GEOLOGY OF THE SNOHOMISH QUADRANGLE

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and

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INTRODUCTION

In the preparation of this thesis, it has been the object of the authors to draw their material as much as possible from original field work and from original statistical compilations. It has been found impossible, however, to truly limit the phases treated to this source. The geology of western Washington, like any science, has grown. Each investigator since the time when J. D. Dana made the first meager observations on the region, down to the present time has added a little to the growing mass of conceptions until a fairly connected history has been worked out.

It is manifestly impossible to attempt a work of this nature without due consideration for the invaluable historical background which has already been established. It has been found in this work that many geologic conceptions have developed which, as time has gone on, have been sufficiently proven to be generally accepted as facts. It has been found impractical, if not altogether impossible in many cases to give due credit to the true originator of each and every idea expressed in the text. Furthermore it would be hard to estimate exactly how many of the views expressed in the present treatise as more or less original conclusions have been influenced by what has already been written on the subject.

A list of the references which were studied in the preparation of this thesis is given in the bibliography, but attention is here called to the works of Dr. Weaver which are summed up, in so far as they apply to the general geology, in Bulletin 13 of the Washington Geological Survey, entitled "The Tertiary Formations of Western Washington." We have used this bulletin constantly as a guide in making our field observations. Much of our work is necessarily a repetition of material contained in this report. In only a few cases have our conclusions differed from those expressed by Dr. Weaver, and in these cases it may be that he has been in possession of facts which we have overlooked.

No attempt has been made to go into detail on the fauna of the Tertiary formations. Such would be merely an unnecessary repetition of the work of Dr. Weaver. Similarly glaciation has been referred to only in a superficial way. The details of the glacial history of the Puget Sound region can be found in the articles of Bretz and Willis referred to in the text.

In the preparation of the economic and structural maps, the precedent set by Dr. Weaver has been followed, and the Tertiary formations have been mapped as they are believed to occur even though covered by an unknown thickness of glacial drift. In one place, however, southwest of Seattle, bedrock lies so deep that the formations can not be reconstructed with any degree of probability. This area has therefore been mapped as Pleistocene.

The strikes and dips appearing on the structural maps are all from original traverses with the exception of those shown at Alki and Restoration points, these being copied directly from Weaver.

The authors are indebted to Mr. Nat Moore and Chief Engineer Ray Smith of the Pacific Coast Coal Company for their generous cooperation and use of the mine maps and original data of the Newcastle and Issaquah mines; to Mr. Lawrence Harris of the Harris-Richmond Coal Company of Issaquah, for mine maps and data of the Superior and Grand Ridge mines; to Mr. Jack Danielson of Renton for the use of mine maps of the May Creek mine; to Mr. C. F. Lawson of Seattle for the use of logs of deep wells in the quadrangle; to Dr. Ralph W. Chaney for the examination and comments on a new flora; and to Mr. R. B. Stewart who has very kindly turned over to us his notes representing several years of detailed study on the area around Duwamish.

PHYSIOGRAPHY AND GEOGRAPHY

Location

The Snohomish quadrangle, including around 817 square miles in total area, lies between latitudes 47° 30' and 48° North, and between longitudes 122° and 122° 30' West. Three-fourths or more of the area lies east of Puget Sound, but the greater width of this body of water is included within the quadrangle along the west edge, while parts of three of the larger islands of the sound, namely Vashon on the south, Bainbridge in the middle, and Whidby on the north, extend into the quadrangle from the west. Two of the larger sound cities lie within the boundaries of the area: Seattle covers a large part of the southwest corner, while Everett falls just within the limits on the north.

Physiography

Physiographically the greater part of the region can be described as a glacial drift plateau with an elevation of between 300 and 500 feet. Below this topographic datum plane on the one hand lie the larger hydrographic features of the area, while rising above it along the southeast corner of the quadrangle are the Newcastle Hills, Squak Mountain, and, in the extreme southeast corner, Tiger Mountain, all three members of what has been termed the Newcastle Uplift which extends across the sound valley from the Olympics on the west to the Cascades on the east. The highest elevation of the region, about 2000 feet, is reached in Squak and Tiger Mountains. Between the Newcastle Hills and Squak Mountain, Tibbetts Creek flows northward in a relatively narrow, deep, short valley, partly of normal erosional origin, partly of glacial origin. Issaquah Creek occupies a similar valley between Squak and Tiger Mountains. Both Creeks empty into the south end of Lake Sammamish less than one mile apart.

As a result of glaciation of the region, fresh water lakes are well represented within the quadrangle. Most of them are small, generally less than one mile across, and lie at the general elevation of the drift plain, but two of them, due to the occupation of their ancestral drainage line depressions by trunk lines of the northern ice, became, upon the final retreat of the glacier, prominent elongated bodies of water with surfaces well below the fifty-foot contour line. Lake Washington, the westernmost of the two, is twenty miles long, and averages from one mile to one and one-half miles wide. Mercer Island, lying at the widest part of Lake Washington, south of the center, is about four and one-half miles long and one mile wide. East of Lake Washington, Lake Sammamish, although formerly almost as long as its larger sister, is at the present time only about eight miles long, due to extensive sedimentation at the north and south with the formation of large fresh water marshes. It is about one mile wide throughout its present length.

The larger lake formerly existed as an estuary of the sound, but was cut off on the south, beyond the limits of the quadrangle, by the delta of Cedar River and converted into a fresh water lake. The Lake Sammamish trough has never been occupied by salt water.

At the east edge of the sheet, a little north of the center, the Skykomish and Snoqualmie Rivers, two of the numerous rivers draining the west side of the Cascades, unite to form the Snohomish which flows in a flood plain from one and one-half to two miles wide northwestward across the northeast corner of the quadrangle to Puget Sound at Everett. Only the northeast corner of the quadrangle is drained by the tributaries of the Snohomish, the divide on the south est lying generally within two miles of the valley.

The Snohomish River has not always followed its present course across the northeast corner of the quadrangle. Between Monroe on the Skykomish, just off the east edge of the sheet, and the town of Snohomish, is an igneous bedrock hill about four miles long, called Devil's Mountain, along the northeast side of which runs a low swampy valley averaging around a mile wide but without any significant stream. It lies at about the same elevation as the rest of the Snohomish River flood plain, and is followed by the roads and railroads leading up the river. The Snohomish River on the other hand follows a much narrower channel along the west side of Devil's Mountain, and although a flood plain has been developed, it is only about one-third as wide as the streamless valley northeast of the hill. Furthermore a considerable stretch of the river at the present time is overlooked immediately on the south by a 150- to 200-foot sedimentary bluff, while the higher slopes of the valley are more gently rounded. In one or two places too, the river hugs the igneous hill on the northeast so closely beneath an almost vertical bluff that the lower 200 feet on that side of the river are impassable. The lower part of the valley is thus more youthful than the upper slopes and decidedly out of harmony with the mature development of the Snoqualmie valley for several miles above Monroe, as shown on the Sultan quadrangle to the east.

The abandoned valley northeast of Devil's Mountain is directly in line with both the Skykomish and Snoqualmie rivers as developed above Monroe, and undoubtedly was eroded by the combined waters of these two rivers at a former time. Contemporaneous with this normal valley development, small subsequent creeks were eroding along the southwest side of Devil's Mountain, their positions and directions of flow being determined by the softer character of the sediments along this line. The valley above the bluff on the south side of the river shows the extent to which this drainage had progressed. Whether this minor drainage development was in both directions from a central divide, or in only one direction can not be stated with certainty, but from the present topography, it appears as if the larger, if not the only important creek flowed northwestward from near the southeast end of the present youthful valley.

Upon the last advance of the glacier from the north, a large lake of water was ponded in the Snoqualmie Valley south of the front of the ice. As soon as the low divide south of Devil's Mountain had become exposed by the retreat of the ice, the excess waters of the lake were diverted from some other outlet to this one. Erosion was rapid enough, due to the large volume of escaping water that, by the time the ice had retreated from the northwest end of Devil's Mountain, the new channel was low enough to continue carrying from the two rivers. The old channel was partially obstructed by glacial drift between the southeast end of Devil's Mountain and Monroe, so that the rivers have never reverted to their old course.

The other Cascade river which debouches within the quadrangle is the Duwamish, the northward continuation of White River, emptying into Elliot Bay at Seattle from the southeast. In its lower course it has developed a wide flood plain which becomes a tide-flat near its mouth. At the south edge of the sheet however, the extent of the valley has been greatly restricted by low bedrock hills.

The Duwamish River, before the cutting of the Lake Washington canal, was the ultimate drainage outlet for the greater part of the drift plateau included within the Snohomish quadrangle. Due possibly to some peculiarity in the mode of origin of the plateau, the drainage is everywhere inward to Lakes Washington and Sammamish, the divide being usually within two miles of either the sound on the west, or the Snohomish Valley on the northeast, the greatest distance being just east of Cathcart where the divide is back three miles from the valley. The waters of Lake Sammamish flow into Lake Washington at the north end through Sammamish River, so that the outlet of Lake Washington carries all the drainage of the plateau. This outlet was formerly by way of Black River from the south end of the lake into the Duwamish River. At the present time it is through the Lake Washington canal by way of Lake Union and Salmon Bay into the sound at Ballard, one of the northern suburbs of Seattle.

Industry

Industrially the region included within the Snohomish quadrangle is one of the most important in the Northwest. Everett and Seattle are both important shipping centers, Everett dealing mainly in lumber, while Seattle, being the closest Pacific port to the Orient, which possesses a good harbor and good terminal facilities, is the natural outlet for much of the produce of the inland region, in addition to being an important lumber shipping port. Seattle is the terminal for two of the large transcontinental railways, the Chicago, Milwaukee & St. Paul and the Northern Pacific as well as for the Oregon-Washington Railroad & Navigation Company, an important coast line on the Union Pacific system.

Both cities are important manufacturing centers, but Seattle is especially so. The Snohomish quadrangle has a greater population than any other quadrangle in the Northwest.

Next to commerce and manufacturing, agriculture is probably the most important industry, particularly the truck gardening, dairying, and poultry farming types. The alluvial flood plains of the rivers and larger creeks are extremely productive, and the uplands, though not particularly fertile, are near enough to a large consuming center to offset in a large part any original lack of fertility.

In the early days, logging was an industry of first importance; today, however, the timber from the greater part of the area within the quadrangle has been removed. Only on Tiger Mountain and on the east end of the Newcastle Hills are logging operations being carried on at the present time. The large engineering difficulties which have had to be overcome in the logging off of the steep higher slopes of Tiger Mountain testify better than words to the value of the resulting product.

Coal is an important resource of the region, and the coal seams at Newcastle were among the first worked within the state. Extensive developments have been made at Newcastle, Coal Creek, and Issaquah by the Pacific Coast Coal Company. At the present time, none of the mines are working very regularly, due to the lack of a demand for coal and to the competition of other districts. Improvements are kept up, however, and developments are going ahead, so that when the need is again raised, these mines will be able to employ several hundred men.

BEDROCK OUTCROPS AND TYPES OF SEDIMENTS

Due to a thick blanket of glacial drift throughout the whole sound region, bedrock outcrops are few within the Snohomish quadrangle and are confined to two general regions. The first area is along the valley of the Snohomish River between Snohomish, Cathcart, and Monroe. The second and most important belt follows the line of the Newcastle Uplift across the south one-sixth of the quadrangle.

In general it may be stated that bedrock occurs at the surface over most of the region east of Lake Washington and south of the north base of the Newcastle Hills, except for the region south of May Creek. The remaining outcrops within the Newcastle Uplift belt appear at isolated points at Columbia City (south Seattle), Georgetown (south Seattle), Duwamish, Alki Point, and Restoration Point.

At none of these smaller places west of Lake Washington does bedrock occur at a greater elevation than 300 feet above the sound, and at Alki and Restoration points, the highest outcrops are practically at sea level. Had the crest of this pre-glacial ridge stood at a very much lower elevation at the beginning of the glacial period, there would be no outcrops at present west of Lake Washington. As it is, what bedrock exposures do occur owe their appearance to especially favorable positions for exposure by erosion of the overlying drift at or near sea level, either by waves along the sound shore, or by river or ice along the Duwamish, or by ice along Lake Washington.

Both Eocene and Oligocene strata appear within the quadrangle; the rocks include shales, sandstones, conglomerates, coal, tuffs, and basic lava flows.

EOCENE

General Statement

The oldest strata outcropping within the basin of Puget Sound proper are of Eocene age, three distinct stratigraphic phases being well marked. Of these the oldest is the typical Puget Group, a term first applied by C. A. White to the great series of coal bearing strata of brackish water origin occurring along the east border of the sound from Chehalis to Bellingham. Near the top of this group is a thick series of lava flows, comprising the second phase of the Eocene. Immediately overlying and underlying one of the uppermost igneous flows, and recognized as yet only from the Duwamish Valley at the south edge of the Snohomish sheet, the third division, which is marine Eocene closely related faunally to the Tejon of California, is found. At the top of the Eocene, the sediments revert again to the brackish water coal-bearing type, some 3500 feet of which overlie the lavas in the Newcastle-Issaquah region, presumably without intermediate marine beds.

In the present thesis it is proposed to extend the term Puget Group to include all three of the above phases of the Eocene, since the marine and igneous phases are interbedded with the typical brackish water beds in such a way as to make the limitation of the term to the brackish water phase alone impracticable. Different divisions of the lava phase will be described and given formational names under the Puget Group.

The base of the Eocene is nowhere exposed within the sound basin proper, and the relations of the Eocene to underlying formations are unknown, although presumably it is unconformable on the old schists and quartzites which occur in both the Cascades to the east and the Olympics to the west. Cretaceous beds may however intervene.

Only the upper members of the Eocene, as represented in the Puget Sound basin, are exposed within the limits of the Snohomish quadrangle, the lowest horizon being the lavas along the axis of the Newcastle Uplift east of Lake Washington. The Eocene strata outcrop in general along the south side of the Newcastle Uplift, along the axis of the Newcastle anticline which is the dominant structural feature within the quadrangle. On Squak and Tiger Mountains, the axis of the anticline follows in general the highest part of the present topography. In the Newcastle Hills, however, the drainage divide lies from one to two miles north of the anticlinal axis along a zone of Oligocene sandstones. The only other Eocene outcrop along the Newcastle Uplift is at Duwamish station, where the anticlinal axis is again exposed. Eocene igneous rocks also occur in the northeast part of the quadrangle, making up Devil's Mountain between Snohomish and Monroe.

In the following detailed discussion of the divisions of the Puget Group, it has been thought best to consider the eruptive phase first, since, although both the brackish water and marine phases occur in the zone below the lava, or parts of it at least, they are best developed above it.

