origin of

Cascade Landscapes

mackin
& cary

ORIGIN

OF

CASCADE LANDSCAPES

FRONTISPIECE

Picket Range in upper Skagit area, Northern Cascade Mountains. Snowfields occupy a former ice-filled cirque. Grass is enroaching on ice-polished rock surfaces.

State of Washington
DANIEL J. EVANS, Governor
Department of Conservation
ROY MUNDY, Director

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Information Circular No. 41

ORIGIN OF CASCADE LANDSCAPES

By
J. HOOVER MACKIN and ALLEN S. CARY

STATE PRINTING PLANT, OLYMPIA, WASHINGTON
1965

For sale by Department of Conservation, Olympia, Washington.
Price, 50 cents.

FOREWORD

The Cascade Range has had an important influence on the lives of a great many people ever since man has inhabited the Northwest. The mountains were a barrier to Indian travel; they were a challenge to the westward migration of the early settlers in the area; they posed serious problems for the early railroad builders; and they still constitute an obstruction to east-west travel. A large part of the timber, mineral, and surface water resources of the State come from the Cascades. About 80 percent of the area covered by glaciers in the United States, exclusive of Alaska, is in the Cascades of Washington. This region includes some of the finest mountain scenery in the country and is a popular outdoor recreation area.

The Cascade Range is a source of economic value to many, a source of pleasure to many others, and a problem or source of irritation to some. Regardless of their reactions, many people have wondered about the origin of the mountains—How and when did the Cascades come into being, and what forces were responsible for the construction job? This report, "Origin of Cascade Landscapes," gives the answers to these questions.

The original block diagrams and text upon which this report is based were prepared in 1947 by J. Hoover Mackin and Allen S. Cary. The material was not published at that time but has been used in the interim as instructional material in geology classes at the University of Washington and in other schools. In response to continued requests for their use, the drawings and also the text were recently revised by the authors, and we in the State Division of Mines and Geology are very pleased to publish this answer to frequently asked questions about the Cascades.

The authors have studied the geology of the Cascades over a period of many years, Dr. Mackin as professor of geology at the University of Washington and, more recently, at the University of Texas, and Mr. Cary as engineering geologist in charge of investigations for the U.S. Army Corps of Engineers in Seattle.

As compared with many areas in the United States, the geology of the Cascades is complex and difficult to decipher. For example, from a vantage point on the rim of the Grand Canyon one stands at the portals of a geologic library that is unsurpassed in the orderly display of the books, in their completeness, and in the excellent condition of the text and illustrations; i.e., the fossils, the ripple marks, and the crossbedded sands. Nowhere is the work of running water more in evidence. The Canyon cuts flat-layered rocks of several contrasting types, crossed everywhere by sets of vertical joints in symmetric patterns, so that the major elements of the Canyon landscape are horizontal terraces and tablelands separated by vertical cliffs. Each cliff meets the next higher terrace in a right angle and merges into the next lower terrace through a gently decreasing slope that approaches the symmetry of a mathematical curve. In the absence of the mantle of vegetation under which the gently rolling landforms of the humid eastern United States are modeled by slow creeping of the plant-held soil, the arid Canyon country is sluiced by cloudburst runoff that is in the highest degree selective in etching out each layer and crack in the living rock, so that the Canyon landscape everywhere exhibits fine-line detail with every line crisp and sharp, and with distinctive combinations and spacings of lines related in a precise and orderly manner to the jointing and the layering. Perspective is as evident here as in a photograph looking down a railway track on the prairie.

The Canyon walls are an orderly rock record of eventful chapters of earth history through eons of geologic time, easily read by any interested person. The game of puzzling out that history yields intellectual satisfaction that enormously increases the enjoyment of the Canyon and of varied landscapes everywhere.

In the Cascade Range there is no comparable vantage point from which one can quickly grasp the essentials of the rock structure and the processes of erosion that are sculpturing the Range. All but the higher ridges and peaks are mantled by forest. Where rivers and roadcuts provide glimpses through this cover it seems that the geologic library has been through many an earthquake and fire. But several generations of geologists have straightened out most of this confusion, put the books in order, and restored many of the torn pages. This essay translates into nontechnical terms the rock record of the origin of Cascade landscapes. It is written in such a way as to provide at least an outline of the kind of evidence and reasoning on which each interpretation is based.

Marshall T. Huntting, Supervisor
Division of Mines and Geology
Olympia, Washington

December 15, 1964

CONTENTS

ILLUSTRATIONS

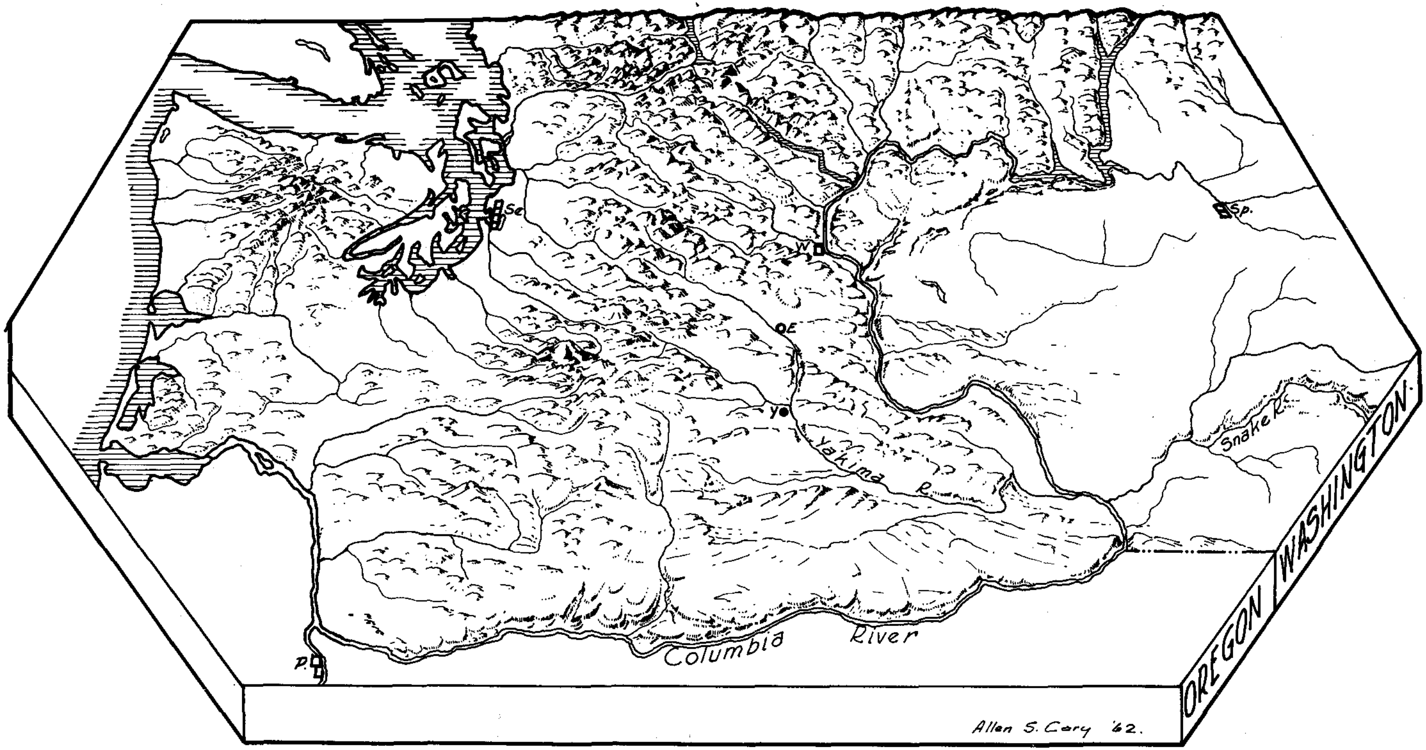


FIGURE 1.—THE CASCADE RANGE IN THE STATE OF WASHINGTON

The Range divides the State into two parts, wholly different in every geographic aspect. The crest rises from about 3,000 feet at the south, where it is cut by the Columbia Gorge, to about 10,000 feet near the Canadian border. Neither the crest nor the east or west margins are sharply defined; the overall trend is north-south, but spurs of the mountains trend northwest and southeast into adjoining lowlands. Most of the rivers of the Range show the same northwest-southeast alignment, diagonal to the trend of the Range. The Columbia River, with its two great bends, to the northwest and southeast, and its lower course directly westward across the Range, seems to be independent of all the other topographic elements. The origin of these and other major features of the present geography is developed in the accompanying block diagrams, which depict the evolution of central Washington over a period of about 60 million years. For convenience in comparing the diagrams, the locations of the following cities are shown in each: Seattle, Se; Portland, P; Spokane, Sp; Yakima, Y; and Wenatchee, W. Ellensburg, E, is shown on only two of the diagrams.

ORIGIN OF CASCADE LANDSCAPES

By J. Hoover Mackin and Allen S. Cary

THE COLUMBIA GORGE

The Gorge of the Columbia in the Cascade Range has long been, to man and a host of animals that preceded him, primarily a passageway through the mountain barrier. Every traveler between the lowlands "East of the Mountains" and the coast "West of the Mountains," whether on Indian trail, pioneer wagon road, or modern highway, is conscious of this purely utilitarian aspect of the Gorge.

The Gorge lacks the vastness and play of colors that catch the breath on the rim of the Grand Canyon, but it is, to most forest dwellers at least, far more appealing. Every bend of trail or highway opens new vistas of sombre ledges or of conifer-green slopes descending to the water's edge. Puffing trains and bright-roofed villages in apparent toy size on the opposite bank give contrast and dimension to the scene. The mood changes with hour and season and with storm and calm; whatever the mood, nearly everyone who passes through the Gorge is in some degree aware of its beauty, and leaves it with something more than he brought into it.

But for many of those who traverse it, the Gorge does something more than speed the journey and please the eye — it arouses curiosity. The first question is, How was it formed?

Myths, as of a splitting asunder of the mountains by a benevolent Great Spirit to permit a reunion of Indian lovers, used to provide answers to both the How? and the Why? of gorges like that of the Columbia, but they no longer satisfy. Centuries of this kind of thinking were ended, less than 200 years ago, by a Scottish physician who pointed out simply that, if river valleys were merely cracks in the earth's crust incidentally occupied by running water, then it would be in the highest degree unlikely that all the tributary valleys would join the trunk valley at its level, and that because the innumerable branching valleys of a river system are usually at the same level at their junctions, and because all the branches, large and small, tend to fit the valleys in which they flow, then the valleys must have been shaped by the rivers. This reasoning is now the commonplace basis for understanding river erosion landscapes everywhere. It is a part of the heritage of the average modern traveler, permitting him to invent an answer to his question that would not have occurred to the keenest thinkers of the Middle Ages: That by grinding sand and gravel along its bed, the Columbia has cut its own channel downward from the crest of the Range.

The bed-cutting process is slow by any human standards, but the fact that the Gorge is steep-walled indicates that the bed cutting was exceedingly rapid relative to the over-all rate of other geologic processes, such as landsliding, rill-washing, and the downhill creeping of soil, that tend to reduce the slopes of the valley sides. Bare ledges that rise vertically above the river mark the position of rock types so nearly immune to these valley-side erosion processes that they have been little modified by them during the whole period of canyon cutting. Each forested slope between these bastions expresses, by its declivity, the lesser resistance to erosion of the rocks in which it is sculptured. Every change in slope and every topographic detail of the Gorge walls has meaning.

