

## *Keechelus Problem, Cascade Mountains, Washington*

AARON C. WATERS

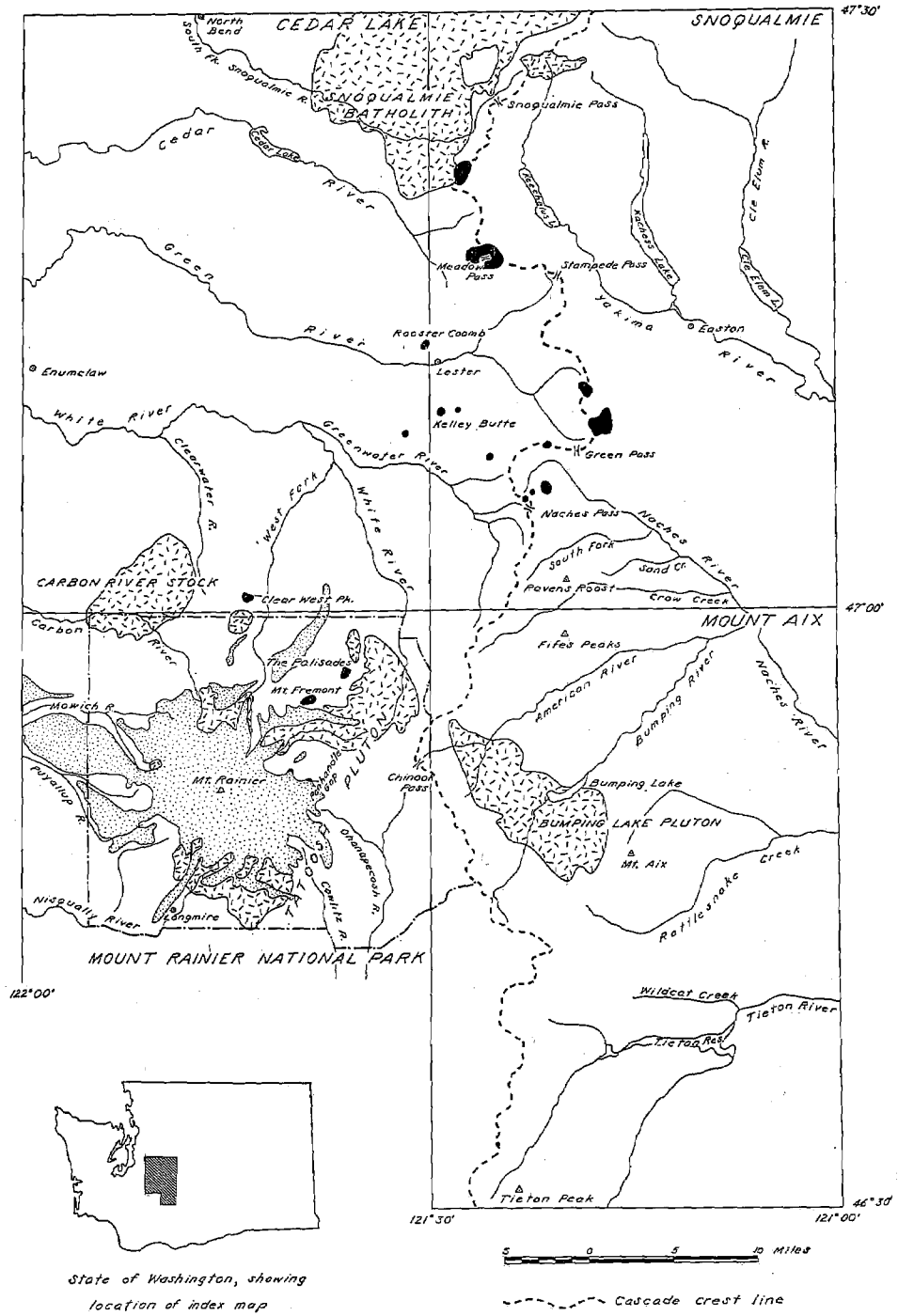
*Department of Geology  
The Johns Hopkins University  
Baltimore, Maryland*

SMITH AND Calkins (1906) defined the *Keechelus andesitic series*, and indicated that at Naches Pass it is divisible into post-Miocene unaltered lavas, and an older group of moderately altered and structurally deformed volcanic rocks of Miocene age. Later workers, without studying the Naches Pass area, extended and redefined the Keechelus series, suggested changes in its position in the geologic column, and brought forth other concepts of its stratigraphy. The result is confusion: the Keechelus andesitic series has been described as including rocks that range in age from Eocene to Recent.

This paper attempts to relate the stratigraphy of the Tertiary rocks in Mount Rainier National Park to the Keechelus andesitic series as exposed near Naches Pass. It confirms most of Smith and Calkins' basic concepts. Their upper Keechelus consists of lavas and explosive products that formed during a volcanic phase which accompanied the emplacement of the Miocene to Pliocene Snoqualmie and Tatoosh plutons (Fuller, 1925; Fiske, Hopson, and Waters, *in press*). Their lower Keechelus includes the probably lower Miocene Fifes Peak formation (chiefly basalt and basaltic andesite lavas and mudflows) and the concordantly underlying Stevens Ridge formation (chiefly rhyodacite ash flows) of Mount Rainier National Park. Eocene and lower Oligocene rocks outside the Snoqualmie quadrangle, which some writers erroneously referred to Smith and Calkins' Keechelus, may correlate with the Naches formation, which lies unconformably below lower Keechelus in the Snoqualmie quadrangle, or with the Ohanapecosh formation (perhaps an equivalent of the Naches), which lies unconformably beneath the Stevens Ridge formation in Mount Rainier National Park.

