WASHINGTON GEOLOGICAL SURVEY

HENRY LANDES, State Geologist

BULLETIN No. 22

The Road Building Sands and Gravels of Washington

By MORRIS M. LEIGHTON

OLYMPIA
FRANK M. LAMBORN PUBLIC PRINTER
1919

BOARD OF GEOLOGICAL SURVEY.

Governor Ernest Lister, *Chairman.*
Lieutenant Governor Louis F. Hart, *Vice-Chairman.*
State Treasurer W. W. Sherman, *Secretary.*
President Henry Suzzallo.
President Ernest O. Holland.

Henry Landes, *State Geologist.*

LETTER OF TRANSMITTAL.

Governor Ernest Lister, Chairman, and Members of the Board of Geological Survey:

GENTLEMEN: I have the honor to submit herewith a report entitled "The Road Building Sands and Gravels of Washington," by Morris M. Leighton, with the recommendation that it be printed as Bulletin No. 22 of the Survey reports.

Very respectfully,

HENRY LANDES,

State Geologist.

University Station, Seattle, November 1, 1918.

TABLE OF CONTENTS.

CHAPTER V. THE DISTRIBUTION AND CHARACTER OF THE ROAD-BUILDING SANDS AND GRAVELS BY COUNTIES—*Continued:*

CHAPTER V. THE DISTRIBUTION AND CHARACTER OF THE ROAD-BUILDING SANDS AND GRAVELS BY COUNTIES—*Continued:*

CHAPTER V. THE DISTRIBUTION AND CHARACTER OF THE ROAD-BUILDING SANDS AND GRAVELS BY COUNTIES—*Continued:*

CHAPTER V. THE DISTRIBUTION AND CHARACTER OF THE ROAD-BUILDING SANDS AND GRAVELS BY COUNTIES—*Continued:*

TABLES.

PLATES.

FIGURES.

THE ROAD BUILDING SANDS AND GRAVELS OF WASHINGTON

CHAPTER I.

INTRODUCTION.

The problems of road-building have been revolutionized within the last few years by the almost universal change from horse-drawn, steel-tired conveyances to motor-driven vehicles. This change has brought heavier loads, greater speed, and increased traffic for our highways to bear. Not only has the traffic become more severe, but a new mode of destruction has been introduced. Instead of confining the wearing processes chiefly to abrasion and crushing, as was the case with the steel-tired, horse-drawn vehicles, the driving wheels of motor cars viciously attack the life of a road by shearing the constituents from their position and throwing the loose materials, together with the binder, from the wheel courses. Thus the need of greater maintenance has become imperative and the cost increased. On the main highways, however, where the traffic is exceedingly heavy, even maintenance has been found to be insufficient and uneconomical, and highway engineers have turned to some type of paving in their recommendations to meet traffic demands.

CHOICE OF MATERIALS IMPORTANT.

Under the new conditions a careful selection of materials to be used in ordinary macadam for light to medium traffic and in pavement for heavy traffic has assumed great importance. Other things being equal, the life of a road is thereby increased and the cost accordingly lessened.

In 1911, the Washington Geological Survey conducted a survey of the bedrock formations of the state and collected a large series of samples which were tested for road-building purposes. The results were published in Bulletin No. 2 of the Survey's series. Since that time gravels have come more and more into use for road surfacing, due largely to their ready availability as contrasted with the expense and labor of quarrying and crushing the hard rock. At present gravel is used predominantly for road-metal in the majority of the counties.

The change from crushed rock to gravel was a change to a type of material which had not previously been studied. The general distribution and quality of the gravel deposits in the different parts of the state were only partially known. Hence, the need of a study was apparent and the Washington Geological Survey was authorized to undertake the work, the results of which are published in the following pages of this bulletin.

FIELD STUDIES.

THEIR CHARACTER.

All of the counties of the state which have important highways were traversed during this investigation. Four counties which are dependent chiefly on water transportation were not surveyed, these being San Juan, Island, Kitsap, and Wahkiakum.

Usually the county being studied was surveyed in company with the County Engineer. The representative gravel pits and many of the minor ones were examined for the purpose of observing the character of the material as it occurs in the natural deposit, its availability, and of determining its geologic relations so that its probable extent might be inferred in areas where there might be future need for such materials. In Chapter V, in connection with the discussion of each individual county, a small map is included showing the probable ex-

Relief Map of Washington, showing the State Highways authorized by the Legislature. Scale, about 21 miles to the inch. (After relief model manufactured and copyrighted by the Burgie Relief Map Establishment, Rochester, N. Y.)

1. Pacific Highway
2. Sunset Highway
3. Olympic Highway
4. State Road No. 4
5. State Road No. 5
6. McClellan Pass Highway
7. State Road No. 7
8. State Road No. 8
9. Inland Empire Highway.
9a. Inland Empire Highway—First Division
9b. Inland Empire Highway—Second Division
10. State Road No. 10
11. State Road No. 11
12. State Road No. 12
13. Central Washington Highway
14. North Central Highway
15. State Road No. 15
16. State Road No. 16
17. State Road No. 17
18. State Road No. 18
19. State Road No. 19
20. State Road No. 20.
21. State Road No. 21
22. State Road No. 22
23. State Road No. 23
24. National Park Highway

tent of the gravel formations, as well as several of the chief gravel pits from which material is being obtained and from which samples were collected for testing.

SCOPE OF THE STUDIES.

The studies made were, therefore, of a two-fold nature: A field examination to determine the nature, extent, and manner of occurrence of the gravel deposits; and laboratory tests to ascertain their probable quality for gravel macadam and the various forms of pavement in which sand and gravel are used. As a result of one season's field work and some months of laboratory investigation, a definite knowledge of the gravel formations of the whole state, and of their quality, was gained, and a basis formed for more extended studies in the future, as increased traffic demands may necessitate. It was impossible, however, to cover most of the counties in detail. When the large area of the state is taken into consideration, it is obvious that the amount of work which can be done in one season limits the investigation to little more than a careful reconnaissance. To cover one county in detail, to make scores of test-pits at new points in order to verify the actual existence of suitable materials, to collect samples from each place, and to put them through a series of tests to determine their adaptability for various road uses, would require several months' time, and the aid of several assistants. And to cover the thirty-nine counties of the state in this way would obviously consume several years. Neither time nor funds were available for such intensive study, but it is believed that ample data were obtained to meet the needs for the next several years, and a basis laid for more extended studies in the future.

The samples were collected partly from pits now in operation and partly from gravel sources not yet touched. They were so chosen as to represent as nearly as possible the average run of the material. The size of most of the samples was approximately fifty pounds, but in some cases a smaller amount was taken, the amount depending on the number and the kinds of tests desired.

INSPECTION OF THE MATERIALS IN SERVICE.

In almost every case an inspection of the roads was made to determine the wearing and cementing qualities of the materials in actual service. These inspections were made in most cases with the County Engineer, who was usually able to supply the desired information as to how long the materials had been in use, the means used in grading the materials in the process of surfacing, the thickness of the surfacing, the manner of spreading, the mode of packing the material, the readiness with which it packed under traffic, the plan of upkeep and patrol, and various other items of information which should be in hand for properly judging and comparing the wear of road materials in actual service, under a given set of conditions. Such information was also desired in the interpretation of laboratory results, but in the testing it was not possible in all cases to gauge the tests and make a thorough scientific analysis of the problems presented, due to the fact that the Testing Engineer in charge had but limited time in preparation for army service, and after his departure another technically trained man could not be obtained. However, as far as possible it was the first principle of this investigation to judge the quality of a given road-metal by its efficiency in actual service, where such knowledge was at hand.

NEED OF TRAFFIC CENSUS.

There are some factors which limit any attempt to judge the efficiency of a given gravel in actual practice or to compare its efficiency with that of another gravel.

One of these factors is the difference in the amount of traffic which different roads may have or different parts of the same road may carry; also the character of the traffic with respect to type of vehicles used, whether automobiles, trucks, wagons, or buggies; the size or weight of loads carried and their proportion to the total traffic; the dominant rate at which they travel, whether the road is chiefly a thoroughfare for local traffic of ordinary speed or a highway followed largely by cross-country tourists; the time of year at which the most severe traffic occurs, whether at a time when the road materials are so thoroughly dry that they ravel most easily, or during the wet season when the wheels are likely to cut deeply, or at an intermediate season when the amount of moisture in the ground is just right to afford the maximum strength in bearing power. In addition to these there are other factors such as mode of construction, time of construction, character of maintenance, etc., etc., which limit the degree to which the efficiency of a metal on one road may be confidently compared with the metal on another road.

A better basis, however, may be afforded in the future for such comparisons when the engineers in charge of the highways in the different counties have instituted a scientific system of ascertaining the traffic demands on a given highway and records made of the same. In a few counties considerable data have been collected in this respect, while in most counties little more than an initial attempt has been made and in some counties none. A record for one year means something, but lacks scientific thoroughness and dependability. A traffic census of several years' duration is by all means to be preferred.

The terms "light traffic", "medium traffic", and "heavy traffic" are variously used and do not seem to have a commonly accepted meaning. Some engineers employ the terms in a comparative way in speaking of the different amounts of traffic on the different roads in their own county. A certain highway may average less than 250 vehicles per day, but if this happens to be the largest record in the county, the highway carrying such traffic is said to have "heavy traffic", and the others are classified as "light" or "medium", according to the general estimate. Again, some use the terms with respect to the average weight of loads hauled over a given road.

Thus, confusion is bound to arise in the interpretation of just what is meant in the use of these terms. Accordingly, it would seem expedient and wise to define such terms and urge a common acceptance of such usage. Attention is therefore called to the definition of these terms by the Office of Public Roads and Rural Engineering, appearing in Bulletin 370 of the U. S. Department of Agriculture, Office of Public Roads and Rural Engineering, page 9. Here "light traffic" is defined as a traffic of less than 100 vehicles per day; "moderate traffic", 100 to 250 vehicles per day; "heavy traffic", over 250 vehicles per day.

GENERAL KINDS OF LABORATORY TESTS MADE.

The kinds of laboratory tests which were made on a given sample depended upon what kind of service it was likely to be put in the future, whether for road surfacing, concrete pavement, or some other form of road service. In a few instances, however, samples were tested for their value in Portland cement concrete, not because the gravel of that vicinity was likely to be used in paving, but to determine its value for bridge purposes and other local uses.

Besides the tensile strength tests and tests of the organic content of the sands, chemical analyses were made to determine whether or not alkali was present in the sands and gravels of Eastern Washington. Field compressional tests were also made of the concrete pavements which were being laid in several of the counties, including Whatcom, Skagit, Pierce, Spokane, Thurston, and King.

ACKNOWLEDGMENTS.

Appreciation is herewith acknowledged of the services of the various County Engineers, who so heartily cooperated in this study by giving of their time and knowledge of local conditions and in most cases by personally conducting the investigator over their respective counties, thus making it possible not only to examine the various deposits but to note the actual service which the materials were rendering on the roads.

Sincere thanks are also extended to Mr. James Allen, State Highway Commissioner, and the members of his Department, for service and counsel cheerfully given. Much aid was also given by Mr. C. N. Reitze, District Engineer of the Portland Cement Association, and his assistants. Helpful counsel was generously contributed by Professor A. H. Fuller, formerly Dean of the College of Engineering of the State University of Washington, by Mr. R. H. Thomson, Consulting Engineer of Seattle, and others whose judgment in matters of highway construction is especially valued.

The tests on the samples collected were undertaken by Mr. A. W. Swartz, formerly Chemical Engineer of Snohomish County, whose technical training and experience fitted him for this work. The various lines of investigation were in part nearly completed and in part well started when he was called for war service. Subsequently, the remaining concrete cylinders which had not been previously broken, were ably tested for their compressional strength by Mr. Everett G. Snell, Instructor in Civil Engineering, in the State University

of Washington. The completion of the other tests was accomplished partly under the latter's direction and the writer's, and by the aid of various students from the University whose services, though inexperienced, were fortunately secured at this time of shortage of skilled labor due to war conditions.

CHAPTER II.

GENERAL DISTRIBUTION OF THE SAND AND GRAVEL FORMATIONS OF WASHINGTON.

GENERAL STATEMENT.

Deposits of sand and gravel are generally abundant in the northern part of the state, where extensive glaciation occurred during the last Glacial Epoch. This is generally the case in any area in the United States where the effects of the last glacial action were felt. The Puget Sound region, the Olympic Mountains, the northern Cascades, and the Okanogan Highlands were all intensively glaciated, and in these sections a plentiful supply of sand and gravel may be found, with but few exceptions. Fortunately, sand and gravel were carried by streams for long distances south and west from their glacial source, thereby giving these materials a more extensive distribution than would have been the case if confined to the glaciated area. The Chehalis River Valley is an excellent example on the west side, while the Columbia River Valley, the Spokane River Valley, numerous coulees which cross the Columbia Plateau, and the Snake River Valley may be cited for the east side.

Unfortunately, the Willapa Hills of southwestern Washington, the Palouse Country of eastern Washington, and the uplands south of the Snake River were not glaciated, neither were these affected to any notable extent by glacial drainage. Consequently there is a scarcity of good sand and gravel deposits. In most instances recourse must be taken in these parts to crushed rock for road-metal, except where railroad or motor truck transportation can be economically employed in bringing in sand and gravel.

The gravels of Washington vary so widely in kind, quality, and occurrence that a general description will hardly suffice. However, within a given area they have similar characteristics to a considerable degree, thus making it possible to discuss more clearly the actual qualities of the sand and gravel by districts or provinces.

The state, for this purpose, may be divided into eight gravel provinces, as shown in Plate II, three on the west side, four on the east, and one along the Columbia River Gorge. The three on the west side are: the Olympic Mountain Province, the Puget Sound Province, and the Southwestern Province. The four on the east side are: the Okanogan Province, the Columbia Plateau Province, the Yakima River Province, and the Blue Mountain Province. The one along the Columbia River Gorge through the Cascade Mountains may be termed the Columbia Gorge Province.

DESCRIPTION OF THE SAND AND GRAVEL DEPOSITS BY PROVINCES.

OLYMPIC MOUNTAIN PROVINCE.

The Olympic Mountain Province, as shown in Plate II, includes all of the counties west of Puget Sound and north of the Chehalis River. These are Mason, Clallam, and Jefferson counties, and the northern two-thirds of Grays Harbor County.

The counties adjacent to the Sound and to the Strait of Juan de Fuca were affected by the glaciation of Puget Sound, and in many places there are extensive deposits of gravel typical of the Puget Sound region. This is especially true of Mason County and of the Olympic Highway where it follows Hood Canal. The gravel is generally firm and tough, well rounded, and of the granitic and siliceous variety. In most cases, it may be obtained directly from the roadside, thus making road construction and maintenance a simple matter so far as surfacing is concerned. On the peninsula on which Port Townsend is situated the gravel is present in patches but not abundant. In several cases, good pits are situated

Relief Map of Washington, showing the various gravel provinces in the state. Scale, 1 inch equals about 44 miles.
(After relief model made and copyrighted by the Burgie Relief Map Establishment, Rochester, N. Y.)

several miles from where the material is needed. Aside from the fact that the deposits are scattered, much of the country is wooded or covered with underbrush, thus obscuring such landscape features as suggest gravel content. The materials along the beach south from Port Townsend are too sandy to use without screening out the excess portion.

Clallam County is more fortunate. A large gravel flat exists for several miles on either side of the Dungeness River, from which material of excellent character can be obtained, save where it is locally coarse and bouldery. Large deposits are being drawn upon where the Olympic Highway crosses Morse Creek, and local deposits occur southwest of Port Angeles. A cemented conglomerate is being quarried and crushed near Joyce which has especially good qualities of cementation and wearing value. Beyond Lake Crescent gravel occurs continuously in a broad belt along the Soleduck River to the coast. Some of the pebbles are soft, but in the main the gravel is good and well graded, and its occurrence in such large quantities along the roadway makes the situation extremely favorable, and especially so during the present time of large spruce production.

South of the Olympics, abundant gravel is found along the Chehalis River, but the intimate relations of good and poor material require caution in making selections. West of Montesano, the tributary streams to the Chehalis River contain low benches of gravel which have so much soft material that it cannot be used at all for good concrete and only for surfacing secondary roads having the lightest traffic. East of Montesano, however, such tributaries to the Chehalis as the Satsop River, the Cloquallam River, and Mock Chehalis carry good gravels. All along the Chehalis itself there are gravels of first quality which are like those of Puget

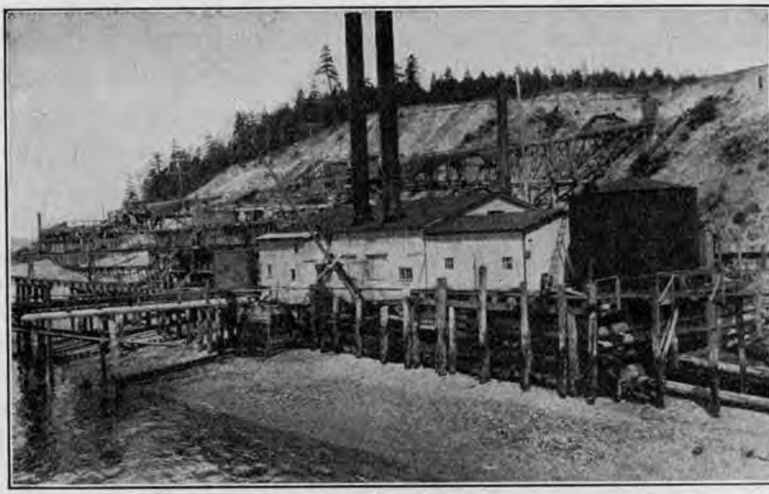
Sound and which, in fact, are a part of the same glacial outwash. They occur both in benches along the stream and in the stream itself. Those in the stream-bed are somewhat superior for concrete, due to the constant washing of the waters and the consequent elimination of soft material. After a mile or so below Montesano, in the lower reaches of the stream where its current is sluggish, the sand and gravel are mixed with a large amount of silt, thus discouraging any attempts to obtain material here.

PUGET SOUND PROVINCE.

The Puget Sound Province comprises all of the counties adjacent to Puget Sound on the east and south, and, in addition, the counties of Kitsap, Island and San Juan (Plate II). This province has some of the best gravels to be obtained anywhere. Those at Steilacoom, southwest of Tacoma, are perhaps as well known as any. They are composed of granites, diorites, basalts, quartzites, and other firm and siliceous rocks, and are well graded. Great quantities are exposed here in the bluff overlooking Puget Sound.

Other similar occurrences are farther south, near the property of the Du Pont Powder Works, and farther north in the south part of Tacoma, on Vashon Island, at Three Tree Point, at Richmond Beach north of Seattle, on Whidby Island, and elsewhere. In most of these instances, the deposits are so situated in bluffs 100 to 300 feet high that the material can be easily excavated, brought down by gravity, screened, washed, and put into loading bunkers or cars, boats, trucks or other conveyances. (See Plate III).

On the upland southwest of Tacoma, there is an extensive gravel plain of fresh and firm material. Pierce County has opened a large pit in this deposit at Lakeview. For concrete, this gravel contains an excess of



Plant of the Pioneer Sand and Gravel Co., Steilacoom.

the coarse aggregate, so that there is waste and extra handling in securing the correct proportion of the fine, unless a part of the sand is imported. Similar large gravel prairies lie to the south of Olympia, of which Chambers Prairie and Rocky Prairie are important examples. All of these are great outwash plains of the ancient glacier, and, save for variations in grading, are of practically the same quality.

Sand and gravel are exposed here and there in street grading in both Seattle and Tacoma, and many small pits have been opened to supply local needs. In the recent paving project in Snohomish County, sand and gravel were obtained from the bed of the Skykomish River, near Sultan, from the Snohomish River at Snohomish and east of Monroe, from the Stilaguamish River at Arlington and near Silvana and certain other local sources. In Skagit County, material was secured from the Skagit River, and in Whatcom County from local deposits near Bellingham, Ferndale, and the Nooksak River near Nugent's Bridge. The sand and gravel along the Nooksak River and the Skagit River contain some pumice from Mt. Baker which make them somewhat inferior to the gravels further south in this Province.

SOUTHWESTERN PROVINCE.

The Southwestern Province includes all of the area south of the Chehalis River and south of the Thurston-Lewis County line. It comprises Lewis, Cowlitz, Clarke, Wahkiakum, and Pacific counties, and the southern part of Grays Harbor County (Plate II).

This province is almost entirely devoid of anything like the glacial gravels of Puget Sound except that small portion of the Chehalis Valley from Centralia north, which was invaded by glacial outwash through the Skookumchuck Valley and across Mound Prairie. The Twin City Sand and Gravel Company of Centralia has opened a large pit in these deposits.

Gravels of inferior quality for concrete, but suited for roads of light traffic, are found along the north and south forks of Newaukum River, and fairly hard basaltic gravels along the headwaters of the Chehalis River near Doty and Pe Ell. Along Willapa River, Nemah River, and Nasel River, in Pacific County, there are also gravel bars scattered along the streams, and some gravel benches, but in no case is the material fit for concrete work. On the west side of Long Island, in Willapa Harbor, there are sands which are different in character from the others of the province and which might be used for concrete if the organic content can be removed by washing. The Nahcotta Sand and Gravel Company of Raymond obtain their sands from here. The pebbles in this deposit are small and too few in proportion to the amount of sand to supply coarse aggregate, without wasting an excess of the sand.

A few gravel bars are distributed along the Cowlitz River, as at Castle Rock, but usually, the abundance of cobbles necessitates crushing and the larger proportion is composed of fairly dense pumiceous rocks. Along the Columbia there is considerable bank-gravel, but too frequently it is interbedded or overlain with so much clay as to make it difficult and costly to handle. Along the North Fork of the Lewis River the gravels contain considerable soft pumice, which make them doubtfully good even for concrete sidewalks or for surfacing highways with light traffic.

In Clarke County there is a wide area of upland gravels bordering the Columbia River which in most localities unfortunately contain enough decayed and soft pebbles to prevent their being used for other than road surfacing. At Vancouver, sand for concrete is brought by Minsinger Brothers and Company from the Columbia River near Ellsworth, where it is dredged from the middle of the river; masonry sand from the vicinity of the inter-state bridge, and gravel for coarse aggregate from the Willamette Valley.