The traveler who is not curious; who sees only the depth and width and length of the Gorge and neglects its fourth dimension, which is time; who is content with the Gorge as a still picture, and fails to recognize that the present scene is only one changing frame of a moving picture, the earlier frames of which can be equally vivid; who does not see, in the daily toll of mud and sand washed seaward by the river, the certainty that the walls of the Gorge must become less and less steep until the whole rugged range is reduced to faint slopes near sea level; this traveler has seen the Gorge only with his eyes, not with his mind.

An understanding of the scenery of the present Gorge in terms of past, present, and future erosional activity of the Columbia and its tributaries immediately raises another question. The river must have started to flow westward before it could begin to cut, and certainly it could not have begun by flowing <u>up</u> the east side of the Cascades. To answer the question, How did the river originally get its course across the mountain barrier? the inquisitive traveler must know more than can be learned by observation within the Gorge itself.

The lowland west of the Range, in the vicinity of Portland, is underlain largely by flows of black lava known as basalt. The individual layers are essentially horizontal, and the undulating hill-and-valley topography of the lowland is cut in them. These same flows make conspicuous lines of ledges in the Gorge walls, readily followed by the eye as they rise gradually from near sea level at the west base of the mountains to more than 3,000 feet above sea level near the center of the Range. Less readily, because they are here much crumpled and wrinkled, but none the less certainly, the flows can be traced down again almost to sea level at the east base of the Range. And the same flows, again essentially horizontal, underlie all the lowlands between the Cascades and the Rocky Mountains 100 miles to the east.

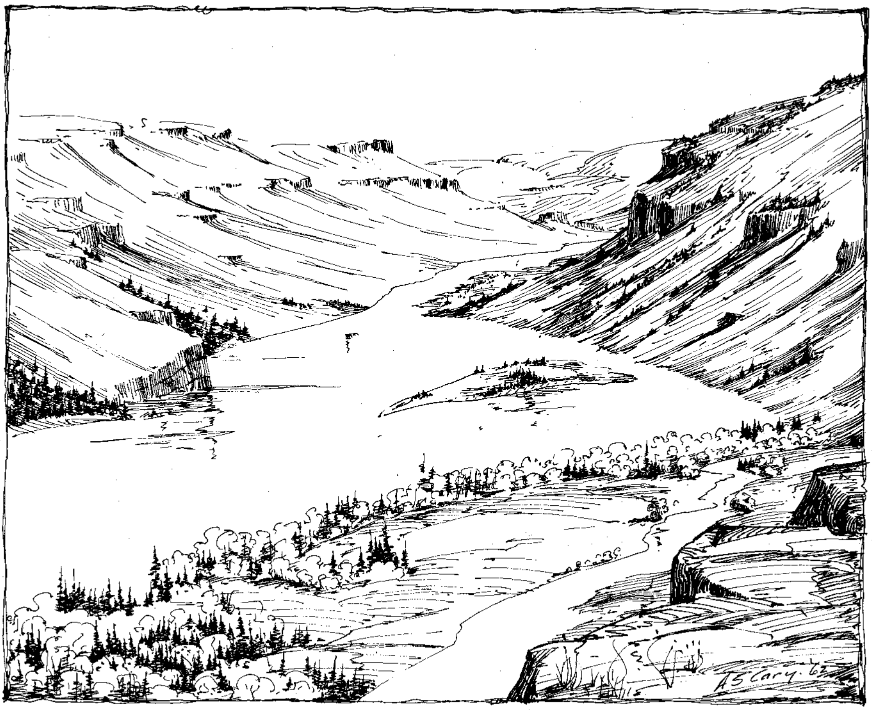


FIGURE 2.—Columbia River Gorge through the Cascade Range.

East of the Cascades, and in the Range itself, thin layers of snow-white sediment occur sandwiched between the basalt flows. Fine as flour, these sediments consist almost entirely of the microscopic shells of simple lake-living plants called diatoms. Each layer of sediment rests on one flow and is covered by the next later flow. Individual layers, clearly representing deposits formed in successive lakes, are traceable over hundreds of square miles with little change in thickness. Thus the lakes in which the diatoms lived were large and shallow, and it follows also that lava flows covered by the lakes could have had only very low original slopes. Several lines of evidence, to be considered later, indicate that the flows originated in vents east of the present Cascades, and that they spread westward across where the Range now stands. West of Portland the flows are interbedded with layers of indurated sands and muds containing marine fossils that fix the approximate position of the ocean shore line of the lava plain.

These relationships provide the inquisitive traveler with a picture of a vast lava field extending without interruption from the Rocky Mountains to the Pacific Ocean. Nowhere on the present surface of the earth is there a counterpart in size to this ancient lava field of the Northwest. The Cascade Range must have formed by the slow uprising of a great north-south crustal arch in the western part of the lava plain.

This concept, based primarily on the fact that originally the flows were almost flat but are today clearly uparched where they cross the Range, is confirmed by evidence of a wholly different sort.

Some of the lake and stream sediments that lie between the lava flows east of the mountains contain fossil logs and leaves representing types of trees such as sequoia, cedar, cypress, maple, and elm, that now flourish only in humid areas. The lush green forests called to mind by these plant fossils and the bones of camels, horses, deer, and predators of cat and dog ancestry help to round out the picture of a well-watered land of lake-dotted lava plain and woodland fringe. But they do something more, for no one with a spark of curiosity can observe the fossilized trunks and leaves, in the midst of present-day barren slopes that support only stunted sage, without being impressed by the magnitude of the climatic change from the past to the present. Again comes the question, Why? One has merely to look westward to see the reason for the present aridity: The high Cascades are an effective barrier in the path of moisture-laden winds from the Pacific. It is only one small additional step to the idea that, when humid forests flourished here during long intervals between the spreading of individual lava flows, there was no Cascade Range.

One more point needs to be made to bring us back to the principal question of the moment, which was the origin of the westward course of the Columbia through the mountains. A land of lakes and green forests must have had rivers, and there are, in fact, layers of river gravel in some places between the lava flows east of the mountains. Some of these old gravel layers are made up in part of pebbles of highly distinctive rock types identical with those now being carried by the Columbia from its headwaters in the Okanogan Highlands and in the northern Rockies, and available nowhere else in its drainage basin. They prove that the ancestral Columbia was doing business, much as at present, on the surface of the lava plain, and it seems reasonable to believe that the river then flowed westward down the slope of the plain to the sea and that, as the Cascade arch grew across its path, the river maintained its westward course by downcutting in the slowly rising barrier.

The river had to contest its passage, not only with the growing crustal arch, but also with flows of gray lava, known as andesite, that spread from volcanoes developing along the axis of the Range. These andesite flows, by damming the river, caused numerous local changes in its position, but the details of these vicissitudes are unimportant for present purposes. Our inquisitive traveler has seen enough to know that the Columbia River is older than the Cascade Range, that the growth of the Range, by buckling or arching of the earth's crust and by local volcanic eruptions, never so far exceeded the rate of cutting by the river as to turn it back, and that the river will, in all probability, still be flowing westward when the Range shall have been eroded away.

MENTAL FIELD EQUIPMENT FOR A CASCADE EXCURSION

Certain principles of what may be called the scientific appreciation of scenery, kept between the lines in the preceding chapter on the Columbia Gorge, now need to be brought into the open to serve as a basis for the discussion to follow.

Before attempting to paint the human face, Leonardo da Vinci sought to understand it; first, by study of the bony framework and musculature that give shape to its features; second, by a searching analysis of the play of inner and outer stresses that are expressed by it; and third, by an investigation of its changes from youth through maturity to senility. The student of the face of the earth focuses his attention on the same general elements, which he calls structure, process, and stage. Structure includes all the bedrock relationships that control the configuration of the landscape. Process refers to the erosional and depositional agencies, such as glaciers or rivers, and the slope-modeling mechanisms, such as slow soil creeping or rapid washing, the contrasted effects of which are responsible for all details of surface expression. Stage relates to the place of the given landscape in the orderly sequence of changing forms through which it has passed and will pass with progress of the cycle of erosion, from the youthful stage characterized by the rapid downcutting of streams into the newly uplifted range, through the mature stage of maximum ruggedness, to the gently rounded forms of the subdued hills of old age. All three of these elements—structure, process, and stage—are blended in every erosional landscape; if the traveler keeps them in mind he will meet new landscapes with the same kind of understanding with which he meets old friends.

Nearly all scenic vistas give rise to two sets of questions, one with respect to the origin of the landscape, and the other as to the origin of the rocks in which it is cut. These questions are wholly different and must not be confused if the observer is to think clearly about either of them. The walls of the Grand Coulee in eastern Washington are composed of basalt flows that may bring to mind the fiery lava fountains and rivers of the Hawaiian volcanoes. The Coulee was cut by melt-water floods from a glacier that once lay as a white blanket several thousand feet thick over all of north-central Washington and southern Canada. But the ice sheet missed a titanic struggle with the molten lava for space in the

Coulee area by about 15 million years. For comparison, if you were reading this at 8 o'clock this evening, the glacial melt waters would have been cutting the Coulee at 10 o'clock this morning, whereas the lavas would have been already cold and hard before the founding of Rome. So while the visitor to the Coulee will be interested in both its aspects, he will do well to deal with them one at a time.

Every adult carries in his mind a rather definite sense of the rightness of things, and of what can and cannot happen. These convictions are based primarily on what he has learned, in a very short interval of geologic time, and in a very small area of geographic space; he may be quick to reject, as preposterous, any concept that does not conform to them. "A glacier tongue, flowing in a valley in the Cascades, cannot cut its bed below sea level because ice cannot flow uphill, and besides, ice floats"—(but the Lake Chelan trough <u>is</u> glacier cut, and its bottom <u>is</u> several hundred feet below sea level). "A block of rock as big as a barn, originally traversed by many cracks, cannot be carried a mile by a glacier without falling apart"—(but hundreds of such blocks <u>were</u> carried tens of miles by the glacier that moved south across the Columbia Plateau nearly to Waterville). "Molten lava is such sticky stuff that no single lava flow can spread out, as a nearly flat, thin sheet, over 100 square miles"—(but the basalt flows of eastern Washington <u>were</u> spread as thin, nearly flat sheets, and many individual flows cover thousands of square miles).

Skepticism about conclusions that are "inherently improbable" is altogether good if it leads to a re-examination of the evidence and the reasoning on which they are based. Were it not for this method of testing his ideas, rather than on the basis of his little bundle of prejudices, man could never have learned, in the few thousand years since savagery, *all* the host of *incredible* things he has learned about the world around him. The very best advice that can be given to the non-geologist interested in the origin of Cascade landscapes is that given by the White Queen to Alice—to practice believing "six impossible things before breakfast" each morning. And yet he should keep skeptical fingers crossed. The rule is simple: The more unbelievable the interpretation, the more powerful must be the reasons for accepting it as a hypothesis. The evidence and logic for the interpretations advanced here cannot be stated fully in this essay, but enough are given to guide the interested reader to more complete accounts in reports listed on page 35. The reader is further cautioned that the account set forth here is an integrated moving picture resulting from a gathering together of many hypotheses by many workers from many hundreds of observations. Future workers will undoubtedly clarify some of the obscure or *blurred parts in the* picture, and some wholly new interpretations may change certain of its details, but on the whole it is rather definitely demonstrable.

