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A Profile Study of the New Quebec Crater

BY

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FIGURE 1. An early photograph of the New Quebec Crater, No. 2086L-8216, taken by the U.S. Air Force on June 20, 1943.

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INTRODUCTION

The New Quebec Crater*, located in the Ungava peninsula in northern Quebec, is one of the most interesting topographical features of the Canadian north. Thanks to two expeditions (1,2), led by Dr. V. Ben Meen in 1950 and 1951 respectively, general information concerning this crater has now been made available both to interested scientific institutions and to the general public.

Since no complete history concerning the recognition of the crater has yet appeared it seems appropriate to record this briefly here. Apart from the occasional visits of Eskimos, whose old camp sites have been found on the crater rim, the crater seems first to have been noted on the trimetrogon survey photographs of the U.S. Army Air Forces, taken on their operations over the Ungava peninsula during the summer of 1943 (*see* Figure 1). Because of its striking appearance the crater was a useful navigation landmark in a wilderness of irregular lakes and rocky barrens. It was first plotted on the Wakeham Bay Sheet (111D), AAF Preliminary Base, scale 1:500,000, an AAF Aeronautical Chart printed in February 1945 for restricted use. The feature appeared on this map as a circular lake about 2 miles in width, with a fine-stipple ruling, surrounded by closely spaced radiating hachures and designated with the word "Crater". Since then it has appeared on all large-scale topographical maps of this area published in both Canada and the United States (*see* Appendix A).

In the summer of 1946 the Geodetic Survey of Canada had several field parties in northern Ungava for the purpose of establishing astronomic control points. The Royal Canadian Air Force transported these parties and in the course of these flights the crater became a well-known landmark. F/L (now S/L) Jake F. Drake mentions sighting the crater on July 20, 1946, and taking pictures, but ice conditions prevented a landing on that date. Later, on July 28, F/L (now W/C) William K. Carr landed in the crater to avoid a line squall and tied up to the northeast shore (3). It was on this occasion that some empty tin cans were left on the shores of Crater Lake. One of these was later found by Dr. Meen's first expedition.

As far as can be ascertained the first published reference to a possible origin for the crater appears in a book by Nicholas Polunin (4). The author, in describing the Ungava operations of 1946, makes the following reference to the crater:—

> "The next morning, 14th August, we were up at daybreak for the start, but the weather on this occasion (and it was by no means the first) prevented us from moving—at least for the time being. There was a thick wet mist and at the same time not a little wind. As we rather

* Previously referred to elsewhere as the Ungava Crater and the Chubb Crater.

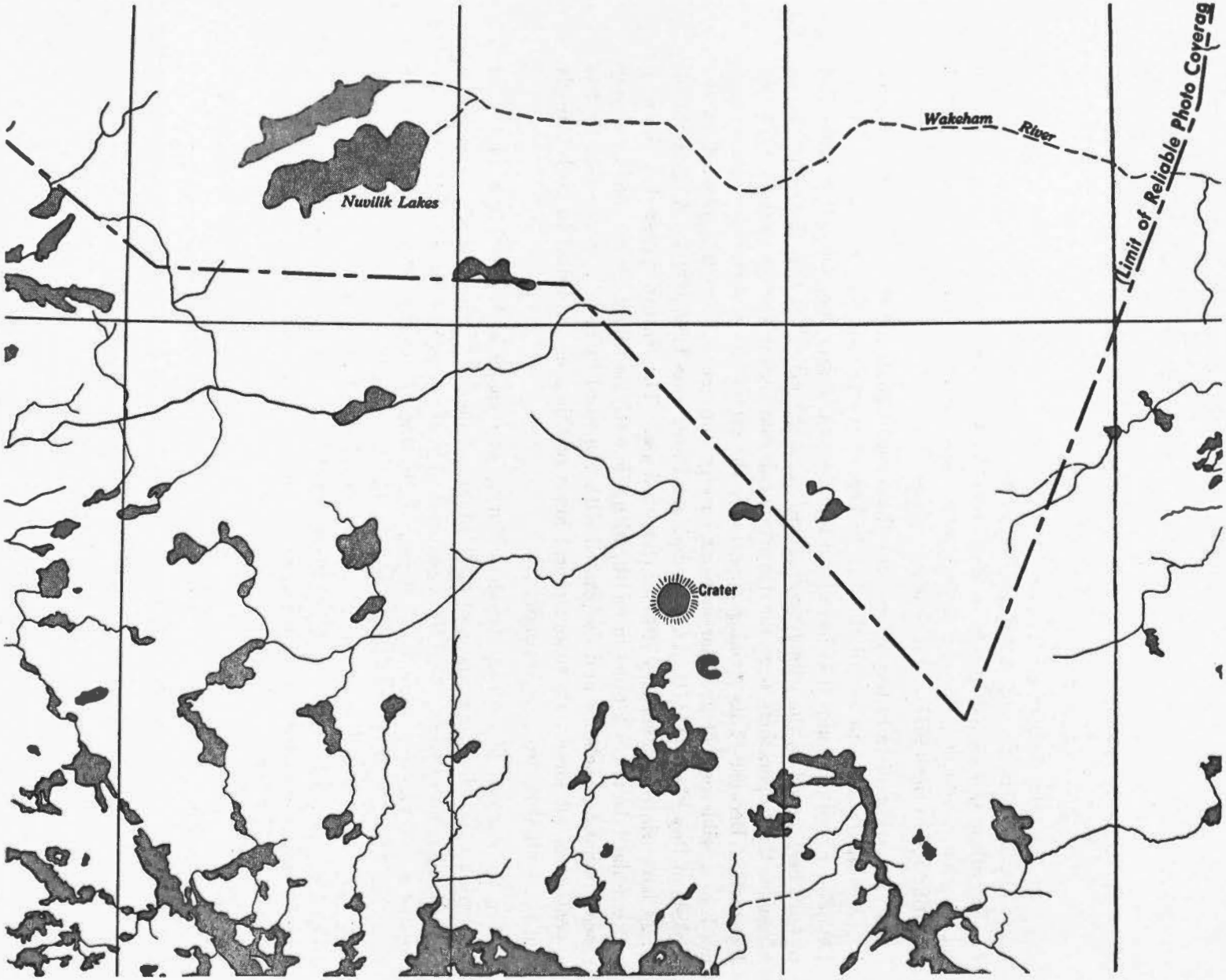

FIGURE 2. The first appearance of the New Quebec Crater on a topographic map; a portion of the Wakeham Bay Sheet (111), AAF Preliminary Base, printed in February 1945.

miserably and disgustedly went back to bed, Jake told me of a 'crater' he had flown over and photographed a few days previously in north-eastern Ungava, near the headwaters of the Povungnituk River. It was the better part of three miles across, had a considerable lake in the centre, and looked as though it had been caused by some vast explosion or at least impact."

In July, 1948, the crater was again photographed in the course of the trimetrogon survey of Ungava carried out by the R.C.A.F. As a result of these photographs C. B. Bassett of Legal Surveys, Ottawa, wrote the Geological Survey of Canada on June 2, 1949, asking for an interpretation of the feature. The following memorandum from Dr. Fortier appears on the files of the Geological Survey:—

"To Chief Geologist Date June 6, 1949.

Subject—Letter from Mr. Bassett re interpretation of Air Photographs

One of the pictures submitted by Mr. Bassett had already been chosen for our collection as an example of a meteorite crater. Comparison of these pictures with those shown in the chapter on meteorite craters, especially in Arizona, in Lobeck's textbook on 'Geomorphology' will convince anyone of the similarities of the features at the two localities. Such a crater to be of volcanic origin would have to be of recent formation, which is not likely in the Canadian Shield.

