CROSBY REPORT TELLS HISTORY OF EARLY AGES

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to their imperfect fluidity, these lavas did not, as a rule, extend far from the vents, which were chiefly confined to the great fissure, the characteristic, also, of subordinate and branch fissures. From this period date the most, at least, of the old, eroded rhyolite volcanoes and plugs scattered over the plateau for 50 to 100 miles east of the Cascades and protruding as steptoes through the subsequent great flows of basalt. The more important only of these steptoes have been named and mapped, including: Newberry Crater (Paulina Mountains), Pine Mountain, Powell Butte, Horse Rdge, Smith's Rock, Gray's Butte, Haystack Butte, Hampton Butte, Glass Buttes, Wagontire mountain, Horse Mountain, Juniper Mountain, Coyote Hills, etc.

Deep Deposits Formed.

Although the relatively acid and sluggish lavas of this period did not spread far from the vents, and contributed but little, and that little very locally and irregularly, to the upbuilding of the general surface of the plateau, they have, nevertheless, by virtue of their hardness and durability, played an important role as drainage controls, or natural dams retarding and regulating the discharge of rivers. In fact, it would be difficult to find a more striking or pertinent illustration than is presented in the old stock or mass of rhyolite to which we owe Benham Falls, the most important and most beautiful cascade of this shooting river, a natural dam site, and above it a natural reservoir site as well.

The sediments of this period, consisting of alternate beds of ash, lapilli and lava, are known to geologists as the Clarno formation of the John Day valley and attain here a thickness of about 400 feet.

Following the Clarno formation, in Miocene or mid-Tertiary time, volcanism still prevailed, but the lavas were, predominantly, of more basic type—basaltic rather than andisitic or rhyolitic. The eruptions were for a long time of a highly explosive character, yielding in what is now the John Day valley and, presumably also, in the region traversed by the Deschutes river, a vast thickness, possibly several thousand feet, of stratified ash or tuff, constituting the John Day series. This was followed, still in the Miocene period, by gigantic fissure eruptions of basalt—the many successive thick flows aggregating 2000 to, possibly, 4000 feet in thickness. This is the great Columbia lava formation, which, naturally, attains its maximum development in the valley of the Columbia, and is, presumably comparatively thin where it mantles the crest of the Blue mountains. The numerous dikes of basalt cutting through the underlying formations mark in part the channels through which the lava has come up from the interior of the earth.

Following this great outpouring of lava, the most extensive in geologic history, and almost completely filling the broad and deep valleys of the Columbia and Snake rivers, in late Miocene time, further explosive eruptions spreading over the lava plateau of Central Oregon hundreds of feet of ash, now consolidated to tuff and constituting the Mascall formation.

Unconformably above the Mascall beds was deposited in Pliocene or late Tertiary time, 100 feet, more or less of water-worn gravel and overlying rhyolite tuff and lava. This is the Rattlesnake series of Merriam and of its occurrence in the Benham falls district there can be little doubt.

Great Valleys Filled.

Whether the stupendous eruptions of the Cascade volvanoes result in any part of the district in lava, cinders or ashes (dust and lapilli) depends upon the distance from the vent. Cinders pile up around the vent in steep cones. The ashes are spread over areas proportional to their fineness and to the force and shift of the wind, but attain notable thickness only within moderate distances, possibly scores, but not hundreds, of miles from the vent. The lava or molten rock, if issuing in sufficient volume, as in the great fissure eruptions, may, however—especially if the topography or surface gradient be favorable—spread over truly vast areas, even many thousands of square miles.

The throw of the great Cascade fault being up to the west and down to the east, the normal movement of the extruded lava has been, to a large extent, upstream, or, more exactly, into a closed basin, accumulating like water in a reservoir and attaining its maximum thickness or depth in the lowest parts of the original valleys. It was thus that in Miocene time the great valleys of the Columbia on the north and the Snake on the south were filled to overflowing and to a depth at their lower ends of fully 4000 feet.

Some conception of the length of the peologic periods is afforded by the prodigious amount of erosion required to reopen the lava-flooded canyons and then, after they had been filled by the Mascall and Rattlesnake formations, to open them again and to their present profound depths.

Glaciers Played Part.

