Morphological Analyses of Glacial Valleys and Estimates of Sediment Thickness on the Valley Floor: Victoria Valley System, Antarctica

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南極大陸 Victoria Valley System の氷蝕谷の形態解析と谷底堆積物の厚さの推定

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要旨: 南極大陸ビクトリア谷系に分布している氷蝕谷の横断形態を，モデル式 $Z=aX^b$ を使って解析した．この式で，X と Z はそれぞれ谷底中央からの水平距離と高さの座標値で，1970 年に撮影された 1:60000 の空中写真から，写真測量によって求められた．係数 a と指数 b は最小 2 乗法によって決められる．13 カ所の断面の解析の結果得られた指数 b の値は，1 以下から 5 以上までと幅広く，値がほぼ 2 に近いヨーロッパや北アメリカでの結果と異なっている．

以上のことから，指数が 1.5～2.0 前後の断面と，それ以外の値をもつ断面とでは，形態が非常に異なっていることが判明した．その解釈として 2 つの説明，1) 氷蝕の違い，2) 塩風化による斜面発達の過程の違い，が考えられた．

谷底堆積物の厚さの推定が行われた．これはモデル式を谷底に外挿して岩床の高度を推定し，地表面との高度差を算出して得られた．直接検証するデータは無いが，間接的な方法では，これらの推定値が妥当な範囲にあることが判明した．

Abstract: The morphology of glacial valleys in the Victoria Valley system, Antarctica, was quantitatively analyzed employing the model $Z=aX^b$. In this model, the X and Z coordinate values are the distances from and the heights above the valley center as determined by photogrammetric techniques from 1:60000 high-altitude aerial photography obtained in 1970. The coefficients "*a*" and exponents "*b*" were determined by the method of least squares. Values for the exponents ranged from approximately 0.6 to 5, indicating that the glacial valley cross-sections could be approximated by profiles varying from shallow V's to quintic parabolas. These values differ from those obtained for glacial valleys in Europe and North America, where parabolas with exponents from 1.5 to 2.0 have been found to approximate valley cross-sections. Consequently, it appears that there are distinctive morphological differences among groups of glacial valleys. Two possible explanations for these morphological differences are presented: 1) different modes of glacial erosion; and 2) slopes at different stages of evolution by salt weathering. In addition to morphological factors, estimates of

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the depth of sediments in the valleys were also attempted by extrapolating the model-generated curve beneath the surface deposits to the valley floors. The difference between the photogrammetrically measured surface elevations and the estimated bedrock elevations yielded the depth estimates. Examination of the results indicates that these estimates are reasonably correct when appropriate segments of the valley wall are chosen for the curve fitting.

1. Introduction

Landforms in Antarctica have not been subjected to detailed quantitative studies due to the inaccessibility of the region, and to the lack of suitable topographic maps and aerial photographs. In 1970, however, the U.S. Navy recorded high-altitude aerial photographs of the dry valleys at 1: 60000 scale for the U.S. Geological Survey mapping program (MACDONALD, 1977). This photography, for which control points established by field surveys and subsequent aerial-triangulation are available, is a valuable source of topographic information. Utilizing these photographs, photogrammetric techniques can readily provide the X, Y, Z terrain coordinates required for quantitatively analyzing the landforms of the dry valleys.

The authors obtained the aerial photographs and control data for the Victoria Valley system, the largest among the dry valleys (Fig. 1). Photogrammetric procedures were then devised to analyze and compare the morphology of the glacial valleys with those distributed in Europe and North America. In this paper the method of establishing mathematical models for the morphology of the valleys is described, as is a method of estimating the thickness of sediments covering the valley floor.

2. Victoria Valley System—Study Area

As the largest among the numerous dry valleys in the southern Victoria Land, the Victoria Valley system comprises a study area of approximately 1000 km^2 consisting of five large interconnecting valleys: Victoria, Barwick, Balham, McKelvey and Bull Pass (Fig. 2). These northeast-southwest and northwest-southeast oriented valleys are 2 to 5 km wide with floors 800 to 1200 m below the adjacent peaks. Quaternary deposits mantle the floors and the walls are often covered by gelifluction deposits. Lake Vida with an elevation of 343 m is the point of lowest elevation in the study area.

The Victoria Valley system is bounded by inland ice plateau to the west and the Victoria Lower and Clark Glaciers to the east. Local mountain ranges and glaciers occupy the northern margins, and, on the south, the Olympus Range separates the valley system from the Wright Valley. Geologically, the region is underlain by igneous, metamorphic and sedimentary rocks of Precambrian to Mesozoic age (ALLEN and

