar features of the rock surface topography at the damsite led the writer to the conclusion illustrated by Fig. II that the present Capilano River deviates at point a, Fig. II, from its pre-glacial valley and passes at the damsite D into that of another, shorter stream which was located west of the Capilano Valley. In the figure the plain lines represent the writer's conception of the pre-glacial drainage system. The dash lines represent those portions of the present lines of drainage which came into existence after the last ice age.

In an early stage of the last ice age a valley glacier with increasing width and thickness descended through the Capilano Valley towards the Burrard Inlet. The bottom of the valley was located close to or below the present sea level.

The rock ridge, of which the highest part is at the damsite D, was an obstacle in the path of the glacier. Therefore its northeasterly slope was steepened by glacial scour.

Before the glacier had become so thick that its upper surface was at el. 400, the western valley located south of the ridge, with bottom elevation 300, was free of ice and occupied by a creek. However as soon as the surface of the glacier rose above el. 400 the ice overtopped the ridge. On account of its steep gradient the ice tongue descending into the valley floor was capable of widening the head of the valley and steepening the slope at the head. The till veneer which was encountered in T 350 and covers most of the rock surface south of the damsite probably originated at that time, and is therefore older than the sediments of the Seymour group.

Once both valleys were filled with ice and the ice surface approached its maximum elevation, about 5000 ft. above the present sea level, the scouring action of the ice became insignificant and the ice accumulated in the sheltered western valley became stagnant. No significant changes occurred on the ice covered land surface until the recession of the ice was far advanced and the formation of the Capilano delta started. At that time the entire area presently occupied by the delta was below sea level. However the western valley, south of the damsite, was well suited to harbour surviving bodies of stagnant ice. The spaces between the ice and till-covered rock slopes were filled with river sediments. Subsequent

melting of the ice caused slumping of the adjacent sediments. This process may account for the conspicuous deformation of the sediments which were observed by Dolmage during the excavation of the drainage tunnel T 350 at el. 350, which is well below the elevation of the crest of the rock ridge. It may also be responsible for the peculiar surface topography of the east slope of the valley shown in Fig. 1 of the main report.

The melting of buried bodies of ice produces depressions on the ground surface known as kettle holes. The formation of kettle holes above the western valley may have caused the shifting of the channel of Capilano Creek towards the western boundary of the Capilano delta.

The second unusual feature of the damsite is the conspicuous berm at el. 470 which disrupts the continuity of the east slope south of the damsite (see Fig. 1 of the main report). Before the slope topography was altered by the excavation and filling operations associated with the construction of a road and the laying of a pipe line the berm was discontinuous as indicated in Fig. 1 of the main report. It is very probable that original portions of the berm, indicated in Fig. 1 by shaded areas are the remnants of a river terrace. Similar remnants with much larger dimensions and at somewhat lower elevations can be seen along the creek within a distance of more than a mile south of the damsite. Local and relatively superficial slides may have occurred as a result of the melting of buried bodies or ice or undercutting by erosion but they are hardly responsible for the origin of the berm.

The complex history of deposition at the damsite is responsible for the erratic pattern of stratification and the occurrence of numerous disconformities in the unconsolidated deposits underlying the east slope of the valley downstream from the dam. In deposits with such characteristics no well defined water-table exists. The water which flows from the reservoir through the submerged upstream slope of the sedimentary ridge towards the exposed downstream slope follows tortuous channels the location of which is unknown. Many of them have no natural outlet. If the outlet of the water vein located in fine-grained cohesionless material beneath a cohesive stratum is not covered with an inverted filter preventing the removal of solids without interfering with the discharge of the water a tunnel is formed by subsurface erosion progressing in an upstream direction. The length and the width of the tunnel increase until a roof collapse occurs. One of the