COLUMBIA GORGE PROVINCE.

The Columbia Gorge Province includes Skamania and Klickitat counties and the southern part of Benton County (See Plate II).

At the present time no highway runs continuously along the north side of the Columbia River between Collins and Underwood. In many places along this stretch sheer cliffs of basalt project to the water's edge in picturesque fashion, and expensive blasting will be necessary to make a road. Elsewhere along the Columbia River, gravel may generally be found. In some cases it is found on high benches, as at the towns of White Salmon, Lyle and Cooks; in other cases close to the river level, as west of Fallbridge. The higher material is usually no larger than pea-gravel, although firm, whereas the lower material has a wider range in size and is fit for concrete. Large quantities of the gravel near Fallbridge were used in the concrete piers of the S., P. & S. Railway bridge across the Columbia at this point. At Maryhill, on the property of Mr. Samuel Hill, there is an excellent deposit of clean, coarse, basaltic sand, which has been found by the County Engineer to be satisfactory for concrete.

YAKIMA RIVER PROVINCE.

The Yakima River Province includes those counties through which Yakima River runs, viz.: Kittitas, Yakima, and the northern part of Benton County (Plate II).

The gravels of this province have a general distribution along the line of the greatest population, that is, along the river, but they vary widely in kind and quality. The gravels occurring in bars on the flood-plain are practically the only ones fit for concrete. The selection of these, however, is usually attended with some uncertain factors, for the proportion of sand is low in some cases, or where it is in abundance it is prone to be too fine. The conditions are also likely to change from year to year as the floods come and go and the material in the stream-bed is shifted. Rising above the flood-plain there is a gravel formation of erratic distribution, locally known as "cement gravel" and known to geologists as the Ellensburg Formation. It occurs on both low and high elevations. Its content of soft pebbles is in some cases so high as to limit its service to roads of light traffic. On Badger Mountain, west of Sunnyside, there are gravels, aside from the soft variety, which consist mostly of flattened quartzite pebbles and a few granites, with a fine sand matrix. These have poor cementing qualities. Along the Columbia River a somewhat similar condition prevails, in that the sand of the gravels is too fine to permit packing. In the vicinity of Richland, on bars of the Columbia, there is a reddish clayey gravel which has been used to some extent on the roads with fair wearing results.

OKANOGAN PROVINCE.

The Okanogan Province comprises all of the counties north of the Spokane River and north of the Columbia River down to Wenatchee. The counties so included are Chelan, Okanogan, Ferry, Stevens, Pend Oreille and the northern part of Spokane County (Plate II).

Along the Wenatchee River a large variety of gravel occurs, ranging from sandy clay to sandy gravel and bouldery gravel. The flood-plains of the stream contain perhaps the best material for concrete purposes, but commonly the pebbles are so large as to necessitate crushing. In the northwest part of Wenatchee, along the Wenatchee River, pits have been opened in materials which may prove satisfactory for concrete. Below Wenatchee, on the east side of the river, the Columbia Engineering and Construction Company operates a pit in a small ridge of gravel to meet local demands. The materials are firm, the sand has good range, and there is but little oversize.

Along the Columbia River east of Brewster and along the Okanogan River to a point north of Tonasket there are high benches composed of silt, sand, and gravel, mostly below the 1700-foot level. The materials, however, are so intermixed and interlayered with a notable percentage of silt that usually the amount of suitable gravel which can be obtained is small. There are, of course, some exceptions, as at Tonasket and Omak. At the latter place the Omak Cement Products Company is using sand and gravel for making concrete irrigation and culvert pipe.

Almost the whole length of the Columbia River, along the west side of Stevens County and through the northern part, is bordered by a terrace of silt and fine sand with local lenses and pockets of gravels, which, because of their fine sandy matrix, are poor road-metal. Above the 1700-foot level, better graded gravels can be found in local deposits.

In Stevens County, gravels occur at high levels in remnants of old terraces along the Colville River, frequently with an excess of sand. At Addy, on the west side of the river, a pit has been opened in a high bench exposing gravels of good quality but carrying a low percentage of pebbles larger than one inch in size. For road surfacing this is excellent. East of Colville the gravel beneath Church Flat is too sandy for surfacing purposes, but with screening would be satisfactory. The low benches along the Colville River consist almost entirely of fine silt. Near Meyers Falls, the river has cut a small canyon in these silts in its rapid descent to the Columbia River, exposing good sections to view.

In Pend Oreille County, gravels are found generally in high terraces along the Clark Fork as far north as Ione, and southwest of Newport along the ancient channel of the Pend Oreille River. Material of a wide range of quality and sizes and rounding may be found here at different levels and localities.

Along the Spokane River, east of the city of Spokane, a wide flat is underlain with gravel to a great depth, which represents glacial outwash from the Coeur d'Alene Mountains. Many pits have been opened to supply the needs of the county for miles around. At different levels and at different places the material varies in size and kind. On the broad flat the gravels are conspicuously granitic, on the high benches basaltic. Both are firm and sound, but the gravel on the flat seems to have a deficiency of sand, while the high benches have a deficiency in gravel, but there are exceptions. In the northern part of the county local deposits of glacial gravel are generally distributed, as is also the case west of the river and north of Cheney.

COLUMBIA PLATEAU PROVINCE.

All of the area south and east of the Columbia River, south of the Spokane River, and north of the Snake River is herein considered as the Columbia Plateau Province. The counties are Douglas, Lincoln, Grant, Adams, Whitman, Franklin, and the southern part of Spokane (Plate II).

This province is quite different from the Okanogan Province in several ways. The topography is that of a somewhat broken plateau, the area is unglaciated except along the northern border, the gravels occur chiefly in coulees which are now almost streamless, and the gravels are almost entirely basaltic in composition.

When the ice sheet which covered the Okanogan Mountain area, lapped upon the northern border of this district, the normal drainage of the Spokane and Columbia rivers was diverted across the plateau in numerous courses, now known as coulees, having a south to southwest direction. The Grand Coulee was one of these. The coulees were filled to a considerable height, and later much of the sand and gravel was eroded away, leaving but remnants of the former deposit. In many cases these remnants occur and are to be looked for, in protected places on the southwest side of isolated hills of rock, or in the recesses of small tributaries. The Sunset Highway from Waterville to Spokane crosses these old water-courses time and again, and the Central Washington Highway follows one or more most of the way from Pasco to Spokane.

The gravels are generally used for road surfacing, and for this they are excellent. In many localities they are the proper size to use without screening, whereas in others there is enough oversize to warrant crushing. Many deposits of coarse sand and pea-gravel have been opened for use as road-dressing. Selection for concrete work must be made with care. Frequently the sand runs coarse without enough fine to fill the matrix or the pebbles are small and too low in proportion. In some cases, too, the pebbles are coated with lime, or cemented together in small lumps, which unfit them for concrete work. The pea-gravel and coarse sand usually occur in the recesses of small tributaries where the glacial waters were not so torrential and conditions were proper for the deposition of the fine.

In Whitman County, except in the northwest portion, these conditions do not prevail. There are large areas of this fertile wheat country where no gravel is to be found. The streams did not carry glacial drainage and hence this region is without the benefits of a well distributed deposit of sand and gravel. It is fortunate, however, that the gravel area in the northwestern portion of the county contains a sufficient abundance at Rosalia, Ewan, Gravel Station, LaCrosse, and other places to supply the remainder of the county, but, of course, the cost of transportation limits their use.

BLUE MOUNTAIN PROVINCE.

The counties lying south of the Snake River—Asotin, Garfield, Columbia, and Walla Walla counties—are included in this province (see Plate II). With perhaps the exception of the Southwestern Province, it is the most destitute of available sand and gravel deposits in the state. None of the glacial outwash from the north reached beyond the Snake River, and it is thought that

A Gravel Road in Western Washington.

(Photo by Webster & Stevens, Seattle.)

the Blue Mountains had no glaciers, unless possibly at the head of the Walla Walla and Touchet rivers. These two streams contain gravel scattered along their courses in bars which have been drawn upon for use on the Inland Empire Highway and local roads east of Walla Walla to Dayton. In the latter locality they are coarse and should be crushed before being used. Taken as a whole, they are generally partly lacking in binding quality. Benches of gravel are distributed along the Snake River, but the great depth of its valley is an obstacle in utilizing them, except at a few places, as at Clarkston in Asotin County. Asotin Creek, west of Asotin, contains coarse material, which, if run through the crusher pit-run, would undoubtedly prove satisfactory for the highway in that vicinity. The roads of Garfield County and on the uplands of Asotin County must be surfaced mostly with crushed rock.

CHAPTER III.

SAND AND GRAVEL FOR GRAVEL MACADAM.

The kinds of laboratory tests to be performed upon samples of sand and gravel for gravel macadam should be determined by the nature of the demands which traffic makes upon the material. At the present time the nature of these demands should be considered in the light of motor traffic, for although the percentage of motor vehicles as compared with horse-drawn vehicles is perhaps not so high in the agricultural sections as in the urban districts, yet the use of the automobile has become important even in the remotest parts of the state, and will become increasingly so. Because of increased production incident to war conditions, and the priority orders of the government for the transportation of war materials by freight, the tonnage of motor truck haulage on the state's highways has gone beyond all predictions, and promises to remain a strong competitor of railroad transportation after the war.

THE ESSENTIAL REQUIREMENTS OF A ROAD GRAVEL.

The gravel in a gravel macadam is subjected to impact, which tends to break and displace the constituents; to compression which tends to crush the pebbles; to abrasion by the shearing of the driving wheels of motor cars and the slipping or skidding of the wheels; and to deterioration by climatic agencies which tend to blow, or wash, the fine cementing materials away and disrupt or weaken the road-bed. These severe conditions demand a gravel which is made of hard and tough pebbles, properly graded according to the various sizes so as to give the maximum degree of compactness and density; and which contain a sufficient amount of clay of the quality that will cement the materials together and yield a minimum of displacement.

The wheels of motor cars develop a grinding or shearing action between the wheel and the road when the machine by its own power is gaining speed, or when the wheels are made to drag by the use of the brake, or when, in passing over uneven places, the driving wheels leave the ground and momentarily race, causing additional shear in striking the ground again. The tendency of cars to slew in turning curves or in turning out to pass approaching vehicles produces much waste at the roadside, some of which is never brought back, even by careful maintenance. If the material is of insufficient thickness, heavy hauling will cause the sub-base to yield, producing ruts, and this increase of irregularities is accompanied by increase in wear. Traction engines or heavily loaded trucks commonly initiate such results.

The state of Washington as a whole is not so severely affected by frost-action as are other states in its latitude. West of the Cascade Mountains deep freezing of the ground is exceptional, while east of the mountains the small amount of moisture in the ground diminishes the effect which would ordinarily result if the ground were full of moisture. The chief effects of climate on gravel macadam in western Washington are: The saturation of the ground with the heavy rainfall of winter, thus weakening the bearing power of the road; and the drying out of the materials during the summer, thus weakening the cementing action of the clay in the macadam and permitting the gravel to ravel. In eastern Washington the gravel macadam is helped rather than injured by the moderate rains and snowfall of winter, but in summer the extreme dryness of the atmosphere so thoroughly removes the moisture from the gravel macadam by evaporation that its cementing qualities are reduced to a minimum and the roads rut and ravel badly.

Winds are also strongest at this time and the road is deprived of much of its binder. Unfortunately, too, the heavy hauling of marketing comes at this season when the efficiency of the roads is the lowest.

CHARACTER OF THE EXAMINATION AND TESTS MADE ON ROAD GRAVEL.

PETROLOGICAL DETERMINATION.

One of the fundamental factors in judging the service-efficiency of a gravel is to ascertain its petrological composition, that is, the kinds of pebbles of which the gravel is composed. A gravel which is made up of pumice, or soft sandstone, or cleavable slate, or pebbles of merely hardened clay, or soft schist, or soft lime-rock, or any other kind of soft rock substance, or any combination of them, is evidently of little value for road-building. Granites, diorites, gabbros, basalts, rhyolites, andesites, quartzites, and other siliceous rocks are, when unweathered, usually very resistant and tough and give life to a road. If, however, these have been weathered so that they have become soft through chemical changes, then they are little better than the ones previously mentioned. In a report of a given gravel, if the composition is stated, together with the percentage of hard and soft, a fair basis is already provided for judging its wearing value for gravel macadam. Thus far, no satisfactory test has been devised to determine the toughness of a gravel. Their heterogeneity in composition and their wide range in shapes and sizes present difficulties in obtaining consistent results. Consequently considerable reliance must be placed on the composition of the material together with other qualities to be considered.

HARDNESS TEST.

The percentage of hard and soft were approximately determined by taking 100 pebbles at random and classifying as "soft" all pebbles which are easily scratched with a knife, and as "hard" those not easily scratched, if at all. This is a test which may well be used in the field, but in the laboratory should be supplemented by the abrasion test.

ABRASION TEST.

Few states have thus far made abrasion tests on gravel aggregates, due to the fact that the standard abrasion test for rock is not satisfactory for pebble aggregates. A modification of this test for rock has been made by the Ohio State Highway Department and adapted for determining the per cent of wear of gravels. This test was recommended for general use by the First Conference of State Highway Testing Engineers and Chemists, called by the U. S. Office of Public Roads and Rural Engineering at Washington, D. C., in 1917.

The aggregate is first screened through screens having circular openings 2 inches, 1 inch, and ½ inch in diameter. The sizes used for this test are equally divided between those passing the 2-inch and retained on the 1-inch screen, and those passing the 1-inch and retained on the ½-inch screen. The material of these sizes is washed and dried. The following weights of the dried stone are then taken: 2,500 grams of the size passing the 2-inch and retained on the 1-inch screen, and 2,500 grams of the size passing the 1-inch and retained on the ½-inch screen. This material is placed in the cast-iron cylinder of the Deval machine as specified for the abrasion test on stone. Briefly described, this machine consists of a frame and two or more cylinders mounted at an angle of 30° with the axis of rotation. The cylinders are of the following size: 20 cm. diameter by 34 cm. deep, inside dimensions. Six cast-iron spheres 1.875 inches in diameter and weighing approximately 0.95 pounds (0.45 kg.) each are placed in the cylinder as an abrasion charge. The iron composing these spheres is of

A Gravel Pit used without stripping away the soil. Such gravel is bound to contain organic matter harmful both to cement concrete and to roads gravelled with this material.

the same composition as those used in the Standard Paving Brick Rattler Test.

After the cast-iron spheres have been placed in the cylinder the lid is bolted on and the cylinder mounted in the frame of the Deval machine. The duration of the test and the rate of rotation are the same as specified for the standard abrasion for stone, namely, 10,000 revolutions at a rate of 30 to 33 revolutions per minute. At the completion of the test the material is taken out and screened through a No. 16 mesh screen. The material retained upon the screen is washed and dried and the per cent loss by abrasion of the material passing the No. 16 screen is calculated.

MECHANICAL ANALYSIS.

This test was made in order to show the gradation in sizes of the constituents and to afford a measure as to how closely the sample from a given deposit measures up to standard specifications. The following mechanical analysis limits are recommended by the U. S. Office of Public Roads and Rural Engineering:

FOR USE IN THE BASE COURSE OF GRAVEL ROADS.

All to pass a 2½-inch screen and to have at least 55 and not more than 75 per cent retained on a ¼-inch screen.

At least 25 and not more than 75 per cent of the total coarse aggregate (material over ¼ inch in size) to be retained on a 1-inch screen.

At least 65 and not more than 85 per cent of the total fine aggregate (material under ¼ inch in size) to be retained on a 200-mesh sieve.

These specifications involve a mixture such that the voids between the larger pebbles are filled with the smaller particles and the mass has a maximum of stability under the weight of traffic.

CEMENTATION TEST.

A gravel which is made up of the most resistant pebbles is of little use for gravel macadam, if the constituents are not bonded together to withstand the disturbing action of traffic. The bond may be iron oxide, carbonate of lime, or clay having binding properties. Some deposits of gravel contain a natural binder while others do not. A good test in the field is the ability of the gravel in the natural deposit to stand with vertical face. Where it does not contain the proper cementing substance, the material slumps in the face of the pit. In such case clay must be added, and its selection should be made cautiously, for not all clays are good binding clays.

The tests on the cementing value of samples of gravel from various parts of the state were made upon the fine material which passed the ¼-inch sieve. Five hundred grams were taken and placed in a ball mill with 90 cubic centimeters of water and 3 steel shot, each weighing 16¾ pounds. The sample was ground for 6,000 revolutions of the machine until a stiff paste was made. The paste was then taken from the ball mill and molded into briquettes one inch in diameter and one inch high, under a pressure of 132 kilograms per square centimeter of 1877 pounds per square inch. Five briquettes were made of each sample and allowed to dry in the air for twenty hours, at the end of which time they were placed in an oven maintained at a temperature of nearly 200 degrees Fahrenheit and kept for four hours. When removed from the oven they were put in a desiccator for twenty minutes and then tested in the small Page impact machine. The number of blows required to destroy a cylinder was taken as the comparative bonding strength of the material used.

TENACITY TEST OF THE BINDER PORTION OF GRAVELS.

To supplement the cementation tests described above, tests were made on the tenacity or coherency of the binder portion of the gravels. Since this test is made on the materials passing the 10-mesh sieve without grinding, while the cementation test was made on the materials after being ground, it is thought that this test would throw some light on the readiness with which the material would pack under traffic before there had been much chance for grinding action.

A stiff paste was made of the material passing the 10-mesh sieve and then molded into cylinders, 25 mm. by 25 mm. (approximately 1 inch by 1 inch). These were thoroughly dried at a temperature of about 200 degrees Fahrenheit, and then broken with the small Page impact machine. The number of strokes necessary to break a cylinder was taken as the relative measure of its tenacity.

The plastic character and adhesiveness of clay can be fairly judged in the field by feeling the mud made from this material, by its adherence to the hands, and its ability to stretch under light pulling. This test may be used in the field where a choice is to be made of two or more available clays for binding purposes.

RESULTS OF THE TESTS.

The results of the tests and examinations made are given in tabulated form in Table I. An inspection of the composition of the gravels in the third column will reveal the fact that practically all of the gravels in the state are made up of igneous and metamorphic rock-pebbles, most of which are firm, durable and resistant to abrasion. There are few if any soft sandstones and shale rocks among them. In most cases they are either granites, diorites, quartzites, and complex metamorphic rocks, or basalts, andesites, and a mixture of the foregoing pebbles. Pumice and soft andesite are local in occurrence, the pumice being confined chiefly to the streams which drain from Mt. St. Helens or Mt. Baker, the soft andesites to the Yakima River Valley. In Pacific County and in certain other localities the basaltic pebbles have been softened by decay, but when the state is considered as a whole and compared with other states, its quality of gravel deposits are believed to rank high.

GRADATION OF THE VARIOUS GRAVELS.

It would be expected that the number of deposits containing gravel properly proportioned as to size would be few. Such is actually the case. In opening a pit in any deposit plans should be made either for screening out the oversize, or, if the proportion of excess size warrants, a crusher should be installed and all of the materials run through "pit-run." This not only provides materials of the proper size and better proportioned, but increases the amount of binder by the increment of rock-dust. Where the sand is in excess amount, a portion should be screened out to insure profitable and sat-

The Apple Way, east of Spokane. A concret pavement whose mix and aggregate were tested by the field concrete cylinder test and abrasion test.

isfactory returns in packing for the large amount of funds invested in the surfacing. Experienced highway engineers are aware of the difficulty of packing a sandy gravel, especially if the sand is a fine sand. This appears to be the case north of Wallula along the Columbia River, and along the Columbia River in northern Stevens County and south from Kettle Falls. Some deposits of coarse sand and fine gravel occur at various points which are excellent for dressing purposes. Some examples are: The granitic deposit in Spokane County on Pleasant Prairie, the quartzite and granite "torpedo sand" 4 miles north of Dartford, the basaltic sandy clay one-half mile southeast of Odessa in Lincoln County, the pea-gravel 3½ miles east of Krupp in the same county; the material of the same character at Asotin and Clarkston in Asotin County, 1½ miles south of Trinidad in Douglas County, at Connell in Franklin County, ¾ mile south of Touchet in Walla Walla County, at Lyle and White Salmon in Klickitat County, and at Wind Mountain and east of Collins in Skamania County. Others will be noted in the description of the various counties in Chapter V, and there are probably others yet to be found and utilized. Spokane County has probably made as extensive and efficient use of these materials as any other county, and has obtained good results in preventing the ravelling of the gravel in the lower course and providing smooth roads of relatively slight tractive resistance.

Many of the basaltic gravels of the Columbia Plateau District in eastern Washington are very scant in their content of binding material. Some of the gravels contain scarcely anything smaller in size than a coarse sand. This necessitates the addition of clay. The amount of clay which can be used with success varies with the climate and the quality of the clay. On the east side of the mountains the use of too much clay results in a dusty road during the long, dry summer, while on the west side, it results in a soft or muddy road during the long, wet winter. Many of the gravels of the west side are also lacking in clay for binder, in spite of the fact that it must be used with caution for the reason just stated. Since there is a great difference in the cementing value of different clays, care should be used in selecting a good binding clay where a choice is possible.

PERCENTAGE OF HARDNESS.

The percentage of hardness was determined, in most cases, by a selection of 100 pebbles at random and calling those "hard" which were not easily scratched with the knife, and "soft" those which were easily scratched. The results are given in Table I.

RESULTS OF THE ABRASION TEST.

Sixty-nine samples of road gravel were tested for their resistance to abrasion. The maximum loss by abrasion on any one of these samples was 32.8 per cent; the minimum loss, 2.2 per cent; the average loss, 10.9 per cent. A further analysis of the results in Table I, gives the following data:

	Per cent loss by abrasion
11 samples of the 69 showed less than........	5 per cent
38 samples of the 69 showed less than........	10 per cent
54 samples of the 69 showed less than........	15 per cent
61 samples of the 69 showed less than........	20 per cent

These results together with the results of the abrasion tests made on samples of gravels which have been used in cement concrete pavements, show that in general the gravels in Washington have a remarkable resistance to abrasion. In fact, it is surmised that possibly their abrasive resistance prevents the contribution of enough rock-dust under motor traffic to keep the binder portion of the gravels renewed. Increased importance is therefore attached to the question of the cementing qualities of the gravel and the use of dressing material wherever such material is available.