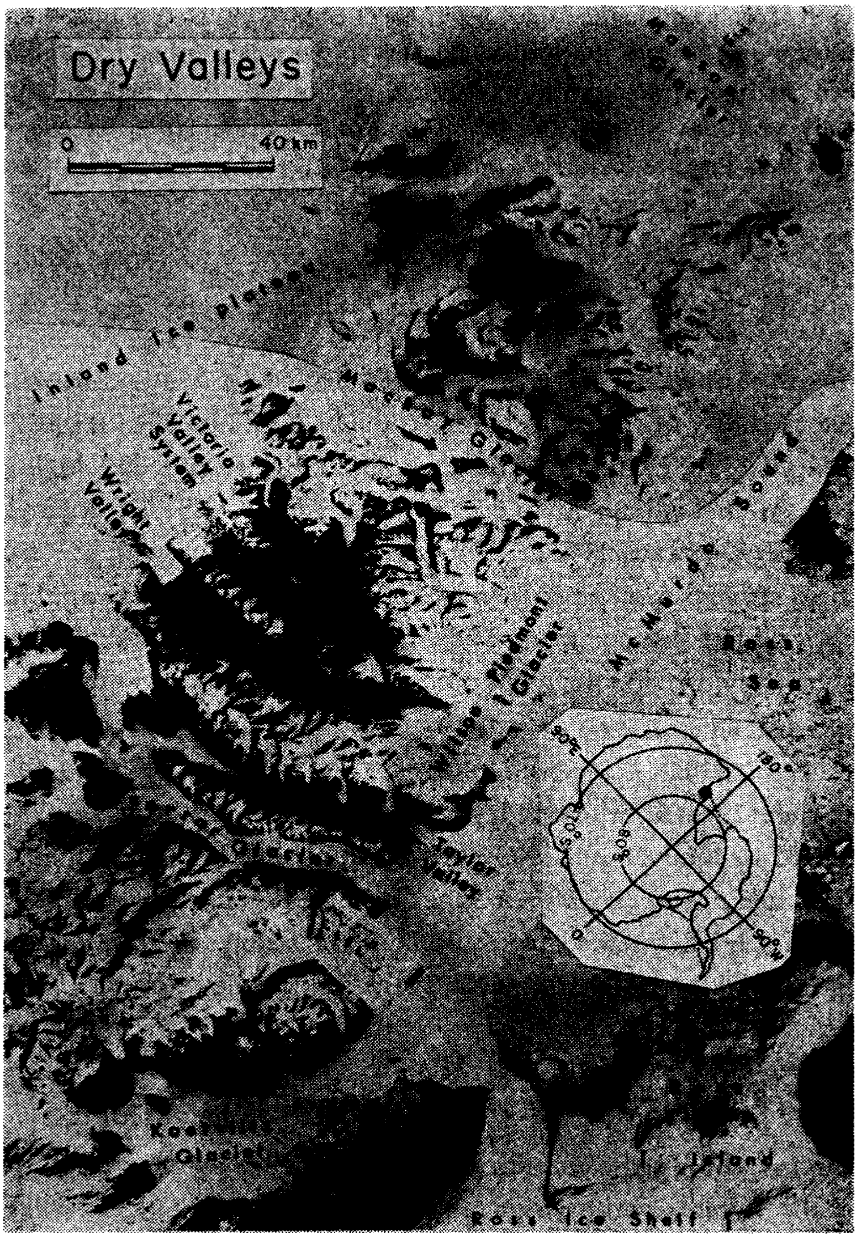

Fig. 1. Landsat view of the dry valleys, southern Victoria Land, Antarctica.

GIBSON, 1962). For example, outcrops of the Precambrian/Cambrian metasediment basement complex (Asgard Formation) and granites are found in the eastern half of the study area (Figs. 3a and b). Numerous dikes of the Vanda Porphyry and Lamprophyres have intruded these granitic bodies and the basement complex is truncted by an erosional surface of low relief, the Kukri Peneplain of post-Ordovician age (GUNN and WARREN, 1962; GRINDLEY and WARREN, 1964). To the west, the Kukri Peneplain is unconformably overlain by sedimentary rocks of the Beacon Supergroup which consists primarily of cross-bedded quartzose sandstone (MCKELVEY and WEBB, 1962; CALKIN, 1971;

Fig. 2. Uncontrolled mosaic of the Victoria Valley system, constructed from high-altitude aerial photographs of 1 : 60000 scale.

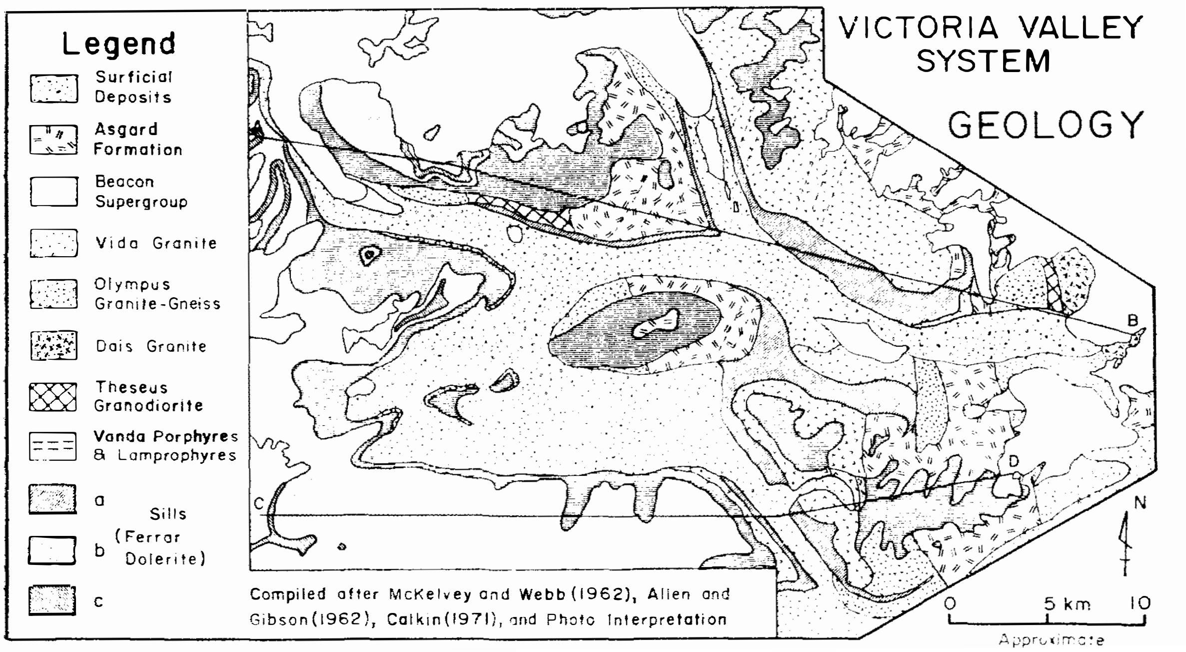

Fig. 3a.

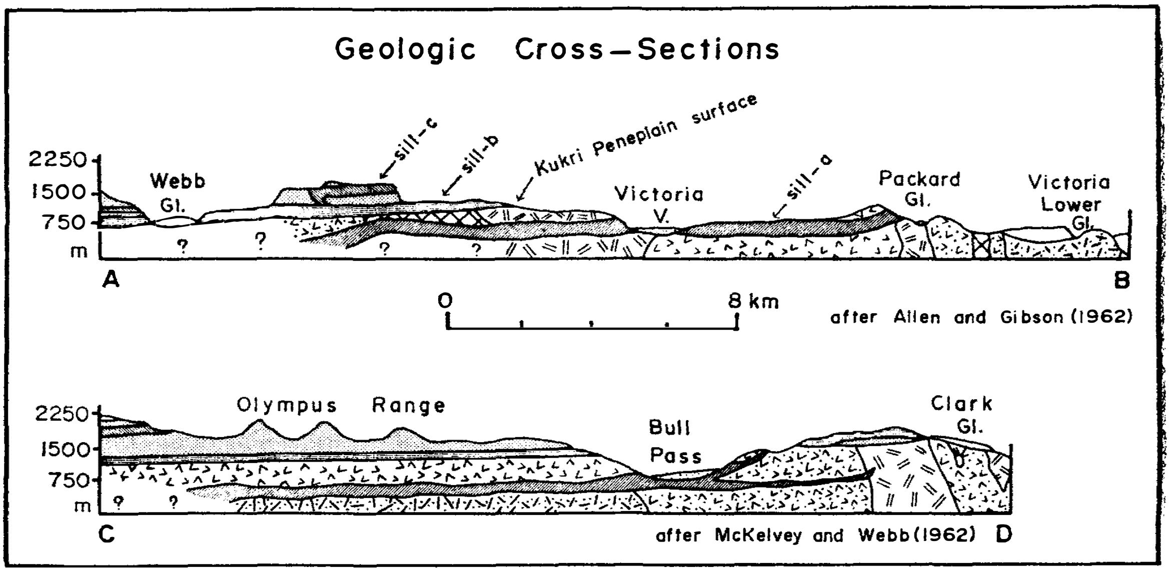

Fig. 3b.