### *Work of Smith and Calkins*

G. O. Smith and F. C. Calkins (1906, p. 8) gave the name *Keechelus andesitic series* to a heterogeneous group of rocks that underlies much of Snoqualmie 30-minute quadrangle. This quadrangle includes the rugged area along the crest of the Cascades from Snoqualmie Mountain and Alta Mountain, north of Snoqualmie Pass, to the north flanks of the Fifes Peaks south of Naches Pass (Figure 1). Although Smith and Calkins considered



State of Washington, showing location of index map

Scale bar: 0 to 10 Miles. Dashed line: Cascade crest line

most of the Keechelus rocks to be altered andesitic lavas and pyroclastics, they included large amounts of dacite breccia (e.g., along the east shore of Keechelus Lake), and of rhyolite and rhyolite tuff (Alta Mountain and elsewhere). Lesser amounts of basalt and of well-bedded tuffaceous shales, volcanic sandstones, and epiclastic volcanic breccias were also included.

Smith and Calkins described a clear-cut division at Naches Pass between an upper Keechelus group, consisting of relatively fresh lavas, and a more deformed lower Keechelus group, consisting of altered lavas, mudflows, pyroclastics, and epiclastic volcanic rocks. They report that some of the younger lava is as fresh as any from recently extinct volcanoes of the Cascade Range, whereas the older rocks are devitrified, and most show even greater alteration with partial breakdown of plagioclase and extensive replacement of the ferromagnesian minerals and groundmass materials.

During their quadrangle mapping of this complex and isolated region Smith and Calkins did not have time to trace out completely the separation between upper and lower Keechelus. They said, for example, that in the Naches Pass area (1906, p. 8):

Along the north side of Greenwater Valley, the boundary between the older and younger rocks can be traced with passable accuracy. In areas farther south, however, the separation was found to be impracticable . . . the older rock is less altered than usual, probably because it consists of massive lava.

In short, the criteria, while sufficient to establish the presence of two distinct groups of these volcanics, fail, except locally, to serve as the basis for the determination of the boundaries between them. On the average, the later andesite is much fresher, less tilted, and less dissected than the earlier.

Concerning the age of the Keechelus andesitic series Smith and Calkins (1906, p. 8) wrote:

---

Figure 1. Index map of a part of the Cascade crest in central Washington, showing localities referred to in the text. The area discussed is chiefly in Mount Rainier National Park, and in the headwaters of Greenwater and Naches rivers immediately northeast of the Park (southwest part of Snoqualmie quadrangle and adjoining parts of Mount Aix quadrangle).

Known Miocene-Pliocene plutonic masses are shown by dash pattern; contemporaneous small stocks and volcanic plugs are indicated in solid black. Bedded rocks, including the "Keechelus andesitic series," are not differentiated. The much younger Mount Rainier lavas are shown by stippling. Geology simplified from Smith and Calkins (1906), Warren (1941), Abbott (1953), and Fiske, Hopson, and Waters (*in press*).

The lower and altered portion of the Keechelus series may without doubt be considered a true geologic unit, and its Miocene age is evident from its relations. In the northwestern part of the quadrangle it overlies the Swauk, Teanaway, and Guye formations, and its unconformable relations to these has been determined by field work.

They also report that in Naches valley the Keechelus andesitic series is overlain by the Ellensburg formation and underlain by the Yakima basalt, both of which were then generally believed to be of Miocene age. It is clear from their writing, however, that Smith and Calkins felt some misgivings about their assignment of a Miocene age to the series. Their dating the base of the Keechelus as no older than Miocene was based in part on its unconformable relation to the Guye formation, which crops out in a small area in the northwest part of the Snoqualmie quadrangle. They described it as consisting of:

. . . detrital rocks with some interbedded chert and limestone and interbedded basalts and rhyolites. . . . The formation is much folded and its structure cannot be worked out in detail, nor can any general section of it be compiled.

The Guye formation had been assigned to the Miocene on the basis of two plants, *Platanus dissecta* Lesq. and *Acer aequidentatum* Lesq. identified by F. H. Knowlton from a small collection of fossil leaves. Concerning this age assignment Smith and Calkins (1906, p. 7) wrote:

. . . the stratigraphic relations to the overlying rocks, added to the lithologic resemblance of the Guye formation (composed of interbedded sediments, basalt, and rhyolite) to the Eocene formations, would have led to its reference to the Eocene were it not for the paleobotanic evidence just cited.

Their assignment of a Miocene age to the top of the Keechelus andesitic series was based on the fact that the Ellensburg formation—then thought to be of upper Miocene age but now considered Early Pliocene (Axelrod, 1950; Chaney and Axelrod, 1959)—overlies the Keechelus andesite at several localities in Naches valley. But Smith and Calkins did not overlook the fact that in most of the area included in the Snoqualmie quadrangle the Ellensburg formation was missing, and hence the fresh lavas of the upper Keechelus might be of the same age as the Ellensburg or even younger. For example, they note that the upper Keechelus lava on the summit ridge near Naches Pass “appears to have been poured out after the extensive erosion which the Cascade Mountains suffered in Pliocene time.” In summary Smith and Calkins (1906, p. 8) state:

The Keechelus series is a lithologic unit, composed mostly of andesites from which the subordinate amounts of other rocks cannot be consistently separated. In age, however, it has not the unity generally required of a formation, for while it is mainly Miocene it contains some material that is almost certainly post-Miocene.

Thus it is evident that Smith and Calkins regarded the Keechelus andesitic series of the Snoqualmie quadrangle as a heterogeneous group of rocks of variable lithology and age, which needed much more detailed mapping and stratigraphic subdivision before extensive correlations were made to it from other regions.

### *Correlations and Revisions Made by Later Workers*

Despite the uncertainties clearly outlined by Smith and Calkins, other workers did not hesitate to assign rocks from many parts of the Cascade Range to the Keechelus andesitic series. Several authors mention the occurrence of "extensions" of the Keechelus series at various localities in the area between the Skykomish basin (W. S. Smith, 1916) on the north and the Columbia River gorge (Felts, 1939) on the south. A few of these correlations were based strictly on the age assignment of the Keechelus rocks to the Miocene, but nearly all were based on partial lithologic similarity, or on dubious evidence of similar stratigraphic position. Such correlations have led to much confusion concerning what is meant by Keechelus. Work outside the Snoqualmie quadrangle, moreover, seemed to indicate that the assignment of a Miocene age to the bottom of the series was in error. Since Smith and Calkins' time there has been a tendency to move the Keechelus andesitic series lower in the time scale, and to correlate its lower part with rocks chiefly of Oligocene and Eocene age. Some examples of these changes for specific areas (see Figure 1) are as follows:

*Mount Rainier area.* Coombs (1936, p. 150) extended the Keechelus andesitic series to include a varied assemblage of altered lava flows, epiclastic volcanic rocks, and swarms of hypabyssal intrusives which underlie over half the area of Mount Rainier National Park.