Y. O. Fortier,
Bureau of Geology and Topography."

In 1949 Professor G. V. Douglas and Mary C. V. Douglas prepared a comprehensive report on Ungava for the Arctic Institute of North America. This has not been published but it may be of interest to quote here from page 442 of Volume III of this report:—

"*The Crater*, (61° 18′ N. Lat., 73° 40′ W. Long.) (Fig. 187) is thought to be meteoric in origin. However, this crater has never been examined on the ground and the theory is based on a study of aerial photographs. If the crater is meteoric in origin it fell nearly vertically, for the elevations on all sides are about the same. It is thought to be post glacial but that it fell at least 10,000 years ago, as the material on the rim has been smoothed out or the rim welt has been susceptible to frost action. The smoothing out can be seen clearly on the right hand of the rim. The circular section and the very steep internal slopes also indicate a meteoric origin."

The photograph included in the above report is R.C.A.F. Photo REA 470-14, taken on July 20, 1948. A copy of this appeared on the front cover of *Sky and Telescope* for November, 1951 (5).

Early in 1950 the prospector, F. W. Chubb, approached Dr. V. B. Meen, Director of the Royal Ontario Museum of Geology and Mineralogy, and called his attention to this crater, thinking possibly it might contain diamonds as do some extinct volcanoes in South Africa (1). Because of the commercial possibilities plans for investigating the

crater were not announced to the public and the "Chubb Crater Exploration Syndicate" was formed and accepted for filing by the Ontario Securities Commission on July 13, 1950 (6). An expedition was jointly financed by the *Globe and Mail* newspaper in Toronto and a group of interested businessmen. As a result of this exploration of the crater, July 21-26, 1950, Dr. Meen became convinced of its meteoritic origin. A second more extensive expedition under the auspices of the Royal Ontario Museum and the National Geographic Society, Washington, was organized by Dr. Meen in 1951 and from July 25 to August 21 detailed studies were made in and around the crater, including a measurement of the depth of the almost circular lake (2). The details of the scientific results secured on this last expedition have not yet been published.

In spite of the early history of the crater outlined above, the staff at the Dominion Observatory were unaware of its existence until the account of Dr. Meen's first expedition appeared in the columns of the *Globe and Mail* on the morning of August 7, 1950. Dr. B. R. MacKay of the Geological Survey of Canada, and the author of this paper visited Dr. Meen on August 15, 1950, and received a first-hand account of his findings. The weight of evidence in favour of this being a genuine meteor crater seemed strong. It was considered that one of the most urgent needs in connection with further scientific study was a detailed air survey of the area in and around the crater. At the request of the Dominion Observatory the R.C.A.F. issued an Operation Order for the necessary photography on August 25, 1950. However, the season available for satisfactory photographic coverage in northern Ungava is short and various circumstances prevented completion of the vertical air photography until the summer of 1953.

In July and August of 1953 Dr. J. M. Harrison of the Geological Survey of Canada spent some time at the crater (7). He supports the meteoritic origin but disagrees with Meen's statement that there is no sign of glaciation in and around the crater. Harrison considers the evidence for the crater being pre-glacial as "overwhelming". Harrison also disagrees with Hoffleit's suggestion (8) that "fossil glacial ice" might have been a major factor in forming the crater.

Dr. Meen recommended that the crater be named "Chubb" in honour of the man who instigated the 1950 investigation. This has not been done, however, since Mr. Chubb did not discover the crater nor did he suggest its meteoritic origin. On June 3, 1954, the Canadian Board on Geographical Names, meeting in Ottawa, accepted the names adopted earlier by the Quebec Geographic Board. These are:—

New Quebec Crater
Crater Lake
Lac Laflamme

The last name is that given to the lake which served as a base of operations for the two expeditions led by Dr. Meen and which was earlier called Museum Lake.

NEW QUEBEC CRATER MAP

During August 1953, a complete air photo coverage of an area 11½ by 10 miles centred on the crater was secured by the Royal Canadian Air Force. The vertical line overlap photography was carried out at a height of 9,400 ft. above sea level, giving a scale on the

FIGURE 3. Montage made from two prints, Nos. REA 659-10 and 659-11 taken by the RCAF on July 15, 1952. This is a view looking slightly east of south across the crater.

original negatives of approximately 1,280 ft. to the inch. A portion of the uncorrected photo mosaic resulting from this survey is reproduced as Figure 4. Several lines across the crater were also flown at a height of 5,540 ft. above sea level, giving photographs of approximately twice the above scale, or 640 ft. to the inch.

Unfortunately the ground control points required for producing an accurate topographical map were not available. Since there might be some years' delay in securing these, and because of the very general scientific interest in the crater, it was decided to produce a map (*see* map pocket) on which the relative positions of the topographical features were correctly shown but where there was an unavoidable uncertainty as to the exact values of both the horizontal and the vertical scales.

The elevations above sea level of 1,700 ft. for both Crater Lake and Lac Laflamme were adopted, as determined by Harrison in 1953 from barometer readings. These values are very close to those found by Meen in 1950 (1).

As a guide to the horizontal scale we have the lake diameter, 9,100 ft., and the rim diameter, 11,500 ft., given by Meen as a result of the 1951 expedition (2). The latter value seemed to agree with the trimetrogon survey material better than the other and the scale (1:25,000) of the printed map accompanying this paper was set on the basis of Meen's rim diameter. It now remains to check this approximate value by any independent methods available in the hope of arriving at a more exact estimate of the true scale of the map.

The results of this procedure, carried out by actual measures on the map after it was printed, are given in Table 1. The first column lists the method used, the second the resulting scale determined, and the third an estimate of the expected percentage probable error. The mile-to-the-inch acetate master used in producing the eight-miles-to-the-inch topographic map (Povungnituk River Sheet) was loaned to the author by the Surveys and Mapping Branch and proved to be the most reliable material available for scale determination. The last three values of scale listed in Table 1 were determined by the two most satisfactory methods and agree reasonably well among themselves. They

TABLE 1

SCALE DETERMINATION FOR PRINTED CRATER MAP

Method	Scale	p.e.
Assuming rim diameter of 11,500 ft	1 : 24,900	
Assuming lake diameter of 9,100 ft	1 : 23,700	
Assuming coordinates of magnetic stations as given on map	1 : 26,400	>5 %
Comparison with topographic 8 miles/inch series, Povungnituk River sheet	1 : 24,260	1 %
Using listed height for air survey flights and measures on original air photos	1 : 24,470	<1 %
Comparison with 1 mile/inch acetate master drawn from trimetrogon survey:—		
10 comparison lines	1 : 24,450	0·3 %
20 comparison lines	1 : 24,520	0·2 %
Adopted true scale of printed map	1 : 24,500	± 0·5 %

were the only ones used in arriving at a final average. It is considered that a scale of 1:24,500 for the printed map is the best that can be adopted, pending the establishment of accurate ground control points near the crater. The probable error of 0·5 per cent is, if anything, estimated on the large side.

The orientation of the printed map must also be considered. Here again, the acetate master map can be used. The bearings of various features visible both on the acetate master and the printed map were compared. From this investigation it has been concluded that the true bearing of the side of the printed map is 354°0 with an uncertainty of half a degree or less. The geographical position of the centre of Crater Lake, as measured on the acetate master, is Lat. 61° 17′0 N, Long. 73° 40′2 W. This position agrees well with that determined from the mean of the magnetic station coordinates.

Since no ground control was available the vertical scale for the contour intervals on the map may have an error independent of the horizontal scale. The establishment of this scale depends on a knowledge of the true height of the aircraft carrying out the survey. The absolute error in measures over a range of 500 ft. above the adopted lake level of 1,700 ft. is probably not more than 3 per cent and may be considerably less. In Table 1 the horizontal scale determined from the recorded height of the aircraft agrees well with that found independently, and this indicates that the listed height of the aircraft cannot be very much in error.