The principal episode of the earlier Quaternary or Pleistocene time was for this region, as for the greater part of the continent, the culmination of glaciation. There is little or no evidence of general glaciation or of an ice sheet covering the upper part even of the Deschutes valley. The valley glaciers, remnants of which now linger on the slopes and in the craters of the higher Cascade volcanoes, including the Sisters and Broken Top, appear never to have extended far down the eastern slope of the range. It is true that a large proportion of the lakes and lakelets dotting the lower eastern slope of the range down to about an elevation of 4400, and to still lower levels farther north, are due to morainal dams. To this class belong Odell and Crescent lakes and many minor examples. Characteristically, they occupy deep and narrow valleys on the rock walls of which the lateral and terminal moraines are readily traced to heights, in some case of 1000 feet or more above the present water level. Many of the lakelets, also, occupy glacial cirques or rock-rimmed basins directly due to the erosive action of the valley glaciers. Equally conclusive evidence of former glacial extension is afforded by the distribution of the bowlder clay or ground moraine. As this would be the case but for the heavy mantle of post-glacial pumice dust and lapilli covering the entire region and obscuring the drift and other surface formations. More convincing, under the circumstances, is the testimony of the washed or modified drift, sand and gravel, especially as regards its topographic influence. A particularly clear example is afforded by the Twin lakes, southeast of Crane prairie, and 10 miles east of the Cascade crest. The only satisfactory explanation of the deep depressions occupied by these lakelets is the subsequent melting of masses of ice buried in modified drift. From these witnesses we learn that the Cascade glacier or ice cap extended at least this far to the eastward.

On the east side of the Deschutes valley we find evidence that Newberry crater was occupied by ice and that from it a glacier advanced several miles down the valley of Paulina creek and to lesser distances down other radiating valleys.

Heat Predominated.

We must conclude, then, that glaciation has not played an important role in the development of the Deschutes valley, not even of this most elevated section of it. If further proof were wanted it would be found in a consideration of the cones of cinder and lapilli dotting the face of the country and dating from the earliest Quaternary time down to the human period and almost to the present. That some of the cones antedate the period of maximum glacial development is practically certain, but so far as noted they have not suffered appreciable, or at least not important, glacial erosion; and yet it would be difficult to find a formation more susceptible to rapid erosion. In this field the two antagonistic agencies, volcanism and glaciation, or fire and frost, have been active for an indefinitely long period, the volcano building up and the glacier wearing down the face of the land. But to the present the forces of fire have greatly predominated over those of frost; though it appears not impossible that with the gradual extinction of the volcanic energy, now so plainly in progress, the glacier may yet be in the ascendant, at least this might be anticipated but for the obvious fact that glaciation is also on the wane.

The chief incidents or phases of the expiring volcanism embrace the formation of the widespread and thick mantle of pumiceus lapilli or comminuted pumice, which, like a snowfall, covers the face of the country, and the building of the latest and still ueroded basaltic flows and cones, the series ending, for the time being, with Lava butte and the flow spreading from its base. This flow turned the Deschutes river over the rhyolite ridge, thus inaugurating Benham falls and permitting the silting up of the broad, shallow basin above the falls, which became thereby an ideal reservoir floor. Contemporaneously, too, with the declining volcanism and glaciation has been the final canyon cutting accomplished by the Deschutes and its principal tributaries north of Benham falls and, especially, north of Bend.

DESCRIPTIVE GEOLOGY OF THE BENHAM FALLS DISTRICT

The Rhyolite Dike

This appears to be, on the whole, the best geological designation of the bold rock ridge standing athwart the Deschutes valley in the latitude of Benham Falls, and to which the river owes this most impressive of all its chutes. The ridge ranges from 100 to possibly 200 feet in elevation above the river; varies in width, roughly, from one-fourth to three-fourths of a mile; and has been traced approximately two miles, from the vicinity of the west side road to the point 2,000 feet east of the head of the falls where the rhyolite is seen to pass under the Lava Butte flow of basalt. So far, it is, in its relation to the valley, a great natural dam, extending from a point on the western slope well above any contemplated flow line across more than half the probable breadth of the valley below that line.

The river first encounters the rhyolite near the western end of the ridge; and, promptly turning to the eastward, closely follows its southern or upstream border to the margin of the new lava. Here, just above the abandoned bridge, the stream turns abruptly to the northward, flowing between the rhyolite on the left and the new lava on the right for half a mile to the apex of the marked reentrant angle of the ridge, where its crest descends to the river level and the river escapes across the ridge, which is bounded on the north by a zone of basalt tuff representing, no doubt, the old Columbia basalt.

