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THE AGE OF THE SPOKANE GLACIATION.

By J. Harlen Bretz.

O.P.

ART. XXVIII.—*The Age of the Spokane Glaciation; by* J HARLEN BRETZ.

The northern part of the Columbia basalt plateau in Washington has been glaciated at least twice. During both glaciations the drainage from the southern margin of the ice sheet was deflected southward across the plateau. During the earlier or Spokane glaciation the volume of the waters was very great and the plateau's southward slope was severely scoured along dozens of huge channels.[1] During the later or Wisconsin glaciation, the volume of escaping waters appears to have been far less. Due to this lesser volume and the failure of the later ice sheet to reach as far as the earlier, only two of the older glacial drainage ways were used.

Because of the nearly horizontal position of the basalt sheets over most of the plateau and the prevailing columnar structure, the high-gradient glacial streams produced almost vertically walled channels, many of them canyons in their proportions. The uniformity in the character of the flows and the nearly uniform southward slope of about 25 feet to the mile over the whole area determined uniformity in this feature of nearly vertical cliffs throughout the area affected.

Since the glacial rivers ceased to flow, these great channels have carried very insignificant streams, most of them intermittent affairs which flow only a few months in the year. Great numbers of lakes and ponds still exist on the irregularly eroded floors, unfilled and undrained by subsequent stream action. The principal change in the abandoned waterways has been the breaking down of the steep cliffs and the accumulation of talus at their bases. The prismatic structure of the basalt provides an abundance of vertical joints along which the rock breaks. The cliff faces thus remain nearly vertical during their retreat. They decrease in height by burial of the lower portions as the talus mounts.

The fallen material is chiefly frost-riven during the winters. Of under-cutting, there is none. Vegetation on cliff faces is a negligible factor. Chemical decomposition is occurring far more slowly than mechanical disintegration. The only additional factor of importance in disruption of the basalt is unequal heating and cooling.

The climate of the plateau today is semi-arid, the rainfall ranging from about 10 inches annually in the southwest to 20 inches in the northeast. Seasonal and annual temperature ranges do not vary much over the region. The presence of many minor water courses in the mature topography of the loess-covered portions of the plateau indicates a former heavier precipitation but their spacing and degree of development show no more noteworthy climatic differences throughout the area than now exist. The rate of retreat of the cliffs therefore has been approximately the same throughout the area during the same time.

There have been, of course, climatic fluctuations affecting the area as a whole since the development of each group of channels. But, so far as the physiographic record goes, such changes have not introduced different dominant factors in the destruction of the cliffs. Insolation and frost action have remained in control. The only effect of consequence has been to change the rate of wastage of the vertical faces of columnar basalt. The cliffs of the older channels have wasted during an interglacial epoch, a glacial epoch (the Wisconsin) and post-glacial time. The cliffs left by the drainage of the later epoch have broken down only during post-glacial time. The rate of wastage of the older cliffs therefore has varied at different times. Since, however, there is no way of determining the changes in rate, this item is ignored in the solution of the problem considered in this paper. It probably would make but little difference with the result.

It seems safe, therefore, to assume that that portion of the plateau which bears the Pleistocene river courses has not had noteworthy climatic contrasts determined by differences in latitude, altitude or proximity to bounding highlands since these rivers flowed.

There are thousands of miles of cliffs formed during the earlier epoch and hundreds of miles of cliffs formed or cleared of talus deposits during the later epoch. The talus in the channels abandoned since the Spokane epoch stands uniformly about three fourths of the total height of the original cliffs; that in the channels used during the

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[1] The Channeled Scablands of the Columbia Plateau, J Harlen Bretz, Jour. Geol., vol. 31, pp. 617-649, 1923.

Wisconsin epoch stands uniformly about half the total height of the original cliffs. The angle of repose in the talus piles lies between 30 and 35 degrees. The post-Wisconsin talus is 35 degrees; the post-Spokane in some places is fully as steep, in others it is nearer 30 degrees.

Among the cliffs of each group, there are exceptions to the ratios used in the following solution. But they are few and in most cases seem adequately explained by exceptional local conditions.[2]

The problem may be stated as follows.