THE PROFILE STUDY OF THE CRATER

This material, in preliminary form, was presented at the meeting of the Royal Society of Canada, June, 1954(9). On the basis of the adopted horizontal scale of 1:24,500 the mean lake diameter is 9,430 ft. and the mean rim diameter 11,290 ft., giving a rim to lake ratio of 1·197. The above figures were found by taking 16 uniformly spaced diameters for both lake and rim and averaging them. Since neither rim nor lake is a perfect circle the individual values of diameter scatter about the mean. The average deviation from the mean in the diameter for a single measure is ±100 ft. for the lake and ±140 ft. for the rim. The centre of the rim is offset from the centre of the lake by 280 ft. in a direction 61° true bearing. This is directly toward the highest point on the rim.

For a study of details of the crater contours the master map used in the production of the printed map was available and was kindly loaned to the author by the Topographical Survey. This is metal backed and is drawn on a scale 1·58 times the printed map. It is hence more suitable for the measurement of fine detail. All measurements of the crater reported below were made on this large scale master map and reduced to feet or degrees by the appropriate scale factors. The unavoidable limitations of the air survey of this area, mentioned earlier, must be born in mind here. Undoubtedly a certain amount of revision in the crater measurements will be necessary when accurate ground surveys become available.

To record the general profile of the crater, unbiased by small local irregularities in the topography, detailed measurements were made along 16 equally spaced radii originating from a point adopted as the best mean position for the centre of Crater Lake. These radii were spaced at intervals of 22·5 degrees from the highest point on the rim, located

FIGURE 4. A portion of the uncorrected photo mosaic made from photographs taken by the R.C.A.F. on August 25, 1953.

in a direction 61° true bearing from the lake centre. It is evident, from a casual examination of the map contours, that one side of the rim is considerably higher on the average than the other. This was reported by Meen (1) as a result of his first expedition to the crater. The measured radii were divided into two groups, those on the high side and those on the low side of the crater, and for identification were lettered from a to p (*see* Figure 8). Since the lowest point on the rim was not exactly opposite the highest point, measures were also made along an additional radius passing through this lowest point. This radius was designated as x. Measurements along it were not averaged in with those along the other equally spaced radii.

The results of these detailed profile measurements are listed in Table 2. The first column gives the radius identification, the eight radii on the high side being listed first. Radius d passes through the highest point on the rim. In addition to general averages,

TABLE 2

PROFILE STUDIES ALONG STANDARD RADII

Designation	True Bearing of Radius from Adopted Lake Centre	Distances from Adopted Lake Centre (in feet)				Inclination to Horizontal		Height Above Lake Level (in feet)		True Bearing of Rim Position from Rim Centre
		To Edge of Lake	To Highest Point on Rim	To Discontinuity in Outer Slope	To Point on Outer Slope at Lake Level	Inner Slope	Outer Slope	Highest Point on Rim	Discontinuity in Outer Slope	
a	353°·5	4,660	5,780	7,180	13,600	34°·3	10°·4	420	175	351°·0
b	16·0	4,700	5,830	7,580	16,200	30·8	7·3	370	175	14·0
c	38·5	4,770	5,950	7,810	16,700	31·4	7·9	395	175	37·5
d	61·0	4,760	5,950	9,190	13,800	31·9	9·4	530	70	61·0
e	83·5	4,940	5,820	6,840	19,600	27·2	8·4	370	230	84·5
f	106·0	4,860	6,060	7,810	(30,000)	33·3	6·8	435	245	108·0
g	128·5	4,690	5,770	6,840	>37,000	30·4	9·5	455	295	131·0
h	151·0	4,570	5,990	6,950	(30,000)	30·1	9·0	400	255	154·0
Means for High Side		4,740	5,890	7,530	21,500	31·2	8·6	420	200	
i	173·5	4,650	5,570	7,010	16,700	32·8	7·0	345	190	176·0
j	196·0	4,740	5,450	6,490	11,900	36·7	10·9	285	120	198·0
k	218·5	4,990	5,420	6,780	12,800	30·9	7·1	220	90	219·5
l	241·0	4,660	5,530	6,430	25,400	32·4	7·5	330	200	241·0
m	263·5	4,620	5,380	5,860	(28,000)	30·9	15·3	295	175	262·5
n	286·0	4,560	5,460	6,430	(31,000)	30·0	5·9	260	135	284·0
o	308·5	4,800	5,670	7,470	31,200	24·8	6·3	290	110	306·0
p	331·0	4,770	5,720	7,240	14,700	29·7	8·2	385	160	328·0
Means for Low Side		4,720	5,530	6,710	21,500	31·0	8·5	300	150	
General Means		4,730	5,710	7,120	21,500	31·1	8·6	360	175	
x	268·5	4,620	5,030			32·2		170		267·0

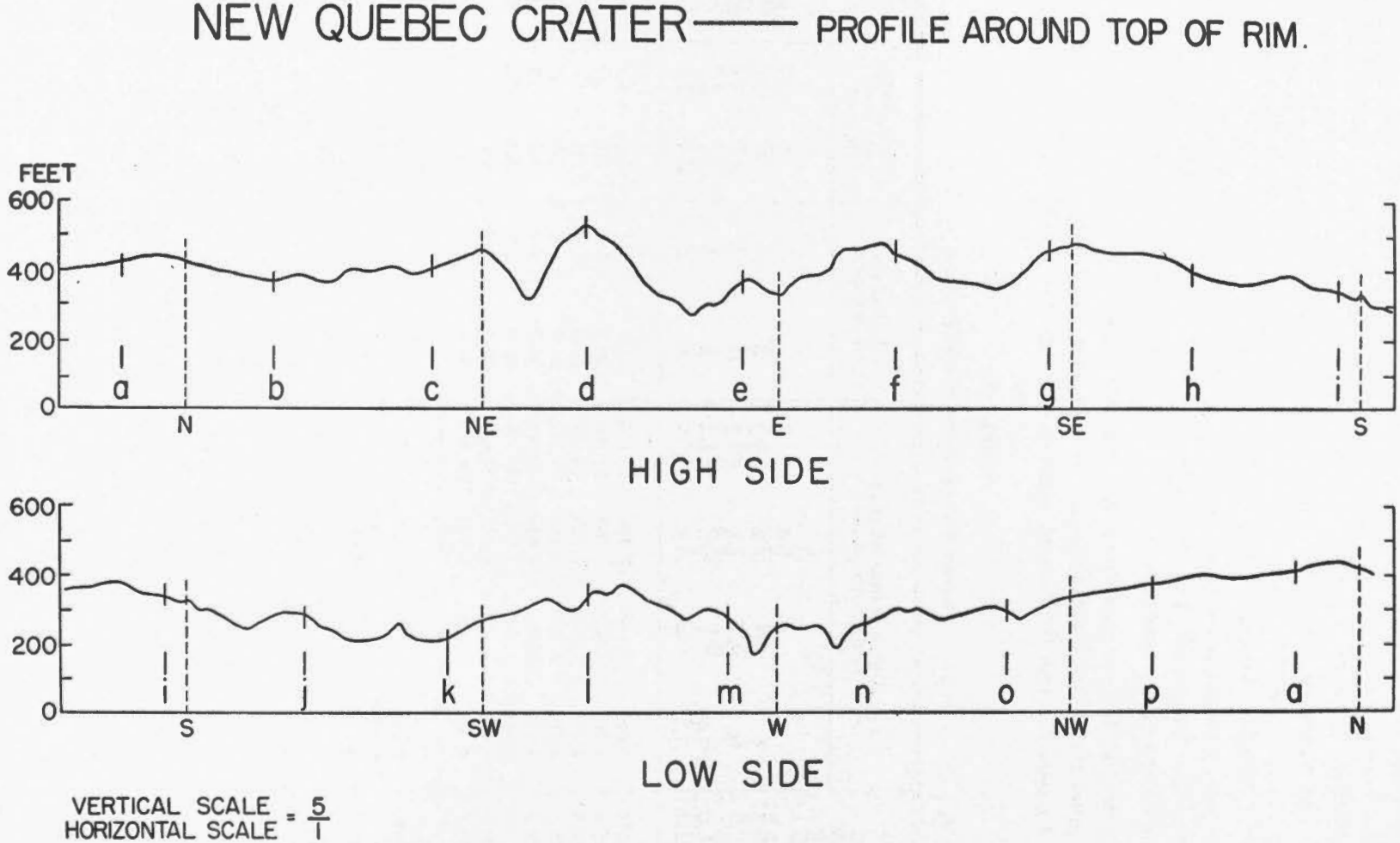

FIGURE 5. The variation in height around the crater taken at the crest of the rim.