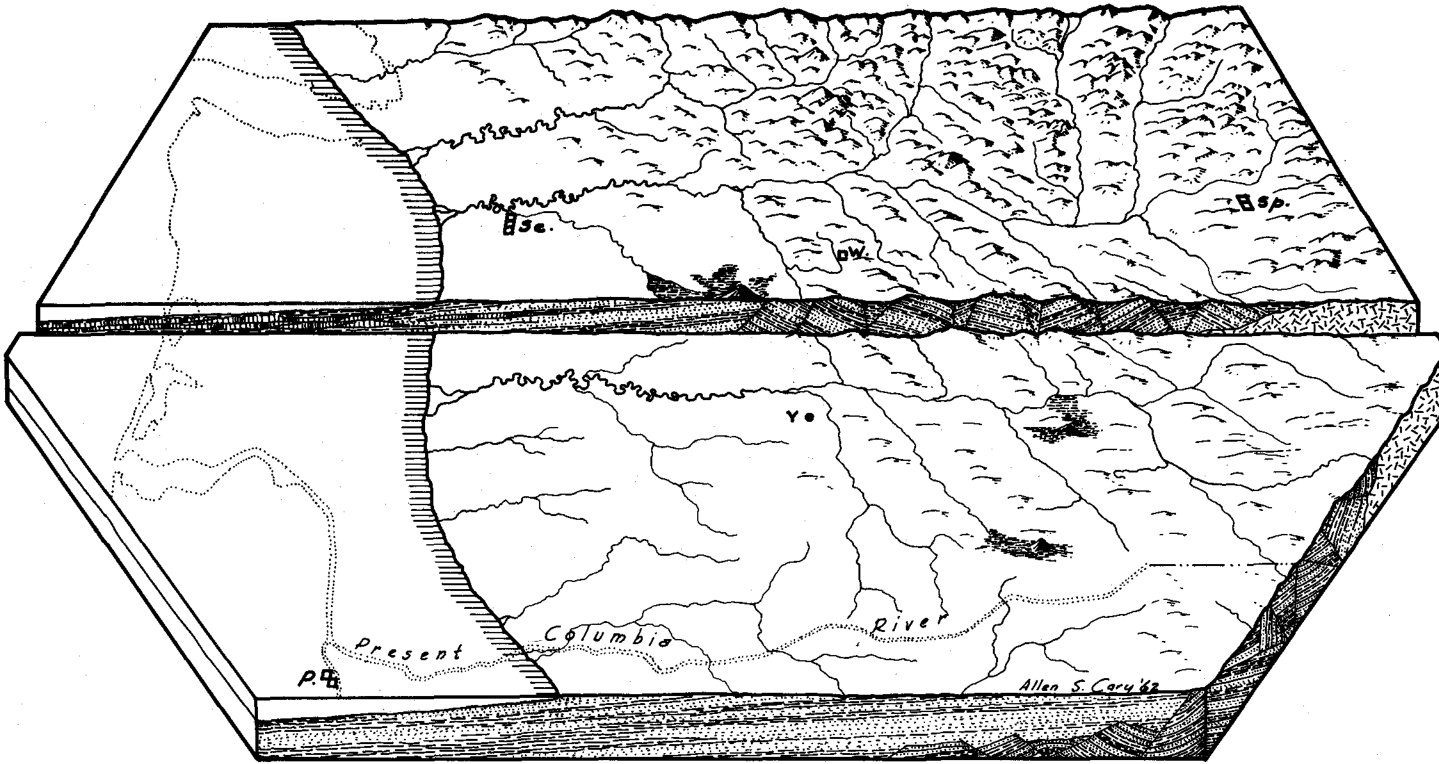
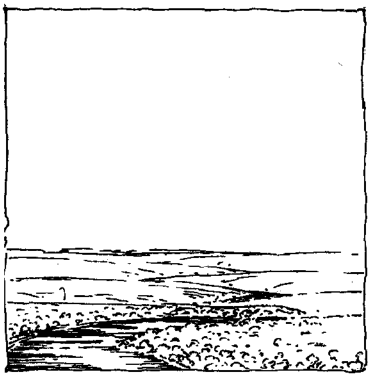


FIGURE 3.—AN EOCENE GEOGRAPHIC PATTERN

The coal deposits of Washington were formed in peat bogs on broad deltaic lowlands, the Weaver Plain, which trended northwest across the site of the Cascades. The oscillating shoreline was sometimes west of the present position of Seattle, as shown, and sometimes to the east. The rivers that wandered on the Weaver Plain derived their loads of sediments from mountains in the northeastern half of the State. Volcanoes were active from time to time in places on the Plain.

COAL FORESTS ON THE WEAVER PLAIN



Coal has been mined extensively in the foothills on both the eastern and western sides of the Cascades in Washington. Within the mountains the coal-bearing strata are so greatly contorted and altered that no commercial mining has been done, but there is no doubt as to the identity of the strata, and it is certain that the coal-bearing beds were once continuous across the entire site of the mountain range.

The succession of layers exposed in mine workings, or in bold ledge outcrops in the mountains, will set the imagination racing if we will only release the brakes. Tree stumps rooted in shale that was once mud in a pond; over them, river-laid sands and gravels now hardened into sandstone and conglomerate; prints of giant palm fronds on the sandstone bedding planes; and the coal seams themselves, representing tens of feet of peaty vegetable matter, at once suggest a subtropical plain traversed by rivers meandering sluggishly between low levee ridges sloping off into flood-plain bogs and lakes. They combine in endless variety the bayou landscapes of the lower Mississippi delta and the vast swamps of the Atlantic coastal plain in the Carolinas and Florida. The picture is in all respects the antithesis of the serrate ridges and glacier-mantled peaks of the present Cascades, but it is on this boggy plain that the evolution of the Cascade landscape began.

Explorers, from Columbus to Admiral Byrd, have, in the course of their pushing back of geographic frontiers, named newly discovered lands in honor of their sovereigns or friends. We are similarly in need of names for elements of past geographies encountered in these explorations, and we call the lowlands where the coals were formed the <u>Weaver Plain</u>, for the late Dr. Charles E. Weaver, longtime professor at the University of Washington, whose studies of the bedded rocks and fossils of western Washington and Oregon over a period of 40 years bring into sharp focus the succession of ancient landscapes outlined here.

The forests of the Weaver Plain were wholly unlike the monotonous green jungle of flowerless scale trees and giant ferns that flourished in the much more ancient Appalachian coal swamps. These Washington forests included a wide variety of broad-leaved trees, conifers , and palms of generally modern aspect, and they were bright with blossoming vines and shrubs. The long reign of grotesque Mesozoic reptiles had been but recently brought to a close, and the animal populations were dominated by primitive mammals, so small that the largest of the swamp browsers and the carnivores that lived by tooth and claw along the levee banks would have come only to a man's waist.

The swamp deposits and river-laid sandstones of the Weaver Plain in the vicinity of Seattle grade westward to mudstones and sandstones with no coal; in place of the plant remains there appear great numbers of fossil shellfish of types that live in warm shallow marine waters. Thus there is coal at Renton, but none at Bremerton. The trend of the shoreline bounding this coast was west of north; coals of the same type as those near Seattle are being mined on what is now Vancouver Island. Interfingering of river deltas and salt-water sediments along this line proves what would in any case be inferred; namely, that the coal swamps were not far above what was then sea level. And it leads to another conclusion that bears significantly on later events.

The sediments of the Weaver Plain are many thousands of feet thick. The many individual coal layers are interbedded with stream deposits and ripple-marked and sun-cracked muds, evidently formed on tide flats subject to periodic flooding and drying; the whole thick pile consists of layers of sediments deposited a little above or a little below sea level. This can mean only that the crust of the earth was depressed many thousands of feet during the period of deposition, and that the rate of crustal depression corresponded in general with the rate of sediment deposition. Wherever and whenever the rate of crustal sinking exceeded the rate of deposition, salt waters spread inland over the the coastal swamps; wherever and whenever the rate of deposition exceeded the rate of sinking, the shoreline was shifted seaward by delta growth. In the general over-all balance between sinking and sedimentation, maintained for a long period of time, we see an example of a repeating habit of the Earth's crustal behavior— the same sinking of the crust now in process on our Gulf Coast at the mouth of the Mississippi. And it is a second fundamental rule of crustal behavior that most of the great linear ranges of the globe have grown out of such belts of deep sinking when, during a later period of lateral squeezing, the thick layers of sediment have been crumpled into folds and raised high above sea level.

But we need to look a little more closely at the geography of the Weaver Plain before we consider the mountain range that was spawned in it. What was the Plain's extent? Whence came its streams? And what long-vanished ranges yielded the thousands of cubic miles of sediment deposited on it?

Answers to these questions are to be found in sedimentary deposits in the eastern part of the present Cascades, in a belt trending generally northwestward, and inland about 100 to 150 miles from the mudflats of the old shoreline. These sediments include thick masses of coarse bouldery materials that must have been derived from the rugged slopes of nearby mountains. The Weaver Plain was 100 to 150 miles wide, its eastern margin was highly irregular, and there were deep embayments of the depositional plain reaching far into a range of mountains from which the sediments of the Plain were derived. It is well worth the little effort that it takes to mentally place one's self on one of the mountain spurs near where Wenatchee now stands, to look southwestward across the tropical forests and swamps of the Weaver Plain to the distant Pacific, to feel the earthquake pulsing of mountain growth along its landward margin, and to watch the rivers at their everlasting task of lowering the high places and filling the low places. For comparable modern scenes we would need to travel to the eastern foothills of the Andes, where the Amazon and the Orinoco issue from the mountains onto the plains of Brazil and Venezuela, or better, to where the Himalayas look down on the jungles of Burma.

One final element is needed to round out this glimpse of the Weaver Plain. There are, interbedded with its sediments, layers of fine-grained volcanic ash, thick masses of angular lava blocks evidently formed by violent volcanic explosions, and flow after flow of basalt. These ash beds, blocks, and flows mark the first of the episodes of vulcanism that run like a theme through the Cascade story—Mount Rainier, Mount Hood, and their companions along the Range crest represent the latest activity.