BARRETT, 1971). Both the basement complex and the Beacon Supergroup are intruded by the Ferrar Dolerite sills of Jurrasic age; 1) sill-a, 2) sill-b, and 3) sill-c (McDOUGALL, 1963; HAMILTON, 1965).

In the Victoria Valley system, relatively moist easterly winds are dominant in the east and northeast portions. To the west of Lake Vida, westerly or southwesterly katabatic winds off the inland ice plateau are common (CALKIN, 1964). Five major glaciers are nourished: 1) Victoria Upper Glacier; 2) Victoria Lower Glacier; 3) Webb Glacier; 4) Packard Glacier; and 5) Clark Glacier. Glaciers also have been responsible for development of numerous cirques fringing the study area, many of which are now mostly ice-free.

According to the detailed study made by CALKIN (1964), the Victoria Valley system had been subjected to two major glaciations; the Insel and Victoria Glaciations. The younger Victoria Glaciation was further subdivided into Bull, Vida and Packard Episodes. CALKIN (1971) also estimated the ages of these glaciations as approximately; 3 million years B.P. for the Insel Glaciation; 1.2 million years B.P. for the Bull Episode; 500000 years B.P. or younger for the Victoria Episode; and 49000–10000 years B.P. for the Packard Episode.

3. Photogrammetric Measurements of Glacial Valley Cross-Sections

In order to photogrammetrically measure the X, Z terrain coordinates representing the glacial valley cross-sections, 40 stereopairs of 1:60000 scale photographs taken in December 1970, were acquired from the U.S. Geological Survey with ground control data. These stereopairs were placed in a Kelsh plotter equipped with a polarized platten viewing system and scaled and leveled to ground control provided by the U.S. Geological Survey. The root-mean-square-errors (RMSE) of the horizontal and vertical control points were computed to be 6.9 m and 5.0 m respectively.

The 5$\times$enlargement factor provided by the Kelsh plotter facilitated the compilation of topographic maps at 1: 12000 scale with contour intervals of 50 m or 20 m. A set of X, Z coordinates for each cross-section was measured at a regular horizontal interval of 60 m, utilizing a grid sheet aligned according to the valley orientation. In order to minimize bias and measurement errors, three Z values were obtained for each X value using three cross-sectional lines 60 m apart. The cross-sectional data consist of those representing valley floors (covered with sediments) and walls (little or no sediments).

The estimated RMSE's for the planimetric and vertical accuracies of the photogrammetric coordinates were ± 8 m and ± 6 m respectively, based on measurements of 22 stereo-models. For morphological analyses such as this one, the accuracy of points (particularly of elevations) relative to one another is of greater importance than an RMSE from a defined datum. In this study the majority of the elevations are estimated to be correct relative to each other to within ± 3 m, which is completely satisfactory, considering the scale of the study.

4. Morphological Analysis of Glacial Valley Cross-Sections and Estimation of Sediment Thickness on the Valley Floor

It has been well established that the general equation (model) $Z=aX^b$ approximates cross-sections of glacial valleys distributed in Europe and North America (SVENSSON 1959; KANASEWICH, 1963; GRAF, 1970; DOORNKAMP and KING, 1971). This model was also employed in this study in order to analyze morphology of the glacial valley cross-sections in the Victoria Valley system, facilitating comparisons with the results of other studies. In this equation, "a" and "b" are determined by the method of least squares using the X, Z terrain coordinates. If the valley floor has not been filled with sediments, all measured coordinates can be entered into the equation in order to mathematically determine the morphology of the cross-section. If the valley floor is covered with thick sediments, however, the valley cross-section is so modified that only the wall segments indicate the valley form as glacially eroded. In such a case, only X, Z values representing the valley walls can be used to compute the value of the coefficient and exponent. If the datum is chosen in such cases so that the mathematically-generated curves reasonably approximate the valley walls, it appears possible to estimate the thickness of sediments on the valley floor by extrapolating the curves beneath the floor and then comparing differences between the surface (measured) and the subsurface (computed) elevations. The idea of the mathematical curve extrapolation to estimate sediment thickness has been expressed by Doornkamp and King (1971, p. 148), however, this idea does not appear to have been previously applied.

4. 1. Method to estimate sediment thickness on the glacial valley floor

Valley cross-sections are generally not symmetrical and an equation must be computed for each half of a cross-section in order to obtain a reasonable mathematical approximation to valley configuration. The following paragraph explains the procedure in detail referring to Fig. 4.

The X, Z coordinates of a cross-section were measured by assigning the valley center as the coordinate origin for the X axis and reading Z values in the elevation above sea-level (Fig. 4 A). Then assuming a certain datum (elevation of the origin), say (a) in Fig. 4 B (step (1)), equations for both sides are computed and the standard errors of estimates (S_z) are calculated. The same computational procedure is repeated for different elevations of the origin (b, c and d in Fig. 4 B). After comparing the S_z's of a, b, c and d for each side, it is found that the S_z of the right side is the minimum when the elevation of the origin is at "b", and that of the left side the minimum at "c"