The rhyolite is throughout a massive and wonderfully homogeneous, hard, compact and resistant igneous formation, which may, probably, best be regarded as the plug or neck of an ancient volcano which has long since been removed by erosion. Plainly enough, the rhyolite is older than both the newer and the older basalt flows by which it is environed and above which it rises as a genuine steptoe. Concerning the course and extent of the rhyolite beyond the east end of the ridge, or the line where it disappears beneath the Lava Butte flow of basalt we can only conjecture; but the probabilities will be discussed in a later section.

The Columbia basalt is the great lava formation of the Columbia plateau, covering continuously and to a vast thickness many thousands and scores of thousands of square miles. From the open fissures and craters of the Cascades the highly fluid molten rock was poured out flow after flow, filling the broad valley of the Columbia and covering to lesser depths all but the higher parts of the broad summit of the Blue Mountains, layers of volcanic dust and lapilli alternating to some extent with the massive sheets of columnar basalt.

Although formed back in Miocene time, the Columbia basalt shows, outside of the canyons, where it has felt the powerful erosive action of the rapid streams, but little evidence of erosion. Where not covered by soil it is still hard and black and exhibits the gently undulating or wavy surface of the original flow, as well as the prismatic jointing and pressure ridges. In fact, it appears probable that where soil is present it has been derived chiefly from volcanic dust and lapilli, and not from the solid lava.

West Side Basalt Newer

In the Benham Falls district, or, more generally, south of Bend, above which the river and the Cascade range are slightly divergent northward, the basalt of the opposite slopes of the valley, the east slope and the west slope, is more or less distinctly contrasted, especially as regards indications of age. The basalt of the west slope has, of course, been derived from the Cascade range; while that of the east slope may most reasonably be referred to the gigantic Newberry Crater and its subsidiary vents within a radius of ten to fifteen miles, which have, no doubt, been more recently active than the neighboring section of the Cascade range. At any rate, the west slope basalt is, at all points south of Bend, decidedly more weathered and older-looking than that of the east slope.

Owing to the more weathered and decomposed aspect of the west side basalt, its outcrops are fewer and less bold. And since it is the older flow we may assume that it extends eastward somewhat indefinitely, or without regard to the western limits of the newer east side flow. In other words, it appears probable that the eastern overlaps the western flow to some extent. And it is a natural suggestion that evidence of such overlap may be afforded by some of the boring of the Benham Falls area. The new boring (1) at Miner's Cabin or Damsite "A" is of special interest in this connection, since it shows, from the surface down, hard, sound basalt for the first 65 feet (eastern and newer flow) followed by brown to red, oxidized and weathered basalt (western and older flow). A similar, in fact an almost identical, record is afforded by Boring No. 5 of the original Minor's Cabin series, and, again, by the boring of the Brooks-Scanlon Lumber Company (8), on the east side road, a little more than two miles south-southeast of Minor's Cabin. Here, also, the drill, after passing through over 60 feet of the hard and comparatively fresh basalt of the eastern flow penetrated the oxidized and rotten basalt of the western flow, and ended in it at a depth of 100 feet.

Rhyolite Ridge Volcanic Neck

We are, thus, justified in concluding that the old, decayed western flow of basalt probably extends at least this far to the eastward; and this is far enough to insure its underlying practically the entire area of the proposed reservoir, save where it may have been removed by the river in the development of its channel. But for this possible exception, we might, then, assume for the reservoir a continuous subfloor of the older and, probably, more impervious basalt.

Whether the flood of basalt from either side ever submerged the transverse rhyolite ridge, is very doubtful. On the west side of the river, north of Benham Falls rhyolite tuff is seen to be capped with basalt. But the rhyolite of the Benham Falls ridge, with its vertical flow structure, must be regarded as a true volcanic neck. The basalt falls far short of covering it now; and since the sharp ridge of rhyolite must have lost elevation by erosion much more rapidly than the broad plain of basalt, we can only conclude that the floods of basalt surged around the rhyolite relief but did not overtop it.

Lava Tunnels

No feature of the basalt is of greater scientific interest or practical importance than the lava tunnel. This exists where after the main part of a flow has cooled and solidified, cracking of the crust allows the still molten residuum to escape, and the tunnel, or a vacant space of some form, naturally results. Whether or not water or some other constituent of the basalt tending to promote its liquidity, determines the location or formation of a tunnel is an unsolved problem; but to the writer it appears more probable that the principal factors are differential cooling, gradient and velocity.

The incandescent lava is cooled and stiffened by contact with the cool earth below and the cool air above. Between the two crusts thus determined it flows most rapidly in the lines of highest gradient (most rapid descent). Where the gradient is low and the movement sluggish, as on upland areas, the lava first solidifies through the entire thickness of the flow; and the more fluid, rapidly moving portions are confined more and more to the valleys or topographic lines of steepest descent. The hottest, most fluid and most rapidly flowing lava will be that freshest from the crater or fissure and the subterranean sources, and when the latter finally fail, the lava within the tunnel drains away and leaves the tunnel empty.