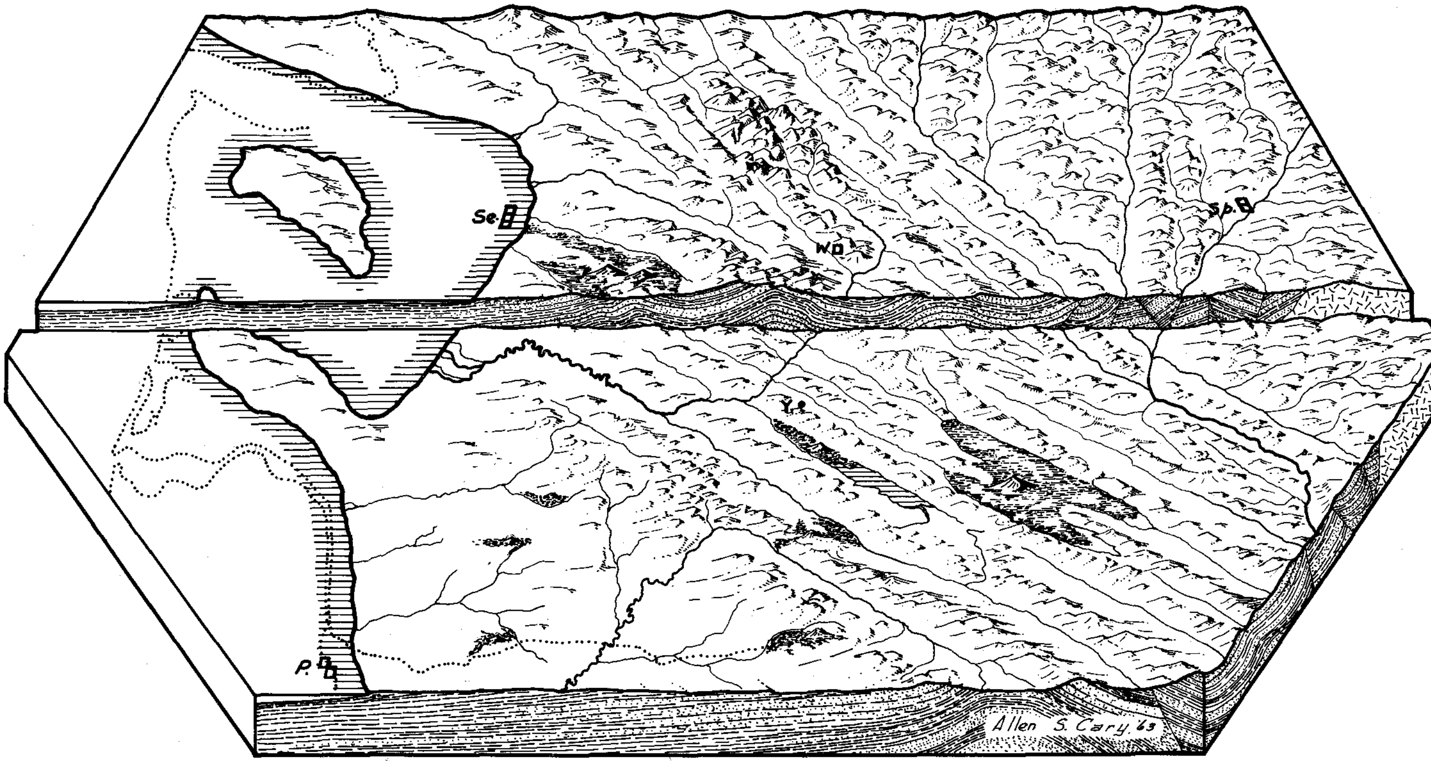
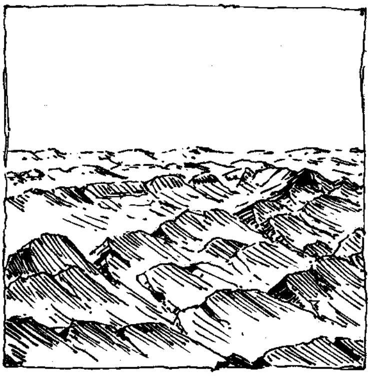


FIGURE 4.—AN OLIGOCENE GEOGRAPHIC PATTERN

The sediments of the Weaver Plain were compressed into northwest-southeast-trending folds, here called the Calkins Range. Although there have been many changes in detail, the general trend of the present drainage lines of the Cascade area was apparently determined by the Calkins folds. The folding was accompanied by emplacement of large bodies of granitic rock and by large-scale volcanic activity.

ORIGIN OF MODERN DRAINAGE LINES IN THE CALKINS RANGE



Stream patterns of mountain areas usually have some evident and direct relationship with the trend and over-all form of the ranges that they drain. Local anomalies in the drainage patterns of mountains have puzzled thoughtful observers ever since Thomas Jefferson's early guesses as to how the Appalachian rivers came to cut through the Appalachian ridges. In the Cascades we are faced, not with local drainage anomalies, but with a wholesale disregard of the trend of the range by its rivers. The range trends north-south, whereas the rivers flow northwestward and southeastward from the crest with such persistence that the pattern, and the problem presented by it, catches the eye on every map and model.

Search for an explanation of the discordant habit of the Cascade streams quickly turns up another problem that is at first equally troublesome. The rocks of the Cascades, as well as its rivers, have a grain, and the grain trends northwest-southeast. The term "grain" is well chosen—a map of the different rock types that form the mountains would look very much like the surface of a piece of plywood, with the many layers of sedimentary rock corresponding in pattern with the regularly parallel and zigzagging design of the hard and soft parts of the annual growth layers in the wood. The troughs, toward which the beds slope, are synclines, and the arches are anticlines; the geologic cutting machines that beveled these folds are rivers and glaciers. The swirls of plywood grain around dark-brown knots have their counterparts where, locally, in the Cascades, the folded layers have been pressed aside by molten material now hardened into masses of granitic rock. Other masses of granitic rock are clearly different in origin, in that the grain of the folded layers passes directly through them without change in direction; these would correspond with dark stains on the plywood, and were formed by intense alteration of the sedimentary rock by hot solutions.

The fact that the folds trend northwestward, diagonal to the northerly trend of the Cascades, indicates that the folding was not related to the uplift of the present Range. This suggestion is confirmed by evidence that is simple and straightforward: The rock strata of the Weaver Plain are just as strongly folded in the Puget Lowland as in the high Cascades. East of the Range the folds pass southeastward beneath the flows of basaltic lava mentioned in the earlier discussion of the Columbia Gorge; the basalt flows rest on the deeply eroded stumps of the folds.

The folds must be younger than the sedimentary rocks of the Weaver Plain, because these rock layers, deposited flat, were arched and buckled in the folding process. The folds must be older than the basaltic lavas of Eastern Washington, because they were more or less completely leveled by erosion before the time of the lava floods. And they must be much older than the present Cascades, because they trend in a different direction.

Thus we date and define a mountain range, long since vanished, that grew out of the boggy lowlands of the Weaver Plain when its thick pile of coal-bearing sediments were crumpled as though in the jaws of a global vise. Following the scheme outlined earlier, we name those fold mountains the Calkins Range, for Frank C. Calkins, kindly elder statesman of the U.S. Geological Survey, a perfectionist in geologic mapping and writing, whose studies in the Cascades in the early nineteen hundreds provide much of the substance on which this essay is based.

We can, by mentally restoring the folded strata where they have been removed by erosion, reconstruct the ridges of the Calkins Range as they would have appeared if upraised so rapidly that erosional lowering during the period of mountain growth was negligible. Had this been the case, a traveler along what is now a continuous lowland route between Portland, Oregon, and Vancouver, British Columbia, would have had to pass over a northwestward-trending range as high as the Alps. Actually, there is no good basis for estimating the relative rates of uplift and erosional lowering of the folds, but the original height of the Calkins Range is not important. The critical point is that the folds seem to have been raised rapidly enough to destroy the earlier westward and southwestward drainage of the Weaver Plain and to determine a new drainage pattern, in which the main streams flowed in northwesterly-southeasterly directions. This drainage pattern, first developed on the folded structures of the Calkins Range, has survived with some modification through all the later stages of growth of the modern Cascades, which it so conspicuously fails to fit. In the contorted roots of the Calkins Range are written the birth records of our modern drainage.

A question as to why the Calkins folds were compressed from the northeast and southwest, rather than from some other direction, involves broad problems of continental architecture that are as yet unsolved. For now, it can be said only that the northwesterly trend of these folds coincided with the trend of Weaver Plain, from which they arose, and with the trend of active ranges along the eastern border of that plain, from which the sediments of the plain were largely derived. The granitic rocks of the Lake Chelan area, which mark the site of mountains that were elevated and destroyed long before the beginning of the times treated here, show the same northwesterly trends; it is therefore evident that the Calkins folds represent merely the last of a long series of crustal yieldings along this fundamental pre-Cascade direction.

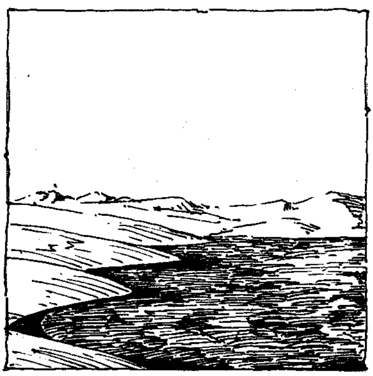
Much of the central and southern parts of the Cascades in Washington consists of volcanic rocks formed by eruptive activity during the growth of the Calkins Range. These rocks, typically exposed along the sides of Lake Keechelus, consist chiefly of lava flows interlayered with sheets of volcanic ash and mudflow deposits. They are in all essential respects the same as the rocks making up Rainier and the other modern Cascade volcanoes, but the great thickness and lateral extent of the Calkins Range rocks indicate volcanic activity on a scale incomparably greater. In many places the Cascade volcanic rocks are associated with granitic rocks formed by cooling and consolidation, beneath the surface, of types of molten material similar to those that formed the Calkins volcanoes.

The eruptions that accompanied the growth of the Calkins Range differ in one important respect from the earlier volcanic activity on the Weaver Plain. The lavas that spread across that subsiding lowland were predominantly black basalt, whereas the lavas and explosive materials of the Calkins Range were predominantly gray andesite. On every continent, and throughout geologic history, lavas of basaltic composition are associated with times and places of crustal depression and sedimentation, and lavas of andesitic composition characterize times and places of mountain growth. The vulcanism of the Cascade area fits this world-wide pattern and takes meaning in terms of it.

A glance at the block diagram will indicate that, whereas the Calkins Range trended northwest, the volcanoes and granitic masses that were formed at that time were rudely aligned in a north-south belt along what is now the axis of the Cascade Range. The alignment is perhaps the first early symptom of crustal unrest along this new axis, prophetic of things to come.

Poring over the pictures in an old-fashioned history book might lead a child to wonder, "Were the people of long ago always fighting battles?" The reader may have an equally bad impression of Oligocene-Miocene times in the Cascade area, and for the same reason; namely, that in dealing with the past we are likely to overemphasize the spectacular events— wars in human history, or mountain building and vulcanism in geologic history. The fact is, of course, that day-to-day conditions were then much the same as now. An extraordinarily rich assemblage of fossil bones preserved in volcanic ash in the world-famous John Day area in eastern Oregon represents a teeming animal population, including forest-living horses, camels, rhinoceroses, and many other herbivores, and both cat- and dog-like carnivores, all very much closer to modern forms than the animals of the Weaver Plain. Both the animals and the plants associated with them indicate that the subtropical climate of the Weaver Plain had given way to warm temperate conditions. Oregon and Washington, green in the west and brown in the east, were then all green, for the Cascade moisture barrier was yet to be raised.