The Keechelus rocks of the Snoqualmie region can be traced with continuity directly across into the Mount Rainier region. . . . Within the Mount Rainier sheet this series outcrops almost continuously along all four of the Park boundaries and extends inward, finally disappearing under the lavas of Mount Rainier.

Coombs commented on the extreme heterogeneity of these rocks and said (p. 165): "The Keechelus series can scarcely be regarded as a unit." Recent geologic mapping of Mount Rainier National Park by R. S. Fiske, C. A. Hopson, and the writer underscores Coombs' doubt about the validity of including all the diverse volcanic and sedimentary rocks older than Mount Rainier volcano in a single stratigraphic unit. We found that the pre-Rainier rocks are divisible into several formations, some of which are separated by

unconformities. They range in age from Eocene to Pliocene (Fiske, Hopson, and Waters, *in press*), and uncertainty arose as to which, if any, of them should be regarded as parts of the Keechelus series.

*Guye Peak-Snoqualmie Pass area.* Coombs (1936, p. 166) also cast doubt on Smith and Calkins' conclusion that the unconformable relation of the Keechelus series to the Guye formation established the Miocene age of the Keechelus. He pointed out that the Guye formation had been assigned to the Miocene on only two fossil plant species, and also noted that the limestones and cherts which Smith and Calkins included as part of the Guye formation have no counterparts in other formations of the Cascades that are known to be Tertiary.

Coombs' doubts as to the age of the fossil flora from the Guye formation—first raised by Smith and Calkins themselves—have been confirmed. Roland W. Brown (as reported in Warren, 1941, p. 810) examined the fossils previously studied by Knowlton, and found that the two supposedly Miocene forms were probably only leaf variations of a single species, perhaps ancestral to *Platanus dissecta* Lesq. But the collection also contained fragmentary specimens of *Ficus*, and excellently preserved specimens of a *Cinnamomum* comparable to, and perhaps identical with, *Cinnamomum dilleri* Knowlton, an Eocene guide fossil abundant in the Comstock flora of western Oregon. These fossils indicate that the Guye formation is of Eocene age. More recently Foster (1960, p. 113) obtained another small collection of fossil leaves from the Guye formation on Coal Creek, near Snoqualmie Pass. These were also identified by Brown, who said: "This is an Eocene assemblage, and probably from the later half of the Eocene."

Foster (1960, pp. 112-113) restudied the Guye formation, subdivided the rocks described by Smith and Calkins, designated a "type area" for the restricted Guye formation, and reported that "On Denny Mountain, the Guye is overlain, apparently unconformably, by the Keechelus andesite breccia that forms the summit ridge."

*Mount Aix quadrangle.* Significant relations bearing on the stratigraphy and age of the Keechelus andesitic series were found by Warren (1941) in his study of the Mount Aix quadrangle, which adjoins the Snoqualmie quadrangle on the south. From the Keechelus rocks exposed along the common border of the two quadrangles Warren separated out and traced southward one unit that he named the Fifes Peak andesite. This, he found, lay beneath the Yakima basalt instead of above it as Smith and Calkins had supposed.

Beneath the Fifes Peak andesite is a group of highly altered and deformed rocks—chiefly epiclastic volcanic rocks, dacite breccias, felsites, and basalts.

Warren suggested that these can be subdivided further, but said (p. 789) that his studies were "too incomplete to burden it with a new name, so that in the present discussion it will be referred to simply as the lower part of the Keechelus." The contact between the Fifes Peak andesite and most of these older rocks is an unconformity (p. 800), and Warren assumed that this unconformity was the one recognized by Smith and Calkins between their upper Keechelus and lower Keechelus at Naches Pass. He therefore correlated the Fifes Peak andesite with Smith and Calkins' upper Keechelus (Warren, 1941, pp. 801, 811). But Warren (personal communication) was unable to visit Naches Pass in the course of his field work. From the evidence given in his report the Fifes Peak andesite could just as well be correlated with the lower Keechelus as with the upper—and, as will appear later, it actually does belong to the lower Keechelus.

In the same year that Warren's results were published R. Y. Grant (1941, p. 591) announced that he had discovered the remains of *Eporeodon*, an Oligocene or early Miocene oreodont, "in the tuffaceous shales of the lower third of the Keechelus andesitic series, as restricted by Warren," near Wildcat Creek in the Mount Aix quadrangle. This locality is stratigraphically below Warren's Fifes Peak andesite. Grant suggested that the oreodont-bearing beds are probably equivalent to the Oligocene John Day formation of central Oregon.

Grant's discovery of an Oligocene or early Miocene oreodont in the rocks below the Fifes Peak andesite, coupled with Warren's discovery that the Fifes Peak andesite underlies the Miocene Yakima basalt, seemed to demand that the age of the Keechelus andesitic series be shifted downward from the post-Miocene and Miocene position assigned to it by Smith and Calkins. It appeared that the upper Keechelus (which Warren had correlated with the Fifes Peak andesite) was lower Miocene, and the lower Keechelus was pre-Miocene. But, as we shall see, Warren's error in correlating the Fifes Peak andesite with the upper Keechelus led to further confusion.