Lava Tunnel Important

The normal topographic relations of the lava tunnel are of special practical importance in connection with this study because of its tendency to follow the axis of the valley as it existed at the time of the eruption and the outpouring of the lava, and also because there exists in the Deschutes valley above Benham Falls, and there in the proposed reservoir area, a magnificent example of the lava tunnel.

The entrance to the tunnel is on the east side of the valley, about one and one-half miles southeast of the main road at a point one mile south of Lava Butte; and probably in Section 35 of Tp. 19 S., R. 11 E. For the discovery of the tunnel and for access to its interior we are indebted to a local fall of the roof, due, perhaps, to the passage of earthquake vibrations.

The general course of the tunnel is northwest-southeast; but it is far from straight, winding much as a surface stream of water might in traversing the same territory. It is said to have been traversed for a mile southeasterly from the entrance; and in company with Assistant Engineer Irving B. Crosby I traversed it to a point nearly one and a fourth miles northwesterly from the entrance.

Erosion Slight.

The transverse dimensions of the tunnel are fairly uniform—say 20 to 30 feet wide and 15 to 25 feet high, disregarding extremes; and the roof ranges from 20 to 40 feet in thickness. The walls are surprisingly smooth, except for the minor drip forms of lava; and the characteristic columnar jointing or basaltic structure is conspicuous by its absence. The floor is sensibly level, save where encumbered by sand washed in through cracks in the roof or by rare falls of rock. The tunnel, however, is not level; but it has a surprisingly uniform northwesterly gradient, agreeing, approximately, with the general slope of the ground above it. Toward the inner or northwestern end of the tunnel, the said derived in part, at least, from the roof, becomes more and more abundant, and finally reaches the roof and closes the tunnel, without, however, appreciable contraction of its bore. As the sand gains in depth it appears to gain, also, in moisture, the appearance being, at the last, that the tunnel is nearing the watertable. Either this supposition is of the tunnel.

One difficulty in deriving the main part or any large part, of the tunnel, sand through the roof is the true or the damp sand conserves with great tenacity the drip water general tightness of the tunnel, the floor and lateral walls being almost absolutely tight, and the roof ditto, so far as could be seen by candle light. The sand is of very uniform character, entirely free from clay clearly of volcanic origin, and identical in character with large volumes of sand which the drill has shown to underlie the Benham Falls reservoir area. To account for its abundant presence in the lower part of the tunnel we need only assume a local collapse of the tunel roof. The tunnel is much newer than the basalt of the western slope and contemporaneous with that of the eastern slope, but older than the gorge which the river has cut in the newer and older basalts, and older still than the volcanic and organic sediments deposited in this gorge and over the general floor of the Benham Falls basin and the prospective reservoir.

Tunnel's Course Sought

We are, naturally, specially concerned to discover, if possible, the probable course of the lava tunnel beneath the reservoir area and its relation to the buried gorge of the Deschutes river. The safest assumption is that, as previously indicated, the tunnel follows the steepest and deepest line of flow of the east side basalt. This would bring it to and into the ancient gorge of the Deschutes river at or above the point where the Deschutes or that time cut through the rhyolite ridge.

That the static pressure and the high liquidity of the column of lava would maintain the discharge to the point of exhaustion, and finally leave the tunnel empty, is most probable; for the loss of heat sustained by the lava in its passage through the tunnel would be inconsiderable; and lava sufficiently fluid to enter the tunnel would be likely to complete the passage. This is the conservative view and certainly accords with the present state of the tunnel, especially with its regular form and smooth walls. It is a perfect conduit, of ample bore and well fortified against loss of heat; but becoming, as it slowly cools, an ideal channel of a subterranean river. It does not appear, however, to have been occupied, even temporarily, by a stream of water, at least not in the part now accessible, for we detected not the slightest trace or indication of stream erosion, or deposition; even the sand with which the tunnel is finally clogged having more the appearance of having been deposited by drip water than by running water.

The tunnel is not only an important contemporaneous structural feature of the great east side flow of basalt; but it is probably throughout, and not alone where the roof has fallen, a comparatively shallow feature; for this sheet of basalt has not been covered, along the probable line of the tunnel, by any later formation, save, perhaps, the floodplain deposits (silt, etc.) of the

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