BASALT FLOODS AND THE BIRTH OF THE COLUMBIA RIVER



The outpouring of the Columbia basalt lava flows dwarfs by comparison all earlier and later volcanic eruptions in the Northwest. Even the statistics are impressive: general thickness in the middle of the lava field, more than 10,000 feet; total volume of lava, more than 25,000 cubic miles; area covered, more than 200,000 square miles. This enormous mass of basalt consists of hundreds of individual flows, from a few tens of feet to a few hundreds of feet in thickness; some exceptional flows attain a thickness of 700 to 800 feet. The lavas, through long fissures, welled up to the surface in white-hot fountains, with little or no explosive activity; there was no piling up of erupted material around vents to form volcanoes in the ordinary sense of the term. Now, even from an automobile window the individual flows, each characterized by one or more palisades of cooling-contraction columns, can be traced for tens of miles along valley walls without notable change in thickness. Because of their exceedingly high fluidity, the lavas spread swiftly and widely in thin flat sheets almost like water floods.

The flows that cover the greater part of eastern Washington apparently advanced in northeasterly, northerly, and northwesterly directions from a poorly defined source area in the southeastern part of the state. Because the pre-lava drainage was generally southward, the growing lava field was bounded at many points by lakes dammed in older stream valleys by the flows. Some of the lake basins formed in this manner were completely filled with sediments carried in by the streams; the basins that still contained water when the next flow advanced were quickly filled to the water line by delta-like masses of clinkery basalt chilled by the water and fragmented by violent steam explosions where the hot lava entered the lake. The sides of canyons cut through the flows by modern streams reveal the ancient pre-lava hill-and-valley landscapes, the bedded silts and clays of the lava-dammed lakes— locally rich with leaf prints and petrified logs and bones— and the clinkery deltas that provide a graphic record of the continuing conflict between rivers of water that were trying to flow southward and floods of lava that were advancing northward and westward against them.

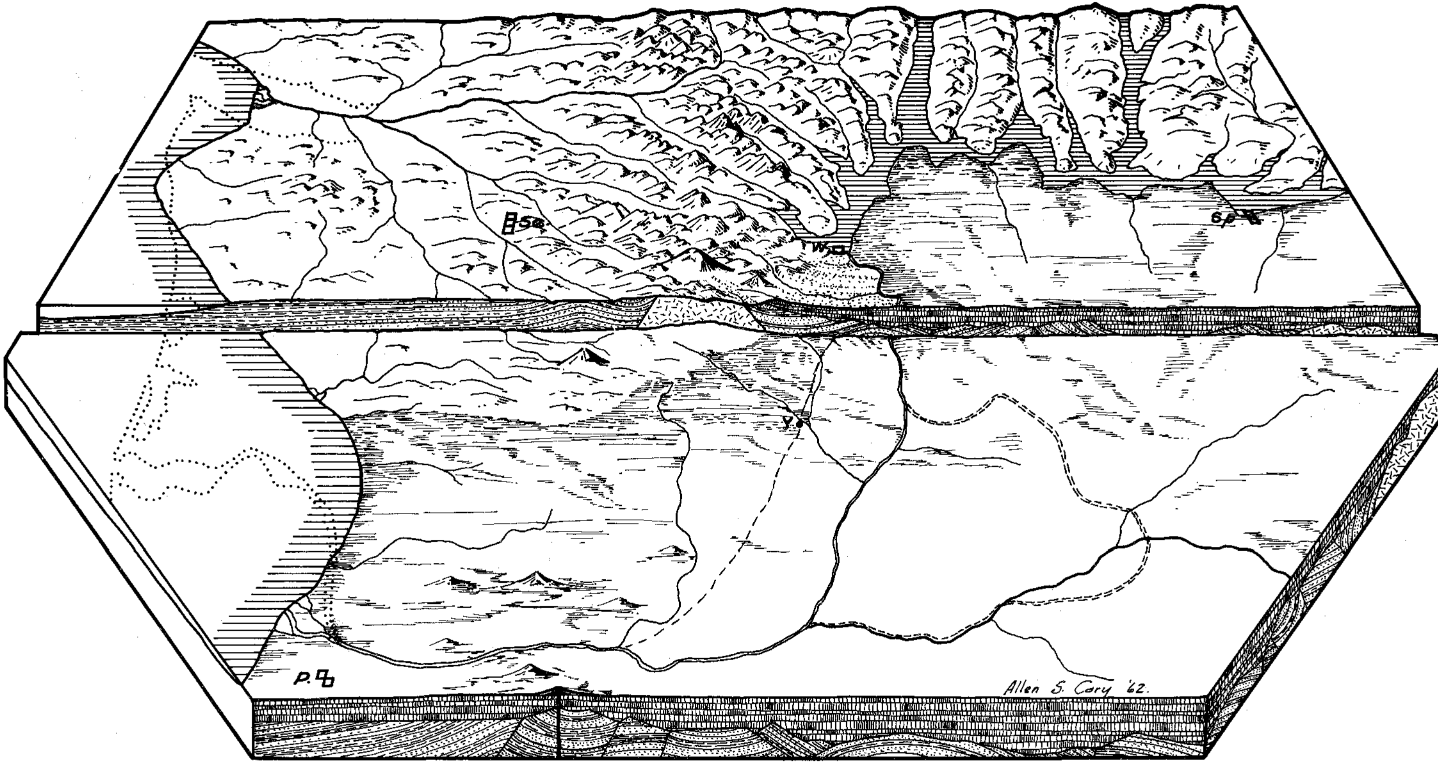


FIGURE 5.—A MIOCENE GEOGRAPHIC PATTERN

The Columbia River Basalt flows were spread in relatively flat sheets across the deeply eroded folds of the Calkins Range and extended westward to the Pacific Ocean. Marginal lakes around the northern border of the basalt mark the present position of the Columbia River. Near Wenatchee the river was forced eastward over the basalt by a great fan of andesitic volcanic detritus from volcanoes in the present position of the Cascades. South of this area the river wandered widely on the surface of the lava field; its positions as shown on the diagram are based on the distribution of distinctive pebble types in gravel deposits interlayered with and resting on the basalt flows.

It is certainly not coincidental that the Columbia River now swings westward in a great arc around the northern margin of the lava field and that, in this arc, it receives numerous long tributary streams from areas of older rock on the north and west, but none from the lava-covered surface on the south and east. The river evidently became established in the gutter between the newly formed northerly slopes of the lavas and the southerly slopes of the old hill-and-valley topography beyond their borders. Streams blocked by the basalt flows backed up behind the lava dams to form lakes, which eventually spilled westward from one to another to form a chain along the gutter. The Columbia established itself by cutting downward to drain the last of these marginal lakes. The northern tributaries of the Columbia are thus the headwater remnants of drainage systems, the lower reaches of which were obliterated by the spreading lava flows; the Columbia itself is foster mother to these orphan streams.

At the present site of the city of Wenatchee the river leaves its marginal position to enter the lava field. The reason for this change is to be seen just to the southwest, where the black basalt flows, which advanced from the east and south, are interbedded with and finally covered by great thicknesses of river-laid volcanic debris, light gray in color, evidently derived from andesite volcanoes that were active in the Cascade area during and after the period of basalt eruptions. These materials filled the gutter along the west side of the basalt field and forced the river to swing eastward onto the basalts. Were it not for this barrier, the Cascade Gorge of the Columbia might be far to the north of where it is now, and the present geographic pattern of settlements and transportation lines centering on Portland might never have developed.

When the outpourings of the flood-basalt eruptions finally ceased, the lava surface extended as an almost featureless plain covering much of Washington and Oregon, and extending entirely across the site of the Cascades to the ocean. Some of the older volcanic peaks along the Cascade axis in Oregon may have stood like islands above the basalt flood, and new volcanoes were doubtless growing on its surface along this north-south belt of increasing crustal unrest. In Washington, the shoreline of the lava sea lapped across the subdued stumps of the Calkins Mountains and a somewhat rougher landscape on granitic rocks farther north. In this frame of our motion picture the topography of western Oregon and Washington certainly differed markedly from what it is now, but the major outlines of the present drainage were rather fully developed, and the distribution of all the principal rock types, except for the modern Cascade volcanoes, was much the same as today. The stage was set for the birth of the Cascade Range.

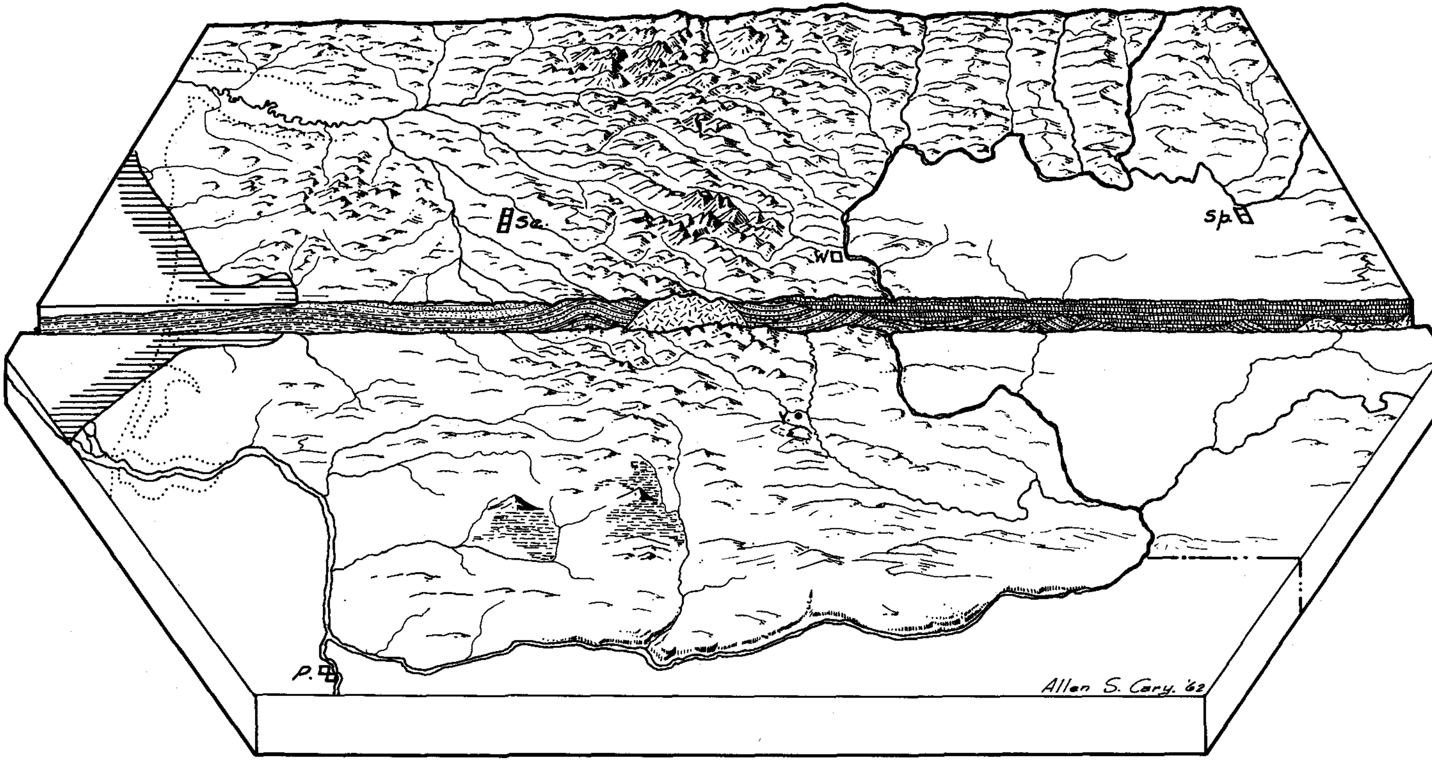
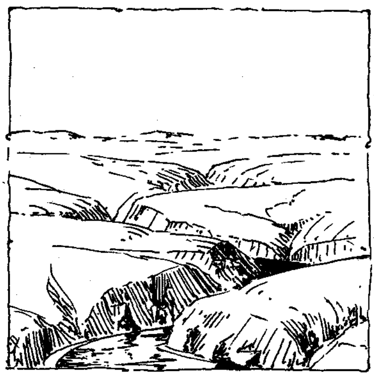


FIGURE 6.—A PLIOCENE GEOGRAPHIC PATTERN

Arching uplift of the Cascades as a north-south range is suggested by the beginning of cutting of the Columbia Gorge. Uplift of the main range was accompanied by folding of the basalt flows along the same northwest-southeast trend as the much older Calkins folds on which they rest. The Columbia River maintained its position by cutting through some of the growing anticlines (as Saddle Mountain, just south of the cross section), but it was diverted eastward by other folds. St. Helens and the other Cascade volcanoes were probably active, but smaller than now. All the major elements of the present geography were established, except the features formed by glaciation.