QUALITY OF THE BINDER-PORTION OF THE GRAVELS.

The quantity of binder present in the gravels has been discussed; the tests on the quality of the binder are now to be considered. An attempt was made in these tests to distinguish between, first, the readiness of the gravel to pack, and, second, the quality of the binder which would later be added by the wear of the road and what its character would be after moisture conditions would permit the action of permanent cementation to go on. Accordingly, the results which are listed under the heading, "Tenacity Value of the Binder," were obtained by the simple process of molding cylinders from a sample of the fine material already in the gravel which passed the 10-mesh sieve, without any grinding (see description of test in the first part of this chapter), and the results given under the heading "Cementation of Binder," were obtained by first grinding to a powder, in a ball mill, material passing the ¼-inch screen and making cylinders of the resultant paste.

Unfortunately, the great length of time required to make the latter test on a given sample and the lack of technical assistants during the present war limited the number of tests to thirty, but by distributing these among the different types of gravel collected from over the state, it is thought that a fairly accurate notion was obtained of the cementing qualities of most of the gravels.

Many of the samples used in the tenacity test were passed through the Tyler Standard Screens in order to analyze the results of the cohesive tests in the light of the gradation of sizes of the material. This was not done for the samples used in the cementation test in view of the fact that the material had to be ground down to a powder in the ball mill. For convenience in considering the results, they have been compiled in tabular form in Table II.

In interpreting the data given under the heading "Tenacity Value," and under the heading "Cementation Value," some caution is required. The figures in the two columns are not to be compared on the basis of numerical value. A basis of comparison may, however, be afforded by running down both columns and forming an opinion as to what are the high values, the medium values and the low values for either kind of test.

As has previously been suggested, the cementation of the gravels is one of the paramount questions in constructing gravel macadam roads in Washington. Most of the gravels are firm and, as observed from data, already presented, their resistance to abrasion is a notable feature. After a careful and rather universal inspection of the roads of the state, the conviction has become more and more definite that the life of the large majority of roads in Washington depends primarily on their cementation. Under motor traffic, their binding qualities are so severely taxed that much of the material is thrown to one side, thus producing much wastage. It is therefore essential that attention be given to the binding qualities of a proposed gravel before it is selected for use. Tests are consequently of importance if they can be made to throw light on this question.

The destructive action of motor traffic calls for a road gravel which will pack rather quickly in order that the ultimate cementing properties of the road metal will have a chance to function. A loose road gravel which refuses to pack yields comparatively little rock powder from abrasion and delays to that extent the cementing action of the rock powder which comes from that source. It is important therefore that the readiness with which the gravel will pack be ascertained, as well as its ultimate cementing value. An examination of the results obtained from the tenacity test, and of the mechanical analyses of the binding material, given in Table II, together with the cementation value of the various samples raises certain pertinent questions. These questions are:

1. Is gradation, or the proportion of sizes, a factor in the readiness with which a road gravel will pack?

2. Is there any importance to be attached to the composition of the clay in the binding material?

3. Is there any relation between the tenacity of the binder and the ultimate cementation of the material?

These questions may be considered in their order and Table II referred to in seeking a solution.

1. *Is gradation, or the proportion of sizes, a factor in the readiness with which a road gravel will pack?* Gradation is generally conceded to be important as far as the percentage of the constituents over ¼-inch in the size to the percentage of those under ¼-inch is concerned, and also the amount of clay in the fine aggregate passing the 200-mesh to that retained on the 200-mesh. That which passes the ¼-inch screen is usually considered the binder. In Table II, Sample Map No. 5 which had 40 per cent retained on the 14-mesh, 93 per cent on the 48-mesh, and 99 per cent on the 200-mesh, with only 1 per cent passing, is shown to have given a tenacity value of zero; in other words, due to insufficient binder a sufficiently plastic paste could not be made from the material to mold a cylinder.

The same may be noted as true of Map Nos. 6, 10, 15, 28, and others. All were deficient in the amount of clay passing the 200-mesh to furnish a bond between the coarser particles. Gradation is thus shown to be an important factor.

2. *Is the composition of the clay of any importance in furnishing an initial set to the material?* In other words, is there any other factor besides gradation which is important? Inasmuch as no chemical analyses could be made and direct evidence obtained, we may turn to other lines of evidence which are suggestive. That gradation is not the only factor is shown by the results in Map Nos. 1, 11, 13, 19, 26, 30, 32, and others. By referring to Table II, it will be seen that in Map No. 1, 22 per cent was retained on the 14-mesh, 58 per cent on the 48-mesh, 71 per cent on the 100-mesh, and 83 per cent on the 200-mesh, with 17 per cent passing the 200-mesh. Yet the tenacity value obtained was only 13. It might be said that this low result was due to too much clay passing the 200-mesh. Map No. 13 shows only 10 per cent passing the 200-mesh with the other sizes apparently well graded, and yet its tenacity value was found to be only 4. Map No. 19 had also 10 per cent passing the 200-mesh with the proportions of the other constituents also apparently proper, yet the tenacity value was low. Map No. 48 and Map No. 52 showed a gradation which was nearly identical, yet the tenacity value of the one is considerably higher than the other. Map No. 70 and Map No. 73 have comparable gradation values, but their tenacity values are in contrast. It seems, therefore, that some factor other than gradation must be operative, and the composition of the clay seems to be the probable one.

3. *Is there any relation between the cohesive character of the binder and the cementation of the material?* It seems that there is in some cases a rather definite relation between the tenacity or cohesive value and the cementation value. In Map No. 70, the binder portion gave low values for both tests. Even though the gradation was about proper, the clay was apparently of such a nature that it possessed no binding qualities in spite of the proper gradation. This would reflect itself in both

the tenacity value and the cementation value. According to the investigations of the U. S. Bureau of Chemistry, "all rock powders that cement are hydrated, i. e., contain water of combination, although it does not follow that all hydrated rock powders will cement. It seems that only a certain kind of water combination is concerned with and measures the cementation value."*

Map No. 73 shows this parallelism of evidence in another way. This sample has a gradation similar to Map No. 70 and has about the same content of clay, but gave a relatively high tenacity value; it also gave a high cementation value. There may be, however, no relation between the tenacity and cementation values of a given gravel. If there is a lack of clay to bind the coarser grains together, obviously the tenacity value would be low. But if the material is ground up and made into a paste, as is done in the cementation test, then a high cementation value may be obtained. This was found to be the case in Map No. 41. In this instance the cementation value misrepresents the packing qualities of the binder. Both tests are, therefore, needed to determine the real nature and deficiencies of the binder. Whereas a low tenacity value may go either with a low or a high cementation value, a high tenacity value should be accompanied by a high cementation value. An inspection of the Table will reveal that this is borne out to a remarkable degree in Map Nos. 23, 37, 52, and 73. A more extended series of tests, however, are needed to definitely establish this. Some variation might be possible if the chemical composition of the coarser material were different from that which passed the 200-mesh.

Map No. 54 might be cited as showing a discrepancy in that the tenacity value is not comparable to the percentage of clay content or the cementation value. But

* U. S. Department of Agriculture, Office of Public Roads, Bulletin 41, 1912, page 18.

in this case it would seem that for the tenacity test the amount of clay is too high and the proportion of coarse sand too low to give a strong test.

At any rate, the amount of evidence here presented, although too slender to draw sweeping conclusions, points to the following principles:

1. The *tenacity value* of the binder of a road gravel may be low if the constituents of the binder are not properly proportioned.

2. The *tenacity value* of the binder may be low if the chemical composition of the clay (probably its hydrated character) is not proper, even though the constituents may be properly proportioned.

3. The *tenacity value* of the binder may be high only if its constituents are properly proportioned and the clay is of the proper composition.

4. If the constituents of the binder are well proportioned and the *tenacity value* of the binder is low, the *cementation value* of the binder is likely to be low. An exception might occur if the composition of the material ground up is unlike the clay.

5. If the constituents of the binder are well proportioned and the *tenacity value* of the binder is high, the *cementation value* of the binder is likely to be high. An exception might follow for the same reason stated in (4).

6. The *cementation value* of the binder is not necessarily an indication of the initial packing qualities of the gravel.

In view of the fact that the readiness with which a road gravel packs is an important factor of economy and may, in some cases, determine the ultimate cementation of the road, and in view of the fact that the cementation test fails to show this and that the tenacity test promises to be valuable in determining this question, it is urged that the tenacity test be made to supplement the cementation test. It is not proposed, however, that the tenacity test be substituted for the cementation test, but that both be made. For the state of Washington, these two tests are deemed of great importance, and should be made before any considerable stretch of road is surfaced with a gravel of unknown properties.

CHAPTER IV.

SAND AND GRAVEL FOR PORTLAND CEMENT CONCRETE, BITUMINOUS CONCRETE, AND SAND FOR SHEET ASPHALT CONSTRUCTION.

Specifications for Portland Cement Concrete and Bituminous Concrete usually treat the sand and gravel as "fine aggregate" and "coarse aggregate", the fine aggregate including all sand grains which pass the $\frac{1}{4}$-inch screen and coarse aggregate those fragments which are retained in a $\frac{1}{4}$-inch screen. Since the requirements of these materials are different, they will be discussed separately.

PORTLAND CEMENT CONCRETE.

FINE AGGREGATE.

The part which sand should play in Portland Cement Concrete is succintly stated by Mr. Cloyd M. Chapman and Mr. Nathan C. Johnson in the *Engineering Record* of June 19, 1915, as follows:

"First, in order that the cement may properly attach to the grains, each grain must be clean—there must be no coating such as would prevent adherence of the cement. Second, since each of these grains make up a portion of the mass, each of them, whether large or small, must bear a portion of the total load imposed on the concrete; and to bear this burden they must be structurally strong. Third, in order that this load may be distributed among as many grains as possible, so that the load imposed on each shall not be beyond its ability to sustain, and also in order that an undue quantity of cement shall not be required, the grains shall be graded in size, so that the medium sized grains may fill between the large grains, the small grains between the medium grains, and the fine grains fill between the small grains."

These functions require tests of the following character to be made on the sand: Mechanical analysis test, determination of voids, tensile strength tests, tests for organic content or the colorimetric test, and such other tests as local conditions may require. In the case of Eastern Washington sands, chemical analyses were made of certain selected samples to determine whether or not the deposits of that part of the state have any alkali content.

DESCRIPTION OF TESTS PERFORMED.

Mechanical Analysis.

In order to determine the gradation in size of the sands from the various gravel samples, a mechanical analysis was made. The fine aggregate was obtained from each sample of gravel by taking that portion which passed a ¼-inch screen. The material was then washed and dried and passed successively through the 10, 20, 30, 40, 50, 80, 100, and 200 mesh sieves. The percentages by weight passing each sieve were calculated and recorded.

Determination of Voids.

The percentage of voids was determined with Le Chatelier's flask. A known quantity of sand, carefully determined, was introduced in the flask, which contained a known amount of water. The sand and water were thoroughly shaken and then left to stand for several minutes, after which a reading was made of the combined volume. The following computation was then made:

$$V = \frac{A+B-C}{A} \times 100,$$

where V=percentage of voids

A=volume of the sand (measured as stated below)

B=volume of water, indicated by the water-level before the sand was added

C=combined volume of sand and water, indicated by the water-level after the sand was introduced.

The volume of the sand was carefully measured in a graduated cylinder, the sand being introduced through a funnel from a height of about 8 inches. The sand was poured against the side of the funnel in such a way that a circular motion was developed and the sand allowed to flow steadily into the graduate.

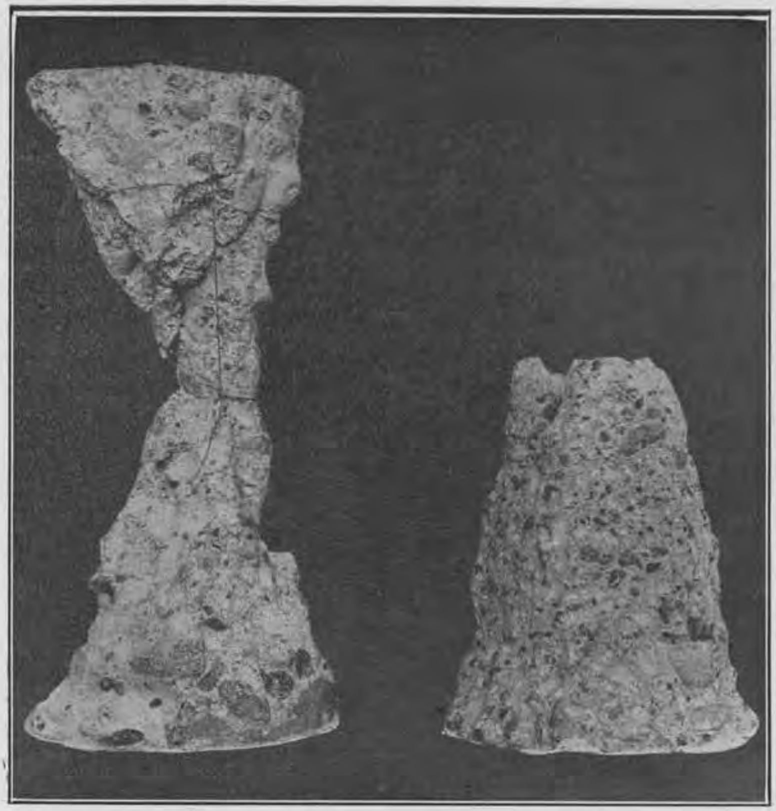
Tensile Strength Tests of Mortar.

Most of the counties of Washington which have issued specifications for concrete pavement include a clause requiring the briquettes made from the sand proposed for use to show a tensile strength at least equal to the tensile strength of briquettes made from Ottawa Standard sand. This test was made on all the sands which came from localities where it seemed advisable to know their concrete making qualities. The recommendations of the American Society for Testing Materials were followed. Both the 7-day and 28-day tests were made on each sample and their tensile strength obtained by the Riehle machine. In each case briquettes were also made of the Standard Ottawa sand and the same kind of cement and their tensile strength ascertained as a basis of comparison.

Colorimetric Test.

As a result of researches carried on at Lewis Institute on the causes of impure sands for concrete and remedies for them, a colorimetric test has been devised which indicates the presence of organic impurities in sands and whether or not they are present in such quantities as would be injurious to concrete. The test is recommended by the American Society for Testing Materials, and the following excerpt is taken from the Proceedings of the Society's Twentieth Annual Meeting, Vol. XVII, 1917, Part I, pp. 327-333:

"A sample of the sand is digested at ordinary temperatures in a solution of sodium hydroxide (NaOH). If the sand contains certain organic materials, thought to be largely of a humus nature, the filtered solution resulting from this treatment will be found to be of a color ranging from light yellow up through the reds to



A remarkable double cone, secured in the compressional strength test of one of the concrete cylinders, and a single cone. Height of the double cone, 12 inches. In almost all cases the cylinders broke by shearing around the pebbles.

that which appears almost black. The depth of the color has been found to furnish a measure of the effect of the impurities on the strength of mortars made from such sands. The depth of the color may be measured by comparison with proper color standards."

The test made in the present series was as follows: A 12-ounce graduated prescription bottle was filled to the 4½-ounce mark with the sand to be tested. A 3 per cent solution of sodium hydroxide (NaOH) was then added until the volume of the sand and the solution, after shaking, amounted to 7 ounces. After shaking thoroughly, the solution was let stand for 24 hours and the color of the supernatant liquid then observed. If the clear supernatant liquid was colorless, or had a light yellow color, the sand was regarded as satisfactory for concrete in so far as organic impurities were concerned. But if a dark colored solution, ranging from dark red to black was obtained, the sand was considered questionable. In such a case reference should be made to the mortar strength tests.

Chemical Analyses for Alkali Content.

Because of the semi-aridity of the climate of eastern Washington, and of the rather common occurrence of white particles and fragments in the sands and gravels which are popularly called alkali, some chemical analyses were made to determine whether these ingredients were actually alkali and of a character harmful to concrete. The analyses were made by the firm of Charles A. Newhall Co., Industrial Chemists and Assayers of Seattle, associated with the Pittsburgh Testing Laboratory. Determinations were made for Silica and other insoluble matter, Iron and Aluminum oxides, Calcium Carbonate, Magnesium Carbonate, Sulphates, Chlorides, and water soluble alkalies.

RESULTS OF TESTS MADE ON FINE AGGREGATE.

Physical Properties

The results of the examination of the physical properties of samples of sand are given in tabulated form in Table III. These include a statement regarding their location, their general character, and composition, sieve analyses, and percentage of voids. It will be noted that the sands from those counties in the Columbia Plateau Province are coarse basaltic sands, and most of them are deficient in fine material, while along the Yakima River in the Yakima District, they are generally deficient in coarse constituents.

The suitability of any particular sand, so far as gradation in size is concerned, may be judged from the following specifications of the Office of Public Roads and Rural Engineering, U. S. Department of Agriculture:

For Use as Fine Aggregate, Cement Concrete, First Class.

"All to pass a ¼-inch sieve, to have at least 20 and not more than 50 per cent retained on a 20-mesh sieve, at least 80 per cent retined on a 50-mesh sieve, and at least 97 per cent retained on a 200-mesh sieve."

For Use as Fine Aggregate, Cement Concrete, Second Class.

"All to pass a ¼-inch sieve, to have not more than 80 per cent retained on a 50-mesh sieve, and at least 97 per cent retained on a tained on a 50-mesh sieve, and at least 95 per cent retained on a 200-mesh sieve."

General notes are made in the "Remarks column" of Table III to indicate the deficiencies of the various samples of sand in meeting the above specifications. Specific remarks as to the percentage of deficiencies are purposely avoided, for the reason that the gradation of the sand from a given pit may vary from time to time and analyses must be made at various stages during the progress of a large job to keep this information up-to-date.

Tensile Strength and Colorimetric Tests.

In Table IV are assembled the results of the tensile strength and colorimetric tests made upon the sands. The average strength of three briquettes having values within reasonable limits, was taken to ascertain the comparative strength of a given mortar of a certain age, made from a certain sand. The strength ratio was obtained by dividing the strength of the sand under test by the strength of the Ottawa Standard sand. In almost all cases both the 7-day and 28-day results are shown. For first-class cement concrete the specifications of the Office of Public Roads of the U. S. Department of Agriculture, require "a tensile strength ratio, when compared to Standard Ottawa sand mortar briquettes, of at least 100 per cent;" for second-class concrete, "a tensile strength ratio of at least 75 per cent."

By referring to Table IV, the adaptability of a given sand so far as determined by this test, may readily be seen. It should not be overlooked, however, that after the removal of considerable material from a pit, new tests should be made, as the character of a pit may change as material is taken out. The results herein given may, however, be taken as an indication of the general quality of the sand. Samples which are marked with an asterisk (*) were tested by the Portland Cement Association, in which case duplications were not made.

The results of the colorimetric tests are stated in terms of color. Where the solution remained clear, the sand is free from organic content; if colored a light yellow, the sand is still satisfactory as far as organic impurities are concerned. But if the solution became dark colored, ranging from dark red to black, the amount of organic matter is dangerous. In the latter case the sand should be rejected for use until it is washed and tested again. These tests emphasize the necessity of precautionary measures in selecting sand for concrete. Pits which have not been stripped of humus soil and rootlets, as shown in Plate V, are likely to nullify all other attempts at securing first-class concrete.

Chemical Test for Alkali Content

As previously referred to, the semi-aridity of the climate of Eastern Washington, together with the common occurrence of white particles of mineral matter in the sands and gravels, made it desirable to make chemical tests for alkali content. Three such tests were made, one of a sample taken from a gravel pit ¾ mile southwest of the Northern Pacific Railway Station at Ritzville, another of a sample collected from a bed of "lime-rock" 2½ miles east of Othello, and a third of a sample obtained from a pit 5 miles south of Quincy, Grant County. The locations of these points are designated on the county maps in Chapter V, as 2 and 4 in Adams County and 42 in Grant County, respectively. In all three cases the white mineral was the constituent analyzed.

The results of the analyses are reported by the Charles A. Newhall Company, Seattle, as follows:

	Map No. 2	Map No. 4	Map No. 42
Silica and insoluble	51.20%	46.00%	30.30%
Iron and Aluminum oxides	3.80%	2.40%	4.70%
Calcium carbonate	33.78%	38.76%	56.18%
Magnesium carbonate	11.20%	12.80%	8.80%
Sulphates	absent	absent	absent
Chlorides	absent	absent	absent
Water soluble alkalies	absent	absent	absent

From the above it is clear that the white substance which is so common in the gravels of eastern Washington, especially on the Columbia Plateau, is not alkali but lime and magnesium carbonate and silica. Their harmfulness lies chiefly in cases where they coat the pebbles, causing a plane of weakness around the pebbles in concrete, or where the particles occur in abundance as constituents of gravel, in which case they lower the strength of the aggregate and decrease its resistance to abrasion. Their variability in amount in different pits, from practically nothing to a considerable percentage, makes careful selection necessary.

COARSE AGGREGATE.

The coarse aggregate used in Portland Cement concrete pavements is subjected to the abrasion, impact, and compression of traffic—a service which is much more severe than in concrete walls, foundations, etc. Cleanliness, hardness, and toughness and proper grading are the essential properties. It would be desirable to make tests for toughness, but the heterogeneity in size and kind of pebbles which usually make up a gravel present difficulties which have not yet been overcome.

Test of Size of Grading of Coarse Aggregate.

In this test a sample was usually taken of the material weighing not less than fifty times the size of the largest stone and when thoroughly dried was passed through screens of the following size, having circular openings: 2-inch, 1½-inch, 1-inch, ½-inch, ¼-inch. The percentage by weight on each screen was determined, together with that which passed the ¼-inch screen, if any.

Abrasion Test.

Abrasion tests were performed on the samples of coarse aggregate in the same way as has been described for "Road-gravel", Chapter III.

FIELD TESTS OF PORTLAND CEMENT CONCRETE.