separate averages for the high and low sides have been listed. The second column gives the true bearing of each radius from the adopted lake centre. These values were determined by assuming the orientation of the printed map determined above.

The next four columns give horizontal distances in feet from the lake centre to specified points along the radius; 1—the shore of the lake, 2—the highest point on the rim, 3—a point where the fairly steep and regular outer slope seems to break and alter to a much more gradual and irregular descent, 4—a point where the topography seems to have reached the level of 1,700 ft. above sea level adopted as standard for Crater Lake and Lac Laflamme. It should be noted here that often the ground rises again from this 1,700 ft. level as we move farther out from the crater. Hence, as pointed out later, the basic level of the topography around the crater may be some tens of feet higher than 1,700 ft. above sea level. The seventh and eighth columns give measurements of the inclinations to the horizontal of the inner and outer rim slopes. These were determined graphically from profiles plotted on a large scale. The tabulated values correspond to the portions of the rim profiles which approximate straight lines, and not to the well-rounded portions near the top of the rim. The outer rim slope given is for the steeper part, that inside the discontinuity mentioned above.

The ninth column lists the elevation of the top of the rim above the lake level and the tenth column gives the same value for the discontinuity on the outer slope. Finally, the last column gives the true bearings of the points where the standard radii cut the mean rim position, taken from the mean rim centre. Since, as noted above, this is displaced somewhat from the lake centre these bearings will differ from those in the second column.

Let us now examine in turn these measured features of the crater profile. The lake radius shows no significant difference on the high and the low side, which is as it should be if the adopted centre is well chosen. On the other hand the mean rim radius on the high side is 360 ft. greater than on the low side, a natural result of the rim centre being offset from the lake centre. It will be noted that the general means for lake radius, 4,730 ft., and rim radius, 5,710 ft., given in Table 2, are not exactly half the lake and rim diameters given earlier. The discrepancy results from the difference in the methods of finding the listed values. In the first case 16 diameters were measured, taken as straight lines across the features. In the second 16 radii were measured from a fixed point and this point, while centre for the lake, was not the centre of the rim.

Along most of the radii it was not too difficult to select a point where the outer slope of the rim flattened markedly. There is far more variation in the position of this discontinuity than in either the lake edge or the top of the rim. It is systematically further out on the high side by about 800 ft. when compared with the low side.

The most irregular value of all is the position where the general level of the ground reaches the 1,700 ft. contour. Along some of the radii this had to be extrapolated and the figure is very uncertain and is included in brackets. In spite of this, however, it is felt that the tabulation of this quantity is of value and it is interesting to note that both the high and low sides give approximately the same average distance, i.e., $4\frac{1}{2}$ times the lake radius. Allowing for the difference between the high and low sides the average

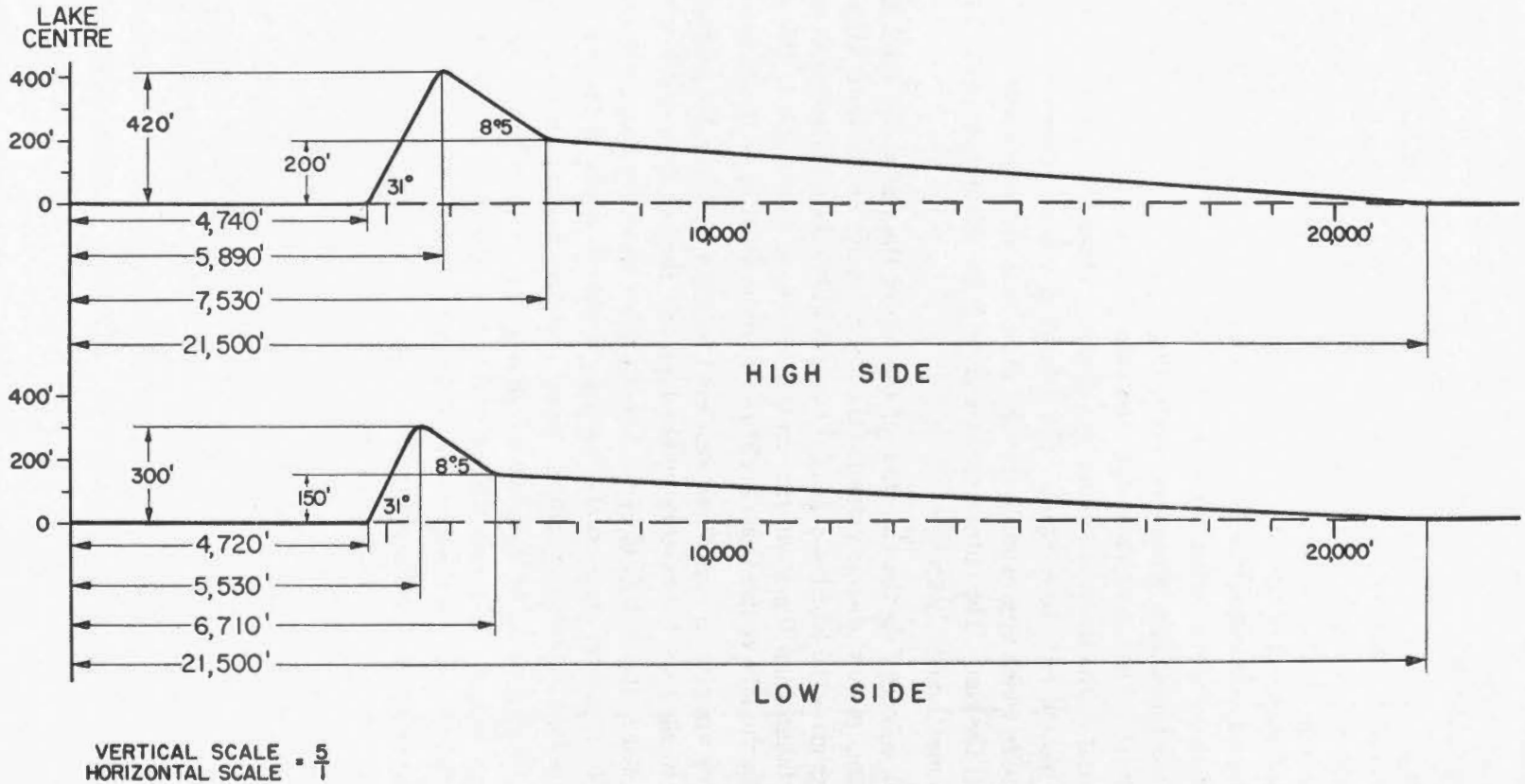

FIGURE 6. Schematic plot of mean values for the high and low sides of the crater, taken from Table 2.

deviation of a single measured value from the mean is 2 per cent for the lake and rim radii, 7 per cent for the radius of the discontinuity in the outer slope, and just over 30 per cent in the distance to lake level on the outer slope.