UPLIFT OF THE CASCADE RANGE



It is easy to bend a telephone book into an arch. But it is very difficult to produce a simple arch in corrugated cardboard in which the corrugations run at an angle to the trend of the arching. The uparching of the Cascades is a mechanical problem of the latter type, in which the corrugations are folded structures in the older sediments, locally stiffened by irregular masses of granite. So, whereas the Range is in a very general way a north-south belt of crustal uplift and vulcanism extending from northern California to Canada, it is everywhere complicated in detail by fractures and bucklings in many directions.

These minor bucklings, incidental to the growth of the main range, are seen to best advantage in the plexus of ridges and valleys on its eastern flank in southern Washington. Each ridge is an anticlinal upfold, and each valley is a synclinal downfold. The folds have the same pattern as wrinkles in a pile of giant rugs, the rugs in this case being sheets of Columbia Basalt. The wrinkles measure hundreds of feet in height and several miles from crest to crest. The Yakima River cut a deep gorge across some of the folds as they arose, and was deflected by others; the Columbia River was finally shifted to its present position during the period of folding. The folds certainly were formed during the uplift of the Cascades, but their northwesterly trends probably reflect the directions of the very much older Calkins Mountains "corrugations" on which the basalt flows rest in this area.

Because the lava sheets originally were almost flat, we can be certain of the nature of the local response of the crust to Cascade mountain-making pressures wherever the lavas are still present; the tilt of the flows can be measured with any desired degree of precision. There is very much less certainty as to the manner of local crustal yielding in the northern and western Cascades, where no such convenient datum planes are available. But it can hardly be coincidental that the deepest sag in the crestline of the Range (Snoqualmie Pass) is in northwesterly alignment with a deep downfold in the basalt flows on the east side of the mountains (the Ellensburg syncline) and that the highest nonvolcanic peaks (as Mount Stuart) are similarly aligned with respect to upfolds in the basalt (as the Table Mountain anticline). Again the implication is that, as might be expected, the general north-south uplift was accompanied in part by minor warping along the ancient northwesterly trend lines.

The period of time during which the Cascades were upraised is approximately 6 million years, of which about 4.5 million are usually assigned to the Pliocene epoch, and about 1.5 to 2 million to the Pleistocene. We have a reasonably clear picture of altitudes and relief before the Range began to grow, early in the Pliocene—the Oregon and southern Washington Cascade area was a basalt plain not far above sea level, and the highest peaks of ancient granite in the Northern Cascades stood not more than three or four thousand feet above sea level. And we know, of course, the height and form of the present Range. But there are few definite data as to the rates of uplift in the meantime, as to the constantly changing succession of landscapes sculptured by erosion in the uprising mass during the long period of mountain growth. What we do know is based very largely on existing landforms, rather than on rocks.

Many of the valleys on the flanks of the Range in Oregon and Washington are steep-sided gorges with scarcely room for railroad or highway on the valley bottoms. But by scrambling up the valley sides the climber commonly may be rewarded by seeing another valley, widely opened in rounded hills that grade up to interstream ridges of moderate to high relief. Here are two distinct generations of topography, a broadly opened surface developed during a period when the stream was cutting downward very slowly or not at all, and a narrow inner gorge produced by greatly accelerated stream cutting. The general effect is that of an enormous

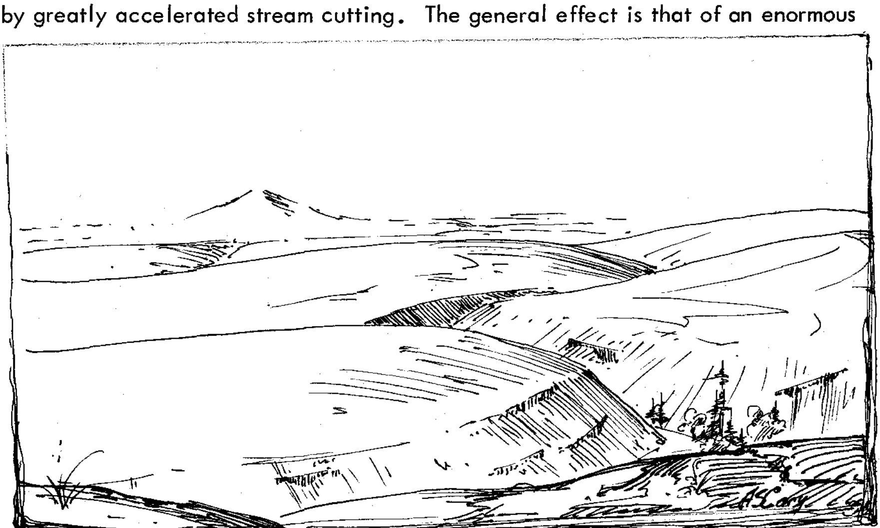


FIGURE 7.—A gently rolling upland surface with canyons cut into it.

rolling golf course trenched in all the low places by deep gullies; the grass on this scale model is the Cascade forest.

This "open valley" landscape is strikingly developed on the Columbia Basalt and all the older rocks on both flanks of the Cascade Range, except in areas of recent volcanic activity. It is much more modified by erosion, but still recognizable, on the axial parts of the Range in southern Washington. If it was ever present, it has been completely destroyed by glaciation in the northern, higher parts of the Range. Most important for present purposes is the fact that in some places it is developed on deposits left by the first of the great ice sheets that invaded the Puget Lowland early in Pleistocene time, and is therefore dated in a geologic sense. This suggests that perhaps one-half to two-thirds of the total uplift of the Range had been completed by early Pleistocene time; that a pause or decrease in the rate of uplift then permitted the streams to open out broad valleys in parts of the uplifted mass; and that the cutting of the narrow inner gorges is due to renewed or quickened uplift during the later part of the Pleistocene. The depth of the stream trenching differs from place to place in such a manner as to suggest that the Pleistocene uplift varied from a few hundred feet on the lower flanks of the Range to a few thousand feet along its axis.

If the rate of uplift had been uniform during the period of Range growth (about 6 million years), and if the total maximum uplift along the axis in the Northern Cascades was about 6,000 feet, then the rate of crustal upheaval would have been 1 foot in 1,000 years. Actually, the total maximum uplift was probably much more than 6,000 feet, because an unknown thickness of rock was removed by erosion from the highest parts of the Range during the period of uplift. The minimum uplift, in Oregon and southern Washington, was less than 3,000 feet. Even in any one area the rate of uplift probably was not uniform, but was interrupted at least once by a period of relative crustal stability; perhaps the rate was more rapid during the Pleistocene than during the Pliocene. The figures are therefore little more than "guesstimates," but they serve to bring out a significant point—that the rate was extremely slow. But the rate of lowering of the surface of the United States as a whole by erosion (1 foot in 5,000 to 10,000 years) is even slower; the Cascade Range stands high simply because its over-all rate of uplift during the past 6 million years has exceeded the rate of erosional lowering. For all we know, the mountains may be going up now as rapidly as at any time in the past, with only an earthquake now and then to mark the restiveness of the earth's crust.

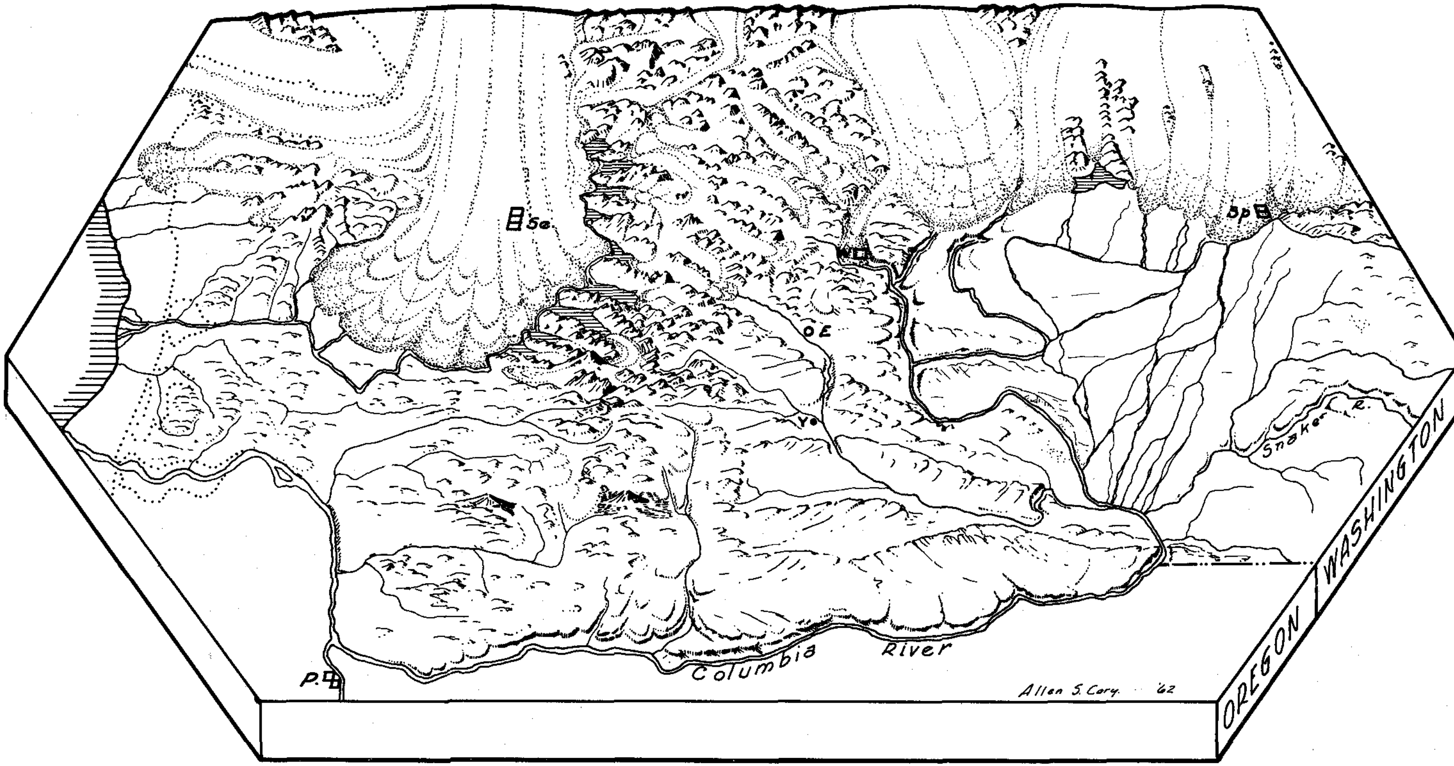
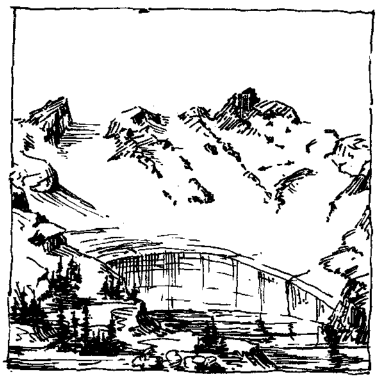