In order to ascertain the quality of the cement concrete which was being put into concrete pavements with accepted brands of cement and various types of gravel, field tests were made of the concrete which was being laid in the counties of Whatcom, Skagit, Snohomish, King, Pierce, Thurston, and Spokane. Following the recommendations of the U. S. Office of Public Roads, cylindrical forms were made, 6 inches in diameter and 12 inches high. The test was undertaken by digging a shallow trench large enough to hold several cylinders in an upright position, alongside the place where the pavement was being laid. The molds were placed in flat, nonabsorbent surfaces and the concrete was put in the molds in layers of 3 or 4 inches and slightly puddled to give a dense product. After 24 hours, they were covered with earth in the same way as the pavement, kept wet for 10 days, and, in every possible way, cured under the same conditions as the pavement. After 60 days, and

The usual type of gravel exposure found along the Olympic Highway, west side of Hood Canal.

in some cases 90 days, the cylinders were taken up, assembled, carefully packed, and shipped to the laboratory for compressional strength-tests. Just before testing they were weighed and measured, and provided with caps of Plaster of Paris for plane bearing surfaces. They were then mounted in the testing machine with a spherical bearing block placed on top of the specimen, the capped specimen being in direct contact with the steel bearing surfaces.

Result of Tests on Coarse Aggregate

In Table V, is given the mechanical analyses of the coarse aggregates which were used in the Field Tests of concrete and which are commonly used in those parts of the state where concrete pavement is being laid. A statement is also given of the location of the pavement where the field tests were made, and a description of the character of the aggregates. The mechanical analyses of other gravels over the state which have thus far not been used in concrete pavements are given in Table I. The reader is also referred to Chapter V for the discussion of the gravel conditions in each county.

Percentage of Wear.

Inasmuch as it is desirable to know the degree of resistance which a given aggregate would offer to abrasion in a concrete pavement the percentage of wear is given for the concrete aggregates described in Table V and also for many of the aggregates described under "Road Gravels" in Table I.

Not many states have included the abrasion test in their specifications, but undoubtedly this will be done more and more in the future. The Ohio State Highway Department at present specifies a wearing value for pebble aggregates used in the concrete wearing surface not to exceed 12 per cent. loss by abrasion. Whatever percentage of wear is adopted by each state obviously should depend in a large measure on the local conditions and the character of the material available.

Table V reveals that most of the coarse aggregates thus far used in cement concrete pavements have a low percentage of wear. The minimum is 2.4 per cent, the maximum 14.8 per cent, and the average 5.2 per cent. All except the Cowlitz River gravels at Castle Rock and the Skagit River gravels at Sedro Woolley showed a per cent loss by abrasion less than 7 per cent, and four less than 3 per cent. The four were from the Chehalis River in Grays Harbor County, from Maury Island, from the Steilacoom deposits, and from the Twin City Sand and Gravel Company's pit at Centralia.

The percentage of wear of 64 other gravels in the state which have not as yet been used for concrete pavement is given in Table I. The average of these is 10.9 per cent, with 32.8 per cent as the maximum and 2.2 per cent as the minimum.

Compressional-Strength of Concrete Cylinders—Made in Field Tests.

All of the cylindrical molds used in this series of tests were 12 inches high and 6 inches in diameter. The location of the field tests, the map number of the source of the aggregate, the brand of cement used, the age of the cylinders at the time of breaking, and the results of the tests showing their compressional strength are given in Table VI. The proportions of mix in all cases were 1:2:3, except in the case of the concrete dock at Dash Point, Pierce County, where the proportions were 1:2:4. The results of the latter are accordingly lower than the others. Most of the cylinders broke into approximately conical forms, but a few broke through the top and bottom, as for example C-3, C-4, and C-10. In view of the fact that the maximum load was high, in the last mentioned cases, it would seem that the cause for breaking through the top and bottom may be credited to the final rupture of the plaster caps, for there was no segregation of the aggregate which would favor this.

An examination of the cones showed that in all cases but one, the breaking took place by shearing around the pebbles rather than by breaking through them. This is taken to indicate that the strength of the pebbles exceeds the mortar matrix, which is the most that could be desired of any aggregate. The only exception to this was in cylinder C-44, which broke through the pebbles. So far as can be judged from one case, namely, the Spokane County cylinders, the gravels of eastern Washington are equal in strength to the first-class gravels of the Puget Sound Province. The former are less resistant to abrasion, however, than the latter, but this may not depreciate the value of the former, for if the aggregate approaches the mortar matrix in hardness the surface of the pavement is less likely to wear rough than if the pebbles are superior in hardness to the matrix.

It would be well if such tests would be made by all the counties who invest in concrete pavements, and include in the specifications that the concrete shall have a compressional strength of at least a certain amount, governed by the local demands of traffic. The inauguration of freight transportation by heavy trucks makes this highly desirable.

Results of Certain Tests Made by R. J. Borhek on the Gravel Aggregates of the Steilacoom Deposit and at Lakeview, Pierce County.

In the spring of 1917, Mr. R. J. Borhek, of Tacoma, made some cylinder tests of the concrete which went into the pavement of Steilacoom Boulevard, between Steilacoom and Tacoma, and also of hand mixed materials from the Steilacoom deposit and from the Pierce County Pit at Lakeview. The conditions under which the molding was done and the curing accomplished is described in Table VII. The cylinders were brought to the Testing Laboratory of the University of Washington and broken by Mr. Everett G. Snell, Instructor in Civil Engineering in the College of Engineering. The cylinders broke into conical forms, such as is shown in Plate VII, one of them giving an almost perfect double cone. The breaks took place around the pebbles in almost all cases, thus indicating again the superiority in strength of the gravel aggregate over the mortar matrix. The voids were well filled.

CHARACTER AND QUALITY OF THE SAND.

The chief points regarding the sand of Washington may be summarized as follows:

1. The sands of the Puget Sound Province are generally first-class in character, being composed of hard, durable, angular to rounded grains of granite, quartz, basalt, andesite, quartzite, and other hard metamorphic rock particles. Some of the deposits are properly

graded in their natural occurrence, but as is the case in almost all areas, they vary to such an extent that mechanical analyses must be made from time to time as material is drawn from a given pit to insure proper control of the gradation for first-class work.

2. In the Southwestern Province the glacial sands and gravels are absent except in a small area north of Centralia, along the Skookumchuck River and that part of the Chehalis River running northwest from Centralia. Elsewhere, basaltic and andesitic sands occur along most of the main streams, with a scant quantity along the minor tributaries. Along the Columbia River the sands are composed of basalt, quartzite, and granite.

3. The Okanogan Province has deposits which are patchy in distribution, being intimately interbedded with silts along the main streams chiefly. Local deposits are being used for concrete pipe manufacture at Omak. The higher benches of the Colville Valley and the high terraces southwest of Newport contain sands suitable for concrete after washing.

4. The black sands of the Columbia Plateau Province are almost entirely basaltic in composition and are generally very strong, but their chief failure is their lack of fine grains to fill the voids and give proper density to the concrete. In a few cases they contain particles of soft lime-rock, rarely as high as 20 per cent, which should be avoided for concrete of first-class strength. Chemical analyses show that the lime particles are not alkali and have no deleterious effect in a chemical way.

5. The Yakima River contains scattered bars of sand and gravel which have high strength in the quality of rock particles, but they show a tendency to contain organic material to a slight extent. Caution is therefore needed in using them and colorimetric tests should be made from time to time during the progress of concrete

A gravel outwash plain in Thurston County, and a highway constructed on it by the removal of the coarse material.

work. The sand also has a tendency to be fine. Coarse sand can be obtained at Naches on the Naches River.

6. The Blue Mountain District is to a large extent void of sand deposits except along the Snake River, the Touchet River, and the Walla Walla River, and the Columbia River. Along these streams good sand can be obtained, but away from them in Asotin, Garfield, and Columbia counties users must import their sand.

GRAVEL.

Some of the gravels of the Puget Sound Province are the hardest and most resistant to abrasion of any gravels tested in the state. This is probably due to their high content of siliceous metamorphic rock fragments. Gravels of the Southwestern Province, especially in Pacific and Cowlitz counties, are, in general, more inferior in character than any others in the state. The gravels on the Columbia Plateau are dominantly basaltic and generally firm and of average wearing value. Some, however, contain pebbles coated with lime, as for example, those northeast of Ritzville, which unfits them for use as coarse aggregate in concrete, by introducing a plane of weakness between the bend of the mortar and the pebbles. Instances of these, however, are comparatively few. The gravels on the slopes bordering the valley of the Yakima River are too soft and weak to be of any use in concrete. The same is also true of the red gravels in the high benches along the lower part of the Chehalis River.

GRAVEL FOR BITUMINOUS CONCRETE ROADS.

In bituminous concrete roads, bituminous materials such as asphalts, heavy asphaltic oils, refined water gas tars, refined coal tars, combinations of tars, or combinations of tars and certain kinds of asphalts are used as the cement to bind together the aggregate. Crushed rock is commonly the mineral aggregate used, for one of the chief factors in this type of pavement is in the inter-locking of the constituents. Gravel is not well adapted because of the rounded form of the pebbles. Where gravel has been used much labor and experimentation has been required to attain the desired coherency.

Aside from the matter of coherency to give stability to the pavement, the pebbles should be properly graded, firm and resistant to abrasion. The Office of Public Roads and Rural Engineering of the U. S. Department of Agriculture specify a gradation of the materials such that all shall pass a 1½-inch screen and be retained on a ¼-inch screen, with at least 25 and not more than 60 per cent retained on a ¾-inch screen.

The gradation, percentage of wear and physical characters of samples of gravel collected from various parts of the state are given in Tables I and V, to which the reader is referred.

The sand which is to be used as fine aggregate in bituminous concrete should pass a ¼-inch sieve, 40 to 60 per cent should be retained on a 40-mesh sieve, and at least 90 per cent retained on a 200-mesh sieve. The mechanical analyses of the various sands are recorded in Table III.

SAND FOR SHEET ASPHALT CONSTRUCTION

A sheet asphalt pavement has a wearing surface composed of a sand of a certain specified grading, fine material or filler, and asphalt cement. The sand and filler should be clean, moderately sharp, and free from loam or other impurities. According to the U. S. Office of Public Roads and Rural Engineering, all should pass a 10-mesh sieve, at least 20 per cent and not more than 30 per cent should be retained on a 40-mesh sieve, at least 40 and not more than 50 per cent should pass the 40-mesh sieve and be retained on the 80-mesh sieve, and at least 25 per cent and not more than 35 per cent should pass the 80-mesh and be retained on the 200-mesh sieve.

It is seldom that a deposit of sand is found which exactly meets these gradation requirements, and so screening is usually necessary to give the proper proportions. The natural run of the deposits over the state is given in tabular form in Table III. From these judgment can be made in a given case regarding the adaptability of material in a given community. It will be noted that in most places in the Columbia Plateau Province of eastern Washington, the basaltic sands are too coarse for sheet asphalt purposes and materials must be imported.

TABLE I. PHYSICAL FEATURES AND RESULTS OF TESTS MADE ON SAMPLES OF ROAD GRAVELS.

Map No.	LOCALITY	COMPOSITION	MECHANICAL ANALYSIS: Total Retained on Screens: 2-inch, per cent	1½-inch, per cent	1-inch, per cent	½-inch, per cent	¼-inch, per cent	Per cent of coarse aggregate retained on 1-inch screen	Per cent of fine aggregate passing 200-mesh	Hardness of Pebbles: H'rd, per cent	Soft, per cent	Per cent of wear	Tenacity value of binder (passing 10-mesh)	Cementation value of binder (passing ¼-inch)	NOTES ON SUITABILITY FOR ROAD-SURFACING
	ADAMS COUNTY														
1	Tokio, ⅛ mile e.	Basaltic, with some pebbles partly coated with lime.	12.0	19.0	25.5	40.5	59.5	43.0	6.1	87	13	16.5	13	300+	Additional clay needed.
2	Ritzville, ¾ mile s. w. station.	Basaltic	10.7	25.3	38.3	65.0	76.2	50.3	5.2	97	3	13.6	......	300+	More binder should be added.
3	Washtucna, 3½ miles n.	Basaltic	6.0	15.5	35.0	60.2	75.2	41.2	7.6	94	6	11.2	47	......	More binder should be added.
4	Othello, 2½ miles e.	Lime fragments	....	....	....	....	....	......	......	0	100	high	4	......	Unfit for road-surfacing.
	ASOTIN COUNTY														
5	Clarkston, City Pit	Basalt, granite, diorite, quartzite.	2.1	9.1	11.1	13.3	22.6	49.1	1.0	99	1	.....	0	322	Additional coarse aggregate and clay-binder needed.
6	Asotin, ¼ mile s.	Chiefly basalt	0.0	0.0	0.0	0.2	2.0	0.0	0.8	98	2	.....	0	......	Best suited for sand-clay road.
7	Clarkston, 6 miles w., along Columbia River.	Basalt, granite, diorite, quartzite.	4.4	31.4	63.0	93.6	95.0	66.3	6.0	98	2	4.2	0	......	Lacking in binding material.
	BENTON COUNTY														
8	Prosser, 5½ miles n. w.	Mostly basalt, some lime fragments.	13.8	31.0	43.5	68.5	77.5	60.1	1.1	90	10	11.0	0	......	Insufficient clay for binder.
9	Prosser, 5½ miles due n. e.	Basaltic	4.0	8.0	16.0	46.0	83.5	19.1	2.0	98	2	.....	12	......	Additional coarse aggregate up to 1½ inch would be beneficial.
10	¼ mile north of No. 9.	Basalt and quartzite	0.0	1.0	3.0	9.0	14.0	21.4	2.3	......	......	.....	0	......	Too largely sand for gravel surfacing.
11	Benton City, 2 miles n. w.	Basalt 50%, quartzite 40%, granite 4%, limerock 6%.	1.0	11.0	51.3	81.3	92.1	55.7	5.6	94	6	.....	6	......	Not enough binding material below ¼ inch.

TABLE I—Continued.

Map No.	LOCALITY	COMPOSITION	MECHANICAL ANALYSIS: Total Retained on Screens: 2-inch, per cent	1½-inch, per cent	1-inch, per cent	½-inch, per cent	¼-inch, per cent	Per cent of coarse aggregate retained on 1-inch screen	Per cent of fine aggregate passing 200-mesh	Hardness of Pebbles: H'rd, per cent	Soft, per cent	Per cent of wear	Tenacity value of binder (passing 10-mesh)	Cementation value of binder (passing ¼-inch)	NOTES ON SUITABILITY FOR ROAD-SURFACING
12	Kiona, s. side of river.....	Quartzite, basalt, granite...	9.0	13.5	38.5	68.4	84.6	45.5	3.8	97	3	.....	....	....	With additional clay should prove satisfactory.
13	Kiona, 1¼ miles n. e.......	Basalt, quartzite, granite...	9.6	24.0	48.0	74.0	81.2	59.1	6.4	90	10	10.1	4	....	Too much fine sand to pack well.
14	Kiona, 4 miles n. e.........	Quartzite, basalt, much lime rock.	4.8	9.6	28.8	57.6	69.6	41.4	17.1	75	25	20.4	12	....	May be dusty in dry weather.
15	Fallon Bridge, 4 miles n. w. of Richland.	Basalt, quartzite, granite...	0.5	9.0	39.0	59.5	67.0	58.2	4.0	98	2	.....	1	....	Binder needed.
16	Kennewick, 4 miles n. w...	Basalt and andesite 46%, quartzite 46%, granite 8%.	5.0	10.6	15.6	29.3	45.0	34.7	21.5	81	19	18.2	120	....	Too high proportion of clay.
	CHELAN COUNTY														
17	Monitor, ½ mile e., Wenatchee River Flat.	Gneiss, granite, basalt, quartzite, diorite.	14.9	29.4	44.7	60.7	72.7	61.4	1.1	99	1	6.4	1	....	Some clay needed.
18	Wenatchee, 9½ miles n., mouth of Swakane Creek.	Granite, schist, quartzite....	0.0	4.0	8.0	28.0	48.2	16.6	8.2	81	19	.....	9	55	Satisfactory for light traffic.
19	Wenatchee, 3¼ miles n. w..	Granite 53%, schist 26%, quartzite 13%, basalt 6%, quartz 2%.	2.6	11.0	16.0	26.7	51.6	31.0	1.4	94	6	7.6	9	262	Some additional clay for binding would be beneficial.
20	Wenatchee, 2½ miles n. w..	Granite, quartzite, basalt, schist.	28.1	51.7	64.5	74.5	81.4	78.4	1.7	96	4	7.8	....	....	Some fine aggregate needed to fill the bonds.
21	Cashmere, 1½ miles s. e...	Granite, quartzite, basalt, schist.	0.0	0.3	4.0	9.0	24.0	16.6	11.2	......	......	.....	227	....	A good natural sand-clay road material.
	COWLITZ COUNTY														
22	Kalama, 2¼ miles n.......	Andesite, pumice, tuff.......	2.9	7.5	11.0	20.2	27.3	4.3	1.2	32	68	32.8	0	....	Too soft except on road having very light traffic.
23	Kelso, 2½ miles s. e........	Andesite 40%, basalt 34%, quartzite 25%, granite 1%.	8.2	39.2	62.0	77.6	81.2	76.5	15.7	88	12	6.1	125	500+	Too coarse for use without crushing, otherwise good.

24	Kelso, 5 miles n. w........	Andesite and basalt chiefly, few quartzites.	12.0	24.2	38.1	48.3	58.0	65.7	8.3	85	15	.....	22	....	Satisfactory, but pit has heavy over-burden.
25	Castle Rock, Cowlitz River	Andesite, tuff, basalt, greenstone, pumice.	.....	.....	.....	.....	.....	.....	.....	80	20	14.8	0	74	Too coarse to use without crushing.
	DOUGLAS COUNTY														
26	Rock Island, 4 miles n. w..	Basaltic......................	0.0	0.0	1.0	4.0	11.2	9.0	7.8	91	9	.....	14	168	Additional coarse aggregate up to 1½ inch would be beneficial.
27	Trinidad, 1½ miles w......	Basaltic......................	0.0	0.0	1.6	13.6	42.4	3.7	8.4	94	6	.....	25	209	Do.
28	Withrow, 1 mile e..........	Basalt 97%, granite 3%.....	22.0	27.1	37.3	48.7	59.0	63.2	1.1	98	2	4.3	0	....	Clay needed or binder.
29	Bridgeport, 6½ miles s....	Basalt and granite..........	5.0	14.8	26.2	37.0	45.0	58.2	4.7	95	5	8.1	0	....	Should prove satisfactory if over-size is eliminated.
30	Bridgeport, 2½ miles s. e..	Basalt 36%, granite 26%, quartzite 23%, siliceous 15%.	0.2	2.6	17.6	29.4	47.8	36.9	7.1	88	12	8.9	16	269	Good surfacing material.
31	Palisades Station, 1¾ miles n.	Basalt........................	0.0	2.5	18.9	41.4	55.3	34.1	1.1	97	3	3.9	1	....	Lacks clay for binder.
32	Orondo, 3 miles s..........	Schist, granite, quartzite....	26.8	34.9	41.3	54.0	61.1	67.6	1.4	82	18	25.1	9	....	Acts well but wearing qualities are poor.
	FERRY COUNTY														
33	Republic, 3 miles e..........	Granite, andesite, limestone, schist, etc.	30.0	42.5	52.5	62.5	70.0	65.0	6.2	94	6	7.1	0	....	Should be satisfactory if over-size eliminated.
34	Republic, 3½ miles w......	Same as 33..................	1.5	16.5	26.6	44.8	59.0	45.1	8.1	88	12	.....	3	....	Satisfactory for light traffic.
	FRANKLIN COUNTY														
35	Pasco, 3 miles n. e.........	Basalt, quartzite, granite...	31.1	51.4	68.8	79.8	85.0	75.0	11.3	97	3	6.5	15	456	Satisfactory when crushed pit-run.
36	Pasco, ¼ mile s. e. of depot.	Basalt 74%, granite 15%, quartzite 11%.	12.8	22.8	46.4	66.5	74.3	70.6	0.6	98	2	4.6	....	....	Deficient in binding material.
37	Pasco, 4 miles n. w........	Basalt and quartzite........	0.0	8.8	24.9	61.5	76.6	32.5	6.9	96	4	4.9	67	375	Should prove satisfactory.
38	Eltopia, ½ mile n. e.......	Basalt........................	6.2	16.4	25.8	40.3	60.6	42.5	4.3	97	3	5.2	2	....	With additional clay should prove satisfactory.
39	Connell, southern limits...	Basaltic......................	0.0	0.0	0.0	0.0	2.5	0.0	5.5	.....	.....	.....	0	....	Good for sand-clay road and excellent for dressing.
40	Connell, ½ mile s. e.......	Basaltic......................	1.6	4.1	18.9	35.9	55.0	34.3	4.8	98	2	9.8	0	198	Probably needs additional clay for binding.
	GRANT COUNTY														
41	Ephrata, 4 miles n. e......	Basalt........................	0.0	0.0	4.1	16.0	32.0	12.8	6.3	97	3	4.3	0	447	Additional coarse aggregate up to 1½ inch would be beneficial; excellent for top course.
42	Quincy, 5 miles s...........	Basalt, lime coated..........	13.0	21.2	28.8	46.4	60.8	47.3	10.4	85	15	23.2	4	....	Should prove satisfactory if over-size eliminated.
43	Trinidad, 2½ miles n. e., deep roadway cut.	Basaltic......................	10.2	30.2	49.0	62.5	71.8	65.8	8.7	89	11	.....	8	....	Satisfactory if over-size is eliminated.

TABLE I—Continued.