General Statement of the Eruptive Phase

The eruptive rocks of the Eocene vary from almost typical hornblende andesites in the Newcastle Hills and at Squak Mountain and Duwamish, to pyroxene andesites at Devil's Mountain and to an acidic olivine basalt in one flow in the Duwamish Valley.

Tiger Mountain Andesite

The Newcastle anticlinal axis, in that part of it which lies east of Lake Washington, is followed by a thick series of andesitic lava flows which are stratigraphically the lowest rocks exposed in that region, though they are undoubtedly underlain by a thick series of brackish water strata. Nowhere has the base of the volcanics been found, so that the true thickness of the series can not be stated, but calculating from the depth to which Tibbetts Creek has been cut between the Newcastle Hills and Squak Mountain without having exposed the base of the lavas, at least 4000 feet are represented from the top of the series down to the lowest horizon exposed. Since this thick volcanic series has been given no definite name in the literature, it is here proposed to call it the Tiger Mountain Andesite.

Tiger Mountain and Squak Mountain, the two highest points in the quadrangle, owe their prominence to the greater resistance to erosion offered by the andesite. In the Newcastle Hills, however, the topographic expression of the igneous rock is not so pronounced. Although on the southwest side of the uplift the andesitic rocks, which here border the highlands, present a bold front overlooking the lower regions on the south, the north side of the igneous belt is scarcely differentiated, speaking in terms of relief, from the sandstone which makes up the greater mass of the Newcastle Hills. In reality, the highest elevations are in the sandstone. The contact, however, is followed over most of its length by parts of two creeks, the westernmost of which is not shown on the topographic map.

That the terrain is composed of a large number of superimposed individual flows is indirectly evidenced by the differences in texture and in detailed mineral composition of rocks from different localities, though due to the deep weathering of the bedrock, probably to be correlated with the humid climate and former luxuriant forest growth, distinct contacts between flows were nowhere observed.

Near the top of this eruptive series, however, direct evidence of the multiple nature of the terrain is given by the occurrence of successive lava flows separated by variable thicknesses of brackish or fresh water sediments carrying the fossil remains of plants. This relation is shown both on the north limb of the anticline at the road cut near the north end of Etta Cartney Lake, and on the south limb at several points along the May Creek road at the base of the Newcastle Hills. At the former locality the following stratigraphic section, representing all but the very lowermost beds exposed in the outcrop, was measured:

Top

Andesite	5 ft.
Sandstone	5 "
Andesite	5 "
Arkose, containing numerous igneous pebbles, and with a 3-ft. flow breccia near the middle, and a 3-ft. hard fossiliferous shale at the top	15 "
Flow brecciated andesite, being particularly broken up at the base	10 "
Soft dark gray sandstone derived from igneous material	3 "
Very hard sandstone derived from igneous materials.	5- "
Total . . .	48 "

There are thus at least four separate flows ranging from three to ten feet in thickness and separated by clastic beds averaging around five feet in thickness. Similarly, along the May Creek road at least six lava flows show, though not more than three in a single outcrop.

In a few places, and more specifically near the top of the series at Newcastle, consolidated fragmental rocks occur which are in the nature of tuff breccias, probably occurring as distinct beds. Owing to the nonresistant character of the tuffs and breccias as compared with the solid flows, which are themselves none too resistant to weathering under Puget Sound conditions, the former could be much more common than is indicated by the infrequence with which they are observed.

The flows proper are rarely homogeneous. The majority of them show a flow breccia or agglomerate structure, caused either by movement in the lava stream after partial solidification had taken place, with the coincident breaking up of the solid rock into fragments which, upon final freezing, were separated by the solidified residual lava, or else in some cases possibly caused by the congealing of successive crusts, with subsequent breaking up and submersion of these crusts into the liquid lava during movement. Since in general the blocks constitute a large percentage of the total agglomerate and are in most cases just as coarsely, or if any different, even more coarsely crystalline than the final consolication product, the former case probably constitutes the rule and the latter the exception. The lava blocks of earlier formation so formed, range in size from a fraction of an inch up to a foot across, or in a few exceptional cases, up to two feet across, but average well below one foot. They are generally either pinkish or dark gray as contrasted with the general medium gray, or in a few cases creamy-gray color of the solidified residual lava. The pink color is due to oxidation of the lava near the surface of the flow, while the main mass was still molten. Under these conditions hematite was formed instead of a hydrated oxide of iron.

The included blocks give the impression of having been originally angular, but with the sharp corners later softened by reaction with the residual lava. At the surface where weathering is advanced, they have not decomposed as rapidly as the matrix, and tend to break out as units, but in fresh cuts, fractures pass from the blocks uninterruptedly across the interstitial rock without any regard to the boundary between them.

At a few places near the top of the series of flows, pieces of silicified wood and fragments of sandstone and shale occur included near the base of some of the flow breccias. This foreign material was picked up from the surface over which the lava flowed.

Vesicular layers were nowhere observed in the Tiger Mountain andesite east of Lake Washington. This is not at all remarkable for it is to be expected that the outcropping edges of vesicular beds, being more porous like the fragmental volcanics, will rapidly weather to soil by the chemical action of the atmosphere, together with the even greater destructive action of plant life which finds along such well watered zones ideal conditions for growth. But in the road cuts along May Creek and Etta Cartney Lake, where the unweathered upper contacts of lavas with sedimentary rocks show, vesicular layers should naturally be expected. Their absence probably means that either they once existed and were eroded off before deposition of the overlying sediments, or, much more probably, the lava was in a so-called dry state, having lost all of its occluded gases and vapors. The viscous state of the lava as shown by flow brecciation tends to confirm this view. Erosion could hardly have been so effective in removing all traces of a crust and still leave the thin flows so uniform in thickness, with practically plain upper surfaces. The igneous rock at the upper contact is not glassy, but is just as coarsely crystalline as the main mass of the flow.

The Tiger Mountain Andesite east of Lake Washington is referred to at several places in the literature as an intrusive mass of rock, and is popularly so viewed by the miners in that region. It is possible that there may be a number of sills in the series, but during the investigations carried on preparatory to this report, with the exception of a feeder dike noted near the top of Tiger Mountain, no evidence was found to suggest any type of rock body other than sub-areal flows.

That the greater part of the series was formed as flows is shown by the prevalent flow breccia structure which is not characteristic of sills, by the presence of tuffs and tuff breccias, and by the occurrence near the top of the terrain of interbedded sediments which contain a considerable percentage of material derived directly from the underlying andesites, showing that the lava rock is in general older than the sedimentary rock.

The fact that the interbedded sediments contain abundant plant remains indicating fresh water origin, and are made up in part of andesitic material which could only be true under the condition that the lava was being eroded between successive flows, proves definitely that the lavas are, at least in part, continental. It is to be expected that the flows would follow the drainage lines, and would thus become intercalated with fresh water deposits.

West of Lake Washington, the only place that the Tiger Mountain andesite occurs within the Snohomish quadrangle is at Duwamish station on the Duwamish River at the south edge of the sheet. Here it outcrops on both the north and south limb of the Newcastle anticline, with some 500 feet of brackish water beds exposed between the base of the andesite and the axis of the anticline. Two thousand feet north of the northern anticlinal outcrop, the same andesite is again brought to the surface by a fault, the south side of which has gone down relative to the north side.

The thickness of the andesite along the anticlinal axis in the Duwamish Valley is around 150 feet.

Eight hundred feet above the andesite is the Allentown basalt which, although exposed only on the south limb of the anticline just off the edge of the present sheet, is so closely connected with the andesite at Duwamish station as to warrant its description in this thesis. Above the basalt and lying still farther to the south, well within the Tacoma quadrangle, a hypersthene-augite andesite is exposed. Whether this is the uppermost igneous member in the Duwamish Valley can not be stated with certainty since the region farther to the south was not examined, but from a study of the structural maps of Charles E. Weaver, this is apparently the case.

Of the three flows in the Duwamish Valley, only the lowest at Duwamish station can be correlated petrographically with the andesites east of Lake Washington in so far as the latter have been studied. This thin layer of andesite may represent only one of the uppermost zones occurring in the Newcastle Hills, the rest of the series being deeply buried below the surface, or it may be the attenuated representative of that whole series. The former is the more probable. In either case, it is evident that contemporaneous sedimentation was far more important in the region which forms the immediate border of the sound at the present time than in the region east of Lake Washington. Granted that the andesite at Duwamish represents only the very uppermost of the andesites occurring in the Newcastle Hills and Squak Mountain, and that the rest of the series is present but deeply buried, it is separated from the next underlying band of andesite by over 500 feet of sediments as compared with possibly 15 to 20 feet between flows in the regions east of Lake Washington.

The andesite at Duwamish is quite similar to the typical Tiger Mountain andesite both structurally and petrographically. Flow breccia blocks ranging up to four feet across are exposed in the east side of the hill at the interurban station.

Associated with the andesite and outcropping in the residual knob about 1000 feet to the north is a bed of volcanic tuff enclosing in several places lens-like masses of a fine grained andesite which apparently represents the remains of a very thin flow. There is a little indication that some of the tuff collected under water but this is not marked. Decomposition and replacement by calcite has been very marked in the porous unstable material so that some specimens show 40 per cent calcite under the microscope. The feldspars are not so easily replaced as the glass, and in one or two cases, fragments of augite were observed completely surrounded in a sea of calcite.

Marine Eocene beds closely overlie the andesite; in the smallest, farthest north rock hill, lying east of the railroad, fossiliferous shale occurs along an irregular contact within one inch of the andesite. That the igneous rock was extruded in the form of a flow and not intruded as a sill is shown by the rough bedding of the shale parallel to the contact, and by the absence of shale inclusions in the igneous rock, and of igneous stringers into the shale. The slight baking which this shale shows was caused by a post-Oligocene dike which breaks through at this point.

It is probable that this particular area of the Tiger Mountain andesite was extruded into a shallow marine bay. Marine beds immediately underlie and overlie the andesite, and there is as yet no reason for assuming a special uplift between these two horizons so that the lava could be spread out above water. The exact contact at the base of the flow is nowhere well enough exposed so that this point could be determined definitely.

Megascopically the typical Tiger Mountain andesite is generally medium gray in color, sometimes with purplish, greenish, and olive tinges; many of the agglomerate blocks, however, are decidedly pinkish-gray. The feldspar phenocrysts are opaque white, and range in size in a few cases up to one-half inch largest dimension, though the average is around one-eighth inch; a quarter of an inch is a common maximum size.

Petrographically the andesite, from Tiger Mountain to Duwamish, is very close to a typical hornblende andesite. The plagioclase is acidic labradorite, generally decidedly zoned and, as phenocrysts, makes up 25 per cent of the rock. Green to brown hornblende or its alteration product makes up 3 to 5 per cent. Augite occurs but very sparsely except in two specimens, one from near the top of Squak Mountain and the other from the upfaulted north limb of the andesite at Duwamish. In both cases the augite is the only ferro-magnesian mineral left though present in amounts less than one per cent. Accessories are apatite, frequently brown and pleochroic, and also magnetite which is universally present. The groundmass, which makes up around 70 per cent of the rock, is typically andesitic in texture, frequently showing flow structure around the phenocrysts. A chloritic alteration of the ferro-magnesian minerals and of the groundmass, often accompanied by kaolinization of the feldspars and the groundmass, is almost universal. Calcite is of variable occurrence as an alteration product, though it is not generally present. The iron oxides, both hematite and limonite, are of frequent occurrence, often as an alteration product of the chlorite. One rock section from the top of Tiger Mountain shows a peculiar secondary occurrence of feldspar in patches, probably albite, this being the only occurrence of its kind in the whole suite of rocks examined.

Except along lines that were scoured by glaciation, the andesite at the outcrop is generally decomposed. The product which represents the extreme alteration short of soil is in most cases a deep brown clay containing soft white chalky prisms, and preserving the texture, or at least the relation between feldspar phenocryst and groundmass, of the original rock. The feldspar is the last constituent to alter, and in many cases occurs as more or less clear, glassy prisms in the already long decomposed groundmass.

Allentown Basalt

This rock type does not outcrop within the limits of the Snohomish quadrangle but borders the south edge so closely that its description is included in this thesis. The fresh rock outcrops in a quarry at Quarry station, just across the Duwamish River from the andesite outcrop at Duwamish station. A similar exposure occurs along the railroad cut about a mile southeast near Steel's bridge. The easternmost occurrence is in the form of scattered decomposed fragments along the Seattle water pipe line south of the Campbell school. On structural grounds this basalt should also occur in an east-west belt between Georgetown and Duwamish, but bedrock is so deeply buried in this region that no trace of it can be found.

The Allentown basalt is 500 feet thick at Quarry station but apparently thins to the southeast. It is separated from the underlying Tiger Mountain andesite of the Duwamish Valley by 800 feet of brackish water and marine sediments.

In contrast to the brecciated nature of the andesite, the darker colored basalt is massive with a tendency toward rough columnar jointing. Apparently only one flow is represented. The rock is finely vesicular near the top of the quarry, the individual blow-holes ranging from one-sixteenth to one-fourth of an inch, the former size predominating. At the more densely crystalline base also some vesiculation shows though it is neither prominent nor universally developed. It will be recalled that the Tiger Mountain andesite nowhere shows the development of blowholes.

The basal contact of the basalt is well exposed on the north face of Quarry hill. The underlying rock is a beautifully laminated steel-gray argillaceous sandstone, perfectly conformable with the overlying basalt. It is in no way altered by the igneous mass, nor was it at all weathered before the superposition of the basalt. The lamination is undisturbed and extends right up to the contact which it parallels. Subaqueous flows are marked by the violent disturbance of both the lava and the underlying formation at the contact due to the profuse development of steam. Often the two rocks are so interkneaded that it is impossible to draw the exact contact, and blowholes find a prominent development in the border phase. The underlying sedimentary rock is also more extensively baked than in the case of a dry contact. Evidently the Allentown basalt, as it occurs at Quarry station was not formed under these conditions. Since the sediments were in no way disturbed by erosion or weathering before the basalt was extruded, the conclusion is that the lava flowed over a land surface that had just previously, within a year or less, been a site of deposition. This surface was in all probability a delta-like surface which was under water at certain seasons of the year and dry at others.

The northern outcrop of the basalt at Steel's bridge shows all the criteria of subaqueous deposition except that blowholes are not abundantly developed. They occur, however, in the underlying coarse sandstone as well as in the basalt. Silicified wood fragments were found in the base of the lava rock.

The basalt at Steel's bridge has been greatly disturbed by diastrophic movements. The rock has yielded to folding stresses along a small sharp anticline pitching steeply to the southwest, not by bending, but by crushing, so that at present 600 feet of auto-clastic "andesite breccia," with the fragments ranging in size from subcrystalline up to ten-foot blocks, shows between an unbroken mass of the original rock at the north and a similar mass at the south, and for 150 feet south of the latter. Some of the crushing may have been caused by fault movement along this zone, but there is as yet no evidence to support the possibility of a very extensive fault. Along the railroad cut the south limb of the anticline has been overturned, but it swings back rapidly to the normal attitude on leaving the face of the excavation.