FIGURE 8.—A PLEISTOCENE GEOGRAPHIC PATTERN

Continued growth of the Range and the anticlinal folds to the east is indicated by stronger relief and deeper incision of the rivers than existed in Pliocene time. But the major change from the Pliocene was the advance of glaciers from Canada—west of the mountains the Juan de Fuca and Puget Sound lobes, and east of the mountains a composite lobe that extended southward across the Columbia River. The coulee system in eastern Washington was cut by the temporarily diverted Columbia and by floods resulting from the sudden release of ice-dammed lakes in Idaho and Montana, particularly in the Clark Fork valley. At the same time, all the major valleys of the Northern Cascades were occupied by local glaciers, which carved the present alpine scenery.

ICE SCULPTURES THE PRESENT SCENE



The Great Smoky Mountains of western North Carolina are generally comparable with the Northern Cascades in rocks and structures, altitude above sea level, and relief, but the two ranges are completely unlike in landscape forms. The skyline of the Smokies is a blending of gently sweeping curves of rounded slopes and summits, like rollers at sea after a storm; the Cascade skyline is a harsh jumble of sharp-crested ridges and peaks like a choppy sea at the storm's climax, with snow and ice for foam. The rivers of the Smokies rise in a system of branching headwater tributaries in faint valleys that merge with the rolling upland; the Cascade valleys head abruptly in great amphitheater-shaped basins shadowed by vertical cliffs. Lakes and waterfalls are rare in the Smokies; in the Cascades they are numbered in the thousands.

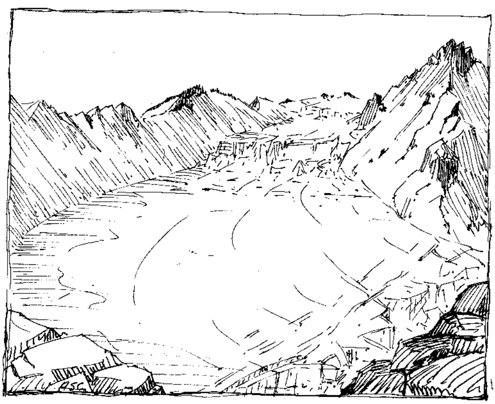
Every Cascade mountaineer will shudder at the thought that, were it not for an accident of timing and climate, his wild peaks, which can be approached only by rope work on sheer rock faces and overhangs, would be identical with the southern Appalachian summits, where an "ascent" requires only a little extra pressure on an automobile accelerator. The late Pliocene Cascades <u>were</u> like the modern Smokies; the landforms that characterize the higher parts of the present Range were cut by Pleistocene ice.

If there were at the present time no glaciers anywhere on the surface of the earth, the contrast between the scenery of the Smokies and that of the Cascades would be an exceedingly difficult problem for the student of landforms. It would take a very imaginative man to suggest that the Cascade scenery was modeled by rivers of <u>ice</u>, and to theorize with regard to the manner in which these incredible ice streams flowed, and eroded, and deposited. And if he were so brave as to publish these fantastic ideas, he would have to spend the rest of his life defending himself against the attacks of his skeptical colleagues.

Fortunately, we are relieved of the need for such inventing and theorizing. Glaciers are now active on the higher peaks in the Cascades and in many other ranges. We can <u>see</u> the manner in which they are nourished by snows that accumulate from year to year, and the gradual change from snow to ice under the weight

Before glaciation

Rolling Cascades before being cut by ice.



During glaciation

Ice sculptures the present scene.

A harsh jumble of sharp-crested ridges and peaks.

As it looks today

FIGURE 9.—Snow Lakes Basin and Temple Mountain before, during, and after glaciation.

of the yearly increments. We observe that at a depth of 75 to 150 feet ice flows like a viscous fluid, and we can descend into crevasses at the head of a flowing glacier to study the rock-quarrying processes by which it eats its way into the mountain slopes that support it. And if we had time, we could, like Mark Twain in the Alps, ride down on the glacier, together with the mass of rock fragments that it carries, to the lower levels where it melts away into a stream of milky water. Finally, by work in areas from which glaciers are now retreating, we can become familiar with the unique landscape features produced by them, and the equally distinctive characteristics of their deposits.

It requires only very little imagination, when the matter is approached in this way, to mentally restore in the Cascades the ice that must have been there in the recent past. The northern interior parts of the Range were so deeply covered that only the highest peaks and ridges stood out as rocky ledges above a continuous ice mass that flowed eastward and westward from the divide areas. All the larger troughlike valleys on the flanks of the Range were occupied by rivers of ice many miles in length, and locally, as in the Lake Chelan trough, many thousands of feet in depth. The ice streams on Mount Rainier serve reasonably well as models, but to find present-day glaciers comparable in size with those that made the Cascade scenery what it is, we must look in Alaska and in the high ranges of southern Asia.

Vastly larger ice masses that occupied the lowlands east and west of the Range are restored in the Pleistocene diagram (fig. 8, on p. 24) on the same basis; that is, to fit the distribution of distinctive landforms and deposits produced by them.

The lowland glacier east of the mountains pushed southward from its Canadian source area, engulfing all but the highest mountain ridges in northeastern Washington, and continuing far enough to block the valley of the Columbia River at several points along the northern margin of the basalt field. Debris heaped along the ice border is traceable almost continuously from the Cascades to the Rocky Mountains. Repeated catastrophic emptying of lakes dammed by the glacier in the mountain valleys of Idaho and Montana produced floods of enormous magnitude which, sweeping across the northern part of the lava field, cut a system of great coulees that stand high on the list of geologic wonders of the world. These Pleistocene floodwaters and the ice sheet that gave them birth, together with the much older Columbia Basalt flows, determine the physical setting of the Columbia Basin irrigation project and the entire geographic pattern of man's activity in eastern Washington.

The surface of the ice in the Puget Sound Lowland west of the Cascades sloped southward from an altitude of about 7,000 feet at the Canadian border to a few hundred feet above sea level at its southern terminus; in the vicinity of Seattle the glacier was more than half a mile thick. The flowing mass had the shape of a tongue of tar, with slopes from the center eastward and westward to the foothills of the Cascades and the Olympics on either side. On the basis of the very intense glacial erosion seen in both these Ranges, it might be expected that ice streams would have issued from them to augment the mass of the Canadian glacier that filled the Lowland, but surprisingly enough this does not seem to have been the case. Instead, fingers of Canadian ice actually pushed upstream into the mountains, blocking the lower valleys to impound extensive lakes, some still existing and others, long since drained, represented only by bedded clays on the valley floors. Melt water from the ice sheet and the mountain glaciers found its way southward from lake to lake, in the gutters between the ice mass and the mountain fronts, to enter the Pacific via the Chehalis River.

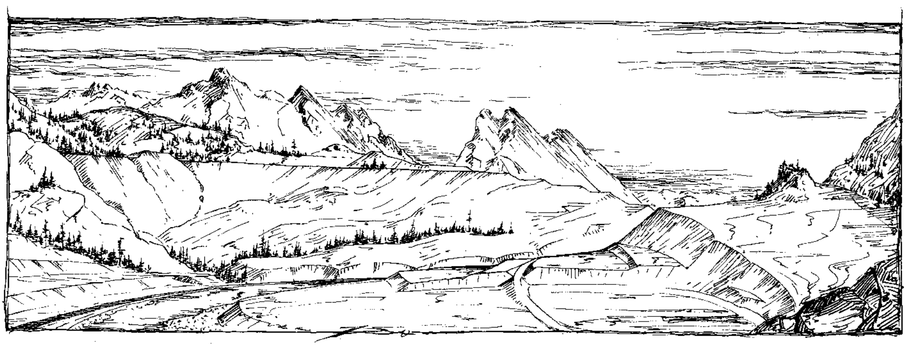


FIGURE 10.—Big morainal embankment built across the Skykomish Valley by melt water from Canadian ice that filled the foreground area while alpine glaciers were sculpturing serrate ridges in the middle distance.

The effects of glaciation in the Puget area are less spectacular but quite as profound as those in the Cascades and the Columbia Basin. Had it not been for the climatic accident that filled it with ice, the Puget Lowland would be similar in all essential respects to the Willamette and Sacramento Valleys that are aligned with it in Oregon and California. The relatively flat river plains and soil-mantled slopes of those valleys are replaced, in the Puget Lowland, with masses of gravel, sand, and clay deposited by the glacier and its melt waters and then modeled by the glacier into elongate hills streamlined in the direction of ice movement. The maze of Puget waterways, some more than 1,000 feet deep, are troughs reamed out by the ice. Puget Lowland seaport cities 100 miles inland from the Pacific coast, the plan of the communication network of the Lowland, its numerous lakes of varied origin, and many aspects of its agricultural and industrial development, all are related directly or indirectly to ice action.

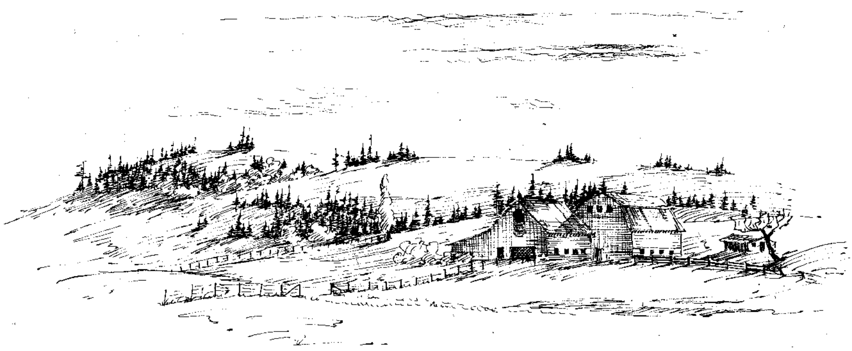


FIGURE 11.—Ice-rounded hills in the Puget Lowland area, less spectacular than the mountains but revealing in their well-rounded shapes their origin under the Canadian ice.