Map No.	LOCALITY	COMPOSITION	MECHANICAL ANALYSIS: Total Retained on Screens: 2-inch, per cent	1½-inch, per cent	1-inch, per cent	½-inch, per cent	¼-inch, per cent	Per cent of coarse aggregate retained on 1-inch screen	Per cent of fine aggregate passing 200-mesh	Hardness of Pebbles: H'rd, per cent	Soft, per cent	Per cent of wear	Tenacity value of binder (passing 10-mesh)	Cementation value of binder (passing ¼-inch)	NOTES ON SUITABILITY FOR ROAD-SURFACING
	GRANT COUNTY—Cont.														
44	Hartline....................	Basaltic......................	0.0	9.1	13.6	19.1	35.1	38.7	2.8	94	6	7.8	2	......	Lacks clay for binder, otherwise satisfactory.
	GRAYS HARBOR COUNTY														
45	Elma, 2¼ miles w.........	Basalt 35%, siliceous 51%, quartzite and sandstone 14%.	7.9	9.1	13.1	27.9	37.7	35.2	0.2	95	5	2.2	0	117	Satisfactory if additional clay is added for binder.
46	Elma, 1 mile s. e., Cloquallam River bridge.	Basalt 66%, sandstone, 14%, siliceous 14%, granite 6%.	10.8	18.6	30.6	53.9	73.1	37.6	1.2	95	5	3.7	......	......	Additional binder needed and over-size should be crushed or eliminated.
47	Newton, 4 miles n.........	Mostly basalt, some sandstone and metamorphics.	3.1	11.2	24.2	51.5	67.4	35.0	1.0	94	6	6.3	3	......	Satisfactory with addition of some binder.
48	Humptulips, 8 miles n. e..	Mostly basalt and andesite.	22.1	32.3	34.4	49.8	60.0	57.3	11.2	92	8	5.4	26	151	Considerable over-size, otherwise satisfactory.
49	Black River, E½, Sec. 33, T. 16 N., R. 20 E.	Basalt and andesite 77%, siliceous 16%, granite 7%.	6.4	12.4	20.8	41.2	54.1	38.4	0.5	95	5	.....	0	......	Satisfactory with addition of binder.
50	Montesano, 4 miles s. e., Chehalis River.	Basalt and andesite 88%, siliceous 9%, granite 3%.	2.2	8.5	17.2	42.7	66.4	25.7	0.9	96	4	2.9	......	......	Do.
	KITTITAS COUNTY														
51	Roslyn, 2 miles w.........	Granite, basalt, rhyolite, quartzite, diorite.	14.0	19.0	24.9	39.7	55.8	44.6	11.0	90	10	7.6	25	262	Satisfactory with elimination of over-size.
52	Thorp, 3 miles s. e.......	Basalt 85%, quartzite and schist 11%, granite 4%.	27.3	41.6	48.5	52.3	62.2	77.9	7.8	88	12	18.0	51	490	Only fairly resistant, but otherwise satisfactory if crushed.
53	Kittitas, 1½ miles s......	Basalt 75%, lime fragments 25%.	22.4	37.4	54.4	73.8	85.0	56.2	7.5	75	25	22.6	11	......	Satisfactory for light traffic when crushed pit-run.

	KLICKITAT COUNTY														
54	Roosevelt, 7 miles n. w., White's Pit.	Basalt, andesite, quartzite..	15.1	24.3	34.3	45.8	57.8	50.8	7.5	84	16	10.2	28	500+	Satisfactory when over-size is eliminated.
55	White Salmon, n. e. part..	Basalt, quartzite............	0.0	0.0	5.6	8.4	16.8	33.3	4.9	95	5	.....	2	405	Addition of coarse aggregate up to 1½ inch would be beneficial.
56	Lyle, ¾ mile n. w.........	Mostly basalt, few quartzites.	0.1	0.4	2.4	13.6	28.0	8.5	2.8	95	5	.....	82	....	Do.
	LINCOLN COUNTY														
57	Lorene, ½ mile w..........	Basalt 85%, granite 14%, quartzite 1%.	16.0	24.5	31.0	38.2	52.0	30.0	2.6	93	7	8.1	10	....	Satisfactory when over-size is eliminated and clay is added.
58	Davenport, 4 miles w......	Basalt 40%, clay pebbles 60%	8.0	10.5	15.0	26.0	34.0	44.0	11.1	40	60	very high	12	....	Unsatisfactory. Too high proportion of clay pebbles.
59	Wilbur, ¼ mile n..........	Basaltic with considerable lime.	10.5	24.5	34.5	55.0	66.0	46.6	1.1	91	9	9.4	3	....	May prove satisfactory when crushed pit-run.
60	Wilbur, 2½ miles w........	Chiefly basalt...............	8.0	17.0	25.8	38.8	56.3	43.8	0.8	98	2	.....	....	....	Satisfactory with addition of clay for binder.
61	Govan, ½ mile s. w........	Basaltic.....................	0.0	0.0	0.0	5.0	8.0	0.0	6.9	......	......	.....	0	....	Good material for sand-clay road.
62	Almira, 1¼ miles n. e.....	Basaltic.....................	12.8	20.8	29.4	39.0	48.2	50.7	1.3	98	2	10.2	0	....	Satisfactory if crushed pit-run.
63	Krupp, 3½ miles s. e.......	Basaltic.....................	0.0	0.0	3.0	18.9	51.9	57.7	1.5	95	5	.....	7	....	Some clay needed for binder and addition of coarse aggregate up to 1½ inch would be helpful.
64	Odessa, ½ mile s. e........	Basaltic, sand and clay.....	0.0	0.0	0.0	1.0	6.7	0.0	13.6	......	......	.....	45	....	Makes excellent sand-clay road.
65	Lamona, 5 miles s. w......	Basaltic.....................	14.0	18.5	27.0	36.0	47.0	57.4	0.9	95	5	6.2	0	....	If crushed pit-run should prove satisfactory.
66	Sprague, 1½ miles w......	Basaltic.....................	12.0	16.9	30.2	52.4	86.9	39.8	0.5	89	11	8.4	....	....	Do.
67	Sprague, 3 miles n. w......	Basaltic.....................	0.0	10.0	23.0	37.2	52.2	44.1	1.2	90	10	7.9	71	....	Satisfactory with addition of clay for binder.
68	Harrington, 1¼ miles s. w.	Basaltic.....................	1.0	8.5	11.5	25.5	42.0	27.3	0.8	93	7	8.2	0	....	Do.
	OKANOGAN COUNTY														
69	Tonasket, Pheasant Pit...	Granite, andesite, schist.....	5.0	11.4	18.2	42.4	51.2	35.5	0.6	87	13	10.6	....	....	Satisfactory with addition of clay for binder.
70	Omak, ¾ mile e., Omak Creek.	Andesite, granite, schist, basalt.	13.7	25.7	41.3	56.8	66.9	55.0	6.9	91	9	7.1	1	68	Has poor binding material, otherwise satisfactory.
71	Brewster, 5½ miles n. e....	Granite 43%, basalt 36%, rhyolite 13%, quartzite 7%.	10.4	20.7	30.1	46.1	54.7	50.5	1.3	94	6	.....	0	....	Some clay needed for binder.
72	Carlton, 3½ miles s. w....	Basalt, andesite, rhyolite, granite, diorite.	5.3	9.7	14.8	30.3	39.3	37.6	12.5	91	9	.....	58	....	May possess too much clay, otherwise good.

TABLE I—Continued.

Map No.	LOCALITY	COMPOSITION	MECHANICAL ANALYSIS: Total Retained on Screens: 2-inch, per cent	1½-inch, per cent	1-inch, per cent	½-inch, per cent	¼-inch, per cent	Per cent of coarse aggregate retained on 1-inch screen	Per cent of fine aggregate passing 200-mesh	Hardness of Pebbles: H'rd, per cent	Soft, per cent	Per cent of wear	Tenacity value of binder (passing 10-mesh)	Cementation value of binder (passing ¼-inch)	NOTES ON SUITABILITY FOR ROAD-SURFACING
	PACIFIC COUNTY														
73	Palux River, near mouth..	Chiefly weathered basalt, some sandstone.	2.3	9.2	20.9	56.6	74.6	28.0	6.9	71	29	17.8	59	500	Too soft except for very light traffic.
74	Williams Creek, near mouth.	Same as 73..................	6.4	8.5	25.5	51.8	69.2	36.7	1.1	76	24	16.5	....	....	Do.
75	Holcomb, 1 mile n........	Basalt 92%, rhyolite 6%, granite 1%.	12.7	34.3	65.0	94.2	99.7	65.2	slight	88	12	10.2	....	....	Clay needed for binder, otherwise satisfactory for light traffic.
76	Raymond, 6 miles s........	Mostly basalt, some sandstone.	5.0	13.4	32.4	65.0	85.0	38.1	2.1	89	11	14.3	70	....	Do.
	PEND OREILLE COUNTY														
77	Newport, 1½ miles s. w....	Quartzite, granite, schist....	9.1	23.5	40.9	63.5	73.5	57.5	2.4	94	6	10.7	26	95	With elimination of over-size is excellent.
78	Penrith, 1 mile w..........	Same as 77, but fragmental.	1.2	6.8	18.0	24.9	32.0	56.3	4.5	72	28	21.5	2	254	Low wearing value probably will shorten the life of this material.
79	Cusick, 4 miles s. e........	Same as 77..................	19.2	25.0	33.4	40.2	45.6	73.2	1.4	91	9	11.3	20	....	Satisfactory if crushed pit-run, or over-size is screened out.
	SKAMANIA COUNTY														
80	Carson, 4 miles e., Wind Mtn. Pit.	Mostly basalt................	0.0	0.0	5.1	36.5	62.7	8.1	3.3	97	3	.....	....	488	Satisfactory where used, but addition of coarse aggregate up to 1½ inch would be beneficial.
	SPOKANE COUNTY														
81	Trent, 5 miles n. e........	Mostly granite...............	0.0	0.0	2.0	5.5	26.0	8.0	3.1	74	26	.....	11	126	Excellent dressing material.
82	Paradise, 1 mile s. e.......	Quartzite 99%...............	0.0	2.0	10.2	27.2	43.3	23.5	4.0	98	2	4.8	27	....	Gives excellent satisfaction on road.
83	Dartford, 4 miles n........	Quartzite, granite, basalt...	0.0	0.0	0.0	0.0	2.8	0.0	3.2	.....	.....	.....	0	....	Good dressing material.
84	Galena, ¾ mile n..........	Mostly basalt, few granites, quartzites and schists.	9.5	24.5	37.7	61.8	73.8	47.5	2.6	94	6	7.6	4	135	Satisfactory when crushed pit-run.

	STEVENS COUNTY														
85	Kettle Falls, ¾ miles s....	Granite, quartzite, slate, diorite, greenstone.	4.1	11.0	21.0	54.2	67.8	30.9	0.5	92	8	.....	0	87	Clay needed for binder.
86	Colville, ½ mile e., City Pit.	Granite, quartzite, schist....	4.4	9.1	17.8	39.7	54.9	32.4	1.0	88	12	19.1	....	....	Satisfactory for light traffic if percentage of sand is reduced.
87	Addy, ¼ mile w..........	Quartzite, basalt, diorite, granite.	0.0	1.9	7.0	24.9	42.1	16.6	3.9	95	5	2.3	0	88	Excellent dressing material.
88	Addy, 9 miles s. w.........	Granite, quartzite, diorite...	5.1	15.1	31.3	42.9	49.8	62.9	2.8	94	6	.....	2	....	Satisfactory with elimination of over-size.
	WALLA WALLA COUNTY														
89	Lowden, 1 mile s. e., Walla Walla River.	Basaltic.....................	3.5	12.1	24.1	36.2	47.6	50.6	0.9	95	5	8.2	58	....	Lacks clay for binder, otherwise satisfactory if over-size is crushed or eliminated.
90	Wallula, ½ mile n. w., Columbia River.	Granite, quartzite, diorite, basalt.	3.8	9.3	17.3	28.4	38.2	45.3	3.1	92	8	.....	2	....	Too much fine sand; crushing of over-size would be beneficial.
91	Two Rivers Station, ¼ mile n. railway cut.	Chiefly basalt, few granites and quartzites.	4.1	9.7	24.0	42.0	58.4	41.1	1.2	96	4	6.9	2	237	Satisfactory if crushed pit-run, and clay is added.
92	Waitsburg, Touchet River.	Basaltic.....................	4.4	16.3	30.6	41.8	51.9	58.9	0.2	94	6	9.1	....	....	Lacks binding material, otherwise satisfactory if coarse is eliminated.
	WHITMAN COUNTY														
93	LaCrosse, ¾ mile n. e.....	Basaltic.....................	15.0	16.0	21.4	44.0	70.0	65.8	3.3	89	11	12.6	89	....	Satisfactory if crushed pit-run.
94	Union Flat Creek, 3 miles n. of LaCrosse.	Basalt.......................	2.4	17.0	27.3	41.1	47.7	57.2	1.2	93	7	9.4	....	....	Some clay needed for binder.
95	Gravel Pit Station, O-W. R. R. & N. Co.	Basaltic, some porous.......	1.8	3.1	9.0	29.1	51.9	17.3	2.6	91	9	10.5	6	500+	Satisfactory.
96	Pullman, 5 miles s. e. South Fork of Palouse River.	Granite, quartzite, basalt...	0.0	0.0	0.0	2.0	13.0	0.0	8.4	88	12	.....	0	....	Good dressing material and satisfactory for sand-clay road.
97	Ewan, n. side of railway..	Basaltic.....................	9.0	24.0	34.5	51.5	70.0	47.0	2.5	95	5	8.2	33	285	Satisfactory if crushed pit-run.
	YAKIMA COUNTY														
98	Selah, ¾ mile s. w........	Quartzite 28%, andesite 29%, basalt 29%, rhyolite 3%.	4.0	12.0	25.5	53.7	69.2	36.9	4.6	89	11	14.5	22	....	Satisfactory for light traffic.
99	Yakima, 4½ miles n. e....	Andesite and basalt.........	.....	.....	.....	.....	.....	....	....	81	19	20.1	75	....	Required crushing. Considerable soft material.
100	Union Gap, ¾ mile e......	Quartzite 12%, andesite 46%, basalt 42%.	.....	.....	.....	.....	.....	....	....	88	12	12.2	15	....	Should be crushed pit-run. Some flat pebbles.
101	Wapato, about 4 miles n. e.	Andesite chiefly.............	12.2	30.2	44.5	65.5	75.0	54.5	3.5	79	21	24.3	42	....	Too soft to use except for very light traffic.
102	Granger, 2½ miles s. e.....	Rhyolite and andesite........	14.0	22.1	29.9	47.4	62.3	38.0	5.1	88	18	19.6	7	....	Do.
103	Sunnyside, 3½ miles s. w., Patch Gravel Pit.	Basalt 46%, quartzite 50%, granite 4%.	11.5	19.6	31.8	43.7	53.9	49.6	6.9	90	10	.....	4	255	Fairly satisfactory.
104	Grandview, 1½ miles s....	Mostly basaltic, "torpedo" sand.	0.0	0.0	0.5	2.0	11.8	4.2	7.4	....	....	.....	4	289	Excellent dressing material and satisfactory for sand-clay road.

TABLE II. COMPOSITION, MECHANICAL ANALYSES, TENACITY VALUE, AND CEMENTATION VALUE OF THE BINDING MATERIAL OF VARIOUS ROAD GRAVELS OF WASHINGTON.

Map No.*	COMPOSITION AND STATE OF WEATHERING	RETAINED ON SIEVES AFTER PASSING 10-MESH (Tyler Standard Screens)					Passing 200-Mesh	Tenacity Value	Cementation Value	REMARKS
		14 Mesh	28 Mesh	48 Mesh	100 Mesh	200 Mesh				
Adams Co.										
1	Chiefly basalt, some lime, little weathered.....	22.0	36.0	58.0	71.0	83.0	17.0	13	300+	
3	Chiefly basalt, some lime, little weathered.....	15.0	31.0	41.0	51.0	66.0	34.0	47	....	
4	Lime fragments..................................	8.0	21.0	29.0	35.5	42.5	47.0	4	....	
Asotin Co.										
5	Basalt, granite, diorite, quartzite, unweathered	40.0	75.0	93.0	97.5	99.0	1.0	0	322	Insufficient binder.
6	Chiefly basalt, fresh............................	27.0	67.0	92.0	97.0	98.0	2.0	0	....	Insufficient binder.
Benton Co.										
9	Basaltic, fresh..................................	40.0	58.0	68.0	78.0	88.0	12.0	12	....	
10	Basaltic, fresh..................................	12.0	59.0	93.0	98.0	99.0	1.0	0	....	Insufficient binder.
11	Basalt, quartzite, little lime, unweathered......	11.0	22.0	45.0	80.0	90.0	10.0	6	....	
13	Basalt, quartzite, somewhat weathered.........	22.0	43.0	61.0	81.0	90.0	10.0	4	....	
14	Quartzite, basalt, much lime....................	7.0	16.0	42.0	69.0	83.0	15.0	12	....	
15	Basalt, quartzite, granite, fresh................	4.0	31.0	81.0	94.0	98.5	1.5	1	....	River material.
16	Basalt, andesite, quartzite, little weathered....	4.5	12.5	52.5	79.5	88.5	11.5	120	....	
Chelan Co.										
17	Gneiss, granite, basalt, diorite, fresh..........	9.0	44.0	81.0	83.0	96.5	3.5	1	....	
18	Granite, schist, quartzite, fresh................	18.0	44.0	69.0	87.0	95.0	5.0	9	55	
19	Granite, schist, quartzite, fresh................	17.0	43.0	66.0	81.0	90.0	10.0	9	262	
21	Same as 19......................................	17.0	42.0	62.0	74.0	87.0	13.0	227	....	
Cowlitz Co.										
22	Andesite-pumice and tuff........................	29.0	66.0	87.0	93.5	96.5	3.5	0	....	Insufficient binder.
23	Andesite, basalt, quartzite, fairly fresh.........	4.0	9.0	26.0	68.0	86.0	14.0	125	500+	
24	Chiefly andesite and basalt, fairly fresh........	6.0	31.0	74.0	91.5	95.5	4.5	22	....	
Douglas Co.										
26	Basaltic, fresh..................................	30.0	52.5	64.5	71.5	82.0	18.0	14	168	
27	Basaltic, fresh..................................	33.0	59.0	82.0	89.0	93.0	7.0	25	209	
28	Chiefly basalt, mostly fresh.....................	27.0	64.0	88.0	96.0	97.5	2.5	0	....	Insufficient binder.
29	Basalt and granite, mostly fresh................	29.0	65.0	88.0	96.0	98.0	2.0	0	....	Insufficient binder.
30	Basalt, granite, quartzite, mostly fresh........	24.0	55.0	76.0	85.0	90.0	10.0	16	269	

31	Basalt, fresh	37.0	74.0	88.0	93.0	96.0	4.0	1	....	
32	Schist, granite, quartzite, partly weathered	21.0	45.0	66.0	78.0	90.0	10.0	9	....	
Ferry Co.										
33	Granite, andesite, fresh	11.0	47.0	87.0	96.0	97.5	2.5	0	....	Insufficient binder.
34	Same as 33	16.0	34.0	56.5	82.5	91.0	9.0	0	....	Insufficient binder.
Franklin Co.										
35	Basalt, quartzite, granite, fresh	12.5	47.5	76.0	84.5	89.0	11.0	15	456	
37	Basalt and quartzite, fresh	22.0	38.0	49.0	66.0	78.0	22.0	67	375	
39	Basalt, fresh	58.0	90.0	95.0	96.0	97.0	3.0	0	....	Insufficient binder.
40	Basaltic, fresh	65.0	75.5	81.5	86.5	91.5	8.5	0	198	Insufficient binder.
Grant Co.										
41	Basalt, fresh	62.5	85.0	87.5	91.0	95.5	4.5	0	447	Insufficient binder.
42	Basalt, lime coated	60.0	79.0	82.5	85.0	90.5	9.5	4	....	
43	Basaltic, fresh	22.5	62.0	82.5	90.0	95.0	5.0	8	....	
44	Basaltic, fresh	39.0	77.0	90.5	94.0	96.5	4.5	2	....	
Grays Harbor Co.										
45	Basalt, siliceous sandstone, fresh	12.5	55.0	93.0	96.0	98.0	2.0	0	117	Insufficient binder.
47	Mostly basalt, partly weathered	23.0	47.5	73.5	89.0	96.0	4.0	3	....	
48	Mostly basalt and andesite, partly weathered	21.5	50.5	72.0	83.5	92.5	7.5	26	151	
49	Basalt and andesite, granite, fresh	12.0	43.0	82.0	92.0	96.5	4.0	0	....	Insufficient binder.
Kittitas Co.										
51	Granite, basalt, rhyolite, quartzite, diorite, fresh.	23.0	50.0	73.0	87.0	94.0	6.0	25	262	
52	Basalt, quartzite and schist, weathered	22.0	51.0	77.0	87.0	93.0	7.0	51	490	
53	Basalt and lime fragments	50.0	85.0	93.0	94.0	95.0	5.0	11	....	
Klickitat Co.										
54	Basalt, andesite, quartzite, mostly fresh	2.0	8.0	49.0	72.0	82.0	18.0	28	500+	
55	Mostly basalt, fresh	52.5	77.5	87.0	91.0	95.0	5.0	2	405	
56	Mostly basalt, fresh	25.0	46.0	58.0	71.0	83.0	17.0	82	....	
Lincoln Co.										
57	Basalt and granite, mostly fresh	37.0	74.5	84.5	88.5	92.5	7.5	10	....	
58	Basalt and clay pebbles	68.0	90.0	95.0	97.0	98.0	2.0	12	....	
59	Basalt and considerable lime	38.5	75.0	89.5	94.5	97.5	2.5	3	....	
60	Chiefly basalt, mostly unweathered	69.0	90.0	95.0	97.0	98.5	1.0	....	....	
61	Basaltic, fresh	51.0	88.0	95.0	97.0	98.5	1.5	0	....	Insufficient binder.
62	Basaltic, mostly fresh	55.0	87.5	94.0	96.0	98.0	2.0	0	....	Insufficient binder.
63	Basaltic, fresh	52.5	81.0	88.5	91.5	95.0	5.0	7	....	
64	Basaltic	22.4	50.0	69.0	81.0	89.0	11.0	45	....	
65	Basaltic, mostly fresh	62.0	96.5	97.5	98.5	100.0	....	0	....	Insufficient binder.
67	Basaltic, mostly fresh	27.5	43.5	53.5	63.5	74.5	25.5	71	....	

* Description of location is given in Table I, after the map number.

TABLE II—Continued.