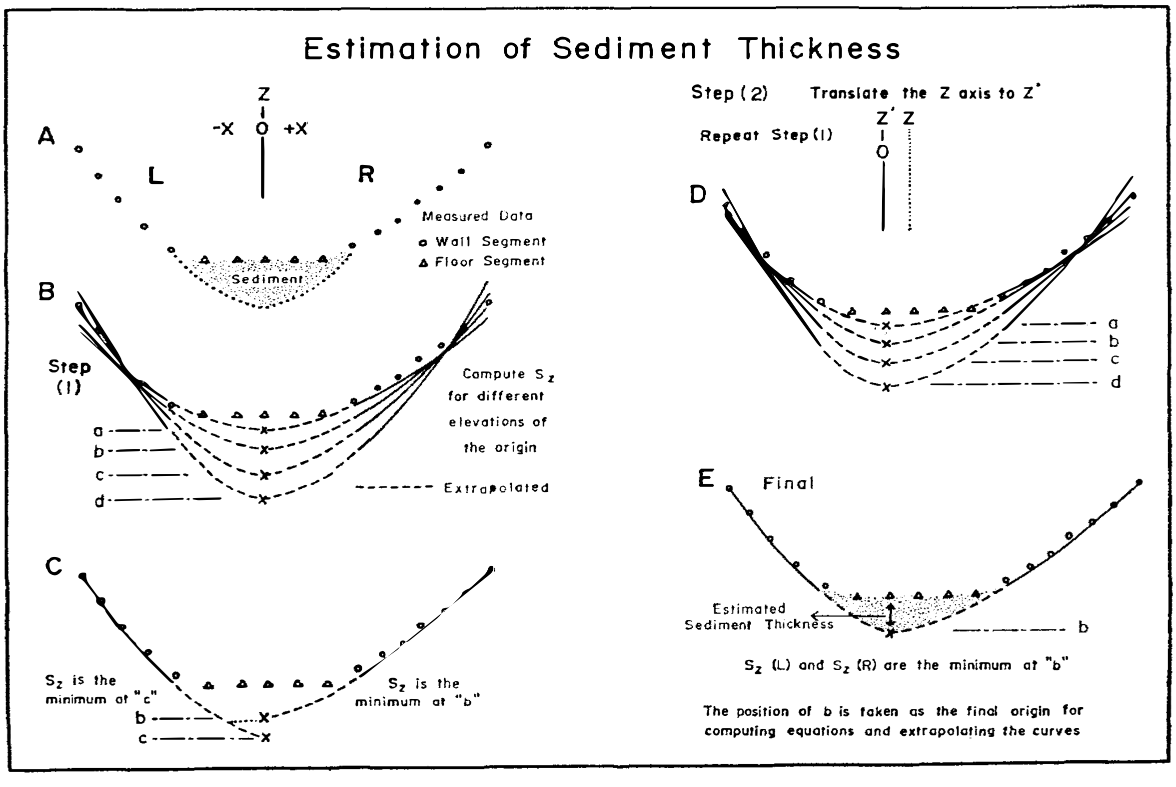

Fig. 4.

(Fig. 4 C). From diagram C, it can be seen that if the coordinate system is translated along the X axis toward the left, the smallest S_z's for both sides may be obtained at the same elevation of the origin. Thus, the Z axis is translated to Z' and step (1) is repeated (Fig. 4 D). By this repetitive procedure, the origin of the coordinate system for which the S_z's of both sides are minimal can be found (Fig. 4 E). Equations for the right and left walls are computed based on the final origin and these are used to extrapolate the curves beneath the valley floor. These equations are also used to analyze the morphology of the valley cross-section. The estimated sediment thickness is then taken as equal to the difference in elevation between that measured for the valley floor and that computed by the equation.

It was necessary to test the reliability of this method before applying it to the valleys in the Victoria Valley system. Two tests were employed: (1) equations were determined for the walls of a glacial valley with no sediments on the floor, and the curves were extrapolated toward the valley floor; and (2) the known thickness of a valley glacier, determined by bore holes, seismic refractions and gravity anomalies, was compared with the thickness derived by extrapolating the curves beneath the glacier.

For the first case, a valley segment completely free of sediments is located east of Lake Vanda in the Wright Valley, just south of the Victoria Valley system (see Fig. 2). This section of the valley has not been subjected to multiple glaciations (CALKIN *et al.*, 1970), and the valley wall is either exposed bedrock or covered by very thin surficial deposits. Three cross-sections parallel to each other and 65 m apart were photogrammetrically measured to obtain 138 sets of X, Z coordinates. Points located on the valley walls were used to determine equations for curves representing each half of the valley. These curves were then extrapolated across the valley floor and a comparison of computed and measured Z values for the extrapolated portion of the cross-section yielded standard errors of about 20 m. This figure may seem rather high: however, the valley floor is very rough due to numerous dikes and the elevation differences between the top of dikes and the depressions between them are on the order of 15–20 m. It can be concluded from this result, therefore, that the extrapolated elevations are reasonably close to the measured elevations of the valley floor.

For the second test, the thickness of the Athabaska Glacier in Canada was estimated by the extrapolation method and compared to values derived from bore holes, seismic refraction measurements and gravity anomalies (PATERSON and SAVAGE, 1963; KANASEWICH, 1963). Using the topographic map "Athabaska Glacier" (1: 10000 scale, compiled from the aerial photographs taken in 1969), 49 sets of X, Z coordinates representing two cross-sections 50 m apart were measured (along line B in KANASEWICH's article). Equations were then determined for the valley walls and extrapolated underneath the glacier. From gravity anomalies KANASEWICH determined (at the cross-section) the maximum thickness of the glacier to be 326 m, whereas the results of the curve extrapolation indicated that it was 344 m; thus the difference of 18 m. Although there is a nine-year difference between the gravity anomaly measurements and the date of the aerial photographs from which the map was produced, the depth of the glacier estimated from the extrapolated curves corresponds closely to that derived from the gravity measurement. From the results of two different examinations of the extrapolation method, it appears reasonable to conclude that the estimation of sediment or glacier thickness by curve extrapolation is reasonably accurate when proper segments of the valley wall are chosen for the application of the equations.

4.2. Morphological analysis of glacial valley cross-sections

Sets of X, Z coordinates for 13 cross-sections were obtained by photogrammetric methods for selected areas of the Bull Pass, Barwick and Victoria Valleys, and the valley containing the Packard Glacier (Fig. 5). Cross-sectional data for the McKelvey and Balham Valleys could not be measured owing to poor image quality and deep shadow cast by the mountains.

The equation $Z=aX^b$ was applied to the wall segment (free of sediments) of each side of the cross-section and values of the coefficient and exponent determined. Since many cross-sections show the step-like profiles, three possible causes were examined: 1) different cycles of glacial erosion; 2) lithological control; and 3) salt weathering (SELBY, 1971). It was concluded, then, that the majority of the steps could be best

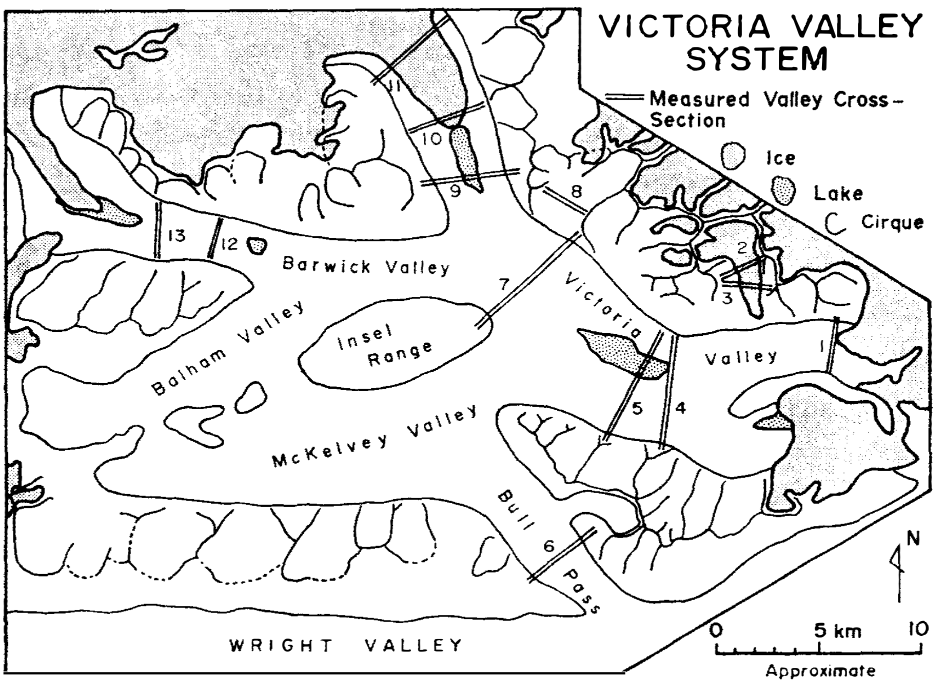

Fig. 5.

interpreted as results of different cycles of glacial erosion, although some irregularities have been caused by lithological influences and in some cases also by salt weathering. Lithological control was ruled out as the major cause because the position of most steps (about 80 percent) does not coincide with lithological changes. The different cycles of glacial erosion was favored on the grounds that: 1) for most cross-sections, the number of steps in the profile and the number of glaciations to which that profile was subjected were the same; 2) elevations of the steps on both sides of the valley were comparable; and 3) it did not appear that salt weathering could have possibly caused such characteristics of the steps stated in 1) and 2). Therefore, the curve fitting was also attempted for each step of a profile, although this was often proved difficult because of the small number of points available for the least squares adjustment within the steps.