Petrographically the Allentown basalt is an olivine basalt. In a hand specimen, the rock is black, coarse basaltic in appearance, with numerous clear glassy phenocrysts of feldspar, variable in size, showing. Considerable magnetite can be seen megascopically. Under the polarizing microscope the rock from Quarry shows a composition of 50 per cent labradorite, 4 per cent magnetite, 3 per cent augite plus olivine (present in about equal proportions), and 43 per cent opaque, dark brown glass. A little secondary uralite has formed from the augite. The texture of the rock would be diabasic if the whole rock were crystalline; the ferro-magnesian minerals have poorly formed boundaries in contrast with the idiomorphic feldspars.

The rock from Steel's bridge is somewhat more decomposed than the basalt from the type locality. Devitrification is advanced in the glass and a larger percentage of the augite has been altered to uralite. An original difference also exists in the presence of a little hypersthene in the Steel's bridge rock which is absent in the specimen from Quarry.

Snohomish Andesite

The igneous rock type termed the Snohomish andesite in this thesis outcrops in Devil's Mountain, a rough steep sided, 600-foot hill, three miles long and two miles wide, lying between the present Snohomish channel and a pre-glacial channel, at the east edge of the quadrangle, about one-third of the distance from the north toward the south end. How much farther east it extends is not known, but not all of the igneous rock mapped by Charles E. Weaver in this region is of the type here described.

Since the base of the series of flows is not exposed, the true thickness is not known, but at least 600 feet show. The upper contact of the series is covered by the alluvium of the Snohomish Valley, which is from a quarter of a mile up to a mile wide on the southwest side of the hill. The immediately overlying formation is therefore not known. Presumably it is the formation described in this report as the Cathcart formation which is Oligocene.

The Snohomish andesite is mapped as Eocene after Dr. Weaver because of the widespread occureence throughout western Washington of basic igneous flows immediately under the Oligocene which in other places are overlain by or interbedded with Eocene sediments. Oligocene flows are known only from the southwest corner of the state.

The Snohomish andesite is to be correlated in time of extrusion with the Tiger Mountain andesite, or possibly with the pyroxene andesite which outcrops in the Duwamish Valley south of the limits of the quadrangle. In the region along the south end of the sheet, however, the period of igneous activity was followed by a time of brackish water sedimentation, during which about 3500 feet of sediments were deposited. These are lacking in the north where apparently the lava flows remained above water until the upper part of the Oligocene.

Like the Tiger Mountain andesite, the Snohomish andesite is probably made up of a large series of flows, but they can not be differentiated. Exposed in an old logging road cut, about half way up the southwest side of Devil's Mountain, is a deeply weathered andesite breccia showing angular pink and gray fragments, up to six inches but averaging one to two inches, enclosed in a uniformly very light gray groundmass. The rock body represented by this outcrop is certainly distinct from the fresh homogeneous dark colored andesite at the top of the hill, and from the massive weathered andesite at the south base of the hill. The stratigraphic position of this breccia relative to the rocks at the top and bottom of the hill could not be determined owing to the lack of any structures in the hill which might give a clue as to the dip of the flows, or as to the position of the anticlinal axis.

In general, while the andesite at the top of the hill is decidedly fractured by weathering, cooling cracks are not characteristic; they do occur, however, at two places. On the side of the highest point at the east end of Devil's Mountain, imperfect columns, standing vertically, are exposed in a low cliff (Fig. 1). They average from two to three feet in diameter and are broken every four or five feet by rough horizontal jointing. The other occurrence, near the center of the hill, is of more than passing interest for the reason that the columns are curved (Fig. 2). They are very perfectly formed, ranging in some cases up to 30 feet in length, and are uniform in cross sectional variation from 6 to 8 inches at the top to around 18 inches at the base. From a roughly vertical line on the face of the outcrop, the columns curve gracefully away on each side, successively lower columns coming in as soon as enough of the space next to the line becomes free by the clearance of the overlying column. The dividing line between the two systems is not absolutely straight but zig zags due to the slight overlap of the heads of the columns from each side.

Examination with the polarizing microscope shows that the Snohomish andesite is a rather typical pyroxene andesite. Of 21 sections examined, all in which the original ferro-magnesian minerals had not been altered to chlorite showed the presence of both hypersthene and augite with one exception. This slide showed about a half of one per cent only of augite without hypersthene, but with five per cent chlorite, so that original hypersthene may well have been altered. The relative percentages of hypersthene and augite are not fixed, but the majority of the specimens show on the average about four per cent hypersthene and one per cent augite. A peculiarity appearing in some of the slides is the occurrence of small elongated prisms of hypersthene margined sharply on both sides of the longitudinal section (but not on the ends) by a relatively thin even panel of augite. The feldspar is labradorite, inclining toward the acidic end. As phenocrysts it averages about 27 per cent of the rock. The minor accessories are magnetite, which is universally present (except in cases of extreme alteration), though it never reaches one per cent of the rock composition, and apatite, one or two prisms of which occur in about one-fifth of the specimens only. The original texture of the groundmass is andesitic, but approaching in some cases a trachytic texture.

With a very few exceptions alteration products are conspicuous, and in several cases they practically replace the original constituents. The most susceptible change is the development of chlorite at the expense of hypersthene and augite. It is also commonly formed as an alteration product of feldspar, the replacement generally beginning at the center of the crystal or in an intermediate zone. Chlorite is always present except in those rocks which are uncommonly fresh or on the other hand in those rocks which have been so thoroughly altered that it has been broken down into simpler minerals. At first it retains the pseudomorphic form of the original mineral, but as the rock becomes more weathered, it develops as ill-defined flecks throughout the groundmass.

A further step in the katamorphic series is the development of limonite from chlorite. Frequently pyroxene pseudomorphs show with a chlorite nucleus and a limonite rim, and, in some cases, with an intermediate, well defined though irregular zone of calcite. The final product is either limonite alone or limonite as a rim enclosing a mosaic of secondary quartz.

Calcite and kaolin are also common alteration products, but they are prominent only in the cases of extreme alteration, The former develops almost entirely from the feldspars; the latter develops to some extent in the feldspars but more abundantly in the groundmass, and especially in that part of the groundmass which was originally interstitial glass.

Along microscopic cracks in the very freshest specimens, as well as in the more altered ones, a deep red oxide of iron, probably hematite, is prominently developed. It is distinctly foreign to the crystallization of the rock.

Macroscopically the fresh Snohomish andesite is much darker than the Tiger Mountain andesite, the general color being a very dark gray, almost black, with brownish, olive, and greenish tinges. The feldspars are glassy instead of opaque, and range in size up to a maximum of a quarter of an inch, greatest dimension, though the average is well below one-eighth of an inch. The presence of the hematite compound gives the feldspars in the hand specimen a brownish to ruby-red tinge.

Brackish Water Phase

The brackish water phase of the Eocene is by far the most important facies in the Puget Sound region and is the Puget Group as first described by White. About 3500 feet of this phase occurs within the Snohomish quadrangle, representing only the top of the formation. The best development, over which outcrops can be found reasonably close to the surface, is on the north side of the Newcastle anticline from the old town of Newcastle, through Coal Creek and Issaquah to Grand Ridge. The phase also outcrops, however, on the south side of the Newcastle Hills near the town of Coalfield, and in the Duwamish Valley from Duwamish station south to Renton, between which points it is interbedded with igneous members of the Eocene

Topographically this chief member of the Puget Group is rather weakly expressed, the tendency being to develop valleys rather than uplands. In the Newcastle Hills, Coal Creek flows most of its length roughly along the strike of this formation between the high Oligocene sandstone hills on the north and the Eocene andesite hills on the south. At Issaquah, Squak Mountain drops off rapidly on the north as soon as this formation is reached. In the region of Grand Ridge and northwestward, the Eocene beds outcrop very sparingly along creek beds, while the Oligocene sandstones form a well marked knob along the southeast side of Lake Sammamish.

The sedimentary types making up this phase are chiefly sandstone and shale, frequently impure as a consequence of the incomplete sorting action under the conditions of deposition. Coal is an important member of the series, several workable seams being present. Carbonaceous shale is well represented throughout the series. In the Newcastle Hills region, although the igneous flows ceased rather abruptly at the beginning of the period of coal formation, volcanic activity was still present in some adjoining region for a considerable time as shown by the presence of an andesite tuff along a creek in the east end of the Newcastle Hills, 2500 feet above the base of the coal series. Considerable tuffaceous material occurs in the Eocene of the Duwamish Valley above the Allentown basalt south of Steel's bridge, where it is interstratified with shale and tuffaceous sandstone. Tuff is also present above the pyroxene andesite which lies off the southern end of the sheet. Conglomerate finds a very minor development within the brackish water phase of the Eocene in so far as the outcrops within the Snohomish quadrangle are representative. With the exception of several fossiliferous calcareous sandstone seams under the andesite at Duwamish, no calcareous sediments are known.

The sandstones are rather coarse bedded and are in places decidedly cross bedded. The shales are both massive and thinly laminated, the carbonaceous shales being particularly liable to give a fine lamination. An interbedding of the sandstone and shale, often with intergradation, is typical.

In color the sandstones range from white or light gray in fresh specimens to various shades of yellow, buff, and in some cases to brown, according to the degree of alteration. The shales may be white, cream colored, or gray when fresh, and weather to shades of brown generally darker than the sandstones. The carbonaceous shales are very dark brown to almost black.

Although the sandstones have not been studied petrographically, hand specimens, when fresh enough, show a very large percentage of feldspar. They are therefore, strictly speaking, arkoses and not sandstones. Petrographic studies by authors who have previously studied these sandstones, especially Dr. Weaver, corroborate this point. Muscovite occurs very prominently in places, sometimes in flakes up to an eighth of an inch in diameter. Horizons where it was especially noted are between the Allentown basalt and Tiger Mountain andesite as exposed in a small creek north of Steel's bridge; immediately beneath the pyroxene andesite in several places south of Steel's bridge, and about 2000 feet above the Tiger Mountain andesite on the east side of the Newcastle Hills, where it is exposed at several places along a small creek. According to Lahee, clastic mica is fairly good evidence of continental origin.

Conglomeratic sandstones of very limited extent occur under the Tiger Mountain andesite at Duwamish, under the pyroxene andesite a half mile south of Steel's bridge, and at the base of the brackish water phase at Newcastle and Etta Cartney Lake. At the two former localities the well rounded pebbles comprising the conglomerate or coarse grit, whichever it may be, are derived from old metamorphic greenstones and quartzites; some of those at Duwamish carry considerable pyrite. At Newcastle and Etta Cartney Lake, on the other hand, the angular fragments are andesite and are clearly derived from the underlying rock mass, showing that some parts of it were exposed to erosion at the beginning of the period of sedimentation.

Attemps to correlate horizons in the brackish water phase of the Eocene from different regions have been unsuccessful, due first to the horizontal variations within the beds but probably more so on account of the relatively few exposures.

The brackish water sediments underlying the Tiger Mountain andesite at Duwamish, as shown by the fossils, are more nearly estuarine than the brackish water deposits found elsewhere, which incline toward continental origin. Two calcareous sandstone beds, highly fossiliferous, underlie the andesite at about 70 and 135 feet respectively. The authors are indebted to Mr. R. B. Stewart for the information that sun cracks occur in the sandstone 66 feet below the base of the andesite, a feature observed by us at no place else within the brackish water series.

This phase of the Eocene is well represented in fossils. Besides those already mentioned which occur at Duwamish, brackish water pelecypods have been found in strata at the old Newcastle mine, and were first described by C. A. White. So many of these species are peculiar to this phase of the Puget Group that they are of little value for correlation purposes. According to White, a few of them are related to species from the Upper Cretaceous Laramie of the Rocky Mountain region. Plant remains, however, are the most abundant and most characteristic fossils. Although the majority of the species are new, a few of them have formed the basis for the age determination of the brackish water phase of the Puget Group as Eocene. Fossil plants occur throughout the series but are best preserved in the laminated argillaceous sandstones or arenaceous shales. Fossil resins are frequently observed.

Duwamish Marine Phase

Marine Eocene beds are very limited in extent and thickness within the Snohomish quadrangle. The only ones so far recognized lie immediately above and below the Tiger Mountain andesite at Duwamish. On lithology alone it is practically impossible to state definitely just where the marine beds begin and where they end, and whether they are interstratified on a small scale with brackish water beds or not. The lowest definitely marine fossil horizon is 26 feet below the andesite. In the absence of any overlying brackish water fossil beds, the strata above have been arbitrarily classes as unmixed marine. Sun cracks occur in the sandstone 66 feet below the andesite. Somewhere between here and the overlying marine fossil horizon, the line between the two types of sediments is to be drawn. Above the igneous flow about 30 feet of strata can be classed as marine.

The chief sedimentary type is more or less massive brown and olive gray sandstone, frequently with a little grit on the one hand, or with an argillaceous filling on the other. This is interbedded with a few thinner seams of gray and bluish-gray shale, often badly weathered to brown. The fossil remains occur in both the sandstone and shale.

Stratigraphically the marine phase is probably equivalent to one of the upper horizons in the Tiger Mountain andesite since it is so closely connected with the westward extension of one of the flows. It is therefore older than the coal-bearing series overlying the andesite at Newcastle, Coal Creek and Issaquah.

The marine beds at Duwamish have yielded a fairly large collection of marine molluscs, although they are in a poor state of preservation. They correlate very closely with the fauna from the Tejon of California.

Geologic Conditions During the Eocene

More than 14,000 feet of brackish water Eocene sediments occur in western Washington. Within this series over 125 seams of coal have been identified, ranging from the lowest exposed horizon (which is not the base) to the top of the series though the important commercial deposits come mainly within the lowest third. Each coal seam represents a period of halted sedimentation during which time vegetation flourished in low swampy areas at or near sea level for some considerable time. Each period of coal forming plant growth was followed by a subsidence, with the consequent burial of the accumulated vegetal debris. The geological conditions of sedimentation which the above considerations of thickness and coal formation imply are unique in the interpretations of geologic history.

For the sedimentation surface to have stood so near to sea level throughout the whole period of accumulation of the series, during which time 14000 feet of sediments were laid down, the sunclinal basin in which the series was collecting must have been subsiding at a rate just about equal to the rate of sedimentation. At times sedimentation gained on subsidence; the surface of deposition was built up above water, and coal swamps and forests were able to grow. At other times the subsidence gained on sedimentation, the land was submerged under water, and the areas over which vegetation had formerly flourished were covered up by sands and muds.