In the case of the inner and outer rim slopes there is no indication of any systematic difference between the high and the low sides. The average deviation of the individual values from the mean is 1·8 degrees for the inner slope and 1·6 degrees for the outer. Considering the inherent errors present in measuring these slopes this agreement is good. However, it is difficult to reconcile these values with the slopes published by Meen who in 1950 gave 45° inner slope, 25° outer slope (1)*, and in 1952 gave 40°–45° for the inner slope (2). Measurement of the inner slope from photographs on pages 6 and 29 of this latter paper, where a point with vision tangent to the lake edge can be chosen, gives 33° and 31° respectively, which seem to agree with those listed in Table 2. Meen does not indicate how his slopes were determined and they would appear to be only rough visual estimates. The eye normally exaggerates the angle of any slope, particularly if it is viewed from above.

There is considerable variation of height around the rim, and the high side averages 120 ft. higher than the low side. The average deviation of individual measurements from the means for the high and low sides is 40 ft. The height of the discontinuity on the outer slope also varies by about this same amount. It is 50 ft. up on the high side as compared with the low. The highest portions of the rim average 200 to 300 ft. higher than those diametrically opposite to them and, since the inner slopes are roughly uniform all the way round the crater, this automatically offsets the rim centre from the lake centre by the measured amount.

To give a picture of the variation in elevation around the top of the rim the height of the crest was measured in relation to true bearings taken from the rim centre. These values have been plotted in Figure 5, the vertical scale being expanded over the horizontal by a ratio of approximately 5 to 1. The positions where the 16 standard radii cross the rim crest have been indicated.

The mean values for the high and the low sides of the crater, taken from Table 2, are summarized schematically in Figure 6.

The 16 individual profiles measured along the standard radii are plotted in Figure 7. The vertical scale has been expanded to 5·18 times the horizontal so that the various features of the profiles can be studied to better advantage. It is unfortunate that we have so little knowledge of the crater profile below the water line of the lake. Meen has published one value only, a depth of 825 ft. for the lake centre (2), and this has been plotted to scale in relation to profile d. The smooth inner slope of the rim has been continued as a dotted line in the figure but its correct position must remain uncertain until additional lake depths have been published.

The 16 profiles reproduced in Figure 7 have been averaged for the high side and for the low side and the final means given in Table 3. In taking these means the steepest portions of every profile, i.e. the slope from the water level up, were placed in coincidence

* In discussing this point with Dr. Meen he pointed out that their party had climbed over the rim at a location between radii "a" and "p" and in Figure 7 it is seen that these profiles are above average in steepness at the top of the outer slope.

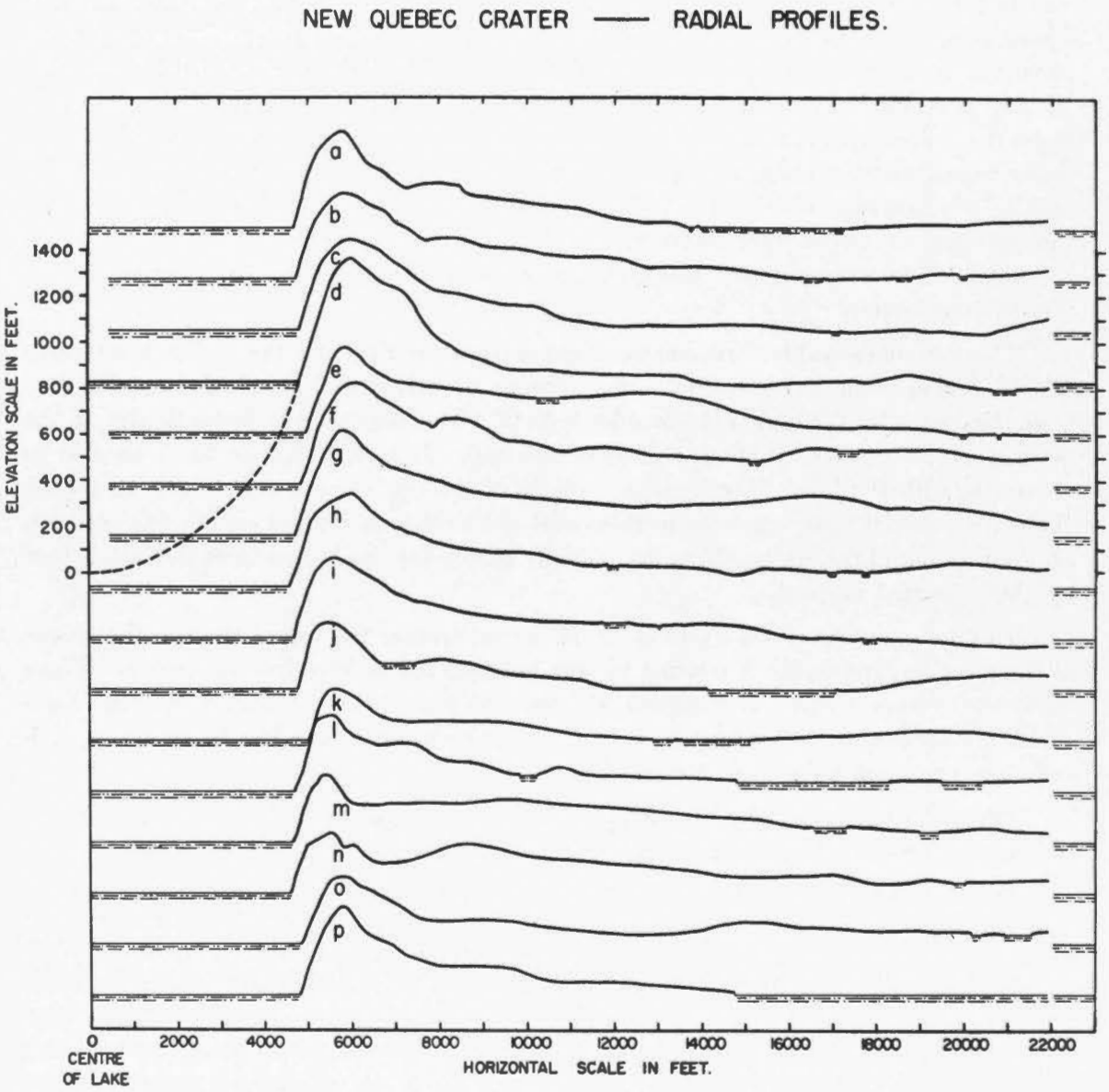

FIGURE 7. Profiles of the New Quebec crater measured along the 16 standard radii. Vertical scale 5·18 times the horizontal.

as otherwise the process of taking means would give an artificially low slope. When these mean profiles are plotted to scale we find a tendency to flatness on the upper portion of the inner slope, before it rounds off for the crest. This gives a 10 to 12 degree incline above the 31-degree drop to the lake level. The feature can be seen on several of the individual profiles in Figure 7. The figures of Table 3 do not reproduce exactly the means of Table 2 because of the difference in the methods of reduction. For example, the crests of the mean profiles are lower in both cases than the means for the ninth column of Table 2. In Table 2 the highest points on each profile are brought together and averaged but when taking the mean profiles for Table 3 the highest points are not all at exactly the same distance from the lake shore and so do not fall over each other and are not averaged together. Other differences may be explained in a similar way.