*Keechelus Lake area.* Foster (1960) recently reported on an area in the Snoqualmie quadrangle north of Keechelus Lake, and about 45 miles north of the center of the region investigated by Warren and Grant. Foster split off the lower part of the Keechelus andesitic series, as mapped by Smith and Calkins in this area, and assigned it "because of lithic similarity, [and] apparently similar structural and stratigraphic position" (p. 115) to the Naches formation, a group of interstratified sedimentary rocks and basalts of Eocene age which Smith and Calkins had mapped as underlying the Keechelus andesitic series in the southern part of the Snoqualmie quadrangle. Foster,

however, retained the name Keechelus andesite for the upper part of the local Lake Keechelus section—exactly the opposite procedure from that followed by Warren. Foster describes his restricted “Keechelus andesite” as a heterogeneous group of highly altered basalts, andesites, and rhyolites, with smaller amounts of volcanic sedimentary rocks. This is the previously mentioned area (Keechelus Lake and Alta Mountain) in which Smith and Calkins found greater amounts of dacite breccia and of rhyolite and rhyolite tuff than they did in other areas of Keechelus in the Snoqualmie quadrangle.

Foster deemed it necessary to designate a new “type area” for the Keechelus andesite. He admitted that Smith and Calkins’ description of the twofold division of the Keechelus far to the south at Naches Pass and Pyramid Peak “could be considered as designating a type area,” but added that “the area is remote, and no one has used it as a type.” The new “type area” proposed by Foster (1960, p. 120) is

on the west face of Rampart Ridge at the latitude of Rachel Lake. . . . These rocks are bedded, and their structure can be mapped, but no general section can be described because the alteration is such that their aspect changes markedly along the strike of a given bed.

This area is poorly chosen as a “type” because of the marked alteration of the rocks. Other reasons that make it unsuitable are the invasion of these rocks by the Snoqualmie batholith, the absence of fossils, and the fact that the area is separated from the main belt of the Keechelus andesitic series by intrusive masses, older formations, and the glaciated valley of Keechelus Lake. Foster gave no section of the rocks, nor does he describe the base of the formation, its top, or any distinctive unit within it. His statements about the base of the formation and its stratigraphic and structural relations to the Naches formation are indefinite and seemingly contradictory (Foster, 1960, pp. 115, 116, 119, 120). From the inadequate information he gave it has not been possible to relate Foster’s new “type area” to the Fifes Peak area described by Warren, or to other occurrences of Keechelus rocks, either within the Snoqualmie quadrangle or outside it.

### *Confusion as to the Present Meaning of Keechelus*

The contributions of Brown, Warren, and Grant have greatly increased our knowledge of the Tertiary stratigraphy of the Washington Cascades, but have left the Keechelus problem unsolved and even more confusing than before. Rocks equated with the Keechelus andesitic series by different authors

range in age from Eocene to Quaternary. Undoubtedly the original Keechelus of the Snoqualmie quadrangle can be separated into more than one formation, as Smith and Calkins had in fact anticipated, but it is unlikely that all the rocks outside the Snoqualmie quadrangle that have been correlated with it are equivalent.

Confusion prevails at present to to what the term Keechelus means. Compare, for example, recent statements by Foster, Fisher, and Abbott: Foster (1960, p. 101) assigned the Keechelus of his area to the Oligocene-Miocene because of the oreodont found by Grant in the Mount Aix quadrangle, but what evidence is there that the oreodont-bearing beds in the Mount Aix area are the equivalent of Foster's "restricted Keechelus" on Rampart Ridge? Fisher (1954) extended the term Keechelus to include volcanic components of the Eocene Puget group. Abbott (1955) says: "The Fifes Peak andesite, inappropriately called Keechelus by early workers, overlies the Keechelus with angular unconformity." Abbott apparently holds that all "true" Keechelus rocks lie unconformably below the base of the Fifes Peak andesite.

Parts of the Keechelus series that can be easily traced have been split off and given new names, leaving the difficult or less well-studied rocks behind in the Keechelus wastebasket. Warren split off the Fifes Peak andesite, and designated the rocks *below* it the "lower part of the Keechelus formation." Foster split off the lowest rocks mapped as Keechelus by Smith and Calkins in his area, assigned them to the Naches formation, and redefined the Keechelus to include only the rocks *above* his enlarged Naches formation. Neither Warren nor Foster investigated the relations at Naches Pass where Smith and Calkins made their separation into an unaltered upper Keechelus and an altered and deformed lower Keechelus. Hence it is not clear what correlations, if any, are to be made between either of Smith and Calkins' two divisions of the Keechelus and the "Keechelus" as defined by either Warren or Foster.

### *Recent Work Bearing on the Problem*

#### Mount Rainier National Park

Mount Rainier National Park lies immediately southwest of the Snoqualmie quadrangle (Figure 1). Recent geologic mapping of the Park has revealed an eventful history of volcanism, sedimentation, igneous intrusion, and deformation during the Cenozoic. Rocks within the Park which formerly had been correlated with the Keechelus andesitic series by Coombs (1936) have

been divided into several formations. The detailed stratigraphy of these rocks, including full descriptions of the newly defined Ohanapecosh and Stevens Ridge formations, are given in a Professional Paper of the U.S. Geological Survey (Fiske, Hopson, and Waters, *in press*).

A condensed stratigraphic table of part of the Tertiary rocks in Mount Rainier National Park is listed in the left column of Table 1.

The oldest rocks make up the *Ohanapecosh formation*, well exposed in highway cuts for several miles both west and east of the settlement of Ohanapecosh in the southeastern corner of the Park. This formation, of late Eocene age, is over 10,000 feet thick. It consists of thick lensoid accumulations of lavas and mudflows surrounded by vastly greater volumes of water-laid clastic rocks, mainly massive tuff-breccias interstratified with thin-bedded volcanic silts, volcanic graywackes, and gritty pumiceous conglomerates. Practically all the material is of volcanic derivation; most of it is andesitic and dacitic in composition, but it includes minor amounts of basaltic and rhyolitic material as well.

The Ohanapecosh formation has been folded and faulted, and is metamorphosed to the zeolite facies. It was uplifted, extensively eroded, and locally weathered to a thick red saprolite before the Stevens Ridge formation was deposited.

The *Stevens Ridge formation*, well exposed on the south flank of Stevens Ridge, overlies the Ohanapecosh formation unconformably (Fiske, Hopson, and Waters, *in press*). It is probably of late Oligocene or early Miocene age. The formation, deposited on a surface of considerable relief, reaches a thickness of about 3,000 feet in Mount Rainier National Park. It is composed almost entirely of rhyodacite ash-flow deposits, but includes subordinate epiclastic volcanic rocks toward the top. Most ash flows contain abundant 1/4- to 2-inch flattened pumice lapilli (largely altered to celadonite and other secondary products), and abundant phenocrysts of rounded quartz and euhedral plagioclase. The matrix consists mainly of devitrified glass shards and small pumice fragments.