The central Cascade Mountains did not exist in Eocene times. A large part of the region which is today rugged mountains was at that time covered by large fresh water lakes which may or may not have been connected with the estuaries to the west. In these lakes, the Swauk and Roslyn coal bearing series were accumulating. The northern Cascades were, however, in all probability a prominent physiographic feature at that time.

Toward the close of the Eocene period, and over much of the area which at present lies west of the Cascades, extensive flows of andesitic lavas were extruded. These came in part from central volcanic vents, in which case they were accompanied by beds of tuff and ash, and also partly from fissure eruptions.

During the height of the volcanic period, the flows came so fast in the area of the present Newcastle Hills and the region to the east that no clastic sediments were allowed to form between extrusions. Toward the close of the period, however, the eruptions occurred at greater intervals, and thin beds of sandstone and shale were able to accumulate during the intervening time. All of the flows did not extend as far west as the present Duwamish Valley so that here sedimentation progressed without interruption, except for the formation of tuff and ash beds, for greater intervals of time.

The igneous flows in the eastern region accumulated in a large part above water, although they naturally followed the lowlands which, during the periods between flows, became the sites of sedimentation. Westward, however, near the center of the synclinal trough, brackish water, standing in estuaries, prevailed. At one time at least, and possibly at others, submersion was great enough for marine waters, carrying a typical marine fauna, to replace the brackish water in the center of the trough. This marine sea was in all probability the northward extension of an Eocene sea which covered a large part of southwestern Washington at that time. Into this northern sea, during its brief existence, was poured at one time one of the lava flows which probably welled out at some place farther east.

Near the close of the Eocene the igneous activity had ceased, at least within the Snohomish quadrangle, and the dominant geologic process again became the slow building up of clastic sediments with interbedded coal seams. No pronounced distortion of the Eocene beds took place at the close of the period, except possibly locally, but the region was lifted well above water so that the geologic processes were shifted from sedimentation to erosion. This condition continued till the upper Oligocene.

Climate

The climate of the Eocene in Washington was tropical. This is evidenced in both the marine fauna and the flora.

OLIGOCENE

General Statement

There are three faunal horizons of the marine Oligocene represented in western Washington, but of these three, only the upper or Blakeley horizon occurs within the confines of the Snohomish quadrangle. The other Oligocene formation described in this thesis is of fresh or brackish water origin. The correlation of this formation, here provisionally termed the Cathcart formation, is not definitely settled, but the fossil plants which are found in it seem to place it in the Oligocene rather than in the Eocene. It apparently underlies the Blakeley formation conformably.

There is no angular unconformity of general development between the Eocene and Oligocene, the supposed relation being one of disconformity. No beds are exposed along the south side of the quadrangle between the Upper Eocene brackish water beds and the Upper Oligocene marine beds. Presumably this interval is represented by a long period of slight erosion of the Eocene beds near sea level.

At one point, on the east bank of the Duwamish Valley between Georgetown and Duwamish station, an angular unconformity is believed to be present and has been mapped as such on the structural geologic map. Oligocene sandstone carrying fossils occurs at a prominent outcrop along the railroad about a mile and a half south of the main Oligocene outcrops at Georgetown. The strike is N. 32° W. and the dip is 66° SW. One thousand feet southeast at the next outcrop, which is the southernmost outcrop until Duwamish is reached, the rock is a hard, very light gray, medium to fine grained sandstone, with a tendency to shale off parallel to the bedding, and characterized especially by an abnormal abundance of small carbonaceous flakes. Obscure casts of small elongated pelecypods were noted. The strike is N. 71° E. and the dip is 38° N., these readings being checked at several places. The beds are definitely in place. The strikes at the two localities are thus approximately at right angles, and the southernmost locality, although not definitely proved to be Eocene, is quite different in lithology from the Oligocene outcrop and contains abundant carbonaceous material which is especially characteristic of the Eocene. Upon this evidence, the contact between the Oligocene and Eocene formations has been drawn between those two points.

One mile southwest of this locality, sandstone, very similar to that of the supposed Eocene described above, outcrops on the east face of the easternmost hill at South Park. It contains abundant carbonaceous flecks, some fossil leaves, and showed at least one small imperfect pelecypod cast. The sandstone is interbedded with a very light gray almost white shale, which, like the sandstone, is very hard. The strike is N. 88° E. and the dip is 61° N. This outcrop has been correlated with the one south of Georgetown, placing it in the Eocene.

Dr. Weaver has mapped the South Park beds as Oligocene, but on what evidence the authors have not been able to determine. It has been assumed (and perhaps, as may turn out later, too quickly) that Dr. Weaver's evidence was structural, but in case that these beds are later proved to be Oligocene, the conclusion here advanced as to the age of the South Park beds will have to be withdrawn.

Cathcart Formation

On the southwest bank of the Snohomish River southeast of Cathcart, a formation outcrops which has apparently been overlooked heretofore. The characteristic feature of this formation is the presence of fossil plants, well preserved, but very difficult to secure as specimens due to the shattered nature of the soft shales and sandstones in which they occur, and to the lack of a tendency to break regularly along the leaf surfaces. A collection of these leaves and stems numbering seven or eight species was sent to Dr. Ralph W. Chaney who very kindly examined them and commented upon their affinities.

According to Dr. Chaney, they resemble closely an Oligocene flora from Oregon which he has had an opportunity to study some time back, but a final and uncontrovertible correlation can not be made at the present time. It is hoped that a better and more complete collection will be made in the near future, which will settle definitely the question as to the age of these beds.

The species determined by Dr. Chaney include the following:

1. Sequoia langsdorfii, which ranges from lower Eocene to Miocene, but is most common in the Oligocene.

2. Corylus macquarrii, which ranges from lower Eocene into the Oligocene but is more common in the Eocene.

3. Cinnamomum of scheuchzeri, which is a common European species, ranging over most of the Tertiary but has not previously been noted from North America as far as could be determined.

4. Platanus-fragments of an undescribed fern and perhaps palm, which are not unlike the species in the flora from northeastern Oregon and maybe of either Eocene or Oligocene age.

Upon the significance of his determinations, Dr. Chaney comments:

"Most of the species are Eocene or Oligocene in distribution. The presence of Cinnamomum and palm may generally be taken to indicate that the flora is not younger than lower Oligocene."

Lithologically, shales, sandstones, and conglomerates are all represented. The shales might be considered the most characteristic since it is in them that the determining feature of the formation is best developed. The different types of sediments are interbedded and grade into each other both horizontally and vertically. At the point where the Skykomish and Snoqualmie rivers come together to form the Snohomish, which is the farthest east outcrop of the region, shale is the dominant sediment present. Passing northwestward along the river which runs parallel to the strike, sandstone begins to come in by horizontal replacement of the shale, and finally, beginning at a point about one mile below the forks of the river, conglomerate begins to become prominent by replacement of the sandstone and shale, though it has been present, interbedded with and especially at the top of the sandstone, for some considerable distance up stream. In the comparatively short distance of about 500 feet after the change begins to be marked, the conglomerate has entirely displaced the other sediments. It extends for a distance of about a mile and a half farther down stream, below which it is not exposed.

The boulders of the conglomerate become coarser down stream so that at the farthest northwest outcrop, large well rounded rocks from eight to twelve inches through are of frequent occurrence though the average size is well below this, being nearer three or four inches. Quartzite, greenstone, and other metamorphics are present, but thoroughly weathered andesite forms a prominent percentage of the conglomerate. It is evidently derived from the Snohomish andesite or a similar Eocene andesite, parts of which must have been exposed to erosion during the formation of this facies.

The shales and, to a less extent, the sandstones occurring in the Cathcart formation tend to weather down into ordinary wooded slopes, but the conglomerate forms a very steep vertical to overhanging bluff about 150 feet high for several hundred feet along the river.

This conglomerate, which is here placed at the top of the Cathcart formation, would have been placed at the base of the overlying Blakeley formation had it not been for the gradual horizontal gradation from the conglomerate to the typical Cathcart sandstones and shales. As it is, the upper part of it might very well be placed at the base of the marine formation above, representing a basal conglomerate.

The determination of the thickness of the Cathcart formation has been very unsatisfactory, due to the fact that neither the base nor the top is exposed. It is relatively thin, however. A thickness of 500 feet can be given as a suggestion, though this figure must not be taken for more than an estimate.

Blakeley Formation

This formation of the Oligocene outcrops in a broad belt along the north side of the Newcastle anticline across the whole breadth of the quadrangle. It is the underlying formation in the hills southeast of Lake Sammamish; in the northern and highest part of the Newcastle Hills north of Coal Creek; at Columbia City and Georgetown, South Seattle; at Alki Point; and at Restoration Point. It also occurs near the north side of the quadrangle in the vicinity of Cathcart. The occurrence farthest south, only recently discovered, is about one mile southeast of Renton in the Tacoma quadrangle, this being the only occurrence known on the south side of the Newcastle anticline.

Barring the possibility of concealed faults, which are very hard to detect with the limited number of outcrops available in any formation in the Puget Sound basin, a section from the east end of the Newcastle Hills northeast to the hills southeast of Lake Sammamish show a rough total thickness of about 10,000 feet of sediments.

The Blakeley formation within the Snohomish quadrangle shows a preponderance of sandstone over the other types of sediments, but shale and conglomerate are also well represented as well as a little tuff.

The lithology at a given horizon is inclined to vary at different localities. East of Lake Washington the formation is almost wholly sandstone, but there are a few exceptions. Conglomerates interbedded with sandstone were noted at one place east of the south end of Lake Sammamish. These beds lie about 10,000 feet above the base of the formation and are overturned on the north limb of the Newcastle anticline about ten degrees. Some dark gray fossiliferous shale also occurs somewhere near the base, but it is comparatively thin. The exact thicknesses of these variations could not be determined since they are each exposed in only one or two places. The only tuffaceous beds noted in the Oligocene were found along the middle slopes of the Newcastle Hills southwest of Lake Sammamish. These beds, which are best described as sandstones thickly studded with pumice, lie at about 8000 feet above the base of the formation, and are closely associated with fossiliferous sandstone.

Sandstones, shales and conglomerates all occur at Columbia City, and correlations can be made with a fair degree of satisfaction with corresponding beds at Georgetown. The datum plane for the correlation is a peculiar conglomerate, made up o of decidedly angular fragments of older rocks imbedded in a matrix of olive-gray to brown clay which itself seems to be derived in a large part from an older shale, worked over into very fine fragments. Rocks that were identified in the conglomerate are vesicular basalt, both fresh and decomposed, in fragments ranging up to three or four inches in diameter; granite (only one small decomposed pebble noted); light and dark quartzite; hard dark colored argillite which weathers to a soft white shaly clay; sandstone; shale; and, although questionably, some very much decomposed andesite apparently similar to the Eocene volcanics. In addition, pieces of decomposed feldspar appear abundantly in the clay matrix. The shale fragments make up a conspicuous percentage of the rock and at Bailey Peninsula range up to two feet in size, frequently showing their original bedding.

The average size of the derived fragments is less than one-half inch. There is no bedded structure that can be noted in the conglomerate.

Siliceous and calcareous concretions are developed in places and are generally very light gray or white in color since they have not been so affected by weathering as the uncemented mass. Light bluish-green to white, more or less rounded nodules of chert up to a quarter of an inch across occur imbedded in the more siliceous concretions.

This conglomerate occurs on the west side of Bailey Peninsula east of Columbia, and up on the streets above the railroad cut back of the brewery at Georgetown. Although it has not been found between these two rather widely separated localities, its comparative thinness (about 100 to 150 feet), together with the limited number of outcrops along its supposed course through Columbia makes it very probable that it is present but not exposed. A line can be drawn on the map connecting the Georgetown outcrop with the one at Bailey Peninsula so that it is always parallel to the strike of the sediments in the intervening region that it traverses. Furthermore, the beds above and below the supposed course of the conglomerate through Columbia City and to the west correlate fairly well with the corresponding horizons at Georgetown.

Overlying the conglomerate, the formation is chiefly shale, sometimes arenaceous, sometimes, as at Georgetown, with a little interbedded sandstone. About 2500 feet of shale lie between the conglomerate and the point where the shale is finally covered by glacial drift. Below the conglomerate, sandstone, frequently with interbedded, fine, normal conglomerate, is dominant, about 2000 feet being exposed. The fine conglomerate occurring at Thirty-seventh Ave., South and Dawson Street, can be correlated with that occurring at Forty-sixth Ave., South and Juneau Street, but this is the only case where two exposures of conglomerate separated by any considerable distance can be definitely stated to be at the same horizon. The two localities mentioned are about three-quarters of a mile apart.

The Blakeley formation at Alki Point is shale with some sandstone, while at Restoration Point it is composed of conglomerate, sandy shale, and shaly sandstone, generally in thick massive beds but sometimes with well marked bedding planes showing. At Cathcart the sediments represented are sandstone and shale, the former frequently finely conglomeratic. The shales, which are quite fossiliferous, appear to lie above the sandstones stratigraphically.

In general the Blakeley sandstones and shales are massively bedded, often with very little show of bedding. The conglomerates are generally interbedded with sandstone.

Like the sandstones of the Puget Group, those of the Blakeley formation are, petrographically speaking, arkoses. In six thin sections which were made from carefully picked specimens from the Georgetown-Columbia belt, so selected that they should be representative of the whole series in this region, the clear colorless minerals which were not definitely feldspar were examined under convergent polarized light for an interference figure. Four of them showed absolutely no quartz, while the other two showed one grain of quartz each. The average feldspar percentage for the six was about 23 per cent. Of this more than half was plagioclase. The rest was unstriated and unzoned but may have been individual crystal fragments of plagioclase broken from a series of originally twinned crystals. All of these feldspar fragments were quite angular in outline. Fresh angular broken grains of augite composed about one per cent of three of the thin sections, and fresh brown hornblende occurred quite plentifully in one of them. For the rest, the rocks examined were made up largely of small rounded fragments of a decomposed, very fine grained basalt, and of a highly altered pyritized greenstone.

Sandstones from east of Lake Washington were not examined in thin section, but many of them showed quite plainly their arkosic character megascopically.

Mica is not common in the Blakeley sandstones but was noted in one case on the northeast slope of the Newcastle Hills in association with a mytilis fossil bed.

Carbonaceous matter is present at a few places in small flecks and in thin irregular short seams, but it is not at all typical of these sandstones.

The shales and sandstones of this formation when unweathered are light gray to very dark gray in color; rarely, as at Fiftieth Ave., South and Hudson Street, Columbia, the shales are white. Both shale and sandstone are commonly weathered to shades of yellow, buff, and brown.

Except at Restoration Point, where conglomerate boulders occur up to a foot or more in diameter, and at Bailey Peninsula and Georgetown in the peculiar conglomerate already described, the pebbles of the Blakeley conglomerates do not commonly exceed one inch in diameter. They are in all cases well rounded except as already described. The original rocks from which the conglomerate pebbles were derived were chiefly a fine grained dense basalt and a greenstone which shows a high percentage of pyrite. These are the same rocks which occur so plentifully as fragments in the sandstones. Other types occurring are vesicular basalt, vesicular andesite, shale, sandstone, and some quartzite. Plutonic igneous rocks are practically unrepresented.