TABLE 3

MEAN PROFILES FOR HIGH AND LOW SIDES

High Side				Low Side			
Distance from Lake Centre	Height Above 1700′	Distance from Lake Centre	Height Above 1700′	Distance from Lake Centre	Height Above 1700′	Distance from Lake Centre	Height Above 1700′
(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
4,740	0	9,340	140	4,720	0	9,320	113
4,855	68	9,900	129	4,835	68	9,900	96
4,970	140	10,500	113	4,950	139	10,500	84
5,085	206	11,600	94	5,065	206	11,600	68
5,200	267	12,800	78	5,180	244	12,800	54
5,315	315	13,900	64	5,295	267	13,900	49
5,430	353	15,100	49	5,410	287	15,100	40
5,545	379	16,200	52	5,525	297	16,200	30
5,660	400	17,400	50	5,640	293	17,400	29
5,775	411	18,500	53	5,755	275	18,500	29
5,890	415	19,700	49	5,870	254	19,700	27
6,005	409	20,800	41	5,985	235	20,800	25
6,120	395	22,000	49	6,100	223	22,000	23
6,235	378	23,100	51	6,215	209	23,100	22
6,350	358	24,300	51	6,330	196	24,300	18
6,465	340	25,400	66	6,445	185	25,400	7
7,040	274	26,600	75	7,020	150	26,600	9
7,610	215	27,700	66	7,590	137	27,700	5
8,190	193	28,900	51	8,170	132	28,900	8
8,760	162			8,740	128		

Examination of the map shows little evidence of the concentric ridges surrounding the crater, mentioned by Meen on page 10 of (1). However, the contour interval of 25 feet is too large to show very much detail of this nature. An examination of the mean profiles shows that there is no general tendency for concentric ridges at fixed distances outside the main rim.

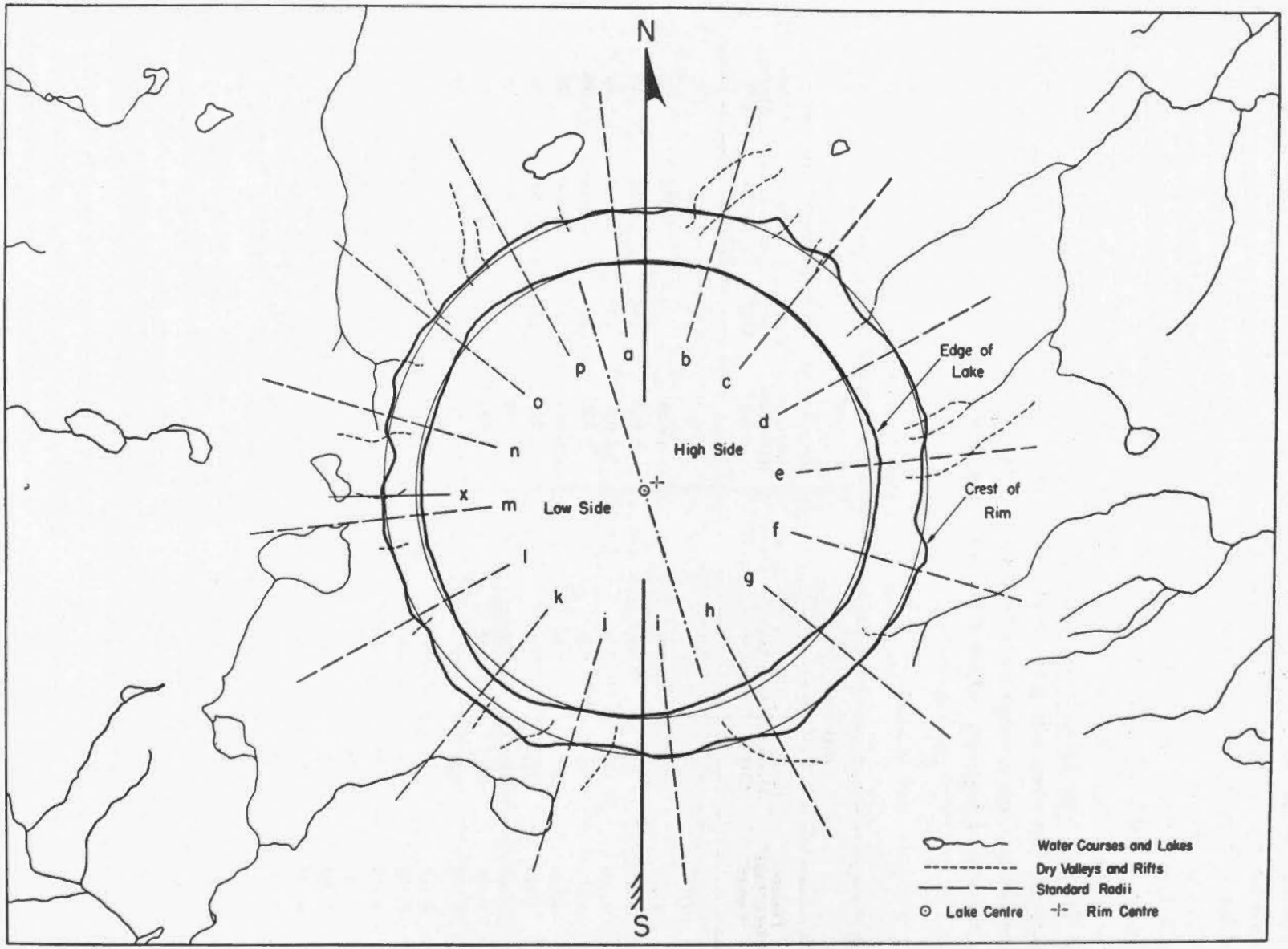

FIGURE 8. Scale plot showing the relation between the rim crest and the lake shore. The radial rifts and valleys and the locations of the standard radii have also been plotted.

As noted by Meen there are a number of rifts or valleys which cross the rim in a generally radial direction. Over 20 of these can be picked out from the map and their position has been plotted in Figure 8, together with the contours of the lake edge and the crest of the rim. For ease in reference the standard radii have also been plotted. Harrison (7) has pointed out that these valleys have been considerably modified by the direction of glacial drift. The glacial groovings and striae can be seen in the photomosaic of Figure 4, particularly on the northeast side of the crater. Evidence of their presence can also be seen in the water courses and valleys plotted in Figure 8. On the average the glacial striae lie along a bearing from 233°–53° true. The valleys intersect the crest of the rim at angles ranging all the way from 0° to 40° to the radial direction, with a mean angle of 15°. On the outer slope of the rim the valleys deviate still further from the radial line.

The magnetic observations recorded on the map were made by W. L. W. Hannaford, Division of Geomagnetism, Dominion Observatory. A standard electrical magnetometer, designed at the Observatory, was used, and the observations were taken as part of the regular magnetic coverage of the Canadian north. In this work no attempt was made to study in detail any magnetic features around the crater, nor to detect possible magnetic anomalies connected with the crater. The magnetic values found are normal for the region. The geographical coordinates listed were derived in the course of azimuth determinations and are not of the accuracy of those for precise geodetic control points.

GENERAL DISCUSSION OF CRATER PROFILES

It is of interest now to examine the mean profile of the New Quebec crater in the light of the general characteristics of explosion craters, both lunar and terrestrial. Baldwin (10) has found empirically two formulae giving relations among the three quantities — rim diameter, rim height, and total depth — for explosion craters. These are:—

$$D = 0 \cdot 1083d^2 + 0 \cdot 6917d + 0 \cdot 75$$
$$E = -0 \cdot 097D^2 + 1 \cdot 542D - 1 \cdot 841$$

where

D is log diameter (feet)
d is log depth (feet)
E is log rim height (feet)

From Table 3 we may conclude that the general average elevation of the terrain outside the crater is approximately 30 ft. above the lake level, or 1,730 ft. above sea level. We can then adopt the following as the best averages for the measurements of the New Quebec crater:—

diameter	11,290 ft.
depth	1,185 ft.
rim height	330 ft.