The *Fifes Peak formation*, an assemblage of basaltic and andesitic lava flows and mudflows, with minor amounts of tuffaceous clastic rocks, concordantly overlies the Stevens Ridge formation. Its maximum exposed thickness in Mount Rainier National Park does not exceed 2,300 feet, but its top is eroded. North of the Park, in the Cedar Lake quadrangle, it attains a thickness of more than 5,000 feet. It is probably of early Miocene age.

This formation, as redefined in the report on Mount Rainier National

Park (Fiske, Hopson, and Waters, *in press*), is equivalent to the main bulk of the Fifes Peak andesite as described by Warren from its occurrence in the Mount Aix quadrangle. It does not include, however, the acidic tuffaceous rocks and ash flows beneath these andesites and basalts, which Abbott (1953) included in his Fifes Peak andesite, but which we assign to the Stevens Ridge formation.

In Mount Rainier National Park the Fifes Peak formation is dominantly lava flows. Olivine basalt and pyroxene basaltic andesite greatly predominate, but there are a few flows of rhyolite. The Fifes Peak lavas are devitrified and slightly to moderately altered: olivine and hypersthene are replaced by saponite, chlorite, or carbonate. Plagioclase phenocrysts are generally fresh, but in places they are altered to clay minerals, carbonate, albite, and epidote.

The Fifes Peak and older formations were folded and eroded, and then, probably in the late Miocene, were invaded by the *Tatoosh granodiorite pluton* and its retinue of satellitic sills, dikes, stocks, and volcanic plugs. The pluton broke through to the surface in places, and initiated a volcanic phase (Fiske, Hopson, and Waters, *in press*), but only small remnants of the pyroclastic rocks then deposited have survived erosion. One of these, a mass of rhyodacite welded tuff at least 800 feet thick, forms The Palisades, in the northeastern part of the Park.

#### Snoqualmie Batholith Area

The Snoqualmie batholith, 45 miles to the north of the Tatoosh pluton, and contemporaneous with it, also deroofed itself explosively (Fuller, 1925). Fuller regards its explosive products in the Cedar Lake quadrangle as the equivalent of Smith and Calkins' upper Keechelus. The underlying lower Keechelus rocks and older Eocene formations of the Cedar Lake area have been invaded and metamorphosed by the Snoqualmie batholith, just as the Fifes Peak, Stevens Ridge, and Ohanapecosh formations were invaded and metamorphosed by the Tatoosh pluton in Mount Rainier National Park. The small remnant of welded tuff at The Palisades, a product of volcanic action during emplacement of the Tatoosh pluton, is probably the time equivalent of Fuller's "upper Keechelus" pyroclastic rocks, which are the products of explosive deroofing of the Snoqualmie mass in the Cedar Lake area. The Fifes Peak and Stevens Ridge formations, invaded by the Tatoosh pluton and its cortege of sills and dikes, might likewise correlate with the underlying Keechelus rocks of the Cedar Lake area, which have been invaded by the Snoqualmie pluton. Warren (1941, pp. 801, 811), however, equated the Fifes Peak andesite with Smith and Calkins' upper Keechelus. On this basis the Fifes Peak and Stevens Ridge formations in the Park should be upper

Keechelus, and the underlying Ohanapecosh formation ought to correspond to Smith and Calkins' lower Keechelus.

In an attempt to resolve these problems a reconnaissance of the Naches Pass area was made, in order to determine whether the formations worked out in Mount Rainier National Park could be related to Smith and Calkins' original upper Keechelus and lower Keechelus.

#### Naches Pass Area

The stratigraphic relations in the Naches Pass area are clear, and permit ready correlation of the formations there exposed with those in Mount Rainier National Park. Moreover, they are essentially as reported by Smith and Calkins in 1906.

The Cascade divide, for about two miles south of Naches Pass, is a nearly flat-topped tableland underlain by the lavas which Smith and Calkins called upper Keechelus. The largest flow is a fresh, highly glassy, dull black pyroxene "andesite," characterized by well-developed, but small and wobbly, columnar joints. As noted by Smith and Calkins (1906, p. 8), it crops out in a huge cliff overlooking the headwaters of the Middle Fork of the Naches River. Adjoining it on the north is a lighter colored and more porphyritic flow of hypersthene "andesite" characterized by a distinctive groundmass of fresh brown glass with an unusual pattern of flow-aligned crystallites. These crystallites include peculiar needle-shaped microlites of pigeonite, single twins of plagioclase with forked ends, and tiny feathery scapolites of hornblende. The phenocrysts are plagioclase, hypersthene, and augite. In both flows 50 to 80 per cent of the rock consists of completely undevitrified glass.

These lavas fill a former valley eroded in the dark-colored lavas and yellow tuffs of the underlying Fifes Peak formation (lower Keechelus of Smith and Calkins). The 300-foot cliff at the head of the Middle Fork of the Naches River gives a cross section of the intracanyon fill. Smith and Calkins (1906, p. 8) state, and we concur, that:

The lava forming this ridge appears to have poured out after the extensive erosion which the Cascade Mountains suffered. . . . Lithologically, some of the lava in the Naches and Greenwater basins appears as fresh as any that might be collected from the slopes of the recently extinct volcanoes of the Cascade Range.