The Blakeley formation is well represented in a fossil molluscan marine fauna, around 200 species being known. East of Lake Washington the species occurring in the sandstones are nearly all pelecypods. In the other regions, however, gasteropods, and scaphapods are well represented. The Blakeley formation is the stratigraphic horizon of the Acila gettysburgensis zone.

Geologic Conditions During the Oligocene

During the greater part of the Lower and Middle Oligocene, the region included in the Snohomish quadrangle was above water. Possibly at one time during this interval, but more probably at the beginning of the Upper Oligocene, the region around Cathcart was the site for a short time of a fresh water lake or of a brackish water estuary of the sea. The region to the south, however, remained above water until the main transgression in the Upper Oligocene of the Blakeley sea over the whole region.

No basal Blakeley conglomerate was developed within the Snohomish quadrangle (unless the one at Cathcart is partly of Blakeley age), but west of here, at Orchard Point, Kitsap County, a conglomerate was formed interbedded with coarse sandstones, which is in the nature of a basal conglomerate. In the Columbia City-Georgetown region, sandstones were the first sediments laid down, while east of Lake Washington sedimentation began with shale. Apparently the early Blakeley sea deepened from west to east. Not long after the beginning of the Blakeley period, however, the muds which had been settling in the region to the east gave way to sands, and these remained the dominant sediments till the end of the period.

Sands prevailed in the Columbia-Georgetown region till about 4,000 feet of sediments had been laid down on the floor of the sea, when the waters were deepened abruptly, and muds were laid down on the sands. The sequence of events in the Cathcart region was similar to that at Columbia. The Restoration Point area apparently remained the closest to shore throughout the whole period, since conglomerates play a conspicuous part in its lithology.

The configuration of the area occupied by the present Cascade Mountains had not changed much in Oligocene times from what it was during the Eocene.

No diastrophic movements of any kind took place at the close of the Oligocene, and sedimentation passed uninteruptedly from Oligocene into Lower Miocene.

Climate

The climate of the Lower Oligocene was subtropical, but by the time of the Upper Oligocene, the change toward a cooler climate had begun, which finally culminated in the glaciation of the Pleistocene.

STRUCTURE

The bed-rock outcrops of the Snohomish Quadrangle are, significantly, grouped about two major anticlinal axes. Close to the southern boundary is a large east-west trending structural system, the Newcastle Anticline, while near the eastern border nine miles from the north end of the sheet is a smaller northwest-southwest striking up-arch which will be termed the "Devil's Mountain Anticline."

The Newcastle Anticline is best exposed in the Newcastle Hills, Squak, and Tiger Mountains, where its resistant volcanic core contributes a prominent feature to the rugged topography. Westward, crossing Lake Washington, the flanks of the anticlinal system are exposed at Columbia City, Georgetown, South Park, Duwamish, Allentown, and Alki and Restoration Points. The anticlinal axis passes through Duwamish striking about North seventy degrees east, crosses Lake Washington a little south of Mercer Island, swings southward, and, in the Newcastle Hills to the summit of Squak Mountain, strikes about North seventy-five degrees West. Near the summit of Squak Mountain the axis again swings northward passing through the north slope of Tiger Mountain with a strike of about North sixty degrees East.

Sediments exposed on the Newcastle Anticline are almost entirely confined to the north limb, the only outcrops on the south limb being located in the low hills east and southeast of Duwamish and in a narrow belt on the north side of the Valley of May Creek near the town of Coalfield.

Upon the limbs of the anticline are developed many minor cross folds whose axes are at about right angles to that of the major system. A well defined synclinal axis passes through the trough of the Duwamish River with an average strike of about North forty-five degrees West. A minor anticlinal axis passes through near the summit of Beacon Hill following the low hills southeastward to Renton. A small axis or "wrinkle" leaves the main axis of this minor fold about a mile and a half east of Duwamish, swinging southward through the hill east of Steel's Bridge. A small synclinal axis parallels the western shore of Lake Washington near Bailey Peninsula striking nearly north and south. A broad synclinal axis exists near the Lake Samammish trough, passing through the north slope of Squak Mountain northward across Issaquah Creek, thence northeastward through Jacob's Lake. A minor anticlinal axis parallel to the main axis of the Newcastle Anticline lies on the north slope of the Newcastle Hills near the south end of Lake Samammish.

Faults are not known to be common, although the thick cover of glacial drift over most of the area conceals much of the structural details. A large fault was encountered in the workings of the May Creek mine. Here the coal seam was caused to "pinch out" on two working faces, one on either side of the main slope. The fault is apparently nearly parallel to the plane of the bedding and of considerable displacement. In the workings of the Issaquah mine a thrust fault with a low angle of dip and a displacement of about ten feet was encountered at several different levels. The strike of this fault is about North fifty-five degrees East or nearly parallel that of the axis of the Newcastle Anticline after its great bend in the vicinity of Issaquah. Near Duwamish station, between the low erosional remnants, Poverty Hill and North Hill, a fault striking parallel to the major anticlinal axis, or nearly east and west, has been recognized by careful correlation of exposures along the hills east of the Duwamish valley. The fault has caused a repetition northward of the north dipping series found on Poverty Hill signifying a relative upward displacement on the north side.

From the axis of the Newcastle Anticline northward the dips show a general gradual gradual increase especially in the Oligocene sediments north of the Eocene-Oligocene contact. Far out on the north limb, in Columbia City and at one exposure a half mile east of the southern end of Lake Samammish, steep reverse dips occur. On the south limb of the anticline, in the old workings of the May Creek mine, the dip at the outcrop was sixty-four degrees to the south. At the foot of the slope three hundred and twenty-five feet below the surface the dips are nearly vertical, some being slightly reversed. In the new workings three hundred and fifty feet eastward a slope was driven down a dip which was reversed at the surface but at a depth of two hundred feet turned back to the south at an angle of about sixty degrees.

East of the quadrangle the major anticlinal axis extends to the summit of the Cascade Mountains in the vicinity of Mt. Stuart, while westward it forms the "back-bone" of the Bald Hills in Kitsap County, finally passing northwestward through the main axis of the Olympic Mountains and possibly out to Cape Flattery.

Evidence obtained, truly in part, from scattered croppings supports the view that the Newcastle Anticline represents a major structural system, overturned, at least in part, to the north, with an east-west axis which plunges gently westward from the Newcastle Hills, becomes slightly unwarped in the vicinity of Duwamish, plunges again beneath Puget Sound, and finally rises to form the core of the Bald Hills.

The Devil's Mountain Anticline near Cathcart is an asymmetrical domal structure with a long axis passing through near the two summits of Devil's Mountain, plunging northwestward south of Fiddler's Bluff at an angle of about forty degrees, and southeastward at a low angle of about five to ten degrees.

POST-OLIGOCENE GEOLOGY AND PRE-GLACIAL TOPOGRAPHY (1)

(1) See C. E. Weaver: The Tertiary Formation of Western Washington, Bull.13, Wash.Geol.Surv., 1916.

At the close of the Oligocene the western portion of the state suffered a slight uplift, resulting in the drainage of the larger portion of the marine embayments. Small salt water bodies remained in Pacific and Wahkiakum counties north of the Columbia river, as well as in the Grays Harbor region. The Puget Sound basin and also a large portion of the Juan de Fuca downfold appears to have been entirely above sea level. These conditions continued also during the time interval of the lower Miocene.

The period between the lower and upper Miocene was one of intense deformational movements accompanied by widespread volcanic activity. At the opening of the upper Miocene two small shallow embayments were formed, one in Clallam county near the junction of the Sol Duc and the Bogachiel rivers, the other east and north of Grays Harbor. By the close of the Miocene the land area of the state was generally much farther westward than at present.

During Pliocene time these conditions still prevailed. The present site of the Cascades was subjected to vigorous erosion and a peneplain surface established. This plane assumed a character of a gently rolling lowland with a few resistant hills in the northern Cascades left as erosional remnants above the general level. Isolated remnants of the Pliocene peneplain have been recognized at widely separated localities both on the eastern as well as the western side of the Cascade Range.

At the close of the Pliocene or early in the Quaternary the old peneplain was subjected to a series of differential uplifts which resulted in the elevation of the present Cascade Range as well as the Sierra Nevada Mountains of California. As a result of this movement a series of northwest-southeast shallow folds was imposed upon the already folded structure of the peneplain surface. These folds greatly influenced the major drainage features of the mountains.

A few of the larger consequent streams of the peneplain surface still persisted, so that dissection in the mountains became governed by a group of complex influences; first, the residual, subsequent and consequent drainage of the Pliocene peneplain; second, the subsequent drainage of the differential Quaternary upwarp; third, the selective resistance of igneous and metamorphic rocks.

Drainage in the Puget Sound trough seems to have been governed primarily by the uneven character of the Quaternary uplift. We find the Lake Sammamish basin located close to a well defined synclinal axis; the Lake Washington basin and Puget Sound in their respective sags across the axis of the Newcastle Anticline; the Duwamish River also following a minor synclinal axis.

Uplifts along the anticlinal axis resulted in the elevation of the Newcastle Hills, Squak and Tiger Mountains as well as the Bald Hills of Kitsap county. The low hills between Lake Washington and the Duwamish river singularly follow a minor upfold.

South of the Newcastle Anticline May Creek was formed as a subsequent stream parallel to the major axis. Similarly in the north, drainage became adjusted on the limbs of the Devil's Mountain Anticline and subsequent dissection isolated its resistant core of volcanic rocks from the overlying sediments.

In the broad intervening area comprising the greater portion of the quadrangle bed rock has not been encountered even in deep well borings. It is probable that the area represents a wide downwarped surface of the Pliocene peneplain. The following wells have been put down in the quadrangle without reaching bed-rock.

1. Lake Ballinger (McAleer Lake), 900 feet,
2. Pacific Hog Ranch (between Kirkland and Redmond), 900 feet,
3. Frye's Packing plant, South Seattle, 900 feet,
4. Country Club, north of Seattle, about 500 feet,
5. Puget Sound Power House near the foot of Union St., Seattle, 470 feet,
6. Supply Laundry at the south end of Lake Union, 700 feet,
7. Sanitarium at Richmond Highlands, 2 wells, 400 feet, and 270 feet respectively,
8. Capt. King, North Trunk Highway, 186 feet,

9. Old Folks Home, east side of Lake Washington, 200 feet,

10. Capt. Johnson, Medina, 126 feet,

11. Mukilteo, 186 feet,

12. Bell street dock, Seattle, 732 feet.

At the initiation of the Glacial Period a definite drainage pattern had been established with prominent north-south valleys in the Puget Sound trough as well as consequent east-west valleys from the Cascade Mountains and subsequent drainage on the limbs of the major anticlines.

Post Pliocene or Early Pleistocene Dikes and Flows at Duwamish

On the east end of the northernmost bedrock hill lying west of the railroad track at Duwamish, a basalt is exposed in one or two spots which is apparently unconformable with the Tertiary series. It is found only on the top of the hill over a diameter of about three hundred feet, and does not show in the outcrops along the sides. Petrographically it is a black, decidedly vesicular, very fine-grained basalt with small lath-shaped phenocrysts of plagioclase and a little hypersthene enclosed in an opaque glassy ground mass. The hypersthene is very pale, grading toward enstatite.

Two basaltic dikes, probably to be correlated with this exposure, at least in time, occur in an old rock quarry on the east side of the smaller hill which lies east of the railroad track. One of the dikes, five and one-half feet in width, is very similar in thin section to the rock described above; the other which is somewhat wider, is a very dense black felsitic rock, and contains, in addition to the orthorhombic pyroxene, some augite.

In addition to the dikes, the thin basal remains of a flow are exposed in section for about twenty or thirty feet along the top of the quarry. It is the same petrographically as the vesicular dike, with which it is closely associated.

All these rock bodies are evidently very closely related to the present topography. They were formed, however, at a time when all the ground surface in this particular region was at the elevation of the present hill tops, and therefore are prior to the present Duwamish valley at this point, which formed between the two glacial invasions. The time of eruption is therefore set between fairly close limits; between the completion of the Pliocene peneplain and the beginning of the Pleistocene period.

GLACIATION

J.Harlen Bretz: Glaciation of Puget Sound Region, Bull.8, W.G.S., 1913.
Willis, Bailey, and Smith,G.O.: Tacoma Folio, U.S.G.S. Geologic Atlas, Folio No.54.

Twice or possibly three or more times during the Pleistocene period the Puget Sound downfold became glaciated. The large glacier which occupied most of the area between the Cascade Mountains and the Olympics as far south as the Black Hills in Thurston County was fed by great snow fields in British Columbia and in the Cascade Mountains. The first known advance of the ice, designated as the Admiralty Epoch, followed the old drainage lines established in the pre-glacial topography. At the close of the Admiralty Epoch the ice retreated leaving a veneer of detritus in its wake. During this period the region was being elevated to 1000 feet or more above present sea level and the Admiralty deposits subjected to vigorous erosion. This period has been termed the Puyallup Interglacial Epoch.

Toward the close of the Puyallup Epoch the ice again advanced in the Puget Sound trough. As this later ice, which is known as the Vashon ice, retreated northward a great pond of water formed between the terminal moraine in the Black Hills to the south and the moving ice wall. Streams from the Cascades and the Olympic Mountains built up great deltas along the margin of this large lake. Later, retreat of the ice beyond the Juan de Fuca downfold caused the ice dam to fail and the waters of the lake drained through the straits to the Pacific Ocean.

The immediate effect of the glacial invasion in the Snohomish quadrangle was the scouring of the higher bedrock hills, the gouging of the established north-south drainage systems, and the burial of the bedrock topography in the depressions.

ECONOMIC RESOURCES

Coal

Evans, G.W.: Coalfields of King Co., Bull.No.3, W.G.S.,1912.
Reports of State Inspector of Coal Mines, 1888-1923.

The brackish water sediments of the Eocene or Puget Group overlying the Tiger Mountain Andesite on the flanks of the Newcastle Anticline contain a series of coal seams, at least ten of which have been exploited. Coal mines within the Snohomish quadrangle are, with the exception of one small operation, all located on the north limb of the anticline.

Mining districts on the north limb are, in the order of decreasing commercial importance, Newcastle, Issaquah, Grand Ridge, and Superior. The lone mine of the south limb is the May Creek Mine.