Given:—(1) A region with nearly horizontal strata, uniformly possessing prismatic jointing, twice during the Pleistocene crossed by huge, short-lived, high-gradient rivers which eroded nearly vertically walled channels and canyons;

(2) the retreat of the cliffs of these waterways, with maintenance of nearly vertical faces, and accumulation of talus at their bases as the only change of consequence in them since their formation;

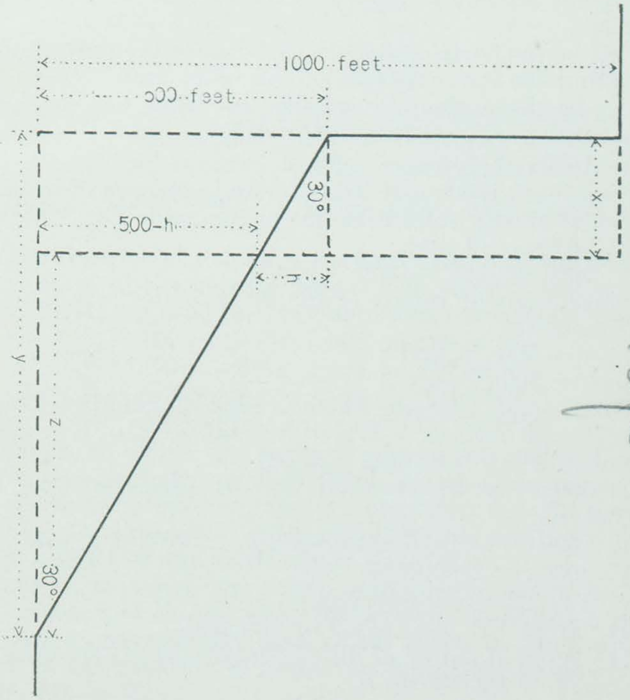
(3) the channels active during each of the two epochs identified by (a) the field evidence of the glaciated areas, and (b) the greater accumulation of talus in the older channels;

(4) the talus in the older channels three fourths the height of the original cliffs, that in the later channels half the height of the original cliffs.

To find;—the relative lapse of time since each glaciation.

The solution is based wholly on the ratio of height of talus to height of cliff. To make a concrete problem, a vertical cliff originally 1000 feet high is taken, and talus fills ⅛, ¼, ⅜, ½, ⅝, ¾ and ⅞ of this original height are assumed. Two factors whose numerical values are

sought, enter into the problem; (1) the amount of material in the talus for each stage, and (2) the average height of the cliff face during the time consumed for each stage. This time will vary directly as the volume eroded and inversely as the exposed average face.



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Numerical solutions were obtained for the seven different fills for three cases.[3]

Case A—Angle of repose 30 degrees, cut and fill of equal density;

Case B—Angle of repose 35 degrees, cut and fill of equal density;

Case C—Angle of repose 35 degrees, fill 60 percent as dense as cut.

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[2] In some places the original structure of the basalt varies from the prevailing monotonous columnar jointing. Ash beds, scoriaceous phases, ellipsoidal structures, prominent platiness in the columns, unusual size of columns; all are variant structures. Subsequent stream work in a few places has removed some of the talus, subsequent aggradation of channel floors in some places makes the apparent ratio of talus height to cliff height greater than the actual, windblown dust and sand in one tract (Drumheller Channels, south of Moses Lake) has added considerably to the talus accumulation, and steeply tilted flows in another place (lower Grand Coulee) have apparently determined unusually rapid growth of talus. All these variants were considered during the field study. The total mileage of cliffs departing from the ratios used is so small that the writer believes the method of attack and the conclusion here reached as to relative ages not to be invalidated by their existence.

[3] I am greatly indebted to Professor O. C. Clifford, of Armour Institute of Technology, who has proposed the assumptions on which the time ratios are calculated, formulated the mathematical procedure and made the computations here presented.

To show the method used, case A is worked out in detail for a fill half way up on the cliff. In figure 1, let the original height of the cliff be 1000 feet, and let *h* be as shown,

x be the distance the cliff has retreated when the talus has accumulated to half the original height of the cliff,

y be the horizontal distance between the present cliff face and the lower margin of the talus, and

z be the horizontal distance the talus has extended beyond the original foot of the cliff.

(1) $1000x$ therefore $= 500y/2$

Since both $1000x$ and $500y/2$ contain an area of overlap which is mostly solid rock but partly talus fill, this area may be ignored and

(2) $500x + xh/2 = (500 - h)z/2$

Since angle of repose of the fill is 30 degrees, then by trigonometry

(3) $y = 500\sqrt{3}$, and

(4) $z = 500\sqrt{3} - x$

From small triangle which is part of the eroded area

(5) $\tan 30$ degrees $= h/x$, or $h = \tan 30^\circ x$, or $h = x/\sqrt{3}$

Substituting for h and z in (2)

(6) $500x + x^2/2\sqrt{3} = (500\sqrt{3} - x)\ (500 - x/\sqrt{3})\ /2$

Clearing

(7) $1000x + x^2/2\sqrt{3} = 250000\sqrt{3} - 1000x + x^2\sqrt{3}$

(8) $2000x = 250000\sqrt{3}$

(9) $x = 125\sqrt{3}$ or 216 feet.