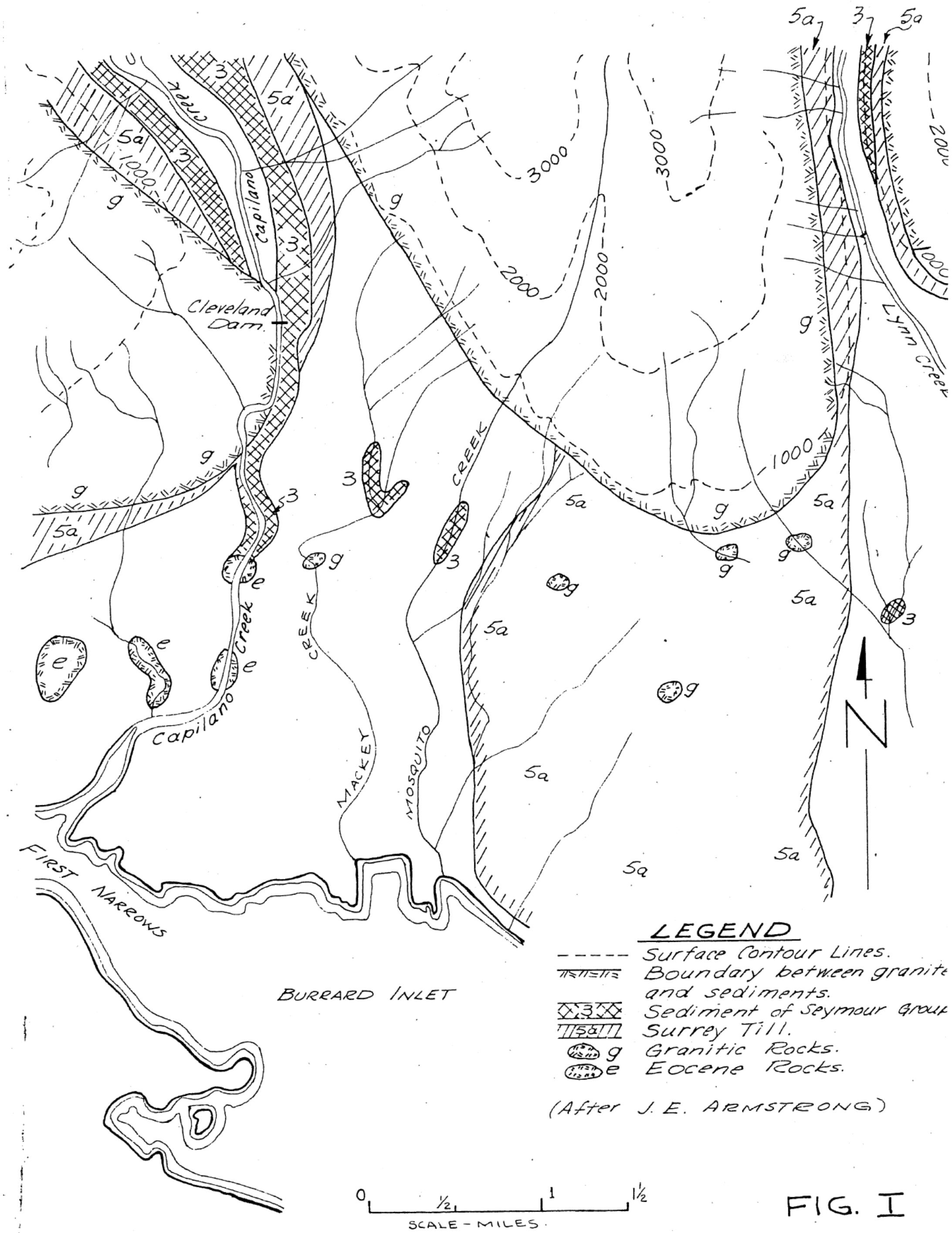

FIG. I

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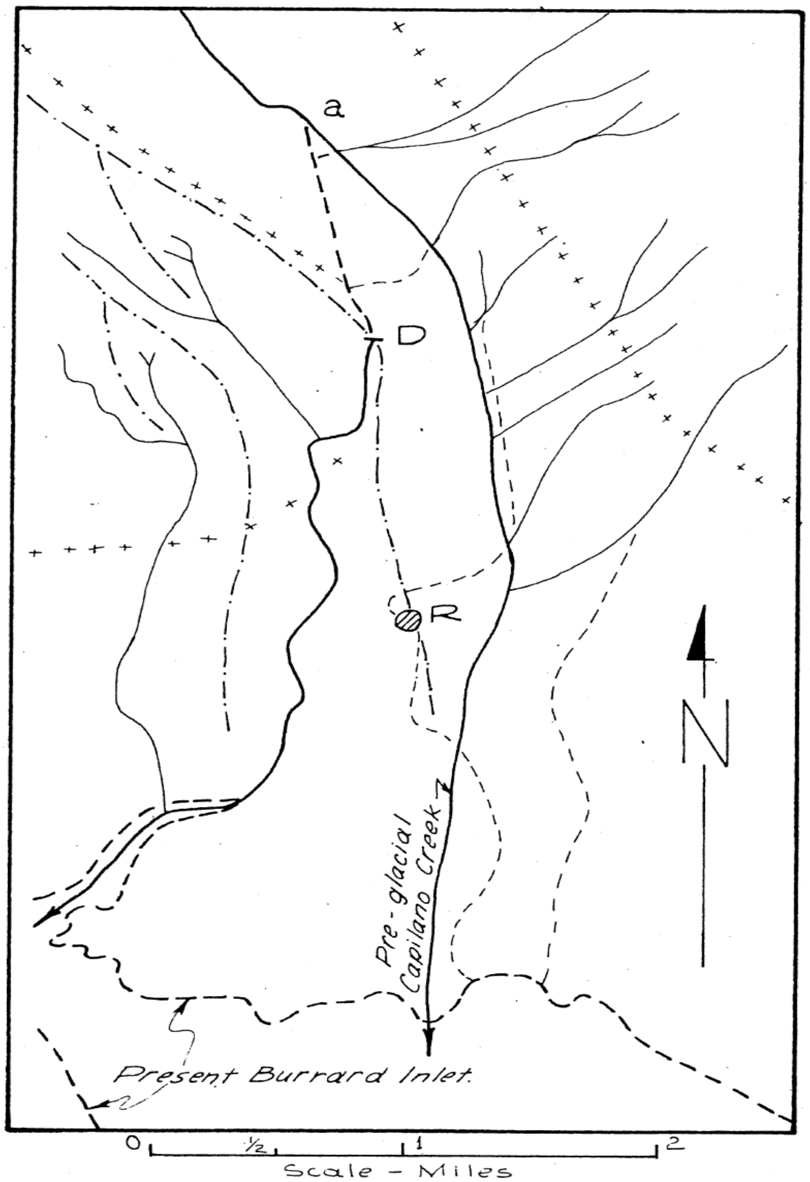

LEGEND

D - Damsite, R - Rock outcrop.
——— Pre-glacial Drainage.
– – – – Present Drainage and Coastlines.
—·—·— Watersheds.
+ + + + Boundaries of Capilano Delta.

FIG. II

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