Using the value $D = \log 11{,}290 = 4 \cdot 0526$ in Baldwin's equations we find that for a typical explosion crater with this diameter the corresponding depth is 1,535 ft. and the rim height 655 ft. The depth of the New Quebec crater does not agree exactly with Baldwin's curve as it is just 77 percent of the average value. Still, this difference is only $0 \cdot 11$ in

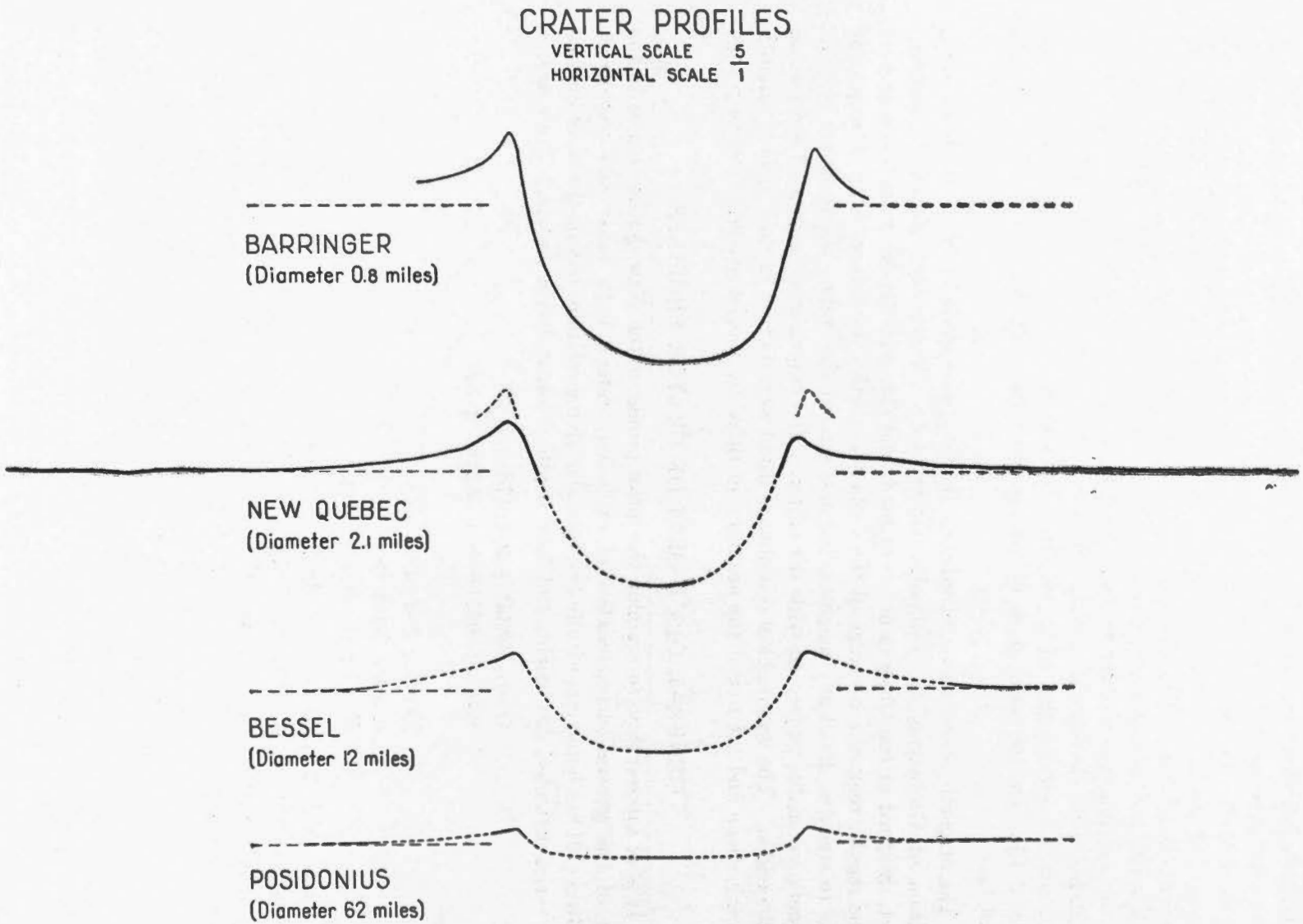

FIGURE 9. Comparison of the profiles of two terrestrial craters and two lunar craters. The measured portions of the profiles are indicated by the solid lines.

the log and is well within the general scatter in Baldwin's Figure 12 on page 132, *loc. cit.* The observed rim height shows a greater divergence from the standard, being barely 50 percent of the computed value.

However, a more basic figure than the above is the true depth of the crater below average ground level. This is found by subtracting rim height from the depth and is 1,535 − 655 = 880 ft. for the standard crater profile. The measured quantities are 1,185 − 330 = 855 ft., a very good agreement with the predicted value. It is obvious then that the New Quebec crater differs from the average explosion crater of corresponding size chiefly in the rim height, which is about half the expected value. Reference has already been made to the evidence of glaciation which has taken place since this crater was formed. It is likely that the rim height has been considerably reduced by this agency.

In Figure 9 the profiles of four craters are plotted for comparison purposes. The horizontal scales have been adjusted so that the craters as plotted have a uniform diameter. The vertical scales are in each case five times the horizontal scales. The Barringer crater profile was measured from a contour map prepared by Roswell Miller, III, and N. C. Harding in 1951, and kindly forwarded to the author by D. Moreau Barringer, Jr. The New Quebec crater profile was plotted from the two mean profiles listed in Table 3 of this paper. The values for the two lunar craters were taken from MacDonald's lists (11).

In comparing the New Quebec crater with the Barringer crater the well-rounded rim of the former is evident and leaves little doubt that it has been considerably ground down by glacial action. The tendency to flatness on the upper part of the inner slope, mentioned earlier, also supports this view. The rim height for the standard crater, taken from Baldwin's formula, has been plotted as a dotted line above the observed profile. The highest point on the rim is at true bearing 61° from the centre and the average of the high side is at true bearing 72°. The bearing of the glacial groovings is 53° true and Harrison (7) has given the direction of glacial drift as from the southwest towards the northeast quadrant. It is probably not coincidence that the low side of the rim is in the direction from which the glacial drift has come. Harrison suggests that as the glacial age developed the water in the crater would freeze and form a solid surface over and around which the glacial ice would flow. Relatively little in the form of glacial debris would then be trapped in the crater itself. The correctness of this view is supported by the close agreement between computed and measured depth of the crater below the general ground level. On the other hand the abnormally low and rounded rim would indicate that much of the original rim material was carried around and over the crater by glacial action and deposited to the northeast of the feature. In view of the above discussion it is felt that any connection between the high and low sides of the crater, and the direction of travel of the meteoric mass which may have formed the feature, is rather doubtful. The uniform inside slope around the rim and the nearly circular shape would also indicate that the crater-forming explosion acted symmetrically in all directions. The offset position of the rim with respect to the lake is a necessary consequence of the rim being higher on one side than on the other.

If the crater rim ever did extend to a height corresponding to the average for explosion craters it means that a depth of several hundred feet of rim was carried away by glaciation.

This could only have been in the form of broken rock fragments as it is difficult to imagine the basic layers of granite being worn away to this extent. Since this crater was formed in ancient granitic gneisses and since most of the comparison craters were formed in softer and lighter material, it is possible that the original rim height for New Quebec differed from the average given by Baldwin's equation.