The computational results indicate that the approximation of computed curves to the measured profiles is generally good with an average standard error of estimate of about 6 m. Although previous studies have indicated that the glacial valley cross-section can be adequately represented by semi-cubic to true parabolas (exponent of 1.5–2.0, SVENSSON, 1959; KANASEWICH, 1963; GRAF, 1970; DOORNKAMP and KING, 1971), the values of exponents obtained in this study vary widely from less than 1 to over 5. The equations were arranged by the values of the exponent in increasing order and were then grouped (Table 1). From Table 1 it is recognizable that "straight lines", "semi-cubic parabolas", and "true parabolas" exhibit horizontal distances and reliefs within a similarly limited range. Schematic curves constructed from the average values of the horizontal distances and reliefs of each group are presented in Fig. 6. It is evident from Fig. 6 that the valley wall does not necessarily overdeepen with an increase of the exponent value as GRAF (1970) reported in his study. It can be clearly recognized from this illustration that the curves with exponents greater than 2.25 (2.5 in Fig. 6) represent a profile which is distinctively different with much broader and gentler configuration from those approximated by other curves. On the other hand, the upper part of the profiles approximated by "straight line", "semi-cubic parabolas" and "true parabolas" show very similar gradients.

Since the relationship between glacial processes and the resultant morphology of the cross-sections remains unclear, the relationship between the form of the profiles and lithology was first examined. It must be noted, however, that there is no conclusive evidence for establishing a definite relationship between curves and lithology. The majority of the "straight line" have developed on the profiles consisting of two different kinds of rocks and "true parabolas" approximated the profiles with one kind of rock (see Table 1).

Glacial processes are probably the main factors responsible for the differences in

Table 1. Equations arranged and grouped by exponent values.

Cross-section	Coefficient (a)	Exponent (b)	Horizontal distance (m)	Relief (m)	Gradient (degree)	Lithology*
3 G L	0.561×10^{1}	0.630	456	266	30.3	AF, s-a
Straight lines ($0.85\leqq b<1.25$)						
9 S L	0.142×10^{1}	0.873	960	569	30.7	VG
6 G L	0.138×10^{1}	0.874	1680	908	28.4	s-a, VG
10 G	0.392×10^{0}	0.976	2160	706	18.1	OGG, AF
5 S L	0.483×10^{0}	0.996	744	350	25.2	VG, s-a
8 S	0.311×10^{0}	1.083	1056	577	28.7	s-a, VG
11 S L	0.155×10^{0}	1.176	852	433	26.9	VG, s-b
1 S	0.122×10^{0}	1.236	1020	643	32.2	TGD
		Average	1210	598	27.2	
Semi-cubic parabolas ($1.25\leqq b<1.75$)						
4 S L	0.482×10^{-1}	1.336	900	426	25.3	VG, s-a
13 S L	0.156×10^{-1}	1.481	1140	524	24.7	OGG
8 G	0.580×10^{-2}	1.535	1584	486	17.1	s-a, VG
9 S U	0.575×10^{-2}	1.594	1584	722	24.5	VG
3 S L	0.337×10^{-2}	1.696	1044	443	23.0	VG
12 S	0.180×10^{-2}	1.743	1440	567	21.5	OGG
		Average	1282	528	22.7	
True-parabolas ($1.75\leqq b<2.25$)						
13 G L	0.212×10^{-3}	1.921	2100	512	13.7	OGG
2 S L	0.491×10^{-3}	1.947	840	243	16.1	s-a
2 S U	0.272×10^{-3}	2.051	912	320	19.3	AF
6 S L	0.395×10^{-4}	2.150	2700	938	19.2	VG
3 S U	0.115×10^{-3}	2.172	960	346	19.8	VG
		Average	1502	472	17.6	
Others ($b\geqq2.25$)						
11 G L	0.643×10^{-5}	2.275	2748	428	8.9	OGG
12 G	0.171×10^{-4}	2.318	1620	462	15.9	s-a
10 S	0.215×10^{-5}	2.516	2400	683	15.9	VG
9 G U	0.110×10^{-5}	2.524	3396	896	14.8	OGG, AF
9 G L	0.124×10^{-5}	2.553	2580	637	13.9	OGG
4 G L	0.126×10^{-6}	2.669	3780	446	6.7	VG, s-a
2 G L	0.239×10^{-5}	2.671	900	158	11.6	s-a
2 G U	0.132×10^{-6}	2.902	1608	265	9.4	s-a
5 G L	0.989×10^{-9}	3.181	4416	390	5.0	VG, s-a
3 G U	0.427×10^{-8}	3.510	1200	274	12.9	s-a
7 S	0.213×10^{-12}	3.851	3180	647	11.5	s-a
1 G	0.576×10^{-12}	4.291	2820	371	7.5	OGG
7 G	0.320×10^{-17}	5.543	4380	484	6.3	AF, s-b
		Average	2694	474	10.8	

S—Steeper side G—Gentler side U—Upper step L—Lower step

* AF — Asgard Formation
VG — Vida Granite
OGG — Olympus Granite-gneiss
TGD — Theseus Granodiorite
s-a — Ferrar Dolerite sill-a
s-b — Ferrar Dolerite sill-b
Order of list from lower to upper in the profile.