Map No.*	COMPOSITION AND STATE OF WEATHERING	RETAINED ON SIEVES AFTER PASSING 10-MESH (Tyler Standard Screens)					Passing 200-Mesh	Tenacity Value	Cementation Value	REMARKS
		14 Mesh	28 Mesh	48 Mesh	100 Mesh	200 Mesh				
Okanogan Co.										
70	Andesite, granite, schist, basalt, mostly fresh.	14.0	36.0	63.0	82.0	90.0	10.0	1	68	
72	Basalt, andesite, rhyolite, granite, diorite, partly weathered.	19.0	43.0	57.0	66.0	76.0	24.0	58	....	
Pacific Co.										
73	Chiefly basalt, much weathered................	16.0	36.0	62.0	79.0	89.0	11.0	59	500	
76	Mostly basalt, partly weathered...............	40.0	69.0	83.0	90.0	95.0	5.0	70	....	
Pend Oreille Co.										
77	Quartzite, granite, schist, fresh................	28.0	52.0	65.0	84.0	90.0	10.0	26	95	
Spokane Co.										
82	Quartzite..	17.0	44.0	61.0	83.0	91.0	9.0	27	....	
83	Quartzite, granite, basalt, fresh...............	48.0	80.0	91.0	95.0	97.0	3.0	0	....	Insufficient binder.
84	Mostly basalt..................................	34.0	64.0	82.0	87.0	91.0	9.0	4	135	
Whitman Co.										
97	Basaltic, mostly fresh..........................	57.0	73.0	79.0	84.0	90.0	10.0	33	285	
Yakima Co.										
100	Quartzite, andesite, basalt, partly weathered..	21.0	55.0	82.0	92.0	95.5	4.5	15	....	
102	Rhyolite and andesite, much weathered........	58.0	83.0	98.0	91.5	95.5	4.5	0	....	Insufficient binder.

* Description of location is given in Table I, after the map number.

TABLE III. COMPOSITION AND MECHANICAL ANALYSES OF SANDS TESTED FOR USE IN CEMENT CONCRETE.

Map No.	LOCALITY	CHARACTER OF THE SAND	RETAINED ON SIEVES								Passing 200-Mesh	Percentage of Voids	REMARKS ON GRADATION OF SIZES
			10-Mesh	20-Mesh	30-Mesh	40-Mesh	50-Mesh	80-Mesh	100-Mesh	200-Mesh			
	ASOTIN COUNTY												
5	Clarkston City Pit........	Basaltic, angular sand......	27.2	50.9	69.7	85.8	90.2	92.7	96.8	98.8	1.2	35.4	About 5 to 10 per cent of sand below the 20-mesh should be added.
	BENTON COUNTY												
9	Prosser, 6½ miles due n. e.	Rather fine, sharp, granitic and basaltic sand.	14.9	34.6	67.4	88.3	93.5	98.0	99.3	91.3	8.7	....	Satisfactory.
10	Prosser, 6¾ miles due n. e.	Do	4.8	25.0	67.4	82.8	92.4	95.8	97.4	99.0	1.0	38.4	Satisfactory.
12	Kiona, south side of river.	Basalt, quartzite, andesite, and granite. Subround to angular.	....	....	....	....	....	....	....	....	....	....	
	CHELAN COUNTY												
17	Monitor, ½ mile e..........	Chiefly granite, some basalt, subangular.	34.3	48.6	67.4	76.4	83.8	86.8	93.8	98.5	1.5	36.6	Satisfactory.
19	Wenatchee, 3¼ miles n. w.	Granite, basalt, and some weak schist, angular to rounded.	53.6	75.4	86.4	91.4	94.0	97.0	97.4	99.2	0.8	36.6	Deficient in sand passing the 20-mesh.
20	Wenatchee, 2 miles n. w....	Granite and basalt, subangular.	11.6	31.2	58.3	75.2	86.2	91.5	96.6	99.3	0.7	34.2	
	CLARKE COUNTY												
105	Minsinger Bros., Vancouver.	Andesite and basalt, fragmental volcanic sand, some rusty grains.	11.6	41.8	76.8	86.4	94.4	98.4	98.8	99.8	0.2	37.8	
	COWLITZ COUNTY												
23	Kelso, 2½ miles s. e........	Basalt, quartzite, and andesite. Rounded to angular.	3.0	15.4	40.9	67.9	85.3	90.4	91.9	98.0	2.0	....	Some coarse sand needed.
25	Castle Rock, Cowlitz River bar.	Andesite and basalt, sharp..	26.0	52.4	86.4	91.4	96.4	98.2	98.6	99.6	0.4	37.2	Deficient in fine sand.
	DOUGLAS COUNTY												
26	Rock Island, 4 miles n. w..	Chiefly granite, some schist and basalt, mostly angular.	48.6	79.8	90.4	93.8	96.6	98.4	98.6	99.6	0.4	35.1	Fine sand should be added.
28	Withrow, 1 mile e..........	Chiefly basalt, few granite grains, angular.	48.4	80.8	94.8	98.0	99.2	99.8	99.8	99.8	0.2	34.9	Deficient in fine sand.

TABLE III—Continued.

Map No.	LOCALITY	CHARACTER OF THE SAND	RETAINED ON SIEVES 10-Mesh	20-Mesh	30-Mesh	40-Mesh	50-Mesh	80-Mesh	100-Mesh	200-Mesh	Passing 200-Mesh	Percentage of Voids	REMARKS ON GRADATION OF SIZES
30	Bridgeport, 2½ miles s. e..	Granite and basalt, subrounded to sharp.	44.0	72.0	87.6	92.0	96.0	98.6	99.0	99.8	0.2	29.5	Do.
31	Palisades Station, 1¾ miles n.	Basalt, with few lime fragments, no coating on grains.	46.6	82.6	93.8	96.6	98.4	99.4	99.7	99.9	0.1	38.3	Do.
	FRANKLIN COUNTY												
39	Connell, southern limits...	Basaltic sand, angular.	35.4	88.2	98.6	99.6	99.9	....	....	....	....	38.1	Deficient in fine sand.
	GRANT COUNTY												
41	Ephrata, 4 miles n. e......	Chiefly basaltic, coarse and sharp.	55.2	92.8	98.2	99.2	99.5	99.7	99.8	99.9	0.1	39.7	Some fine sand needed.
106	Ephrata, ½ mile w., Pruitt Pit.	Chiefly andesite, porous, fragmental and fine.	....	....	....	....	....	....	....	....	....	....	Too fine for good concrete.
	GRAYS HARBOR COUNTY												
45	Elma, 2½ miles w..........	Basalt, quartzite, rhyolite, rounded to angular.	31.4	51.0	82.4	94.4	98.6	99.6	99.8	99.9	0.1	36.1	Some fine sand needed.
46	Cloquallam River, 1 mile s. e. of Elma.	Basalt, quartzite, rhyolite, granite, rounded to angular.	53.6	72.8	83.4	89.6	96.2	99.0	99.2	99.8	0.2	....	Deficiency in fine sand.
49	Black River, E. ½, Sec. 33, T. 16 N., R. 2 W.	Granite, basalt, and siliceous fragments, subrounded to sharp.	42.6	61.4	81.6	90.6	95.6	98.2	98.6	99.6	0.4	31.9	Do.
50	Chehalis River, 4 miles s. e. of Montesano.	Chiefly basalt, some granite, fairly well rounded.	32.6	61.3	76.3	92.8	95.3	97.6	98.6	99.1	0.9	29.6	Do.
107	Wynooche River bar, 1 mile s. e. of Montesano.	Angular basalt, andesite, and quartz.	16.9	44.4	63.6	79.9	90.7	94.7	97.3	99.0	1.0	39.9	Satisfactory.
	ISLAND COUNTY												
108	Ft. Casey, Hesselgrave Pit.	Rounded to angular grains of granite, basalt, quartzite, and greenstone.	15.1	27.7	49.7	64.9	82.9	97.2	98.2	100.0	0.0	34.3	Satisfactory.
*141	Whidby Island, Ft. Casey Pit.	Do.........................	30.2	48.1	66.1	74.2	86.6	95.9	98.6	....	....	26.0	Satisfactory.

	KING COUNTY												
109	Maury Island, Vashon S. & G. Co.	Chiefly basalt, some quartz and quartzite, subrounded.	35.6	63.2	78.7	86.9	94.9	99.1	99.4	99.9	0.1	....	Some fine sand needed.
*110	Richmond Beach..........	Granite, basalt, quartzite, and greenstone. Angular to subrounded.	27.3	48.4	65.1	77.5	88.4	97.2	98.7	....	....	27.5	Satisfactory.
*111	Between Enumclaw and Auburn.	Granite, basalt, and quartzite. Subrounded to angular.	37.4	61.8	79.0	88.8	95.2	98.5	99.4	....	....	26.5	Deficiency in fine sand.
*112	Between Duwamish and Renton Junction, local pit.	Do...........................	21.0	48.8	74.8	88.5	96.5	99.5	99.8	....	....	30.0	Satisfactory.
*113	Three Tree Point..........	Granite, basalt, andesite, and greenstone, subrounded.	26.0	48.1	64.6	77.4	89.4	97.5	98.9	....	....	26.5	Satisfactory.
	KITTITAS COUNTY												
51	Roslyn, 2 miles w.........	Basalt, sandstone, granite, and quartzite, angular.	42.4	67.2	80.8	86.8	92.6	97.4	97.8	99.8	0.2	33.4	Deficient in fine sand.
52	Thorp, 3 miles s. e.........	Basalt, quartzite, quartz, and rhyolite, subrounded.	44.4	72.4	88.6	94.2	97.4	99.0	99.4	99.8	0.2	33.5	Do.
53	Kittitas, 1½ miles s.......	Basalt, andesite, and rhyolite, subrounded.	63.4	75.2	82.0	85.6	91.9	97.9	98.3	99.9	0.1	....	Do.
	KLICKITAT COUNTY												
55	White Salmon, n. e. part..	Chiefly angular grains of basalt.	29.5	40.7	52.9	59.4	73.0	93.0	91.1	98.7	1.3	41.1	Satisfactory.
	LEWIS COUNTY												
*114	Centralia, Twin City S. & G. Co. (average of three separate tests).	Basalt, quartzite, quartz, granite, and hard metamorphics, rounded to angular.	37.5	54.1	70.5	80.4	89.3	96.2	97.6	99.7	0.3	34.4	Some fine sand needed.
	LINCOLN COUNTY												
59	Wilbur, ¼ mile n..........	Angular grains of basalt....	62.5	87.0	94.4	96.0	97.1	98.2	98.5	99.6	0.4	....	Large deficiency in fine sand.
60	Wilbur, 2½ miles w........	Angular basalt..............	96.5	98.0	99.0	99.6	99.8	100.0	....	....	....	43.2	Do.
62	Almira, 1¼ miles n. e......	Angular basalt, some lime, coating of silica on some grains, but not injurious.	43.1	73.1	79.9	91.3	94.3	95.5	97.6	99.2	0.8	42.3	Deficiency in fine sand.
65	Lamona, 5 miles s. w......	Angular basaltic, slight coating of silica on one side of grains, not harmful.	63.4	96.7	99.4	99.9	100.0	....	....	....	....	42.8	Large deficiency in fine sand.
68	Harrington, 1¼ miles s. e., Witt Pit.	Basalt, angular.............	62.4	97.5	99.9	100.0	100.0	....	....	....	....	42.0	Large deficiency in fine sand.

* Samples with asterisk (*) were tested by the Portland Cement Association.

TABLE III—Continued.

Map No.	LOCALITY	CHARACTER OF THE SAND	RETAINED ON SIEVES 10-Mesh	20-Mesh	30-Mesh	40-Mesh	50-Mesh	80-Mesh	100-Mesh	200-Mesh	Passing 200-Mesh	Percentage of Voids	REMARKS ON GRADATION OF SIZES
	OKANOGAN COUNTY												
69	Tonasket, Pheasant Pit...	Grains of granite, basalt, and quartzite, subangular.	40.3	70.3	88.7	92.7	96.9	99.0	99.2	99.7	0.3	35.5	Deficiency in fine sand.
	PACIFIC COUNTY												
115	Long Island, w. side, Nahcotta S. & G. Co.	Mostly well-rounded and polished black chert, quartzite, quartz, and andesite.	16.0	31.5	51.5	63.5	73.5	88.5	97.0	98.0	2.0	34.2	Some of the fine sand passing 50-mesh sieve should be screened out.
	PEND OREILLE COUNTY												
77	Newport, 1½ miles s. w....	Angular andesite, quartz, basalt, granite, quartzite. Fine particles.	19.7	38.4	45.4	47.9	69.1	91.1	93.1	99.2	0.8	36.5	Too much fine sand passing 50-mesh.
79	Cusick, 4 miles s. e........	Angular grains of quartz, feldspar, quartzite, and basalt. A little fine mica.	13.5	36.0	63.0	76.0	88.2	97.2	98.0	99.8	0.2	....	Satisfactory.
	PIERCE COUNTY												
*116	Steilacoom, Pioneer S. & G. Co.	Granite, andesite, basalt, quartzite, and other hard metamorphics. Angular to subrounded.	30.8	62.8	82.4	91.6	96.7	99.2	99.6	100.0	0.0	29.5	Some fine sand needed.
*117	Tacoma S. & G. Co.......	Do..........................	37.2	67.8	82.0	89.8	94.7	98.4	99.1	100.0	0.0	28.5	Do.
*118	Steilacoom	Do..........................	13.6	36.1	62.6	82.8	94.3	99.0	99.5	100.0	0.0	32.0	Satisfactory.
*119	Steilacoom	Do..........................	21.4	51.2	76.7	90.8	97.9	99.7	99.9	100.0	0.0	29.0	Satisfactory.
134	Steilacoom	Do..........................	40.8	71.1	89.7	94.2	97.7	99.1	99.6	99.8	0.2	....	Considerable fine sand needed.
	SKAGIT COUNTY												
120	Skagit River, 1 mile s. w. of Mt. Vernon.	Angular grains of basalt, quartz, schist, andesite.	5.0	20.0	58.0	82.0	95.5	99.0	99.3	99.8	0.2	41.3	Some coarse would improve this sand.
*121	Skagit River, Burlington bridge.	Do..........................	28.6	59.2	77.4	86.1	93.3	98.5	99.3	100.0	0.0	27.0	Some fine sand needed.
*122	Skagit River, w. of bridge, Sedro Woolley (average of six separate tests).	Do..........................	38.7	51.4	67.5	77.4	85.8	94.3	96.9	100.0	0.0	....	Satisfactory.
	SKAMANIA COUNTY												
80	Carson, 4 miles e., Wind Mountain Gravel Pit.	Rusty angular basalt, andesite, and quartzite.	75.0	94.4	98.4	99.1	99.6	99.9	100.0	....	....	42.7	Large deficiency in fine sand.

	SNOHOMISH COUNTY												
*123	Skykomish River, between Monroe and Duval.	....	54.0	64.4	73.8	82.1	91.4	97.7	98.8	100.0	0.0	23.5	Lacking in sand between 20- and 50-mesh.
*124	Skykomish River, 2 miles s. of Startup (average of three separate tests).	....	31.2	57.1	77.3	86.5	93.4	98.2	99.6	100.0	0.0	27.5	Some fine sand needed.
*125	Skykomish River, Sultan Pit (average of two separate tests).	....	29.4	60.2	83.6	92.4	96.8	99.0	99.5	100.0	0.0	29.5	Do.
*126	Stilaguamish River, Arlington, (average of three separate tests).	....	27.9	60.4	80.9	89.7	95.3	98.4	99.4	100.0	0.0	29.5	Do.
*127	Stilaguamish River, 1½ miles e. of Silvana (average of four separate tests).	....	38.6	63.4	80.9	90.3	96.5	99.2	99.7	100.0	0.0	28.5	Do.
*128	Stilaguamish River, 1 mile e. of Arlington.	....	25.4	57.5	81.0	90.1	95.5	98.8	99.3	100.0	0.0	29.5	Do.
*129	Snoqualmie River, 2 miles e. of Monroe (average of two separate tests).	....	41.0	59.0	72.8	82.8	92.1	98.4	99.2	100.0	0.0	27.2	Do.
*130	Snohomish City Pit.......	....	33.1	55.0	69.0	79.3	91.7	98.2	99.3	100.0	0.0	26.5	Satisfactory.
*131	Monroe, 2 miles e. (side-hill pit).	....	36.8	52.9	68.1	79.1	89.9	97.4	99.1	100.0	0.0	26.0	
	SPOKANE COUNTY												
132	Mead, 1½ miles n..........	Sharp quartz, quartzite, and basalt.	2.8	30.3	84.8	95.0	98.4	99.5	99.6	99.7	0.3	40.3	Satisfactory.
133	Dishman, 4½ miles s. e., Shelley Pit.	Chiefly basalt, some granite, quartz, and quartzite, rounded to angular.	24.9	67.4	89.4	94.3	97.8	99.8	99.0	99.9	0.1	35.9	Deficiency in fine sand.
	STEVENS COUNTY												
87	Addy, ¼ mile w............	Basalt, quartzite, granite, and quartz. Subrounded to angular.	50.0	81.2	92.8	96.0	98.0	99.2	99.3	99.9	0.1	35.7	Large deficiency in fine sand.
	WALLA WALLA COUNTY												
89	Walla Walla River, 1 mile s. w. of Lowden.	Angular basalt, some lime fragments, about 5 per cent.	18.0	56.1	80.6	89.1	94.6	98.1	98.9	99.5	0.5	39.2	Some fine sand needed.
90	Wallula, ½ mile n. w., Columbia River gravel bar.	Basalt, quartzite, andesite, and granite. Rounded to angular.	7.5	13.8	18.8	24.8	49.8	81.5	85.0	96.0	4.0	....	The sand passing 50-mesh should be reduced to at least 20 per cent.

* Samples with asterisk (*) were tested by the Portland Cement Association.

TABLE III—Continued.

Map No.	LOCALITY	CHARACTER OF THE SAND	RETAINED ON SIEVES 10-Mesh	20-Mesh	30-Mesh	40-Mesh	50-Mesh	80-Mesh	100-Mesh	200-Mesh	Passing 200-Mesh	Percentage of Voids	REMARKS ON GRADATION OF SIZES
	WALLA WALLA CO.—Cont.												
91	Two Rivers Station, ¼ mile s., O-W. R. R. & N. Co. Railway cut.	Chiefly basalt, few soft lime fragments. Angular.	19.7	44.7	69.7	80.5	92.7	98.9	99.2	99.9	0.1	38.3	Satisfactory.
92	Waitsburg, Touchet River.	Basaltic grains, mostly rounded.	55.7	81.3	91.3	93.0	95.5	98.2	98.7	99.9	0.1	....	Deficiency in fine sand.
	WHATCOM COUNTY												
135	Lummi Island, Village Point.	Granite, quartzite, basalt, etc. Rounded to angular.	28.2	49.8	70.4	80.4	90.2	97.5	98.2	99.8	0.2	....	Satisfactory.
*136	Nooksak River, Acme Pit..	....	31.0	44.3	67.2	69.9	84.8	95.4	99.7	100.0	0.0	....	Satisfactory.
137	Nooksak River (Nugent's bridge (average of four separate tests).	Basalt, andesite, granite, and quartzite. Angular to subrounded.	26.8	53.6	78.0	88.5	94.2	97.8	98.8	100.0	0.0	29.2	Some fine sand needed.
*138	Ferndale, 1 mile s. w., Clarkson Pit.	....	30.1	57.4	73.0	83.5	92.8	98.3	99.2	100.0	0.0	29.5	Do.
*139	Lynden, County Pit.......	....	26.6	66.8	90.0	95.5	97.7	99.2	99.7	100.0	0.0	31.0	Do.
*140	Bellingham, Lind Pit (average of four separate tests).	....	18.0	45.7	63.3	81.7	91.7	97.8	98.9	100.0	0.0	29.3	Satisfactory.
	WHITMAN COUNTY												
93	LaCrosse, ¾ mile n. e......	Angular grains of basalt. Coarse.	91.5	99.1	99.6	99.7	99.8	100.0	....	....	....	....	Large deficiency in fine sand.
94	LaCrosse, 3 miles n., Union Flat Creek.	Angular grains of basalt with few lime fragments.	47.7	87.5	97.5	99.0	99.6	99.8	99.9	99.9	0.1	42.3	Do.
95	Gravel Pit Station, O-W. R. R. & N. Co.	Porous, angular basalt.....	73.7	98.3	99.5	99.8	99.9	99.9	99.9	100.0	0.0	45.1	Do.
97	Ewan, n. side of railway..	Angular basaltic grains.....	83.3	99.4	99.9	100.0	....	....	....	....	....	47.7	Do.
	YAKIMA COUNTY												
103	Sunnyside, 3½ miles s. w., Patch Gravel Pit.	Soft andesite, basalt, and quartzite. Angular.	12.1	17.6	33.7	68.1	89.2	96.4	97.9	99.7	0.3	44.0	Some coarse sand needed.
104	Grandview, 1½ miles s.....	About 80 per cent durable basalt and 20 per cent soft lime fragments. Angular.	16.8	68.5	93.2	96.0	99.2	99.2	99.3	100.0	0.0	42.2	Deficiency in fine sand.

	YAKIMA COUNTY (Con'd)												
141	Naches, Naches River bridge.	Angular basalt, some quartzite and lime fragments.	17.8	46.1	76.2	87.4	94.4	98.2	98.9	99.8	0.2	36.9	Satisfactory.
142	Yakima River, n. e. of Yakima on Marble Spur of N. P. Ry.	Rounded to angular basalt, diorite, andesite, and quartzite.	....	....	....	....	....	....	....	....	....	....	
143	Yakima River, Lower Moxee bridge, 2½ miles s. e. of Yakima.	Do........................	28.3	37.9	50.6	72.2	91.0	94.1	99.5	100.0	0.0	31.2	Some coarse sand needed.
144	Yakima River, just s. of Donald-Wapato bridge.	Do........................	29.8	56.7	80.3	89.0	95.0	98.3	98.7	99.7	0.3	33.8	Some fine sand needed.
145	Yakima River, ½ mile s. e. of Zillah.	Do........................	33.3	51.7	71.8	83.9	93.8	98.4	98.9	100.0	0.0	....	Some sand needed between 20-mesh and 50-mesh.
146	Yakima River, 7 miles s. w. of Sunnyside, Ole Levold's place.	Basalt, black chert, granite, and diorite. Mostly rounded.	23.3	34.1	52.6	67.1	84.1	95.6	96.6	99.5	0.5	31.7	Percentage of sand passing 50-mesh at least 12 per cent too high.

* Samples with asterisk (*) were tested by the Portland Cement Association.

TABLE IV. RESULTS OF TENSILE STRENGTH TESTS AND COLORIMETRIC TESTS MADE ON VARIOUS SANDS OF WASHINGTON.