*Equivalence of the lower Keechelus with the Fifes Peak and Stevens Ridge formations.* The valley filled by the glassy lavas described above was cut in porphyritic basalts, basaltic andesites, mudflows, and yellow tuffs such as are characteristic of the Fifes Peak formation in Mount Rainier National Park. These rocks also have the same stratigraphic position as the Fifes Peak formation, and are therefore correlated with it. Black and gray lavas with

saponitized ferromagnesian, and altered yellow tuffs and breccias, predominate in the Fifes Peak near Naches Pass. On the Cascade crest about two miles northeast of Pyramid Peak, the formation also includes an altered welded tuff of more acidic composition containing flattened blue-green fragments of celadonitized pumice. Fifes Peak lavas with minor amounts of volcanic mudflows are prominent in the headwaters of Crow Creek near the south edge of the Snoqualmie quadrangle. In the Mount Aix quadrangle about two miles south of the border of the Snoqualmie quadrangle, they culminate in the huge pile of mudflows and lavas that form the Fifes Peaks which gave the formation its name (Warren, 1941).

Warren's investigation of the Mount Aix quadrangle demonstrated that the Yakima basalt is younger than the Fifes Peak andesite. He writes (p. 805): "the Fifes Peak andesite formed a rugged shore for the flood of basalt flows—a shore against which the basalt piled up to a height of at least 1,500 feet." On the south wall of Crow Creek, in the southeastern part of the Snoqualmie quadrangle, flows of Yakima basalt also lap westward upon and against the Fifes Peak formation. Pumiceous breccias and conglomerates of the Ellensburg formation also rest unconformably upon the Fifes Peak in the southeastern part of the Snoqualmie quadrangle.

North of Naches Pass canyons tributary to Green River reveal successively older parts of the Fifes Peak formation until in their lower parts great ledges of strongly indurated rhyodacite ash flows, so typical of the Stevens Ridge formation, appear from beneath the Fifes Peak. About four miles west of Lester, in the Cedar Lake quadrangle, the unconformity between Stevens Ridge and the underlying Ohanapecosh strata is well exposed in the bed of Green River. Here a flat-lying dirty-gray ash flow, similar to the basal Stevens Ridge ash flow exposed at The Dalles on White River just north of Mount Rainier National Park, rests on well-bedded Ohanapecosh strata which dip 20 to 30 degrees to the west.

Structure as well as lithology thus indicates that the lower Keechelus rocks of the southern third of the Snoqualmie quadrangle are equivalents of the Fifes Peak and Stevens Ridge formations of Mount Rainier National Park. They lie unconformably beneath the fresh glassy "upper Keechelus" lavas of Naches Pass, and, in the adjoining Cedar Lake, Mount Rainier and Mount Aix quadrangles, they rest unconformably upon the Ohanapecosh formation. The unconformity which Warren found below the Fifes Peak andesite in the Mount Aix quadrangle is evidently the one that separates the Fifes Peak-Stevens Ridge sequence from underlying Ohanapecosh strata, not the one that separates "upper Keechelus" from "lower Keechelus" at Naches Pass.

*Relations of the Naches formation and Ohanapecosh formation.* The reconnaissance on which these notes are based did not extend to the areas underlain by the Naches formation in the southern part of the Snoqualmie quadrangle, but Smith and Calkins' (1906, p. 5) description of the Naches formation suggests that it may correlate with the Ohanapecosh formation. Like the Ohanapecosh it lies unconformably beneath lower Keechelus as mapped by Smith and Calkins, and it has the same lithologic variations found in the Ohanapecosh, even including a prominent rhyolite facies near its base.

Smith and Calkins, however, included at least some patches of Ohanapecosh strata with the rocks they mapped as Keechelus in the northern part of the Snoqualmie quadrangle. Near the summit of Stampede Pass, for example, in an area that they mapped as Keechelus, steeply tilted Stevens Ridge ash flows were seen resting with angular unconformity upon rocks that closely resemble Ohanapecosh strata. On the east shore of Keechelus Lake a huge altered quartz-rich ash flow, resembling the basal Stevens Ridge ash flows of Mount Rainier National Park, overlies thin-bedded strata somewhat similar to the Ohanapecosh, and contains abundant fragments of these strata in its lower part.

*Relation of upper Keechelus rocks to the Tatoosh pluton.* We return now to the glassy upper Keechelus lavas that rest unconformably upon the Fifes Peak formation at Naches Pass. Similar glassy lavas crop out several miles east of Naches Pass along the trough of the syncline followed by the Naches River. There, near Bench March 3119 as marked on the Snoqualmie folio, Smith and Calkins (1906, p. 8) collected a specimen from a flow of "Keechelus hypersthene andesite" and had it chemically analyzed. They describe the flow as characterized by a hyalopilitic texture with abundant brown glass. "It is perfectly fresh, and therefore probably belongs to one of the later post-Miocene flows" (p. 8). This deduction as to its age is confirmed by the appearance of Yakima basalt in the bed of Naches River immediately adjacent to this locality. The chemical analysis of the "Keechelus hypersthene andesite" brought forth this comment from Smith and Calkins (1906, p. 8):

The rock contains an unexpectedly high percentage of silica and the analysis as a whole bears a strong resemblance to that of the Tertiary granodiorite, to be described later, but the andesite is more siliceous. [The andesite contains 62.77 per cent  $\text{SiO}_2$ ; the granodiorite 60.49 per cent.] According to the new quantitative classification, it falls in the same division, tonalose. It is evident that the glass is rich in silica and potash, and that, if it were completely crystallized, it would contain much quartz and considerable orthoclase, both of which are essential constituents of the granodiorite.

These glassy upper Keechelus "andesites" are chemically and mineralogically the same as the rhyodacite welded tuff, related to the Tatoosh pluton, that occurs at The Palisades in Mount Rainier National Park. Moreover a probable genetic connection between Smith and Calkins' upper Keechelus lavas and the volcanic phase of the Tatoosh pluton is indicated by the occurrence, in the area lying immediately north and northeast of the headwaters of Naches River, of a nest of plugs, dikes, and small stocks of the same kinds of rocks found to be associated with the Tatoosh pluton in Mount Rainier National Park (Figure 1). Pyramid Peak, Kelley Butte, Rooster Comb, and other unnamed buttes, which cluster in the area north of Naches Pass and near Lester, are eroded plugs of glassy to microcrystalline hypersthene-augite and hypersthene-hornblende "andesites" (rhyodacites) similar to the Tatoosh plugs of Mount Rainier National Park. Along the Cascade crest northeast of Naches Pass, moreover, Smith and Calkins mapped three quartz-bearing "pyroxene diorite" stocks of the kind that Fuller (1925) proved to have solidified in cupolas and vents through which the magma of the Snoqualmie batholith burst explosively to the surface (Figure 1). Smith and Calkins (1906, p. 9) also thought these stocks were feeders of Keechelus lavas and pyroclastics:

These bodies of diorite are believed to represent the roots of the volcanoes from which the Keechelus volcanics were erupted, the belief being founded upon relations observed in the field and upon the petrographical similarity between the diorite and the Keechelus andesite.