The Newcastle district (see Plate III) is located in sections 25, 26, and 27, T.24 N, R.5 E, about two to five miles east of Lake Washington. Mines within the area from west to east are known as :

1. The Old Newcastle Mine,
2. The Old Coal Creek Mine,
3. The Present Coal Creek, Present Newcastle, or Ford Mine.

The Issaquah mines are located about a quarter of a mile south of the Sunset Highway, west of Issaquah Creek and near the town of Issaquah, in sections 32 and 33, T.24 N., R. 6 E. The Grand Ridge Mines are located north of the Sunset Highway a mile and a half northeast of Issaquah in sections 23 and 26, T.24 N., R.6 E. The Superior mine is located east of the Sunset Highway between Newcastle and Issaquah in the same township, while the May Creek mine is situated near the small town of Coalfield in section 2, T.23 N., R. 5 E.

The coal bearing series is continuous throughout the mining districts on the north limb of the Newcastle Anticline. However, individual seams have not been satisfactorily correlated in the widely separated smaller districts. The most complete section is found in the series at Newcastle and Issaquah (see Plates I and II).

The lowest seam of workable coal, the Jones seam, lies between three and four hundred feet stratigraphically above the Tiger Mountain Andesite at Newcastle and one hundred and fifty feet above the same formation at Issaquah. The seam has a total thickness of about ten feet, with eight and a half feet of workable coal at Issaquah, and is about eight and a half feet thick with but three and a half feet of coal at the Newcastle workings. In the latter district the upper half of the seam is composed of so much soft shale, bony coal and clay that it is not at present considered of commercial grade.

Above the Jones seam at Newcastle and separated by one hundred and forty-five feet of sandstones and shaley sandstones lies a small seam containing about two feet of coal called the Dolly Varden. This seam has not been worked at either Newcastle or Issaquah but is at present being exploited at the small Superior mine.

About fifty feet above the Dolly Varden at Newcastle is a twenty foot bed of impure coal and bone called Ragtime seam. Ninety feet above the Ragtime is the Shoo Fly, a seventeen foot bed of bone and shale containing but three feet of coal. These two seams are so impure that they cannot be worked under present conditions.

The Muldoon seam, the lowest bed of coal that has been extensively mined at both Newcastle and Issaquah, lies about sixty feet above the Shoo Fly. This seam has a total thickness of from six to fourteen feet in the Newcastle district but thins eastward becoming but three and a half feet thick at Issaquah. The intervening beds of sandstones and shales between the Muldoon and the ones also thin appreciably to the east, the interval at the Old Coal Creek mine being three hundred and ninety feet, at the Present Coal Creek mine, three hundred and twenty feet, and, at Issaquah, but two hundred and ninety-five feet.

Fifty feet above the Muldoon at both Newcastle and Issaquah is the May Creek, a five foot seam of good coal containing but six to nine inches of clay and shale impurities. At the Old Coal Creek mine the interval between the two seams is about sixty feet and the May Creek increases to six feet in thickness. Sixty feet above the May Creek at the Old Coal Creek mine is the Bagley, a thick seam varying from seventeen to twenty-five feet in thickness with a parting of bone and shale which thickens eastward to fifty feet at the Present Coal Creek mine and at Issaquah. The upper seam or "split" is designated as the Bagley No.2, the lower is the Bagley No.1. The Bagley No.2 again contains a parting which thickens eastward and becomes about two feet thick at Issaquah. Very little mining has been done on the Bagley seam east of the splits in the Newcastle district due to the poor hanging wall of the No.2 split and the impure grade of the No.1 seam. At Issiquah, however, Bagley No.2 seam has been extensively mined in the new water level workings.

Between the Bagley seam and the next coal bed, the No.3 seam at Old Coal Creek,is an interval of one hundred and sixty-five feet of sandstones, interbedded shales, and carbonaceous material. These beds thicken eastward and at the Present Coal Creek workings the thickness is two hundred and forty feet. Eastward, at Issaquah, the interval is but one hundred and fifty feet.

No. 3 seam contains a sandstone parting which thickens westward to form an upper and lower split, both of which have been worked at the old Newcastle mine. The upper split is from four and a half to five feet thick, while the lower split has a thickness of from four to four and a half feet. Eastward No.3 seam thins rapidly and at Issaquah is only five feet in thickness with but three feet of minable coal. There may be some question as to the correlation of the two districts as there is considerable variation both in structure and in enclosing walls.

One hundred and ten feet above No.3 seam at Old Coal Creek is No.4, the topmost seam that has been extensively worked. At the Present Coal Creek mine the intervening sediments thicken to one hundred and twenty feet while at Issaquah, assuming the correct correlation of No.3 seam, the interval is three hundred and ninety feet. The complete Issaquah section from the Bagley No. 1 upward is one hundred and fifty feet thicker than the Present Coal Creek section and one hundred and eighty-five feet thicker than the Old Coal Creek section. No. 4 seam is quite uniform in character, being about five feet thick throughout the Newcastle district and about seven feet in total thickness at Issaquah. A peculiar feature of No.4 seam is the occurrence of small areas from which the coal had evidently been eroded while yet in the vegetal state. Both hanging and foot walls remain continuous and simply come together in these "pinches."

At Grand Ridge the seams are known to occur within a stratigraphic distance of five hundred feet. The individual coal beds are as a rule smaller and the intervals between them less than in the Newcastle-Issaquah section. The lowest seam worked is about three hundred feet above the Tiger Mountain Andesite, which agrees in general with the distance of the Jones at Newcastle. Direct correlation of the seams has not been undertaken and it is a question if this problem can be definitely solved in sediments of such a variable character. The upper limits of the coal series have been quite satisfactorily located northwest of Grand Ridge and the total thickness computed to be twenty-eight hundred feet which is about twelve hundred feet less than the thickness at Newcastle where the upper contact has again been traced (within at least a very few hundred feet). About a mile northwest of Grand Ridge two small slopes were driven in the early days on seams which are apparently near the top of the series and may be the equivalent of the upper seams at Newcastle.

At the May Creek mine the seams cannot be definitely correlated with the Newcastle-Issaquah series. The lowest seam worked is about ten feet thick. From this bed upward the stratigraphic succession is as follows:

Shale	50 feet
Coal and bone	6 feet
Shale	35 feet
Coal and bone	17 feet
White mass. sandstone	107 feet
Gray shale	7 feet
Gray sandstone	76 feet, 6 inches
Gray shale	33 feet
Carbonaceous shale and a little coal	1 foot
White massive sandstone	114 feet

Conditions of Deposition

During the period in which the sediments of the Puget group were being deposited, a greater part of the Puget Sound trough was occupied by broad, flat deltas of large rivers which flowed across the present site of the Cascades from far to the eastward. The coastline at the time was gently subsiding and massive swamps forming upon the deltas. At times the rate of subsidence was about equal to the rate of vegetal growth and thick beds of carbonaceous material resulted which were protected from oxidation by the fresh or brackish water of the swamp. At times the rate of subsidence was too rapid for the slower pace of plant growth and sands and muds washed over the submerging beds. The rate of sinking appears to have varied from place to place, perhaps dependent to some extent upon the differential loading of this type of sedimentation.

From the time the first sediments were deposited upon the surface of the Tiger Mountain Andesite to the time at which the Bagley Swamp was formed the region near the Old Coal Creek mine seems to have suffered greater movement during periods of subsidence which resulted in the formation of thicker intervening beds of sandstones and shales than farther eastward. During the deposition of the Bagley swamp at Old Coal Creek the rate of subsidence increased to the eastward for a time and the eastern extension of the swamp became submerged by sand and mud. A later halt allowed the completion of the Bagley swamp in the east while vegetation had continued to accumulate in the west. Thus the two eastern splits in the Bagley seam resulted. The center of maximum subsidence remained at Present Coal Creek until the formation of the No.3 swamp, when another center appeared westward in the vicinity of Old Newcastle and by a similar process No.3 was caused to split.

From the time of formation of the upper Bagley split to the time of the No.4 swamp the region near Issaquah was undergoing maximum subsidence for the intervening sediments are here two hundred and fifty feet thicker than at Old Coal Creek, thus showing a thinning to the westward. During the formation of the No.4 swamp a short period of uplift occurred, drainage was rejuvenated, and a portion of the swamp carried away by stream erosion. Later, subsidence occurred and the remains of the swamp covered by sand and locally mud.

From the Bagley seam downward the thinning of the sediments is to the eastward. Since the known seams at Grand Ridge are concentrated in the lower eight hundred feet of the coal series it would appear that deposition in this district was still under the control of the Old Coal Creek submergence center and that periods of sinking were short yet rapid enough to prevent the accumulation of thick beds of plant remains.

In the Newcastle district the average strike of the coal beds is about N.80° W. and the dip is remarkably uniform, varying from 40° to 47° to the north with a slight increase in the eastern part of the field. The strike of the series at Issaquah varies from N.80° W. in the western end of the district, to about N.85° E. in the eastern end. Dips vary from 28° to 30° to the north. In the Grand Ridge district the strike varies from N.30° E. near the portals of the main openings to nearly north and south in the northernmost workings. Dips vary from 28° to 32° to the west. At the Superior mine the strike is about N.80° W. and the dip 32° to the north. The strike at the May Creek mine is about N.60°W. and the dip is variable, ranging from 60° to the south to 85° to the north.

Mines and Mining Methods

Old Newcastle Mine

(Plate III)

The first opening in the Newcastle coalfield was in Sec. 27, T.24 N., R.5 E. Work was begun in 1863 and water level drifts driven on the upper and lower splits of No.3 seam. Later a slope was sunk on the lower split to the third level. The upper split as well as No.4 Seam was worked by means of rock tunnels from the main slope. The coal was practically all worked out within the boundaries of the company's property in Sec.27.

Old Coal Creek Mine

While the Old Newcastle Mine in Sec.27 was being worked out the water level drift on No.3 Seam was continued eastward past the junction of the two splits to the center of the section where a slope was sunk on the seam to the fifth level. No. 4 Seam was worked by means of rock tunnels from the main slope at each level. No. 3 Seam was practically all worked out and work on No. 4 Seam well under way when the mine caught fire and had to be abandoned.

Present Coal Creek Mine

The principal opening of the Present Coal Creek Mine is the Ford slope. This slope was sunk on the Muldoon Seam to the fourth level, 300 feet below sea level and 950 feet vertically below the surface. Rock tunnels were driven down on each level to haulage gangways on No.3 and No.4 Seams. A drift was driven on the Bagley Seam at water level.

Coal is mined by the breast and pillar and the chute and pillar methods. In this district chutes ten feet wide are driven off the gangway every 100 feet. These are continued upward above the first crosscut for 40 feet where the face is gradually widened to a 50 foot breast, leaving a 50 foot pillar between each breast. The pillars are mined by driving a 10 foot chute up from the gangway, splitting the pillar in two. By careful manipulation practically all of the piller coal is mined.

Electric trolley locomotives are used for underground haulage. Hoisting is done by means of a steam driven drum hoist.

Coal from the mine is all treated at the bunkers before shipment. Screen sizing separates three sizes. Everything over 2 1/2 inches in diameter is hand picked. Material under 2 1/2 inches and over 5/8 inches is passed to two Shannon single compartment double cell jigs, while sizes below 5/8 of an inch pass to a Faust tripple compartment jig. After jigging, the coal is passed over electrically driven shaker screens and separated into nut and pea sizes. The bunkers have a total capacity of 1000 tons in 84 hours.

Coal is shipped over the Newcastle branch of the Pacific Coast Railroad to Seattle. The average value of coal at the mine in 1924 was considered to be $3.56 per ton.

The Present Coal Creek or Newcastle Mine is operated by the Pacific Coast Coal Co.of Seattle.

Issaquah

Coal was first discovered at Issaquah in 1862 and several small shipments were made to Seattle, the coal selling for $22 a ton. The first opening was on the Jones seam, the lowest bed in the series. The seam was worked by a water level drift a distance of 1800 feet by 1890 when the mine was closed. Several seams were later opened by drifts at water level and a small slope was sunk on No.3 Seam to the 800 foot level. The east gangway of this level, which was 200 feet below sea level, encountered sand, water, and gravel from the glacial channel of Issaquah Creek and operations were carried to the sinking of a second slope, this time on No.4 Seam. This was driven to the 1700 foot level, 550 feet below sea level. Another east gangway was driven into the glacial channel, resulting in a complete flooding of the mine and from 1904 to 1913 the mine remained closed.

In late years operations have been confined to water level workings on the Muldoon, May Creek, Bagley No.1, and Bagley No.2 Seams.

Coal is mined by the room and pillar and chute and pillar systems. Underground haulage is by means of electric trolley motors.

Mine coal is hand picked and screen sized as at Newcastle, one Shannon single cell single compartment jig being used for the larger sizes, and a Faust three compartment jig for the smaller sizes. The bunkers have a total capacity of 750 tons in 8 hours. At the mine the coal was considered to be worth $3.47 per ton in 1923.

Shipments are made over the North Bend branch of the Northern Pacific Railway.

The mine was last operated by the Pacific Coast Coal Company, of Seattle, but has been temporarily closed since the early part of 1923.

Grand Ridge

The Grand Ridge Mine was opened before 1889 but little work was done until 1893 when a slope was sunk to a depth of 150 feet. The mine did not produce shipping coal until 1893 when the slope was continued to a depth of 330 feet and rock tunnels driven to four seams which were mined until 1914, when the mine closed for two years. In 1916 the mine opened again. New seams were exploited and the old workings extended northward. The mine has been closed since 1921.

The breast and pillar method of mining was used throughout. Electric trolley motors and mules were used for underground haulage. Coal was washed in a Robinson-Howe washer of

50 tons daily capacity. Three classes of coal were produced, lump, nut and pea.

Shipments were made over the North Bend branch of the Northern Pacific Railway. The mine was last operated by the Central Coal Company, of Seattle.

Superior

The superior mine was opened on a bed which is probably the Jones seam of the Newcastle-Issaquah series. A drift 1000 feet long was driven from the outcrop near Tibbetts Creek and production started in 1910. The mine was only worked for about a year. In 1921 the Dolly Varden Seam was opened and a water level drift driven eastward.

A system of breast and pillars is used in this mine. Mine run coal is screened and the larger sizes shipped to neighboring towns by auto truck.

The Superior mine has been operated for several years by the Harris-Richmond Coal Company, of Issaquah.

May Creek

The May Creek Mine was opened in 1910 and a slope sunk to a depth of 300 feet. A prospecting rock tunnel was driven southward 1100 feet beneath the valley of May Creek but upon encountering sand, gravel, and water the mine was abandoned. In 1923 a new slope was sunk 350 feet east of the old workings to a depth of 200 feet. Drifts on either side of the slope encountered faults which caused the seam to "pinch out."

The bedding is so contorted in the slope that it was necessary to turn from side to side in order to maintain an even grade of 32° down the seam. The operators are contemplating another slope to the eastward.

The mine is operated by the May Valley Land Company, of Seattle.