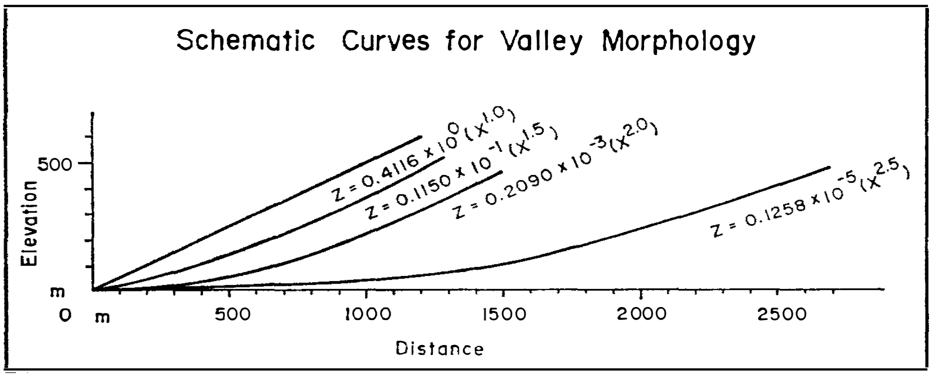

Fig. 6.

morphology. Other factors may include the salt weathering processes proposed by SELBY (1971) and by COTTON and WILSON (1971) which have produced rectilinear slope forms in the dry valleys. It can be pointed out and is of great interest to note that cross-sections of glacial valleys in Europe and North America have been approximated by semi-cubic to true parabolas. In the Victoria Valley system those approximated by exponents of less than 2 have distinctively different morphology as compared to those with exponents greater than 2.25. One of the possible interpretations may be that there are distinctive differences between the modes of glacial erosion which produced profiles of semi-cubic and true parabolic curves, and that which caused profiles with exponents greater than 2.25. For example, with the constant supply of a given volume of glacier ice, the profile of the valley wall may eventually assume a morphology which can be approximated by curves of semi-cubic to true parabolas, and if the volume of glacier ice starts on increase, the valley morphology adjusts to it by widening rather than deepening and the profile becomes gentler. If this is the case, profiles approximated by semi-cubic to true parabolic curves may represent a most efficient morphology to transport glacier ice, hence a stage of equilibrium for glacial erosion and profile development.

Another possible interpretation, incorporating SELBY's slope evolution by salt weathering in the dry valleys, could be that those profiles with exponent values greater than 2.25 represent rectilinear slopes with back-weathered free faces on top of them, and those with exponents of about 1 represent rectilinear slopes without free faces. Possibly, only those profiles approximated by semi-cubic to true parabolas indicate original glacially-eroded forms. In order to truely understand relationships between glacial processes and resultant morphology, however, it will be necessary to conduct field studies.

4. 3. Estimation of sediment thickness

The estimation of sediment thickness was also attempted for the 13 cross-sections using the extrapolation of the mathematically-generated curves. The results are listed in Table 2. For some cross-sections, two values of the estimated thickness were obtained: one by applying the method of least squares to the valley wall profile (extrapolation W), and another only to the lower step of the profile (extrapolation L). In many cases bedrock elevations obtained by both methods indicate similar values at the valley center. The results of the curve extrapolation were plotted by computer in order to display each cross-section (Fig. 7).

The northwest corner of Lake Vida has been drilled as part of the Dry Valley

Table 2. Results of thickness estimation.

Cross-section	Measured[1] valley floor elevation (m)	Estimated bedrock elevation (m)	Difference (m)
1 W[2]	405 (stream)	380	25
2 W	930 (glacier center)	860	70
L[3]	930	890	40
3 W	820 (glacier center)	764	56
L	820	705	115
4 W	342[4] (lake)	317–346	−4–25
L	342	295–331	11–47
5 W	341[4] (lake)	331–352	−11–10
L	341	313–345	−4–28
6 W	595 (valley center)	438	157
L	595	422	173
7 W	360 (valley center)	530	−170
8 W	803 (valley center)	760	43
9 W	390 (lake)	197–330	60–193
L	390	255–358	32–165
W	390 (valley center)	220	170
L	390	230	160
10 W	521 (glacier center)	301	220
11 W	719 (glacier center)	421	292
L	719	399	320
12 W	635 (valley center)	445	190
13 W	675 (valley center)	475	200
L	675	467	208

[1] Indicated by "C" in Fig. 7 for cross-section (12).
[2] The least square fitting applied to the valley wall.
[3] The least square fitting applied to the lower step (cross-sections (9) and (11), to the lower and middle steps).
[4] Since the lake surface is frozen, the discrepancy is not necessarily a measurement error.

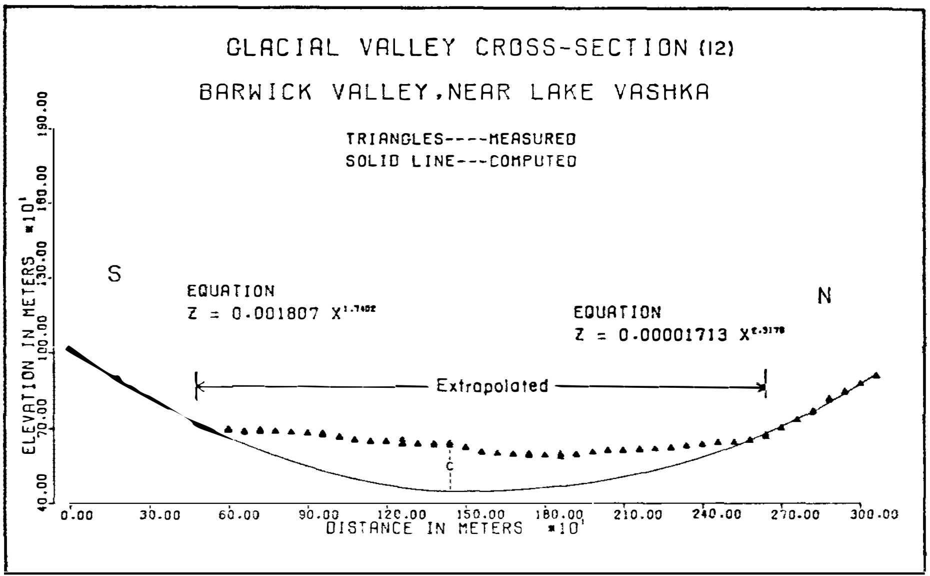

Fig. 7. An example of the computer-plotted glacial valley cross-sections.

Drilling Project (DVDP, McGINNIS and OSBY, 1977) and the detail of the vertical profile is available: however, owing to poor image quality a cross-section at this point was not measured for the estimation. Since comparison of these results obtained by the extrapolation method with data from proven, reliable methods such as drilling and seismic refraction is impossible, indirect, deductive methods will be employed to examine some of the results.

Fig. 8 indicates longitudinal profiles of the valley floor and estimated bedrock elevations of the Victoria and Barwick Valleys, and of the valley containing the Packard Glacier. In the Victoria Valley, the trend of the estimated bedrock profile from cross-sections (1) through (5) closely parallels with the profile of the valley floor and lies at an average depth of 35 m. At cross-sections (9), (10) and (11) the estimated bedrock elevations decrease in the down-valley direction, which is in agreement with the direction of the past and present glacier movements. For the valley of the Packard Glacier, the bedrock profile derived by extrapolation W is a closer approximation to the profile of the present glacier than that represented by extrapolation L. However, if the steps are of cyclic origin, the trend established by extrapolation L would be expected to produce a better result. In this instance, the steps at cross-sections (2) and (3) coincide with lithological contacts, and, consequently, may be due to lithological influences rather that to erosion.