The underwater profile for the New Quebec crater is drawn in Figure 9 for illustrative purposes and is very uncertain, as only the depth at the centre of the lake is known. Taking the entire crater profile as drawn, a very rough calculation gives a greater volume of material in the rim than is the total volume of the crater below the adopted ground level. This takes no account of the material removed by glaciation and if this is added to the rim volume the discrepancy becomes even greater. It is possible that the underwater profile, as drawn, is too shallow and that hence the calculation of the crater volume under the water is too small. What has a much greater effect is the choice of the average ground level which existed at the spot prior to the formation of the crater. Owing to the uneven nature of the surface in the neighbourhood, and to the uncertainties resulting from the absence of accurate geodetic ground control, it is difficult to make a good estimate. It seems evident that the average ground level chosen above is too low and that it should be raised, perhaps by as much as 50 ft. If this were done the discrepancy would disappear. It does not seem profitable to make detailed computations on this point or to pursue the matter further until geodetic ground control has been established and until more is known concerning the profile of the lake bottom.

Let us now consider the question of the slopes on the inside and the outside of the crater rim. The theoretical study of the slope at which any given type of material may be expected to lie is a complicated one, as can be seen by reference to such works as Terzaghi's "Theoretical Soil Mechanics" (12). It is not proposed to discuss this phase of the subject here. We can, however, examine the information available concerning other explosion-type craters.

For 113 lunar craters, with diameters from 1 to 18 miles, Fauth (13) finds a mean inner slope of 33°.5, with no tendency within this group for the average slope to vary with crater diameter. For larger lunar craters Fauth's mean slopes are considerably less. On the earth, where surface changes are continually taking place, the slopes found in a crater should vary more than on the moon, as they will be dependent upon the age and the type of weathering to which the crater has been exposed. In general these changes will tend to decrease the original slopes present when the crater was first formed. The steepest part of the inner slope for the Barringer crater, measured from the profile in Figure 9, is 49° for the high side, 36° for the low side. From pictures of the Wolf Creek crater, published by C. H. Holmes (14), the inner slope seems to average between 25° and 30°. For the two Odessa craters the slopes of the rock walls, apart from the sand fill, are 37° and 26° as measured on diagrams in an unpublished report by Sellards and Evans (15). The inner slopes of the Talemzane crater (16) vary from 22° to 30°, those of the Aouelloul crater attain 20° to 30° (17). Measurements of the plotted profiles of the largest Estonian crater at Ösel (18) give an average inner slope of 28°. From the profiles published for four of the Campo del Cielo craters (19) mean inner slopes of 12°,

12°, 16° and 8° respectively are measured. From the above brief summary it will be seen that the 31° inner slope of the New Quebec crater lies between those found in the relatively recent and well-preserved Barringer crater and the slopes of other terrestrial craters which in general have been modified to a greater extent by weathering. The inner slope for New Quebec is close to but slightly less than the average for craters of similar size on the moon.

A range of values from 1° to 8° has been given for the outer slopes of the lunar craters by Neison (20) and Schmidt (21). The Barringer crater profile has an average outer slope of about 15°, and 5° to 15° is the range given for the outer slope of the Aouelloul crater (17). Outer slopes for the large Estonian crater average about 12° (18). Little other quantitative information is readily available concerning the outer slopes of terrestrial craters. Some have no appreciable outer slopes but wherever one exists it is always described as considerably less than the inner slope. The mean slope of 8°.5 measured for the top of the outer rim wall at the New Quebec crater is equal to the maximum of the outer slopes reported for the moon and is probably near the centre of the range for outer slopes of terrestrial craters.

SUMMARY

To summarize the above profile study we find that the New Quebec crater agrees well with the standard form of explosion craters of comparable size. It has a nearly circular outline, the depth of the crater below ground level is normal and the inner and outer slopes of the rim are what we might expect from a study of other craters. Only in the rim height is there very much divergence from the standard profile and the well-rounded rim crest, together with ample evidence of glaciation at the crater, will explain this. There has been nothing in the present investigation to negative the theory of meteoric origin for this feature. In fact, it is felt that the close agreement between the New Quebec crater and the normal series of explosion craters, considerably strengthens the meteoric theory and, in the absence of any other satisfactory suggestions, leaves a meteoritic origin as the best explanation for the presence of this large symmetrical depression in the Precambrian rocks of the Canadian north.

ACKNOWLEDGMENTS

In conclusion it is desired to thank A. A. Larocque of the Map Compilation and Reproduction Division for his assistance in the determination of the scale of the printed map. Among a number of both service and civilian personnel who supplied the writer with details concerning the early history of the crater particular mention should be made of W/C W. K. Carr, R.C.A.F., and of Dr. B. R. MacKay, formerly of the Geological Survey of Canada. The Office of Research and Liaison, U.S.A.F. Aeronautical Chart and Information Centre, Washington, was very helpful in checking the early appearances of the crater on their maps. Discussions with Drs. Morris Innes and J. A. Rottenberg and with other members of the Observatory staff are gratefully acknowledged, and finally, the author's sincere thanks go to Dr. C. S. Beals for his constant advice and encouragement throughout the course of the investigation, and generally in all problems dealing with the study of explosion craters.

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APPENDIX A

NOTES ON THE APPEARANCE OF THE NEW QUEBEC CRATER ON MAPS OF THE UNGAVA PENINSULA

Date of Map	Series and Sheet in Series	Scale	Source	Plotting of the Crater
1942	Regional Aeronautical Chart, UNGAVA BAY	1:1,000,000	USAAF	No crater plotted
1942	National Topographic Series, POVUNGNITUK RIVER (35 S.E.)	1:506,880	Mines and Resources	No crater plotted
1944, May	AAF Aeronautical Chart, HUDSON STRAIT (111)	1:1,000,000	USAAF	No crater plotted
1945, Feb.	AAF Preliminary Base, WAKEHAM BAY (111D)	1:500,000	USAAF	Plotted with word "crater"
1945, Aug.	AAF Aeronautical Chart HUDSON STRAIT (111) Base No. 2	1:1,000,000	USAAF	Plotted with word "crater"
1946	National Topographic Series, POVUNGNITUK RIVER (35 S.E.)	1:506,880	Mines and Resources	Plotted with word "crater"
1949	World Aeronautical Chart, IACO KOVIK RIVER (2109)	1:1,000,000	Mines and Tech. Sur.	Plotted
1949	National Topographic Series, POVUNGNITUK RIVER (35 S.E.)	1:506,880	Mines and Tech. Sur.	Plotted with word "crater"

APPENDIX B

Official Air Photographs of the New Quebec Crater

Date	Source	Photo Reference Numbers	Remarks
1943, June 20	AAF	1 — 2086 L — 8212 — 8213 — 8214 — 8216	trimetrogon survey, first photos of the crater
1946	RCAF	REA 360 — 18	oblique, distant view
1948, July 3	RCAF	T 193 R — 85 — 86 — 87 — 88 — 89 — 90 — 190 — 191 — 192 — 193 — 194 — 195 — 196 — 197	trimetrogon survey, crater from east trimetrogon survey, crater from west
1948, July 20	RCAF	REA 470 — 14 — 15 — 16 — 17 — 18 — 19	obliques, mostly close-up views of the crater
1952, July 15	RCAF	REA 659 — 7 — 8 — 9 — 10 — 11 — 12 — 13	obliques, mostly close-up views of the crater
1953, Aug. 9	RCAF	A 13842 — (1—39)	39 vertical photographs at 9920′
Aug. 25	RCAF	A 13841 — (1—124)	124 vertical photographs at 5540′
Aug. 25	RCAF	A 13780 — (47—191, 327—349)	168 vertical photographs at 9400′

Note:—Prints of the RCAF photographs listed above may be purchased from the National Air Photographic Library, Department of Mines and Technical Surveys, Ottawa, Ont.