Map No.	LOCALITY	7-DAY BRIQUETS		Tensile Strength Ratio, 7 Days (Per cent)	28-DAY BRIQUETS		Tensile Strength Ratio, 28 Days (Per cent)	COLORIMETRIC TEST FOR ORGANIC CONTENT
		Sand Under Test	Ottawa Standard Sand		Sand Under Test	Ottawa Standard Sand		
	ASOTIN COUNTY							
5	Clarkston City Pit	413	310	133.2	505	353	143.1	Clear.
	BENTON COUNTY							
9	Prosser, 6½ miles n. e.	306	310	98.7	460	353	130.3	Slight discoloration.
10	Prosser, 6¾ miles n. e.	342	300	114.0	405	353	119.9	Clear.
12	Kiona, south side of river	270	310	87.1	376	353	106.5	Slight discoloration.
	CHELAN COUNTY							
17	Monitor, ½ mile e.	330	300	110.0	405	353	127.9	Slight discoloration.
19	Wenatchee, 3¼ miles n. w.	372	300	124.0	470	353	133.1	Clear.
20	Wenatchee, 2 miles n. w.	432	300	144.0	423	353	119.9	Clear.
	CLARKE COUNTY							
105	Minsinger Bros., Vancouver	310	324	95.6	410	350	117.1	Some discoloration but not objectionable.
	COWLITZ COUNTY							
23	Kelso, 2½ miles s. e.	199	373	53.4	200	373	53.6	Clear.
25	Castle Rock, Cowlitz River	256	373	68.6	423	373	113.4	Dark yellow to light red.
	DOUGLAS COUNTY							
26	Rock Island, 4 miles n. w.	376	373	100.8	423	373	113.4	Clear.
28	Withrow, 1 mile e.	463	373	129.5	410	373	109.9	Clear.
30	Bridgeport, 2½ miles s. e.	533	373	142.9	566	373	151.7	Clear.
31	Palisades Station, 1¾ miles n.	343	300	114.3	456	353	129.1	Clear.
	FRANKLIN COUNTY							
39	Connell, southern limits	442	373	118.5	530	373	142.1	Clear.
	GRANT COUNTY							
41	Ephrata, 4 miles n. e.	392	278	141.0	446	336	131.4	Clear.
106	Ephrata, ½ mile w., Pruitt Pit	263	278	94.6	312	336	98.8	Clear.

	GRAYS HARBOR COUNTY							
45	Elma, 2½ miles w.	223	324	68.8	226	340	64.6	Blackish red.
46	Cloquallam River, 1 mile s. e. of Elma	367	278	132.0	505	336	153.2	Reddish.
49	Black River, E. ½, Sec. 33, T. 16 N., R. 2 W.	320	324	98.7	435	350	124.3	Dark yellow to light red.
50	Chehalis River, 4 miles s. e. of Montesano	350	324	108.0	466	350	133.1	Dark yellow to light red.
107	Wynooche River bar, 1 mile s. e. of Montesano	370	342	108.2	480	350	137.1	
	ISLAND COUNTY							
108	Ft. Casey, Hesselgrave Pit	328	324	101.2	393	350	112.3	Light yellow.
*141	Whidby Island, Ft. Casey Pit	315	266	118.4	425	395	107.6	
	KING COUNTY							
109	Maury Island, Vashon S. & G. Co.	393	324	121.3	426	350	121.7	Light yellow.
*110	Richmond Beach	375	335	110.1	531	445	119.1	
*111	Between Enumclaw and Auburn	321	281	114.2	438	386	113.4	
*112	Between Duwamish and Renton Jct., local pit	419	326	128.5	448	432	103.7	
*113	Three Tree Point	309	260	118.8	408	395	103.3	
	KITTITAS COUNTY							
51	Roslyn, 2 miles w.	315	324	97.2	410	350	117.1	Light yellow.
52	Thorp, 3 miles s. e.	363	373	97.3	383	336	114.0	Clear.
53	Kittitas, 1½ miles s.	223	324	68.8	230	350	65.7	
	KLICKITAT COUNTY							
55	White Salmon, n. e. part	295	324	91.6	513	340	150.9	
	LEWIS COUNTY							
114	Centralia, Twin City S. & G. Co. (average of three separate tests).	341	315	107.1	446	383	116.2	
	LINCOLN COUNTY							
59	Wilbur, ¼ mile n.	310	324	95.6	470	350	134.3	Clear.
60	Wilbur, 2½ miles w.	280	278	100.7	....	....	....	Clear.
62	Almira, 1¼ miles n. e.	368	324	113.5	356	350	101.7	Clear.
65	Lamona, 5 miles s. w.	372	324	114.8	433	350	123.7	Slight discoloration.
68	Harrington, 1¼ miles s. w., Witt Pit	352	324	108.7	383	350	109.4	
	OKANOGAN COUNTY							
69	Tonasket, Pheasant Pit	530	342	155.0	522	350	149.1	Clear.
	PACIFIC COUNTY							
115	Long Island, w. side. Nahcotta S. & G. Co.	352	342	102.9	366	350	104.5	Dark yellow to light red.

TABLE IV—Continued.

Map No.	LOCALITY	7-DAY BRIQUETS Sand Under Test	7-DAY BRIQUETS Ottawa Standard Sand	Tensile Strength Ratio, 7 Days (Per cent)	28-DAY BRIQUETS Sand Under Test	28-DAY BRIQUETS Ottawa Standard Sand	Tensile Strength Ratio, 28 Days (Per cent)	CONTENT COLORIMETRIC TEST FOR ORGANIC
	PEND OREILLE COUNTY							
77	Newport, 1½ miles s. w.	405	324	125.0	496	340	145.9	Slight discoloration.
79	Cusick, 4 miles s. e.	332	323	102.8	480	340	141.2	Dark yellow to light red.
	PIERCE COUNTY							
*116	Stellacoom, Pioneer S. & G. Co.	481	335	143.5	610	445	137.0	
*117	Tacoma Sand & Gravel Co.	420	332	126.5	553	431	128.3	
*118	Steilacoom	357	307	116.2	431	410	105.1	
*119	Steilacoom	400	297	134.7	510	432	118.0	
134	Steilacoom	298	324	91.9	632	340	187.9	Dark yellow to light red.
	SKAGIT COUNTY							
120	Skagit River, 1 mile s. w. of Mt. Vernon	295	324	91.0	366	350	104.6	Dark yellow to light red.
*121	Skagit River, Burlington bridge	391	269	145.3	552	387	142.6	
*122	Skagit River, west of bridge, Sedro Woolley (average of six separate tests).	326	292	112.3	474	428	111.5	
	SKAMANIA COUNTY							
80	Carson, 4 miles e., Wind Mountain Gravel Pit	215	324	66.3	375	340	110.3	Clear.
	SNOHOMISH COUNTY							
*123	Skykomish River, between Monroe and Duval	330	315	104.7	492	398	123.6	
*124	Skykomish River, 2 miles s. of Startup (average of three separate tests).	363	309	117.1	548	421	129.8	
*125	Skykomish River, Sultan Pit (average of two separate tests).	349	318	108.9	524	407	127.9	
*126	Stilaguamish River, Arlington (average of three separate tests).	415	316	130.5	532	406	128.5	
*127	Stilaguamish River, 1½ miles e. of Silvana (average of four separate tests).	374	302	122.5	520	414	125.5	
*128	Stilaguamish River, 1 mile e. of Arlington	360	331	108.7	652	422	154.2	
*129	Snoqualmie River, 2 miles e. of Monroe (average of two separate tests).	361	332	109.0	539	436	123.7	
*130	Snohomish City Pit	245	268	91.4	412	414	99.5	

*131	Monroe, 2 miles e. (sidehill pit)	415	309	131.0	545	490	111.2	
	SPOKANE COUNTY							
132	Mead, 1½ miles n.	300	323	92.8	490	340	144.1	Clear.
133	Dishman, 4½ miles s. e., Shelley Pit	293	342	85.6	600	350	171.4	Clear.
	STEVENS COUNTY							
87	Addy, ¼ mile w.	496	324	153.1	530	350	151.4	Slight discoloration.
	WALLA WALLA COUNTY							
89	Walla Walla River, 1 mile s. w. of Lowden	332	342	97.0	493	350	140.9	Clear.
90	Wallula, ½ mile n. w., Columbia River gravel bar	....	....	....	252	350	72.0	
91	Two River Station, ¼ mile n., O-W. R. R. & N. Co. railway cut.	330	324	102.1	456	340	134.1	Clear.
92	Waitsburg, Touchet River	330	324	102.1	....	....	....	Dark red.
	WHATCOM COUNTY							
135	Lummi Island, Village Point	450	324	138.9	570	350	162.8	Clear.
*136	Nooksak River, Acme Pit	241	278	86.7	419	397	105.5	
*137	Nooksak River, Nugent's bridge (average of four separate tests).	359	289	124.0	572	396	144.2	
*138	Ferndale, 1 mile s. w., Clarkston Pit	394	303	130.5	500	397	126.3	
*139	Lynden, County Pit	362	320	113.1	522	465	112.2	
*140	Bellingham, Lind Pit (average of four separate tests).	369	322	114.7	537	466	115.7	
	WHITMAN COUNTY							
93	LaCrosse, ¾ mile n. w.	286	324	88.5	463	340	136.1	Slight discoloration.
94	LaCrosse, 3 miles n., Union Flat Creek	303	324	93.8	496	340	145.9	Clear.
95	Gravel Pit Station, O-W. R. R. & N. Co.	236	324	72.8	346	340	101.7	Clear.
97	Ewan, n. side of railway	242	324	74.7	423	340	124.4	Light yellow.
	YAKIMA COUNTY							
103	Sunnyside, 3 miles s. w., Patch Gravel Pit	147	323	45.5	315	340	92.6	Slight discoloration.
104	Grandview, 1½ miles s.	290	323	89.8	486	340	142.0	Clear.
141	Naches, Naches River bridge	340	323	105.2	523	340	156.7	Light yellow.
142	Yakima River, n. e. of Yakima, on Marble Spur of Northern Pacific Railway.	343	323	106.2	396	340	116.4	
143	Yakima River, Lower Moxee bridge, 2½ miles s. e. of Yakima.	353	323	109.3	388	340	114.1	
144	Yakima River, just s. of Donald-Wapato bridge	330	323	102.1	530	340	115.9	Dark yellow.
145	Yakima River, ½ mile s. e. of Zillah	333	323	103.1	460	340	135.6	Light yellow.
146	Yakima River, 7 miles s. w. of Sunnyside, Ole Levold's place.	303	323	93.8	362	340	106.5	Light yellow.

TABLE V. PHYSICAL CHARACTER AND MECHANICAL ANALYSES OF CERTAIN COARSE AGGREGATES USED FOR CEMENT CONCRETE IN WASHINGTON.

Map No.	SOURCE OF MATERIAL	WHERE USED IN PAVEMENT	CHARACTER OF MATERIAL	RETAINED ON SCREENS					Per-cent-age of Wear	REMARKS
				2-Inch	1½-Inch	1-Inch	½-Inch	¼-Inch		
	CHELAN COUNTY									
17	Wenatchee River bar, ½ mile e. of Monitor. Pit owned by W. E. Taylor.	In 1¼ miles of pavement s. e. of Monitor.	Mostly firm granite, greenstone, quartzite, diorite, basalt, gneiss, and schist. Occasional soft granite.	14.9	29.4	44.7	60.7	72.7	6.4	Crushed for use in pavement.
	CLARKE COUNTY									
105	Dredged from Willamette River by Minsinger Bros. & Co., of Vancouver.	....	....	......	......	......	......	......	3.2	Crushed for use in pavement.
	COWLITZ COUNTY									
25	Cowlitz River bar, at Castle Rock.	Used in street pavement, Castle Rock.	Fairly soft andesite tuff, basalt, greenstone, and some pumice.	......	......	......	......	......	14.8	Crushed for use in pavement.
	DOUGLAS COUNTY									
28	Pit 1 mile e. of Withrow, along G. N. Ry.	Used in local concrete work in Waterville.	Mostly firm basalt, few granites. Some pebbles thinly coated with lime. Much over-size.	22.0	27.1	37.3	48.7	59.0	4.3	Glacial. Fairly well rounded.
	GRAYS HARBOR COUNTY									
46	Cloquallam River bar, 1 mile s. e. of Elma, s. of bridge.	At Elma, in concrete base of asphalt pavement, beginning ½ mile w. of town.	Firm and durable basalt, sandstone, granite, and siliceous rocks.	10.8	18.6	30.6	53.9	73.1	3.7	Fragments of wood in the bar are to be avoided.
50	Dredged from bed of Chehalis River by Grays Harbor Construction Co.	In concrete pavement between Montesano and Aberdeen.	Firm and durable basalt, sandstone, granite, and siliceous rocks.	2.2	8.5	17.2	42.7	66.4	2.9	
	ISLAND COUNTY									
148	Ft. Casey, Whidby Island. Keystone Pit.	Skagit County, McLean Road, Permanent Highway 3 B.	Mostly firm and durable granite, basalt, quartzite, siliceous rocks.	15.5	46.3	67.9	94.3	100.0	3.6	Sand previously screened out.

	KING COUNTY									
109	Maury Island, Vashon Sand and Gravel Co.	Pierce County concrete dock at Dash Point.	Basalt, granite, quartzite, and siliceous metamorphic rocks. Mostly firm.	0.0	1.2	5.8	37.4	79.2	2.9	
	LEWIS COUNTY									
114	Terrace of Chehalis River, at Centralia. Twin City Sand and Gravel Co.	Pavements in and near Centralia.	Granite, quartzite, basalt, andesite, diorite, etc.	......	......	......	......	......	2.9	Wood fragments are to be avoided.
	PIERCE COUNTY									
134	Steilacoom, in bluff overlooking Puget Sound.	Thurston County, Federal Aid Project No. 1, e. from Olympia.	Granite, diorite, quartzite, andesite, and siliceous rocks, mostly of durable character.	9.9	20.0	34.1	70.6	100.0	2.4	The last three mechanical analyses were made by Mr. R. E. Borhek and are included here to show the range in size of materials at Steilacoom.
				3.0	......	55.0	92.4	100.0	......	
				21.0	......	69.0	88.0	100.0	......	
				15.0	......	45.0	82.0	100.0	......	
	SKAGIT COUNTY									
147	Skagit River, Hart's bar, Sedro Woolley.	City pavement of Sedro Woolley, on Bennett St., Township St. to Third St.	Granite, quartzite, porous volcanic rocks.	......	......	......	......	......	11.3	
	SPOKANE COUNTY									
133	Shelly gravel pit, Sec. 24, T. 25 N., R. 44 E.	Apple Way, Permanent Highway 4 B.	Granite, quartzite, basalt, gneiss, schist. Mostly firm.	1.4	6.8	19.5	68.0	100.0	5.2	Some crushed boulders of granite were added to the gravel to increase its coarseness.
	WHATCOM COUNTY									
136	Nooksak River bar, pit near Nugent's bridge, Cedarville.	Deming-Lawrence Road.....	Granite, greenstone, schist, and porous volcanic rocks.	23.4	42.4	75.9	99.3	100.0	5.2	
149	Pit in N. W. ¼ Sec. 27, T. 39 N., R. 2 E. Leased by Chas. Lind.	Blaine-Ferndale Road........	Granite, quartzite, diorite, and siliceous metamorphic rocks.	6.3	23.8	46.8	90.4	100.0	4.4	

TABLE VI. RESULTS OF COMPRESSIONAL STRENGTH TESTS ON FIELD CONCRETE CYLINDERS.

Cyl-inder No.	LOCATION OF PAVEMENT	Source of Aggregate (Map No.)	Brand of Cement	Age (Days)	Weight of Cylinder (Lbs.)	COMPRESSIONAL STRENGTH			
						Load at First Crack	Maximum Load, Lbs.	Maximum Load, Lbs. Per Sq. In.	Average
	KING COUNTY								
Cyl-	Duwamish-Renton Jct. Road:								
C 1	Sta. 15+70	Steilacoom, 134	Superior	221	29.80	....	114,400	4046.69	
C 2	Sta. 22+50	Steilacoom, 134	Superior	217	30.80	....	86,400	3056.23	
C 3	Sta. 81+20	Steilacoom, 134	Superior	204	30.00	120,000	124,400	4400.42	4043.15
C 4	Sta. 76+10	Steilacoom, 134	Superior	201	30.00	120,000	132,000	4669.26	
	Houghton-Medina Road:								
C 5	Sta. 441+81	Steilacoom, 134	Olympic	203	30.20	114,000	118,600	4194.90	
C 6	Sta. 447+44	Steilacoom, 134	Olympic	201	31.50	101,000	101,700	3593.91	
C 7	Sta. 452+32	Steilacoom, 134	Olympic	189	31.00	....	104,400	3692.97	3572.60
C 8	Sta. 449+60	Steilacoom, 134	Olympic	200	31.50	76,000	79,400	2808.62	
	PIERCE COUNTY								
	Permanent Highway 8 A (part of Pacific Highway near Nisqually):								
C 9	Sta. 490+27 to 490+57	Steilacoom, 134	Washington	206	31.40	112,000	116,000	4120.97	
C 10	Same panel	Steilacoom, 134	Washington	205	31.00	104,000	108,800	3848.60	
C 11	Sta. 495+70 to 496+00	Steilacoom, 134	Washington	200	31.50	....	108,000	3820.30	4312.87
C 12	Sta. 495+50 to 496+00	Steilacoom, 134	Washington	200	31.00	....	154,400	5461.62	
C 13	Concrete Dock, at Dash Point	Maury Island, 109	Superior	205	29.00	....	78,000	2759.10	
C 14	Concrete Dock, at Dash Point	Maury Island, 109	Superior	205	29.20	....	79,080	2797.30	2880.31
C 15	Concrete Dock, at Dash Point	Maury Island, 109	Superior	205	29.40	....	87,200	3084.54	
	SKAGIT COUNTY								
	McLean Road, Permanent Highway 3 B:								
C 16	Sta. 306+25	Sand, Skagit River, 120	Washington	254	30.50	....	104,600	3662.95	
C 17	Same panel as C 16, n. end	Same as C 16	Washington	254	30.50	....	114,200	3976.32	3744.19
C 18	Sta. 306+55	Same as C 16	Washington	254	30.40	....	103,200	3593.31	

	Sedro Woolley, Fifth Street:								
C 19	50 ft. w. of intersection, Fifth and Bennett Streets.	Skagit River, 147.............	Superior....	260	30.50	88,000	92,000	3203.34	
C 20	Same as C 19..........................	Skagit River, 147.............	Superior....	260	30.50	116,000	117,600	4050.98	3465.50
C 21	Same as C 19..........................	Skagit River, 147.............	Superior....	260	30.20	64,000	88,000	3064.07	
C 22	90 ft. from intersection of Fifth and Bennett Streets.	Skagit River, 147.............	Superior....	260	30.70	96,000	102,800	3543.60	
	SPOKANE COUNTY								
	Apple Way, Permanent Highway 4 B:								
C 26	Sta. 188+00 to 188+50.................	Shelley gravel pit, 133, with crushed rock.	Lehigh......	200	29.40	99,000	108,600	3841.50	
C 27	Same as C 26..........................	Same as C 26, without crushed rock.	Lehigh......	201	29.30	100,000	105,000	3714.20	3755.70
C 28	Same as C 26..........................	Same as C 27.................	Lehigh......	201	29.50	....	93,600	3310.90	
C 29	Same as C 26..........................	Same as C 27.................	Lehigh......	201	29.80	102,000	117,500	4156.30	
	Mead Road:								
C 30	Sta. 258+70...........................	Sand from local pit, gravel from Hillyard.	Spokane....	197	30.00	....	105,600	3735.40	4322.60
C 31	Sta. 258+70...........................	Same as C 30.................	Spokane....	197	29.80	122,000	138,800	4909.80	
	THURSTON COUNTY								
	Federal Aid Project No. 1, 1917:								
C 32	Sta. 29+62 to 29+92...................	Steilacoom, 134...............	Superior....	206	31.40	....	95,800	3388.80	
C 33	Sta. 30+20 to 30+50...................	Steilacoom, 134...............	Superior....	206	31.20	98,000	103,800	3671.70	
C 34	Sta. 30+50 to 30+80...................	Steilacoom, 134...............	Superior....	206	30.60	110,000	113,000	3997.10	4188.79
C 35	Sta. 40+07 to 40+37...................	Steilacoom, 134...............	Superior....	200	30.25	140,000	158,200	5596.03	
C 36	Sta. 52+48 to 52+78...................	Steilacoom, 134...............	Superior....	197	31.50	118,500	130,300	4609.10	
C 37	Sta. 43+38 to 43+68...................	Steilacoom, 134...............	Superior....	200	27.25	100,000	109,400	3870.00	
	WHATCOM COUNTY								
	City of Bellingham:								
C 38	P. S. T. L. & P. Co., Pole 1979.......	Ft. Casey, Hesselgrave Pit...	Olympic....	202	30.60	....	110,800	3900.00	
C 39	Same as C 35..........................	Ft. Casey, Hesselgrave Pit...	Olympic....	211	30.70	132,000	139,000	4892.60	4316.60
C 40	Same as C 35..........................	Ft. Casey, Hesselgrave Pit...	Olympic....	....	30.80	108,000	119,400	4157.40	

TABLE VI—Continued.