For cross-sections (12) and (13) in the Barwick Valley, the surface elevation of Lake Vashka, 469 m above mean sea-level, may be utilized. This lake is located about 1.8 km down-valley from cross-section (12), and occupies a depression in the sediments

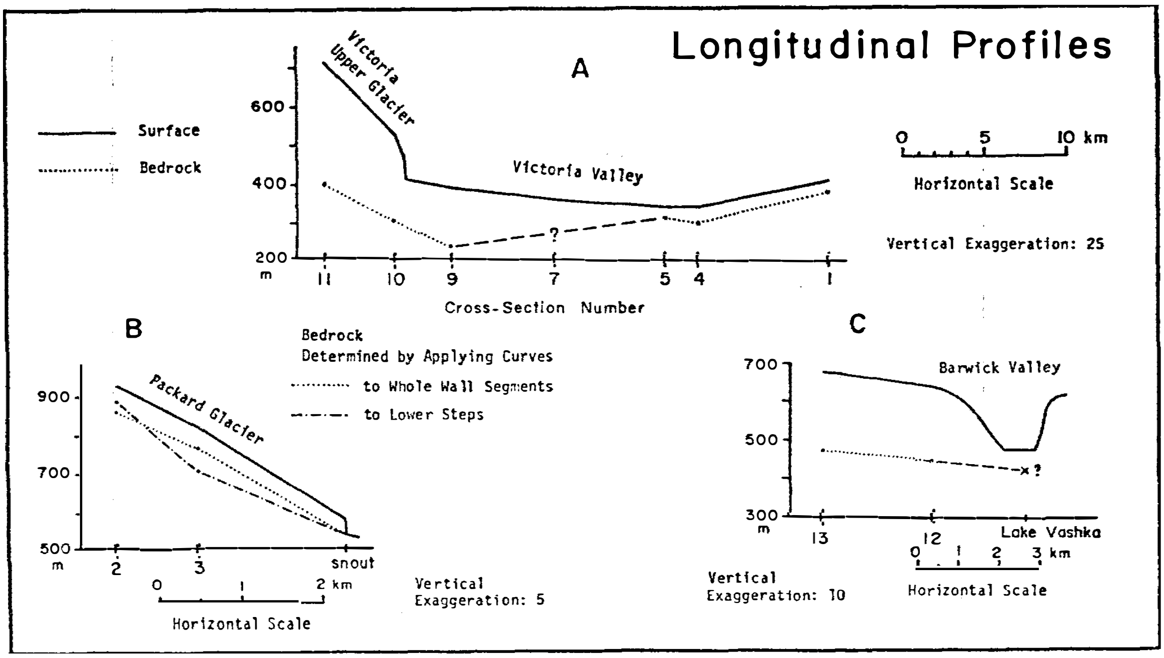

Fig. 8. Measured surface and estimated bedrock profiles of the Victoria and Barwick Valleys, and the valley containing the Packard Glacier.

nearly 150 m lower than the surrounding surface of the valley floor. Bedrock in the vicinity of Lake Vashka, therefore, lies at an elevation below 469 m and the sediment thickness is more than 150 m. Although the glacial valley floor is often irregular (KING, 1970), in the absence of other data suggesting irregularity in this vicinity such as confluences and lithological changes it is probably reasonable to assume that the sediment thickness at cross-sections (12) and (13) is comparable to that in the vicinity of the lake. They may even be considerably thicker, because of extensive terminal moraines deposited during the Vida and Packard glaciations. Consequently, the estimated sediment thicknesses of 190 m and 208 m obtained by the extrapolation method for cross-sections (12) and (13), respectively, appear very reasonable values. From Fig. 8 C the trend of the estimated bedrock profile is seen to correlate with the direction of past glacier movements and with the trend of the present valley floor.

If the structure of a uniform rock unit can be defined with reasonable accuracy, the bedrock elevation may be deduced and the sediment thickness estimated. Since the Ferrar Dolerite sill-a has a relatively uniform structure, the results for cross-section (6) may be analyzed utilizing this sill-a structure. Fig. 9 shows a detailed configuration of the Bull Pass in the vicinity of cross-section (6) with sill-a contacts indicated. The Ferrar Dolerite sill-a is a uniform sheet of 420 m thick, dipping to the southwest at an angle of 3 degrees (ALLEN and GIBSON, 1962). In order to elucidate the structure of sill-a in the vicinity of cross-section (6), a profile from point A to B (profile AB, see

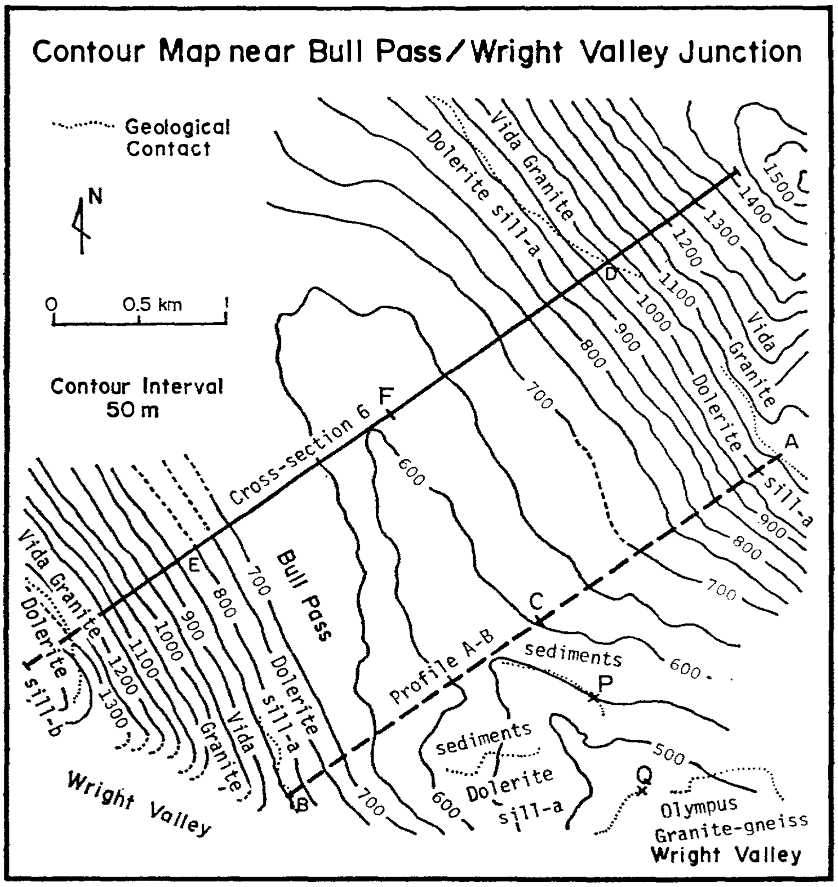

Fig. 9.