General Character of Coal

The coals of the Snohomish Quadrangle are quite uniform in character, all being of a sub-bituminous or lignitic bituminous nature. Some of the seams have a well developed cubical fracture but a conchoidal fracture is more common. Most of the coals lose considerable moisture upon air drying and are subject to spontaneous combustion caused by the rapid oxidation of pyrite and marcasite.

The coals are very suitable for ordinary house range use as they kindle readily and produce a quick fire. As a furnace fuel, however, they are not as satisfactory as some of the higher grade bituminous coals.

In the different coal fields of the quadrangle the moisture content of the coal varies from 4.9% to 10.7% for air dried samples. The volatile matter ranges from 30.1% to 41.9% and the fixed carbon from 33.6% to 50.6%. The ash in the seams considered workable under present conditions varies from 6.38% to 18%.

Coal Analyses

The following analyses of coal seams in place were made by the United States Geological Survey in cooperation with the coal division of the Washington Geological Survey during the years 1909-1910.

The analyses given are those on an air dried basis, and by adding the percentage of air-drying loss (which is given in the table) to the percentage of moisture given, the moisture of the original coal can be determined within one per cent.

RESULTS OF COAL ANALYSES

Coal Seam Sampled	Proximate					Ultimate		
	Air Drying Loss	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon
Present Coal Creek:								
Muldoon	7.2	6.3	37.4	42.6	13.73	.76	5.34	60.83
Muldoon	9.7	5.1	34.9	47.0	13.01	.49	5.27	62.15
Muldoon	7.1	6.2	38.5	44.0	11.28	.59	5.43	63.42
No.3	8.6	6.4	33.8	47.4	12.36	.39	5.30	61.52
No.3	9.7	5.2	36.0	50.6	8.16	.47	5.32	66.00
No.4	8.9	6.5	36.5	47.9	9.07	.41	5.53	64.19
Bagley No.1	6.6	5.8	39.4	43.6	11.15	.36	5.38	62.26
Bagley No.2	4.6	4.9	41.9	38.5	14.68	4.00	5.41	60.64
Bagley No.2	---	5.2	39.7	43.0	12.07	.96	5.34	62.43
Issaquah:								
No.4	8.0	10.7	31.8	47.4	10.1	.38	----	-----
Muldoon	6.6	9.1	31.4	47.4	12.15	1.20	5.27	59.51
Grand Ridge:								
No.1	6.1	8.7	32.3	46.6	12.42	.39	5.42	60.38
No.2	3.8	10.4	33.7	37.5	18.40	.51	5.43	53.26
No.3	9.0	7.6	39.6	42.3	10.5	.54	----	-----
No.4	9.6	6.6	37.0	33.6	22.8	2.51	----	-----
No.7	10.6	6.5	38.8	40.7	14.0	.42	----	-----
Superior:								
Main Seam	5.3	7.9	30.1	46.0	15.96	.72	5.25	58.80
No.0	4.3	8.5	31.0	43.7	16.8	1.68	----	-----

RESULTS OF COAL ANALYSES

Coal Seam Sampled	Ultimate		Heat Value	
	Nitrogen	Oxygen	Calories	British Thermal Units
Present Coal Creek:				
Muldoon	1.45	17.89	5965	10730
Muldoon	1.38	17.70	6130	11040
Muldoon	1.46	17.82	6200	11160
No.3	1.18	19.25	6090	10960
No.3	1.16	18.89	6410	11540
No.4	1.47	19.33	6240	11240
Bagley No.1	1.47	19.38	6195	11150
Bagley No.2	1.25	14.02	6185	11140
Bagley No.2	1.31	17.89	6200	11160
Issaquah:				
No.4	----	-----	5925	10660
Muldoon	1.17	20.70	5920	10660
Grand Ridge:				
No.1	1.13	20.26	5940	10690
No.2	.99	21.41	5275	9500
No.3	----	-----	6085	10950
No.4	----	-----	5155	9280
No.7	----	-----	5955	10720
Superior:				
Main Seam	1.17	18.10	5940	10690
No.0	----	-----	5725	10310

Markets and Competition

It is customary to screen the washed coal to separate several prepared sizes such as lump, nut, pea, buckwheat, and slack, prices varying directly as the size. The larger sizes are sold as house range and furnace fuel. In recent years the Pacific Coast Coal Company has installed a briquet plant to take care of the smaller sizes. By mixing the fine coal with higher grade bituminous coals from other districts and briquetting with a suitable bond, a very satisfactory and popular furnace fuel is obtained. The use of powdered coal has also been developed and many of the largest office buildings in the cities of the state have installed equipment for its use, eliminating to a large extent the smoke nuisance attendant upon coal and oil as ordinarily used.

Practically all of the coal within the quadrangle is sold upon the local markets, its low grade and liability to spontaneous combustion making it unsuitable for long hauls or storage. Due to the proximity of markets and consequent low transportation charges operators are enabled to undersell most of the competing coals in the city of Seattle and nearby towns. However, the low grade of the coal solicits the competition of higher grade bituminous coals from the outside for furnace and steam use. Imports for the year 1923 at the Port of Seattle were as follows:

	Tonnage (1.tons)	Value
Atlantic Seaboard	11,378	$193,366
British Columbia	122,170	918,270
Orient	800	6,526
Gulf Ports	1,000	18,000
Total	135,348	$1,136,162

California oil has been a contending factor on the local fuel markets for many years. A ton of coal with a heat value of 10,000 B.T.U. per pound about equals 4 barrels of fuel oil of .850 Be.gravity. Thus oil at one dollar a barrel compares with coal at four dollars a short ton. There is keen competition between fuel oil and powdered coal, many heating plants being equipped with both oil and powdered coal burning installations in order to take advantage of price fluctuations.

Electricity is rapidly becoming a strong competitor, both in the home and in the industries. Many modern apartment houses and residences are being equipped with electric ranges and heating apparatus. Railroads are being electrified, thus steadily decreasing their demands upon the coal industry.

Production

A total production of about 9,100,000 short tons of coal has been reported from the mines of the Snohomish quadrangle since 1888. From the time of the earliest mining in 1862 until 1888 the total coal mined can be estimated at about 300,000 short tons. Thus the total tonnage mined, up to

January 1, 1924, is, roughly, 9,400,000 short tons.

In the last twenty years the Newcastle mines have been by far the greatest producers in the area, and the Coal Creek Mine at its peak of production in 1917 led all other mines in the state.

The average yearly output of the Newcastle mines for the last ten years has been about 222,000 short tons, and of the Issaquah mines, about 61,400 short tons. During the last eight years of its operation the Grand Ridge mine produced an average of 51,000 short tons annually.

The following statistics of production have been compiled from reports of the State Mine Inspector for the years 1914 to 1923 inclusive. Production from all the mines in the quadrangle during the period between 1888 and 1924 is graphically shown in the chart following.

TOTAL YEARLY PRODUCTION AND AVERAGE DAILY PRODUCTION

OF COAL MINES IN THE SNOHOMISH QUADRANGLE, 1914-1923

(Short tons)

	Newcastle		Issaquah		Grand Ridge	
	Total Produc-tion	Av. Daily Prod.	Total Produc-tion	Av. Daily Prod.	Total Produc-tion	Av. Daily Prod.
1914	244,778	718	80,994	638	21,465	112
1915	238,343	1,285	40,271	660	Closed	
1916	301,563	1,164	42,511	409	24,097	180
1917	368,096	1,269	49,363	320	72,339	352
1918	324,247	1,162	66,652	542	81,929	299
1919	181,072	736	42,047	369	44,422	292
1920	163,182	598	124,629	510	78,565	364
1921	94,164	645	26,255	243	20,790	362
1922	232,255	851	113,279	413	Closed	
1923	211,443	939	19,384	388		

	Superior		May Creek	
1918			1,211	11
1921	1,488	25		
1922	9,554	35		
1923	8,283	43	504	6

Reserves

The reserve supply of coal in the various districts is manifestly an elastic quantity dependent upon current prices and mining conditions. As prices increase it will, of course, be possible for operators to afford greater costs of mining. Consequently, seams that are not considered workable under present conditions can be mined, while depths as great as the market justifies may be exploited.

Assuming that it will be possible to mine throughout the coal area seams that have been worked in either district on the north limb of the Newcastle Anticline to the depth of the deepest slope at Issaquah (550 feet below sea level), the known coal in the proven districts would be enough to support a rate of mining equal to the rate of the maximum yearly productions of all the mines for a period of over 200 years.

The following figures may be taken as an approximate, however, a conservative estimate of the coal reserves in the present known seams:

Length of coal measures from Old Newcastle to eastern edge of quadrangle (along strike)		9 1/2 mi.= 50,160 ft.
Average total thickness of coal seams		33 ft.
Average elevation	650 ft. above sea level	
Depth	550 ft. below sea level	1,200 ft.
Total average lift		1,200 ft.
Average dip		35°
Slope distance		2,092 ft.

Cubic feet of coal (50160 x 33 x 2092)	3,462,845,760
Allowing 25 cubic feet for one ton of coal in place $\left(\frac{3,462,845,760}{25}\right)$	138,513,830 short tons
Deducting 10% for structural irregularities	124,662,447 short tons
Mined to date	9,400,000 short tons
Reserves	115,262,447 short tons

Maximum rate of annual production to date:

Newcastle	324,000	short tons
Issaquah	124,000	short tons
Grand Ridge	82,000	short tons
Superior	10,000	short tons
	540,000	short tons

Period of production $\left(\frac{115,262,447}{540,000}\right)$ 211 years

New Prospecting Ground

As the brackish water or coal bearing series is known to extend westward beneath Lake Washington and a large portion of the southern end of the city of Seattle, it is possible that drilling will some day reveal valuable coal seams within the city as well as in the area between Lake Washington and Old Newcastle.

The coal measures on the south limb of the Newcastle Anticline are at present being prospected in the valley of May Creek. It is probable here that structural problems will be too great to allow the development of an extensive coal field, but, as prices rise, small truck mines might be operated on local pockets between faults and "pinches."

A series of brackish water beds very similar stratigraphically, lithologically, and in fossil content, to the known coal measures, is present in the area near Cathcart. The exposures are not extensive and coal seams have not been found. Drilling in this area might prove the existence of a valuable coal field.

Due largely to the thick cover of glacial drift, the question of the actual extent of the coal seams themselves cannot be answered with present data. Such a problem can only be solved by prospecting operations with chances which must be considered hazardous under conditions such as have confronted the coal mine operator in recent years.

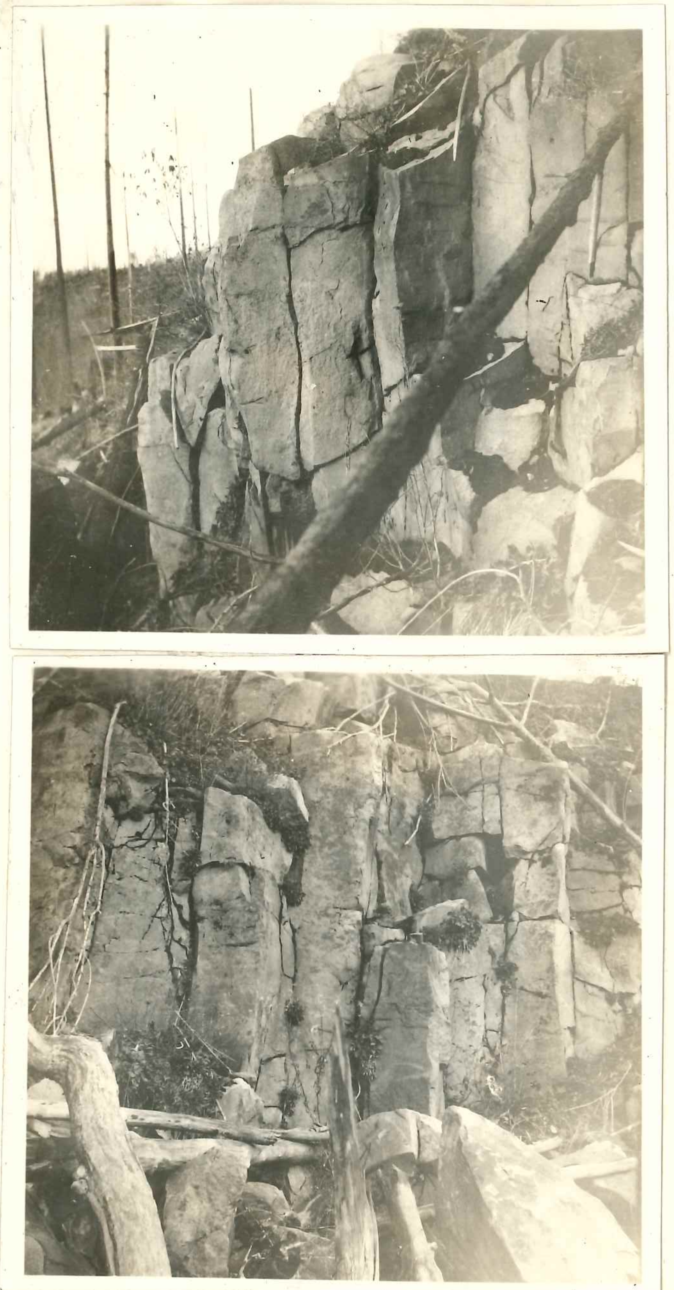

FIG.1.
Columnar Structure in Andesite
near
Summit of Devil's Mt.,
Cathcart, Wash.

FIG.2.
Arrangement of Columns in Andesite
Devil's Mountain, Wash.

FIG.3.
Erosional Remnant on Devil's Mt.
(looking north)
The outcrop at which FIG.2. was
taken is at the summit of this
knoll.

FIG.4.
Flow Breccia in Andesite
Devil's Mountain.