(10) from (5), $h = x/\sqrt{3}$ or 125 feet

(11) Area of cut or of fill$=500(125\sqrt{3}) + 125\ (125\sqrt{3})\ /2$ or 122000 sq. ft.

Since we are here considering only the part deposited in front of the original cliff face and are ignoring the overlap area (see (1)), the average exposure or height of the cliff face for the half height stage of talus growth is $500 + h/2$ or 563 feet.[4]

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[4] Professor Clifford found that the contact between talus and buried cliff is a true parabola. By calculus he obtains the area left under the curve, subtracts this from the whole rectangle to get the area of cut, and divides this area by the distance back from the original face to get the average exposed surface. Values of areas cut and of exposed surfaces thus obtained differ from those in the trigonometric solution herewith presented but the compound ratios yield the same proportional relation that is obtained by trigonometry.

Case A was solved for the heights shown in Table I

TABLE I

Fill	x	Area	Mean Exposure
$\frac{1}{8} = 125'$	13.5′	12000 sq. ft.	879′
$\frac{1}{4} = 250'$	54′	42000	766′
$\frac{3}{8} = 375'$	121′	80000	660′
$\frac{1}{2} = 500'$	216′	122000	563′
$\frac{5}{8} = 625'$	337′	159000	473′
$\frac{3}{4} = 750'$	486′	190000	390′
$\frac{7}{8} = 875'$	680′	219000	322′

As already stated, the time involved in attainment of any stage of talus growth will vary directly as the volume eroded and inversely as the exposed average face.

$$t500 : t125 = \left\{ \begin{matrix} 122000 : 12000 \\ 879 : 563 \end{matrix} \right\} = 108000 : 6760 = 16 : 1 = 500^2 : 125^2$$

Thus the time of one fill is to the time of another fill as the squares of the heights filled. The relative values of t for the stages used in this computation are as follows:

$\frac{1}{8} = 125' = 1t$
$\frac{1}{4} = 250' = 4t$
$\frac{3}{8} = 375' = 9t$
$\frac{1}{2} = 500' = 16t$
$\frac{5}{8} = 625' = 25t$
$\frac{3}{4} = 750' = 36t$
$\frac{7}{8} = 875' = 49t$
$^8/_8 = 1000' = 64t$

Case B, in which the angle of repose was taken to be 35 degrees and the cut and fill to be of equal density, has the same solution as Case A except that tan 35° takes the place of tan 30°. Table II contains solutions for three heights of the talus under Case B.

Case C, in which the angle of repose is taken to be 35 degrees and the fill to be 60 percent as dense as the cut, has to have 60/100 area of fill taken to equal area of cut in the equation of areas for finding the value of x. Thus, for $\frac{1}{2}$ fill

$$500x + xh/2 = 60/100\ (500/\tan.\ 35^\circ - x)\ (500 - h)/2$$

This was computed for the same three heights of talus used in Case B and the values of x, area and mean exposure obtained are also shown in table II.

TABLE II

Fill	x			Area			Mean Exposure		
	A	B	C	A	B	C	A	B	C
					in sq. ft.				
$\frac{1}{4} = 250'$	54′	44.6′	38.9′	42000	35000	25000	766′	766′	760′
$\frac{1}{2} = 500'$	216′	178.4′	155.4′	122000	101000	72000	563′	563′	546′
$\frac{3}{4} = 750'$	680′	401.4′	350.1′	190000	157000	119000	390′	390′	365′

In cases B and C the solution of the compound ratio for times shows that for each case the results come out as in Case A. *The times of fill are directly proportional to the squares of the heights filled.*

Having obtained the same results for different angles of repose and for different densities of fills, it seems fair to assume that, though both enter into the distance cut back, these factors do not vary with the ratios obtained, whatever their values may be. The field evidence indicates that their values are constant throughout the area.

The application of the rule obtained to the physiographic problem of this paper gives us a lapse of time since the Spokane glaciation (36t) two and a fourth times as great as that since the Wisconsin glaciation (16t). Assuming that the Wisconsin glaciation of the northern part of the Columbia plateau is late Wisconsin, as the very strong morainic expression of its drift sheet suggests, this ratio would make the Spokane glaciation equivalent to either the Iowan or early Wisconsin. The record of prodigious quantities of water discharged at the maximum of the Spokane glaciation is very unlike the record of sluggish Iowan ablation in the Mississippi Valley. On the other hand, the scanty till deposits and total lack of terminal moraine on the area covered by the Spokane ice is very unlike the early Wisconsin drift. If, and when, a definite ratio for early and late Wisconsin and post-Wisconsin time is obtained in the Mississippi Valley, the Spokane glaciation may be correlated definitely in the accepted scheme.

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