Fig. 9) whose orientation is parallel to cross-section (6) will be discussed first. Along this profile, the upper and basal contacts of sill-a and sill-a/sediment contact are known. By assuming a similar structure for cross-section (6), sediment thickness estimates from profile AB may be used to estimate the bedrock elevation at cross-section (6).

The orientation of profile AB is nearly southwest-northeast, similar to the direction of the dip for sill-a. The elevation of the upper contact points A and B (Vida Granite/sill-a) are about 1050 m and 850 m respectively. With a distance of 3400 m and the height difference of 200 m between these two points, an inclination of 3.4 degrees is obtained. This value is very close to the 3 degrees reported by ALLEN and GIBSON (1962). The elevation of the basal contact (sill-a/Olympus Granite-gneiss) at the valley center is about 480 m (indicated by Q in Fig. 9). Point P in Fig. 9 indicates the contact between sediments and sill-a, and occurs at an elevation of about 550 m. This is the bedrock (sill-a) elevation at the valley center along profile AB. Profile AB is illustrated in Fig. 10, along with the elevations of the bedrock and the basal contact of sill-a. Since sill-a is a uniform sheet, the upper surface of sill-a may be assumed

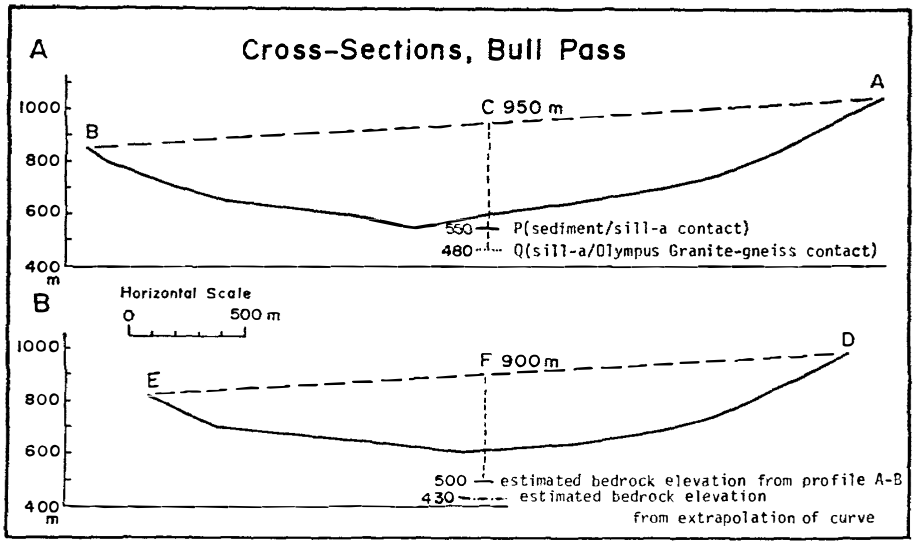

Fig. 10.

relatively flat. Thus, an estimated elevation of 950 m for the imaginary upper contact (Vida Granite/sill-a) at the valley center can be deduced by the linear interpolation between points A and B (indicated by C in Figs. 9 and 10 A). Subtraction of the basal contact elevation (480 m) from the imaginary upper contact elevation (950 m) would yield an apparent thickness of 470 m for sill-a. The true thickness would be slightly less, which is very realistic as compared with the value of 420 m given by Allen and Gibson. Therefore, the structure of sill-a along profile AB elucidated by the sill-a contacts appears correct. Considering the bedrock elevation of 550 m, then, it is probably safe to assume the amount of the vertical erosion of sill-a to be on the order of 400 m in the vicinity of profile AB.

It is now possible to construct the structure of the Ferrar Dolerite sill-a along cross-section (6) and to estimate the bedrock elevation and the sediment thickness from that structure. Along cross-section (6), only one sill-contact (Vida Granite/sill-a, therefore, an upper contact) can be recognized on the photo (point D in Fig. 9). Assuming the structure of sill-a is similar to profile AB (dip of 3.4 degrees to the southwest) and using the elevation of the upper contact of sill-a (point D, 1000 m), an elevation of about 900 m can be obtained for the imaginary upper contact of sill-a at the valley center along cross-section (6) (indicated by F in Figs. 9 and 10). Further assuming that comparable thickness (400 m) of sill-a was eroded along cross-section (6), a bedrock elevation of about 500 m can be estimated: hence the sediment thickness of about 100 m. On the other hand, bedrock elevation estimated by extrapolation of the curve is about 430 m, giving the sediment thickness of 170 m. The discrepancy of 70 m is acceptable for the methodologies employed.

The depth of Lake Vida has been measured by bore hole (CALKIN and BULL, 1967) and seismic refraction (CLARK, 1972). A hole was augered 1 km from the east end of the lake, which is close to cross-section (4), and the depth was found to be 11.5 m. Seismic measurements indicated that it was 38–40 m (no location indicated). The results of DVDP project indicate that the bedrock elevation at the northwest corner of the lake is about 329 m (KURASAWA *et al.*, 1974). These values are conformable with those estimated by extrapolation methods at cross-sections (4) and (5). Although the results for Lake Vida may be inconclusive because of the chance for errors of equal magnitude, overall, the estimates of sediment thickness (also glacier thickness and lake depth) obtained from the equations are satisfactory.

5. Summary and Conclusions

Thirteen cross-sections of glacial valleys in the Victoria Valley system, Antarctica, were morphologically analyzed utilizing the model $Z=aX^b$. The values obtained for the exponent "b" indicate that the morphology of glacial valley cross-sections in this area varies widely, ranging from those approximated by straight lines to quintic parabolas.

There is a distinctive morphological difference, however, between those approximated by semi-cubic to true parabolas and those by profiles with exponent values larger than 2.25. Two possible interpretations of processes responsible for these differences have been presented: glacial erosion and salt weathering. Profiles with exponent values of from 1.5–2.0 appear to represent the most efficient form for the transport of constant volumes of glacier ice and, therefore, an equilibrium between glacial erosion and morphological development. Most profiles with exponents greater than 2.25 were interpreted as representing a form developed during periods of increased glacial erosion resulting from greater volumes of ice flow. In areas subjected to salt weathering processes, those profiles approximated by exponent values of greater than 2.25 could be interpreted as representing rectilinear slopes with back-weathered free faces on top of them, while exponent values of approximately 1.0 represent rectilinear slopes without free face. Possibly, only those profiles approximated by semi-cubic to true parabolas are a result of the original glacial erosion processes.

Bedrock elevations beneath the valley floors were estimated by extrapolating the mathematically generated model curves. Sediment thickness was computed by taking the differences between the surface and estimated bedrock elevations. Although direct comparison of the results with ground surveys could not be made due to the lack of data for the Antarctic region, indirect analyses based on topography and geological structures demonstrate that these estimates are reasonably correct. In general, the results of this study indicate that extrapolation of curves generated by the model $Z=aX^b$ can yield good approximations of the sediment thickness in glacial valleys when appropriate segments of the valley cross-section are utilized.

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