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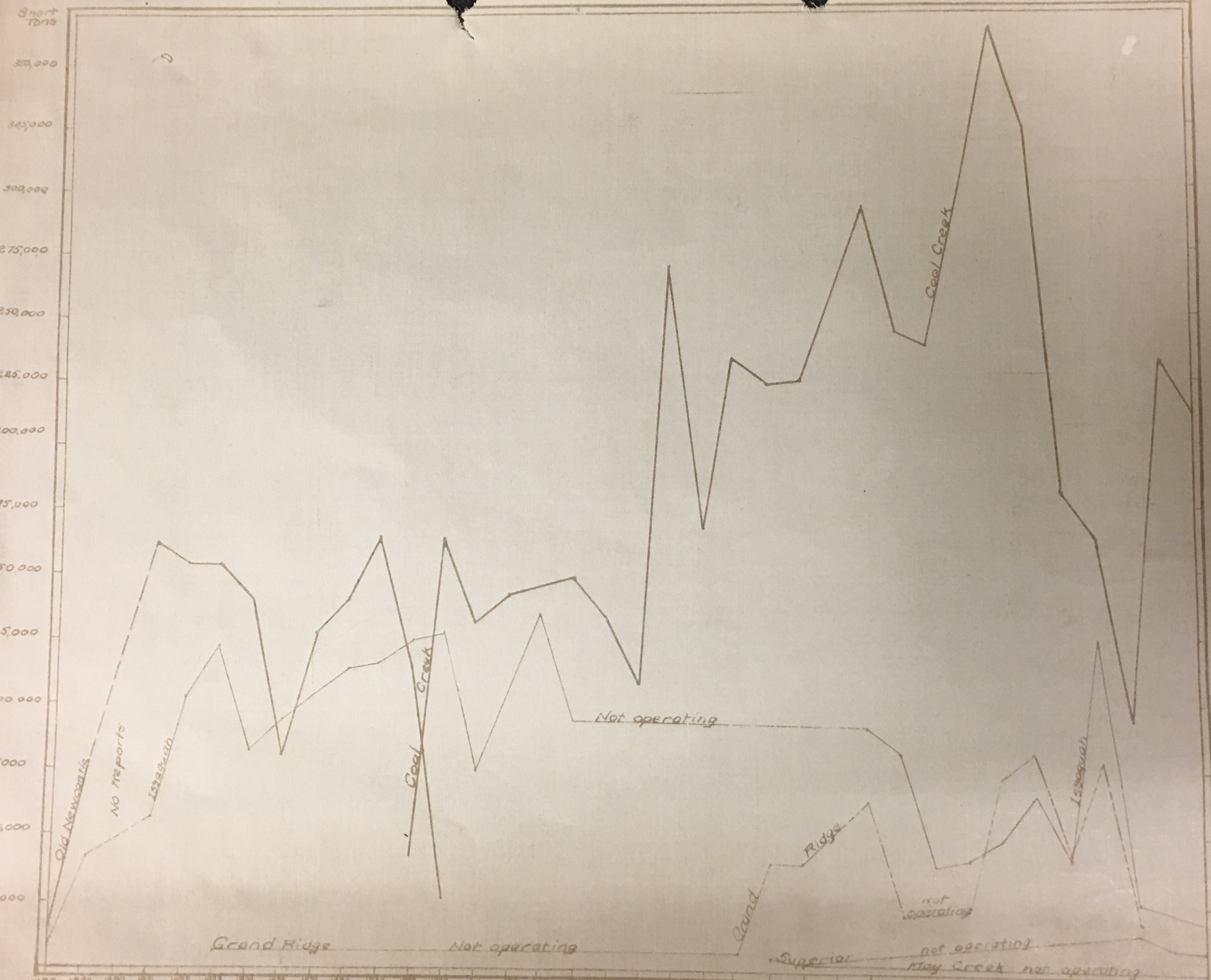
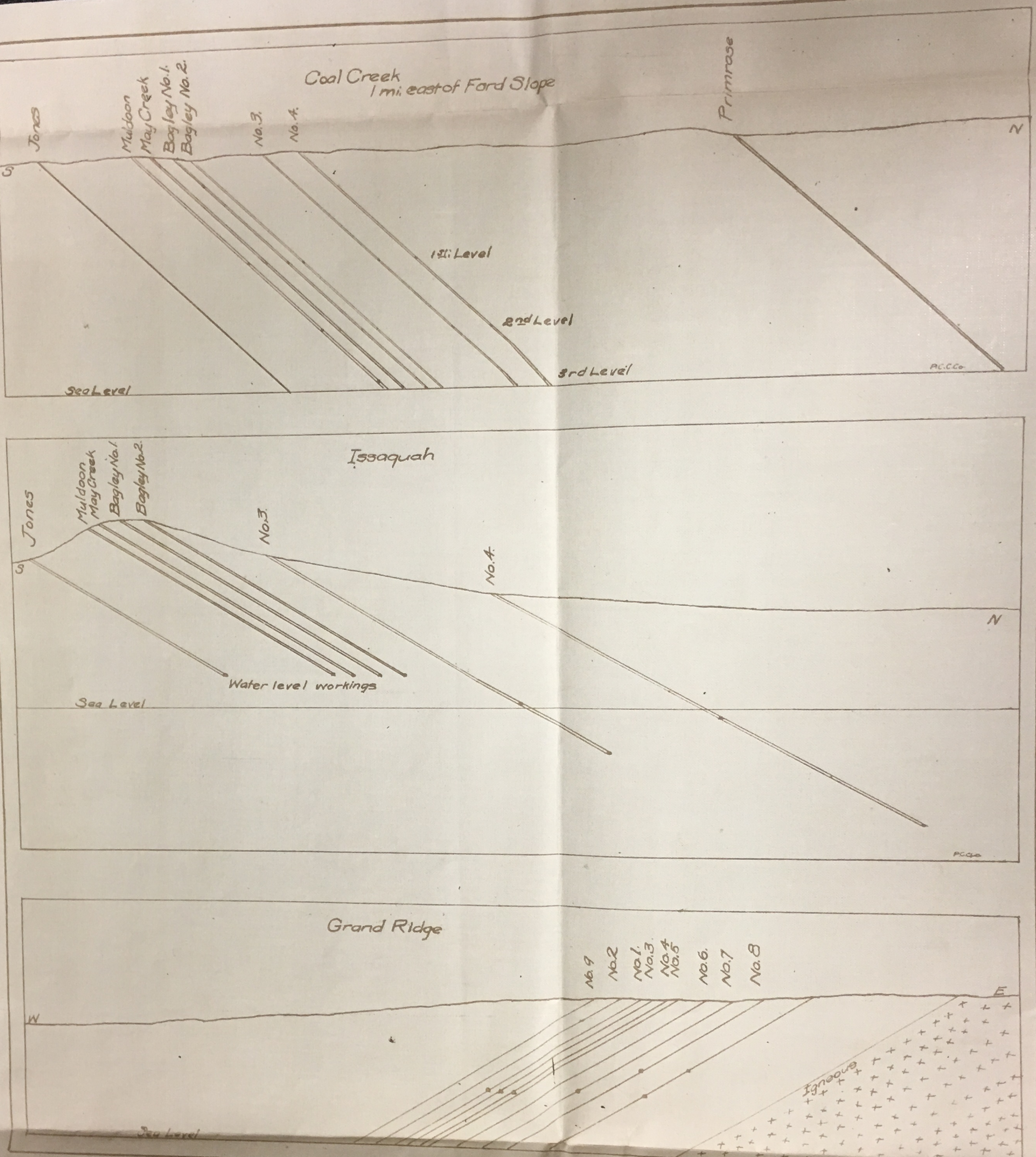
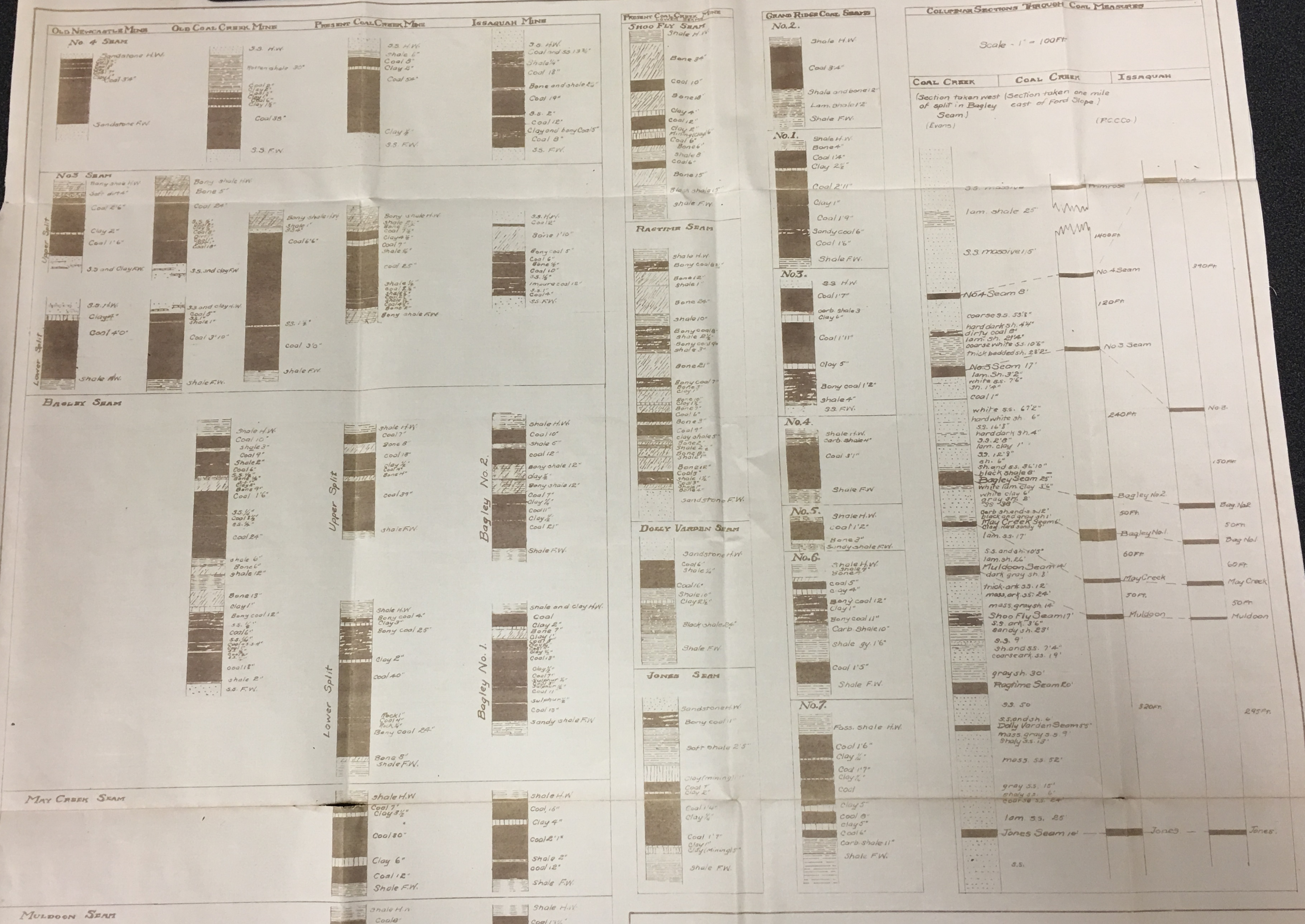


Production of Independant Mines within the Period from 1888 to 1924.



Cross Sections of Coal Fields Showing Working Levels

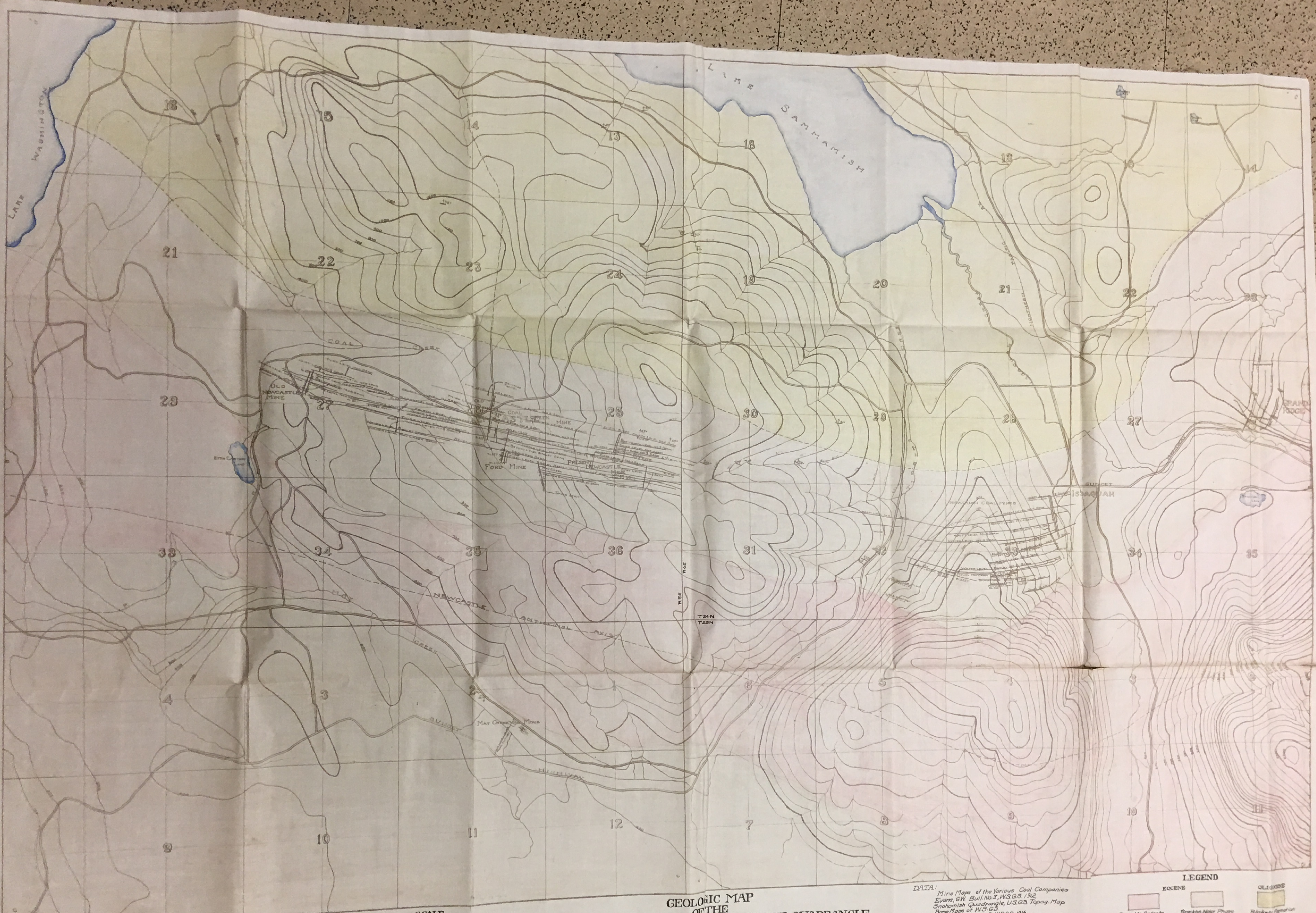
Scale: (Horiz. and Vert.) 1 in = 500 Ft.



COAL SEAMS OF THE SNOHOMISH QUADRANGLE

CROSS SECTIONS OF SEAMS AND COLUMNAR CROSS SECTIONS THROUGH COAL MEASURES

From Records of the Engineers Office, Pac Coast Coal Co. and Bull. 3, W.S.G.S. (Evans).



GEOLOGIC MAP OF THE COALFIELDS OF THE SNOHOMISH QUADRANGLE

SHOWING UNDERGROUND WORKINGS JUNE 1, 1924

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