They describe a transition between intrusive and extrusive rocks at the Meadows Pass stock, which is near the edge of the Snoqualmie batholith in the northern part of the Snoqualmie quadrangle, and suggest (p. 9) that such a transition may also exist at the Green Pass stock, which lies about six miles northeast of Naches Pass and about the same distance northwest of the chemically analyzed flow in Naches valley.

Thus the upper Keechelus lavas of the Naches River area were probably erupted during the volcanic phase of emplacement of the Tatoosh pluton.

*Relation of upper Keechelus rocks to the Ellensburg formation and Yakima basalt.* Smith and Calkins (1906, p. 8) mention another area of upper Keechelus lava, about six miles southeast of Naches Pass, that is of exceptional interest because of the light it throws on the regional stratigraphy, especially the relationships among the upper Keechelus, the Ellensburg formation, and the Yakima basalt. Here they found evidence that part of the upper Keechelus may be equivalent in age, or even younger than the Ellensburg formation:

The only stratigraphic evidence available is afforded by a locality on the ridge north of Crow Creek, where a little andesite apparently overlies the Ellensburg sandstone, but the contact is not well enough exposed to prove this relation.

Near this locality, too, they observed relations that they regarded as proving the Miocene age of the main part of the Keechelus andesitic series (p. 8):

In the southern part of the quadrangle the Keechelus lavas are overlain by beds of the Ellensburg formation, of late Miocene age, while in the same vicinity the Keechelus lava overlies the Miocene Yakima basalt. Thus the main portion of the Keechelus series underlies one Miocene formation and is underlain by others so that its Miocene age is well determined.

Stratigraphic relations seen on the ridge north of Crow Creek, especially in and near Section 19, Township 18 North, Range 13 East near the head of Sand Creek, fully confirm Smith and Calkins' field observations. In Section 19 glassy "andesite" flows are interbedded with pumiceous sedimentary rocks of the Ellensburg formation. One of these flows, moreover, has the same peculiar glassy groundmass with crystallites of needle-like pigeonite and scapolitic hornblende that was noted in the porphyritic flow of upper Keechelus lava at Naches Pass. It may be a remnant of the same flow. Moreover, these sedimentary rocks and intercalated lavas rest, not upon the Fifes Peak basalt, as at Naches Pass, but upon Yakima basalt that crops out in the canyon of Sand Creek. But the evidence at this locality does not justify Smith and Calkins' assignment of the entire Keechelus andesitic series to the Miocene, for the lavas here are upper Keechelus. These rocks are interbedded with the Ellensburg formation and rest on Yakima basalt, and hence are of post-Miocene age; but the lower Keechelus, exposed only a little farther west, consists of Fifes Peak basalts and andesites, and lies unconformably beneath the Yakima basalt.

The Crow Creek divide appears to be the precise locality where Smith and Calkins had difficulty in separating their upper Keechelus and lower Keechelus. Three miles west of Section 19 the divide between Crow Creek and the South Fork of the Naches bears a peak called Raven's Roost (see Figure 1), indicated by the elevation figure 6,221 on the Snoqualmie quadrangle maps. Raven's Roost is underlain by Fifes Peak andesite, but on its east slope the volcanic conglomerates and pumiceous water-laid tuffs of the Ellensburg formation overlie and bank against an erosion surface carved across the Fifes Peak lavas. Perhaps this conspicuous unconformity, easily traced in a continuous exposure for nearly a mile to the east, is the locality of which Smith and Calkins (1906, p. 8) wrote:

In areas farther south, however, the separation [between upper Keechelus and lower Keechelus] was found to be impracticable. Some black andesite quite similar to that of the upper flows was seen, plainly overlain by the Ellensburg formation. The effort to draw a boundary between this rock and the supposed post-Miocene lava was unsuccessful, since the older rock is less altered than usual, probably because it consists of massive lava.

The Fifes Peak lava at Raven's Roost is black to dark gray, and has a deceptively fresh appearance from abundant saponite, an alteration product of the ferromagnesian minerals. This waxy black mineral gives the rock a dark greasy appearance on fresh fracture.

These stratigraphic relations in the area near Naches Pass, Sand Creek, and Crow Creek indicate that Smith and Calkins' "upper Keechelus" lavas are contemporaneous with the part of the Ellensburg formation that is exposed in the southeastern part of the Snoqualmie quadrangle. The cobbles of lava in the Ellensburg there are dominantly of gray to black, porphyritic, highly glassy "andesites" (rhyodacites) containing hypersthene, and either augite or hornblende or both. Oxidized pink to orange-red variants of the same lava are common. Fragments of white to pale pink pumice, however, are by far the most voluminous constituents of the local Ellensburg deposits. Most of the fragile pieces of pumice are little broken or rounded by transport, indicating that the cross-bedded and strongly channeled pumiceous sediments were carried only short distances and deposited quickly by streams whose headwaters were constantly choked with pyroclastic debris from contemporaneous volcanoes. It is significant, too, that careful search of a large exposure of Ellensburg strata will generally reveal at least a few cobbles of typical Tatoosh "sill rocks," or small chips of these intrusive rocks, embedded in fragments of pumice. The source areas of these lava and pumice fragments are the plugs and stocks which lie north and west of the headwaters of Naches River, and which probably connect with the Tatoosh pluton at depth.