These drastic effects of glaciation in the mountains and lowlands are not due to a single episode of glaciation. The great drama of gradual refrigeration culminating in regional glaciation, with forced mass migration of all plant and animal life southward before the invading ice, and their gradual return northward with its retreat, was repeated at least three, and probably four, times during the 1.5 million years of Pleistocene time. The first and most extensive of these invasions dates from early in the Pleistocene; recession of the last glacier began less than 15,000 years ago. The times of glaciation were separated by long intervals when the climate, forests, and animal populations were essentially the same as now.

VOLCANIC GIANTS ALONG THE RANGE CREST

Any discussion of the Cascade volcanoes involves a parade of unavoidable superlatives. They are the largest volcanic mountains and include some of the highest peaks in the West. The Mount Lassen eruption of 1914-15 is the only major episode of violent volcanic activity in this country, exclusive of Alaska and Hawaii, within historic time. An earlier, stupendous eruption of Mount Mazama, of a magnitude beyond the grasp of the imagination even in this atomic age, blew a hole 5 miles across and nearly 2,000 feet deep in the top of the mountain that contains Crater Lake. Mount St. Helens is unrivaled in the symmetrical beauty of its cone, capped in dazzling white by perpetual snows. Rainier is deeply gashed by the largest glacier system in the United States outside of Alaska.

These attributes add up to two significant generalizations:

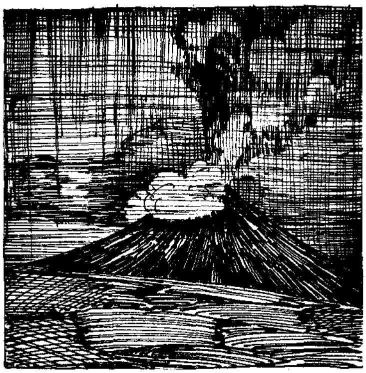
First, the Cascade volcanoes are wholly different from the rather flat floods of highly fluid basalt that covered the site of the Range during the late Miocene. From one end of the Range to the other, the volcanoes consist predominantly of viscous andesite lavas and explosive materials that have piled up around the points of eruption to make steep-sided "mountains of accumulation." Especially in view of the characteristic association of andesite with belts of crustal uplift elsewhere, the alignment of these andesite volcanoes along the Cascade Mountain axis cannot be coincidental; the vulcanism is a superficial symptom of a disorder in the earth's crust along the mountain belt.

The second generalization has to do with the timing of the volcanic and glacial activity relative to each other. Several lines of evidence indicate that the Cascade volcanoes began their growth during the Pliocene, long before the onset of glaciation. Many of the existing Cascade glaciers are on the volcanic peaks because these peaks are the highest in the Range, and it is reasonable to believe that, because the peaks stood high above the Range during most of the Pleistocene, they should have been much more intensely eroded than the lower, nonvolcanic summits. But it is a fact that these lower, nonvolcanic summits, cut in the older rocks of the Range, generally show very much more advanced glacial sculpturing than the volcanoes. This can only mean that on the volcanoes the ravages of ice erosion have been, so to speak, repaired from time to time by new outbursts of lava and explosive materials during and after the ice age. The volcanoes are very old; they have been kept young-looking by recurrent episodes of vulcanism.

Each of the five Washington volcanoes is a substantial volcanic mass in its own right, but all owe their great height partly to the fact that they are built on top of the Cascade Mountains; they are mountains of accumulation, piled on top of mountains of uplift and erosion. At many points around their bases we are privileged to catch glimpses of the ancient hill-and-valley landscapes on which they were erected. These old landscapes have moderate to high relief but are notably less rugged than the present topography around the volcanoes. They tend to confirm the thesis that the Range was high, but not so high as now, during the late Pliocene and early Pleistocene.

Each of the five, from Baker and Glacier Peak that barely raise their heads above the high Cascade peaks in northern Washington, to Adams, Saint Helens, and Rainier that tower into the sky above the lower mountains in the southern part of the State, shows one or more marks of volcanic activity since the Pleistocene ice age. The snow and ice mantle at the top of Rainier is broken by the rims of three cones, one inside the other. Volcanic ash resting on glacial deposits, casts of burned-out logs in lava flows on the flanks of the mountains, and hot sulfurous gases and hot springs issuing from their crests or flanks indicate that these giants are not dead, but only sleeping.

AFTERWORD



It is a circuitous approach to Cascade scenery that starts on a tropical coastal plain trending northwestward across the site of the present Range, and continues through a succession of landscapes of which only vestiges remain.

An alternative approach, seriously considered at the outset, would be to explain sets of distinctive landforms that characterize parts of the Range, with emphasis on the geologic processes by which they were modeled. This method has some advantages, but Cascade landscapes are so varied in type that a comprehensive account of them would tend to develop into a systematic treatment of the origin of landforms; that is, it would cover much the same ground as excellent books now readily available to any interested person. And it would also duplicate, to a greater or less extent, a number of articles dealing with the geology of special places in the State; these are listed on page 35.

It will be evident by now that in the historical approach adopted here the plural form— landscapes— refers not so much to present scenes from place to place in the Cascades as to vistas of the geologic past, restored by the mind's eye from any single vantage point. Three easy steps take us backward in time:

Because normal erosional processes have operated in the immediate past— the past few thousand years— much as at present, we can be sure that a little while ago, geologically speaking, the landscape was the same as now in type, but somewhat different in detail. On rocky headlands exposed to the fury of storm waves, and in badlands during a cloudburst, or on frost-riven cliffs, the changes may be rapid even by human standards. On a gentle grassed or forested slope the changes may be imperceptible in a lifetime, but the difference is only a matter of rate— the fact that the material creeps or is washed downslope, however slowly, means that if the base of a hill remains fixed, its slopes must be flattened. Conversely, if the base of a hill is cut rapidly by stream or ocean waves, its slope tends to become steeper.

The whole gamut of hill slopes, with every gradation from craggy cliffs to smooth, soil-mantled slopes is repeated again and again on the sides of the Yakima Gorge between Ellensburg and Yakima, depending on whether the individual meanders of the river are now shifting toward and steepening the slope by cutting at its toe, or moving away, and permitting erosional processes on the slope to lower it. These and all landscapes everywhere are evolving before our eyes, and there are reasons, usually not far to seek, for every element of their form. A good question to ask about any landform is, How was it different, a little while ago, assuming that conditions were then the same as now?

The next step in this historical approach to the appreciation of scenery is a longer one—a few tens of thousands of years in length. It depends on the familiar proposition that every geologic process produces its own distinctive landforms, both erosional and depositional. Cirques cut in the flanks of Cascade peaks, where there are now only lingering snowbanks in midsummer, mark the heads of glaciers that we can replace mentally just as surely as though we had been there to see them. The flat gravelly prairies around Fort Lewis, remote from any existing river, summon up a picture of melt-water rivers, shifting about on alluvial plains at the ends of glaciers in Alaska and on the south coast of Iceland. Shorelines, deltas, and bottom sediments testify to the existence of lakes in low parts of the Columbia and Yakima valleys that are now dusty dry. In a very real sense, most of the landscape features of Washington are holdovers from the not-very-remote past, when climatic conditions were very different from the present ones. We live in Pleistocene scenery, minus the glaciers.

The third step is in millions of years, to ancient scenes wholly unrelated to present landscapes, but which can be mentally restored with equal confidence on the basis of evidence recorded in the rocks. A coal bed near Cle Elum or Black Diamond means an Everglades; a stratum of sandstone with fossil shells near Issaquah, a Pacific Beach; a sheet of basalt in Grand Coulee, a Hawaiian river of lava; a layer of fine-grained volcanic ash, the fallout from the eruption of an ancient Krakatoa.

And these same strata have an altogether different significance—where they are tilted or folded and faulted they bear evidence of the movements of the earth's crust that formed Calkins Range and raised the Cascades to their present height.

We can look the other way, into the future development of Washington landscapes, as far as the imagination can reach. Because there have been several glacial stages in the past million years, separated by long intervals when the climates were as mild as now, it is not unreasonable to expect, some thousands of years hence, a recurrence of the same severe climatic conditions that filled the whole Puget Lowland with ice from Canada. And because Cascade volcanoes have been intermittently active for several million years, and last active within the past few thousand years, we may reasonably expect that one or more of these sleeping giants may awaken during the next few thousand years.

But these visualizations of the future on the basis of the past fail to take into account something new that changes all the rules— the advent of Man. Already he has in many places assumed command, for better or worse, of the surficial geologic processes by which landscapes are shaped. If the explosive growth of scientific knowledge continues, it is not altogether unlikely that he may modify climate to suit his needs, even to averting future glacial stages. Eventually, perhaps, he may even learn to exert some control over those seemingly immutable internal forces, manifested by volcanoes and earthquakes, that have kept the crust restive since the beginning of geologic time.

LIST OF SELECTED READINGS

Barksdale, J. D., 1941, Glaciation of the Methow Valley, Washington: Jour. Geology, v. 49, no. 7, p. 721-737.

Bretz, J H., 1932, The Grand Coulee: Am. Geog. Soc., Spec. Pub. 15, 89 p.

Bretz, J H., 1959, Washington's Channeled Scabland: Washington Div. Mines and Geology Bull. 45, 57 p.

Campbell, C. D., 1962, Introduction to Washington geology and resources: Washington Div. Mines and Geology Inf. Circ. 22R, 44 p.

Coombs, H. A., 1936, The geology of Mount Rainier National Park: Washington Univ. Pub. in Geology, v. 3, no. 2, p. 131-212.

Coombs, H. A., 1939, Mount Baker, a Cascade volcano: Geol. Soc. America Bull., v. 50, no. 10, p. 1493-1509.

Danner, W. R., 1955, Geology of Olympic National Park: Seattle, Washington Univ. Press., 68 p.

Fiske, R. S., Hopson, C. A., and Waters, A. C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geol. Survey Prof. Paper 444, 93 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Washington Div. Mines and Geology map.

Mackin, J. H., 1961, A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south-central Washington: Washington Div. Mines and Geology Rept. Inv. 19, 45 p.

Mackin, J. H., 1941, Glacial geology of the Snoqualmie-Cedar area, Washington: Jour. Geology, v. 49, no. 5, p. 449-481.

Misch, Peter, 1952, Geology of the Northern Cascades of Washington: The Mountaineer (Seattle), v. 45, no. 13, p. 5-22.

Snavely, P. D., Jr. and Wagner, H. C., 1963, Tertiary geologic history of western Oregon and Washington: Washington Div. Mines and Geology Rept. Inv. 22, 25 p.

Verhoogen, Jean, 1937, Mount St. Helens; a recent Cascade volcano: California Univ., Dept. Geol. Sci., Bull. 24, no. 9, p. 263-302.

University of Washington Geology Department Staff, 1963, A geologic trip along Snoqualmie, Swauk, and Stevens Pass highways: Washington Div. Mines and Geology Inf. Circ. 38, 51 p.

Weaver, C. E., 1937, Tertiary stratigraphy of western Washington and northwestern Oregon: Washington Univ. Pub. in Geology, v. 4, 266 p.