The flows of Yakima basalt and the water-laid debris of the Ellensburg formation overlapped farther and farther westward upon the rugged highland of Fifes Peak andesite as Tatoosh volcanism continued. Near the Tatoosh vents, the less mobile lava flows and coarse mudflow deposits interdigitate with the pumice-rich water-laid deposits of the Ellensburg formation.<sup>1</sup>

<sup>1</sup>The statements made herein apply only to the Ellensburg formation as developed in the Naches valley of the Snoqualmie quadrangle, and near Nile in the Ellensburg and Mount Aix quadrangles. In these areas the Ellensburg formation contains much coarse volcanic conglomerate and coarse mudflow material, and is composed almost entirely of debris that evidently came from Tatoosh vents. Farther east, in the Yakima area, the Ellensburg formation is much more complex, consists of finer-grained sediments, and has received abundant sedimentary detritus from other sources than the explosive eruptions from the Snoqualmie and Tatoosh plutons (Waters, 1955, pp. 673-675; Fiske, Hopson, and Waters, *in press*).

CORRELATION CHART OF LOWER AND MIDDLE TERTIARY ROCKS, CENTRAL WASHINGTON

	Mount Rainier National Park (Fiske, Hopson and Waters)	Southern Third of Snoqualmie Quadrangle (Smith and Calkins, 1906)	North Part of Mount Aix Quadrangle (Warren, 1941)
PLIOCENE	L		
	U		Ellensburg formation
MIOCENE	U	Tatoosh Pluton and associated volcanic rocks	Yakima Basalt
	M	(Unconformity)	(Unconformity)
	L	Fifes Peak formation	Lower Keechelus Andesitic Series
OLIGOCENE	U	Stevens Ridge formation	Fifes Peak Andesite ("Upper Keechelus")
	M		? Oreadont-bearing beds ?
	L	(Unconformity)	(Unconformity)
	L		? Unconformity ?
Eocene	U	Ohanapecosh formation	"Lower Keechelus"
	M		Naches formation

In summary what I regard as the probable correlations of the rocks in Mount Rainier National Park, the southern part of the Snoqualmie quadrangle, and the northern part of the Mount Aix quadrangle are indicated in Table 1.

The confusion that has prevailed regarding the use of the terms upper Keechelus and lower Keechelus, however, cannot be completely resolved by returning the name Keechelus andesitic series to the rocks (and their stratigraphic equivalents) originally assigned to the series by Smith and Calkins. Perhaps the best way out of this confusion is to abandon the name Keechelus andesitic series, and make use of the better defined formations—the Ellensburg, Fifes Peak, and Stevens Ridge—each of which appears to correlate with a part of the original Keechelus andesitic series. This suggestion is also in keeping with Smith and Calkins' intent, for it is clear that they anticipated that the series must ultimately be split up into two or more formations (1906, p. 8).

#### *Acknowledgments*

The geologic mapping of Mount Rainier National Park, which has been drawn on heavily for stratigraphic information in this paper, was done by Richard S. Fiske, Clifford A. Hopson, and the writer. Both Fiske and Hopson helped materially with the interpretations made here, and Fiske also participat-

ed in the reconnaissance of the southern part of the Snoqualmie quadrangle.

Paul Hammond, geologist for the Northern Pacific Railroad, guided us to outcrops of interest in the Green River valley. Frank C. Calkins, Walter C. Warren, J. Hoover Mackin, Howard A. Coombs, and Richard V. Fisher have read the manuscript and made helpful suggestions. The field work was accomplished, and most of the report written, during the tenure of a National Science Foundation Senior Postdoctoral Fellowship.

### *Literature Cited*

- Abbott, A. T. 1953. The geology of the northwest portion of the Mount Aix quadrangle, Washington: unpublished Ph.D. dissertation, Univ. of Washington, Seattle.
- . 1955. Volcanic and sedimentary stratigraphy in the Cascade Range, east of Chinook Pass, Washington (abstract): *Geol. Soc. America Bull.*, 66: 1641.
- Axelrod, D. I. 1950. Studies in late Tertiary paleobotany. VI. Evolution of desert vegetation: *Carnegie Inst. Wash., Pub.* 349, pp. 23-48.
- Chaney, R. W., and D. I. Axelrod. 1959. Miocene floras of the Columbia plateau: *Carnegie Inst. Wash., Pub.* 617.
- Coombs, H. A. 1936. Geology of Mount Rainier National Park: *Univ. Wash. Publ. Geol.*, 3: 131-212.
- Felts, W. M. 1939. Keechelus andesitic lava-flows of Washington in southward extension: *Pan. American Geol.*, 71: 294-296.
- Fisher, R. V. 1954. Partial contemporaneity of the Keechelus formation and the Puget group in southern Washington (abstract): *Geol. Soc. America Bull.*, 65: 1340.
- Fiske, R. S. 1960. Stratigraphy and structure of lower and middle Tertiary rocks, Mount Rainier National Park, Washington: unpublished Ph.D. dissertation, Johns Hopkins University, 163 pp.
- Fiske, R. S., C. A. Hopson, and A. C. Waters. *In press*. Geology of Mount Rainier National Park, Washington: U.S. Geol. Survey.
- Foster, R. J. 1960. Tertiary geology of a portion of the central Cascade Mountains, Washington: *Geol. Soc. America Bull.*, 71: 99-126.
- Fuller, R. E. 1925. The geology of the northeastern part of the Cedar Lake quadrangle, with special reference to the deroofed Snoqualmie batholith: unpublished M.S. thesis, Univ. of Washington, Seattle, 96 pp.
- Grant, R. Y. 1941. A John Day vertebrate fossil discovered in the Keechelus series of Washington: *Am. Jour. Sci.*, 239: 591-593.
- Smith, G. O., and F. C. Calkins. 1906. Snoqualmie folio, Washington: U.S. Geol. Survey, *Geologic Atlas United States*, No. 139, 14 pp.
- Smith, W. S. 1916. Stratigraphy of the Skykomish basin, Washington: *Jour. Geol.*, 24: 559-582.
- Warren, W. C. 1941. Relation of the Yakima basalt to the Keechelus andesitic series: *Jour. Geol.*, 49: 795-814.
- Waters, A. C. 1955. Geomorphology of south-central Washington, illustrated by the Yakima East quadrangle: *Geol. Soc. Am., Bull.*, 66: 663-684.