Cylinder No.	LOCATION OF PAVEMENT	Source of Aggregate (Map No.)	Brand of Cement	Age (Days)	Weight of Cylinder (Lbs.)	COMPRESSIONAL STRENGTH			
						Load at First Crack	Maximum Load, Lbs.	Maximum Load, Lbs. Per Sq. In.	Average
	Geneva Road, Bellingham to Old Mill Site, west line Sec. 36, T. 38 N., R. 3 E.:								
C 41	Sta. 56+50, Panel 37	Eureka Pit, Lind Gravel Co., 140.	Olympic	252	30.60	....	112,200	3906.60	
C 42	Sta. —	Same as C 41	Olympic	240	30.10	....	134,600	4686.60	4110.90
C 43	Sta. —	Same as C 41	Olympic	230	29.70	104,000	107,400	3739.60	
	Deming-Lawrence Road:								
C 44	Sta. 83+70	Nooksak River, Nugent's Bridge, 135.	Olympic	250	30.90	....	145,800	5076.60	
C 45	Same as C 44	Same as C 44	Olympic	232	31.80	....	120,100	4137.10	4645.03
C 46	Sta. 87	Same as C 44	Olympic	240	30.70	....	135,600	4721.40	
	Blaine-Ferndale Road:								
C 47	Panel 355	Lind Pit, near Ferndale, 149	Olympic	242	31.30	....	132,800	4624.30	
C 48	Panel 355	Same as C 47	Olympic	232	31.50	96,000	104,600	3642.00	4133.15

TABLE VII. PHYSICAL PROPERTIES OF FINE AND COARSE AGGREGATE USED IN TESTS MADE OF STEILACOOM AND LAKEVIEW SAND AND GRAVEL, BY R. J. BORHEK OF TACOMA.

No. of Sample	SOURCE OF AGGREGATE	MECHANICAL ANALYSES — Gravel—Percentage Passing: 2-Inch	1½-Inch	1-Inch	¾-Inch	½-Inch	¼-Inch	Sand (All Passing ¼-Inch): Pass 4-Mesh	Pass 8-Mesh	Pass 14-Mesh	Pass 28-Mesh	Pass 30-Mesh	Pass 50-Mesh	Pass 65-Mesh	Pass 100-Mesh	Pass 200-Mesh	Condition of Molding and Curing	Remarks
1 a	Pierce County Pit at Lakeview, with 30 per cent of fine sand from Steilacoom to give required density.	100.0	95.0	81.0	......	42.5	11.5	97.6	80.0	59.5	......	42.5	13.5	6.5	2.7	1.0	Molded at noon, March 30, 1917, maximum temperature 50°, temperature at midnight 33°. 1½ minute machine mix. Damp sand cured, 14 days, 1:2:3½ mix. Washington Cement.	Mix sticky plastic, would not flatten on dumping.
2 a	From prairie surface at Steilacoom Hospital. Materials unwashed to determine loss in strength due to the sandy loam or silt particles present. Sand of a yellow color.	(¾-inch) 100.0	(½-inch) 90.0	(¼-inch) 55.0	(8-mesh) 33.0	(14-mesh) 28.0	(50-mesh) 8.0	(100-mesh) 0.5	77.0	66.0	50.0	......	15.3	3.0	1.1	......	Molded at temperature of 40°. Hand mix, 1:2:3. Damp sand cured, 14 days.	Plastic consistency. Would not flow upon dumping.
3 a	Steilacoom sand and gravel. Scientifically graded.	100.0	......	50.0	......	17.0	0.0	88.0	60.0	43.0	29.5	......	8.0	2.7	1.0	......	Molded April 18, temperature 40°, rain. 1:3:6 mix, by hand. Damp sand cured, 14 days.	Water, 0.58 per cent.
4 a	Steilacoom sand and gravel, ungraded.	100.0	......	67.0	......	33.0	......	93.0	82.0	66.0	43.0	......	12.0	3.8	1.4	......	Molded under same conditions as 3 a in order to compare ungraded with scientifically graded mixture. Damp sand cured, 14 days.	Water, 0.62 per cent.

TABLE VIII. COMPRESSIONAL STRENGTH OF CYLINDERS MADE FROM AGGREGATES DESCRIBED IN TABLE VII.

No. of Cylinder	Sample No. of Aggregate Used (See Table VII)	Age (Days)	Weight (Lbs.)	Height (Inches)	Cross-Section (Square Inches)	Load at First Crack (Lbs.)	Maximum Load (Lbs.)	Maximum Load (Lbs. Per Sq. In.)	Average
1	1 a	419	30.5	12.00	29.65	....	153,800	5,153.46	
2	1 a	419	30.7	12.04	29.03	....	135,400	4,664.14	5,594.08
3	1 a	420	30.5	12.03	29.34	....	181,800	6,192.91	
4	1 a	420	30.0	11.98	29.03	168,000	184,800	6,365.82	
5	2 a	420(?)	29.9	11.95	29.65	124,000	132,200	4,458.68	
6	2 a	420(?)	29.1	12.03	29.03	....	98,000	3,375 81	3,965.54
7	2 a	420(?)	29.9	12.00	29.65	100,000	103,400	3,419 63	
8	2 a	420(?)	29.3	12.01	29.34	120,000	135,200	4,608.04	
9	3 a	402	30.5	12.03	29.03	....	96,000	3,306.92	
10	3 a	402	31.5	12.08	29.34	68,000	73,000	2,488.07	2,923.01
11	3 a	396	31.5	12.07	29.65	84,000	88,200	2,974.03	
12	4 a	396(?)	30.5	12.02	12.02	....	74,600	2,508.52	
13	4 a	396(?)	30.7	12.10	12.14	....	69,800	2,379.00	2,352.56
14	4 a	396(?)	30.4	12.12	29.03	....	63,000	2,170.16	

CHAPTER V.

THE DISTRIBUTION AND CHARACTER OF THE ROADBUILDING SANDS AND GRAVELS BY COUNTIES.

ADAMS COUNTY

GENERAL STATEMENT.

Adams county is located slightly south of the east central part of Washington, on the Columbia Plateau. Its area is 1912 square miles, and in 1910 its total population was 10,920, or 5.7 persons per square mile. It ranks fifteenth in size and twenty-second in population in the state, thus falling below the average in density of settlement. The chief resource is wheat raising. Several railway lines cross the county in various directions and provide convenient shipping points. The roads which lead to these, over which the wheat is hauled to market, and the through trunk lines, are of prime importance. Only a part of them have been surfaced. The highway from Ritzville, through Ralston, has been metaled, and affords rapid and easy travel—an example of what will probably be the case on other inter-town routes. One state highway, the Central Washington Highway, passes through the county, following a coulee from the boundary south of Cunningham to Ritzville and a shallow depression from there to Sprague. A part of this from Ritzville to Sprague is surfaced.

TOPOGRAPHY.

There are several geologic factors to be considered in constructing highways in this county. The first of these is topography. Adams county is in a plateau country and its range in elevations is from about 2000 feet in the northeastern portion to about 850 feet in the southwestern portion, in the valley of Crab Creek. There are level or nearly level stretches of upland broken here and there by valleys or coulees.* Some of the coulees are quite deep, 500 feet or more, and have steep slopes. In a topography of this sort it would be well if the roads were located according to the contour of the land, so as to obtain convenient and economical grades, rather than along section lines, which is bound to involve difficultly passable hills. The former principle is carried out along the highway north from Washtucna.

SUBSOIL.

The subsoil of the county, which serves as the ultimate foundation of most of the roads, is generally a fine-textured clay which makes a deep, dusty and rutted road in dry weather and a heavy, muddy road after considerable rain. In a few places, as west of Bemis, this clay is intermixed with coarse sand so as to form a natural, substantial sand-clay road. It is said to be always good. If the proportions of sand and clay were known —and they could be ascertained by simple mechanical analyses—man might well duplicate Nature's work in localities where the proper materials are available.

CLIMATE.

The climate is semi-arid, so characteristic of eastern Washington. The precipitation is a little less than 10 inches on the average in the western part of the county, but it gradually increases eastward to a little more than 10. Most of this occurs during the winter, partly in the form of snow. This means that the summers are very dry, so that by harvest time the moisture content of the soil is mostly gone and the roads are prevalently rutted.

* There are valleys in eastern Washington which are streamless or are occupied by insignificantly small streams which are locally called coulees.

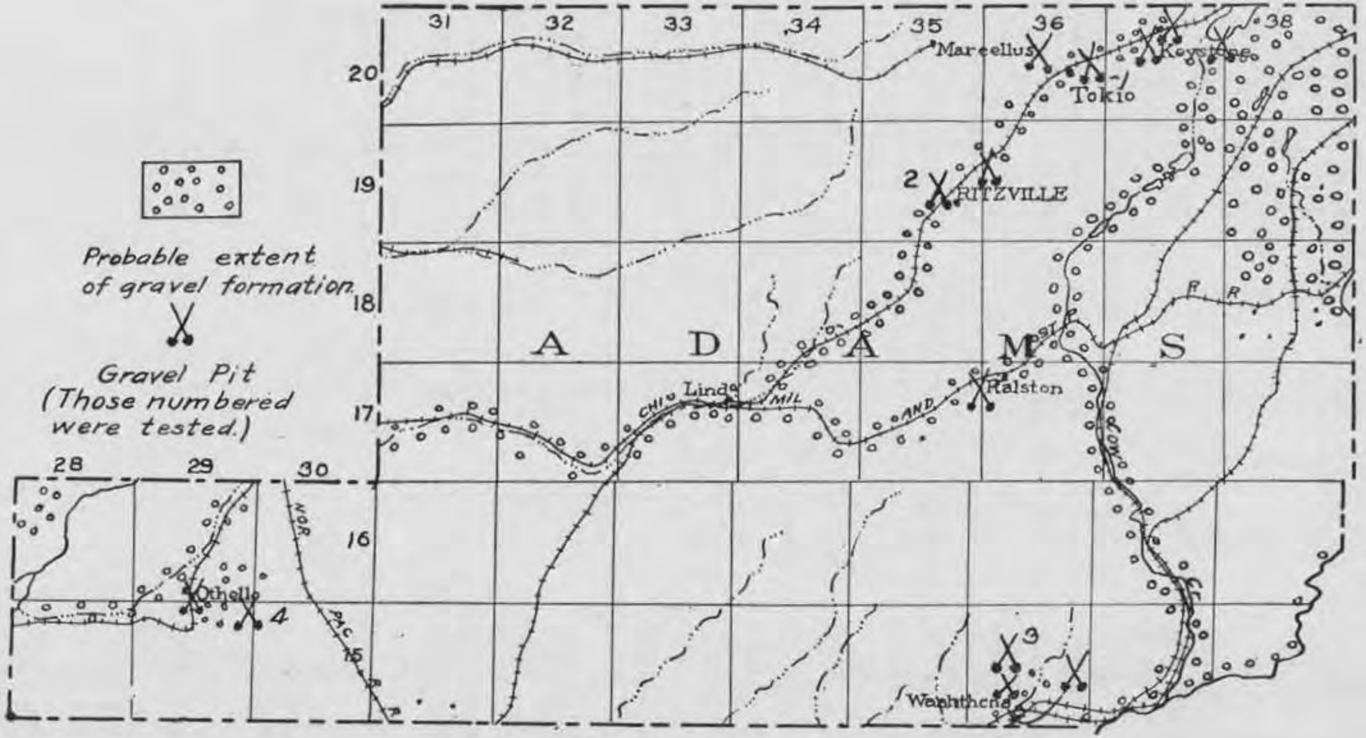


Fig. 1. Outline Map of Adams County.

DEPOSITS OF ROAD GRAVEL.

Distribution

The deposits of road gravel in Adams county are confined almost entirely to the coulees, and to certain flattish areas which lie below the general level of the upland. (See outline map of the county, Fig. 1.) Scattered deposits underlie parts of several townships in the northeastern part. From Sprague to southwest of Ritzville, gravels occur in patches all along the highway, some of them too coarse for use as they are, but if crushed would make splendid road material. Many of them are to be found on the southwest sides of knolls or small hills of rock. The reason for this is that they are parts of a former extensive deposit, most of which was washed away by waters coming from a northeasterly direction, the present deposits being left in protected places on the southwest side of rock projections.

A large gravel flat lies to the north of Keystone. One-eighth mile east of Tokio there is a pit on the south side of the road which exposes sand and gravel beneath 2 to 3½ feet of clay. Most of the gravel is under 2½ inches in size and is chiefly basaltic in composition but differs from the other gravel to the east by containing fragments of lime. Its use on the road here has been found to be satisfactory. Similar material has been used from a pit 1 mile west of Tokio, on the north side of the Northern Pacific Railway, and also from another pit in the S. E. ¼ of Sec. 7, on the south side of the road.

Three-fourths of a mile southwest of the Northern Pacific Station at Ritzville the county owns a gravel flat comprising two city blocks. The materials are basaltic, firm, sub-rounded, and well-graded. There is enough oversize to warrant crushing. The equipment consists of an Aurora and a Ft. Wayne crusher, loading bunkers, belt buckets, and a revolving screen. The material was crushed and screened to 2½ inches, and used on Permanent Highway No. 1 for one mile south of town, built in 1912, and on 2 miles of No. 1 A, which is an extension of No. 1, in 1914. No. 1 was oiled. The road is in good condition.

Other gravels occur along the coulee which passes Ralston. The pit at Ralston is 20 to 25 feet deep and the bottom has not been reached. The materials are well graded from clay to oversize material. After being crushed, they have been used with satisfaction on 4 miles of road north from Ralston, on 5½ miles of road south, and on 2 miles of road west. The coulee in which these gravels lie trends southwestward to westward and joins another at Lind. Materials should be found along the latter for use on the Washington Central Highway.

Within the coulee at Washtucna good road gravels occur. In the south limits of Washtucna the deposits run strong to coarse sand and likewise in some of the high benches north and west of Washtucna. The sand is of the size generally known as "torpedo sand." Coarser gravels lie above this level, as in the S. E.¼ of Sec. 9, T. 15 N., R. 36 E. The S. P. & S. Ry. has a large gravel pit in the southern part of Washtucna, in an eroded bench that stands nearly 100 feet high.

That part of the county between Washtucna and Cunningham is semi-rolling upland, underlain with clay and sandy clay. No road materials occur here except in a few outcrops of basalt in small coulees. Several miles of country west of Cunningham is also barren of good road material.

Some fragments of lime rock have been taken from the creek channel, 2½ miles east of Othello, and used on the road, but found to be unsatisfactory. It is too soft to wear well and after encrusting on the surface it breaks through under the weight of heavy loads.

Some deposits of a fair grade of gravel have been found at Othello, and one mile to the east. At the latter point it contains some basalt but is mostly lime-rock, and of pea-size. If the basalt is sufficient, in quantity, to meet the wearing demands of the road, the pebbles of lime will furnish good binder, and the road should prove satisfactory.

Laboratory Tests

Map Number 1. This sample was collected from a deposit 1/8 mile east of Tokio. (See outline map of the county.) The pebbles are of basalt, but some of them are coated with lime, and lime fragments are scattered through the deposit. There is some oversize, but the constituents are well graded down to sand and clay. The tenacity value of the binder is low, but according to the cementation tests the ultimate cementation under traffic should be good. Some tenacious clay might aid the initial packing of the gravel.

Map Number 2. This sample was obtained from the county pit at Ritzville, 3/4 mile southwest of the Northern Pacific Railway station. The gravels are basaltic, subrounded, and contain enough oversize to warrant crushing the material pit-run. Most of the pebbles appear to be firm, but they gave a loss due to abrasion of 13.6 per cent, which is rather high. The ultimate cementation of the gravel should be good, if some binder is added.

Map Number 3. This sample was taken from a gravel pit on the east side of the road, 3½ miles north of Washtucna. This gravel is composed of subrounded to angular basalt with some lime fragments. The constituents range in size from sand to cobbles and fragments 8 to 10 inches in diameter, thus warranting crushing. The tenacity value is high and the percentage of wear is 11.2 per cent, slightly above the average. This gravel has been used on the nearby road for 2¼ miles, and has given satisfaction. The gravels occur in an eroded gravel bench, rising 75 to 100 feet above the flat at Washtucna.

Map Number 4. This sample was collected from a deposit of lime-rock along the creek channel 2½ miles east of Othello, on the south side of the road. A ledge of the rock is exposed in the creek bank and fragments have been deposited on the inside of the curve by the intermittent stream. The rock is soft and crushes readily. It was used on the local road, but proved too soft to wear.

The foregoing results are given in tabular form, together with those from other counties, in Table I.

ASOTIN COUNTY

GENERAL STATEMENT.

Asotin county, situated in the extreme southeastern corner of the state, and bordered by the Snake River canyon on the one hand and the Blue Mountains on the other, has a topography of high uplands and canyon slopes. In 1916, the population was estimated to be 7,381 by the Census Bureau, or an average of about 12 persons to the square mile.

HIGHWAY CONDITIONS.

The chief highways are the Clarkston-Asotin road, the Asotin-Anatone road, the Asotin-Cloverland road, the Clarkston-Peola road, and the Clarkston-Silcott road. The Clarkston-Asotin road is entirely surfaced, partly with gravel, partly with crushed rock, and partly with asphalt pavement, and is in satisfactory condition. Parts of the others are surfaced, but many miles are still badly in need of metaling. A clay soil covers the uplands, rather thinly on the Anatone ridge and fairly thickly on the Cloverland divide. This ruts badly in very dry weather and muds deeply in wet weather, but in the spring and early summer affords a good, hard road. Along Alpowa Creek, there is a great deal of light, fluffy clay which has no virtue as a road foundation. Some

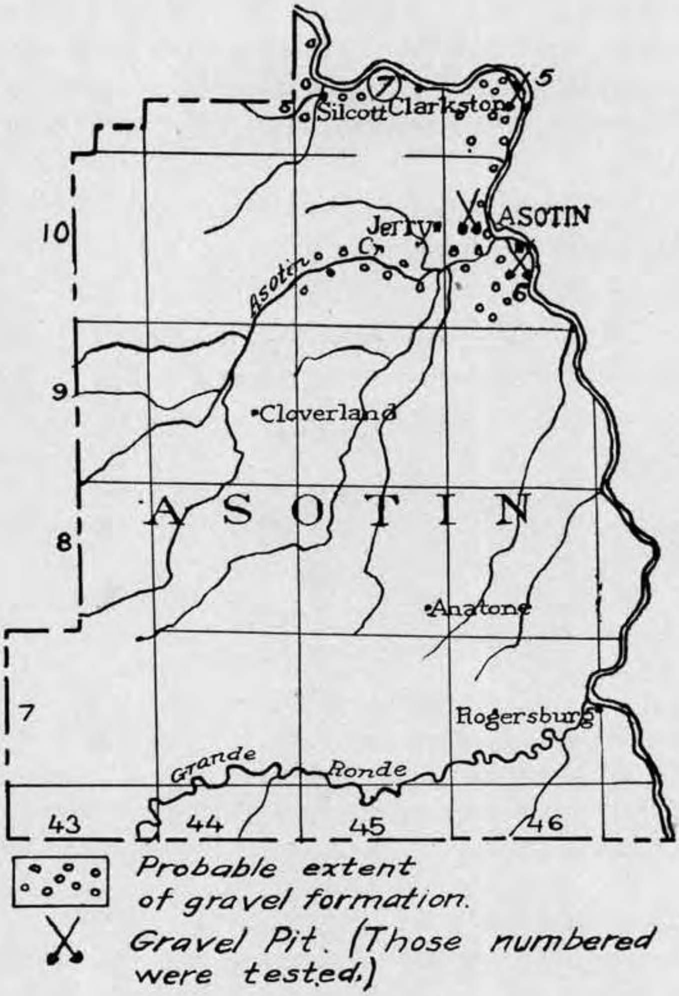


FIG. 2. Sketch Map of Asotin County.

sand stretches occur along the Snake River which are bad in dry seasons.

DISTRIBUTION OF ROAD MATERIALS.

Gravels have such a limited distribution in the county that bedrock will have to be used where the former is not available. Large deposits of gravel, however, occur along the Snake River in benches, as at Clarkston, and in local deposits high above the river, as at Asotin and 3 miles north of Asotin.

Along the Anatone road, a large deposit of coarse gravels occurs at the cemetery about half way up the steep grade which, although not suited in their present state, would make good road-building material if passed through a crusher pit-run. This would reduce the constituents to the proper size, and the dust resulting from the crushing added to that which is already present would probably make good binder. An overburden of 1 to 4 feet of clay would need to be stripped. The pebbles are mostly basalt with a few quartzites. The former are rather angular. On the upland proper, the surface rises gently toward Anatone with about a 3 per cent grade. No gravels are available here, but basaltic rock lies close to the surface as shown by outcrops and fragments around the base of telephone poles. Much of that exposed is porous, but good, firm basalt can be selected in many places.

Along the Cloverland road, although the soil is deeper than along the Anatone road, rock can be obtained near the heads of gulleys. Where the road follows Asotin Creek, a bank of coarse gravels of basaltic composition is generally present, which when crushed would give materials of good gradation, firm quality and probably good binder. In some cases, clay may need to be added to give the proper percentage of binder. About half way up the steep grade, in ascending to the upland, is a shelf on which occurs some old gravels, moderately weathered, but which would probably give fair satisfaction if crushed. Clarkston is situated on a broad bench of gravels, about 100 feet above the river. The town has opened a pit along the river, and the county operates a pit at the western edge. Some large cobbles and a few boulders are scattered through the material, but as a whole the constituents are coarse sand and pea gravel. The materials are slow to bind at first, but after some traffic it packs nicely and makes a smooth road.

West of Clarkston, on the slopes of a higher bench, coarse gravels outcrop, consisting of quartzite, granite, diorite, and basalt. The granites are etched and softened by weathering, but most of the other kinds are still firm and should make good surfacing metal provided it is run through a crusher.

TESTS ON SAMPLES.

Gravels for Road Surfacing

The bedrock of Asotin county was examined and tested in 1911 by the Washington Geological Survey, and the results published in Bulletin No. 2 of the Survey series. Attention is given in the present study chiefly to the gravels. A tabulation of the results of the tests on "Road Gravel" is given in Table I. The location of the places from which the following samples were taken is shown on the outline map of the county, Fig. 2.

Serial Number 5. This sample was taken from the Clarkston City pit, located at the eastern edge of town. The pebbles consist of basalt, granite, diorite, and quartzite, almost all of them are firm, but few are oversize, and the greater proportion, about 75 per cent, is coarse sand. The tenacity test showed it to be low in binding material, but the ultimate cementation value was found to be high. These results are borne out in practice. The material is slow to pack but after having been subjected to traffic it makes a smooth road. A remedy might be found for its slow packing qualities by the addition of a small amount of tenacious clay. The county owns a pit in the same formation at the western edge of town.

Map Number 6. About one-fourth mile south of Asotin, a pit has been opened in the side slope of a gulch, exposing coarse sand and fine gravel in a face 40 feet high. The sand and gravel are chiefly basaltic, cross-bedded, with irregular stringers of silt. For ordinary surfacing it is too fine, but if properly mixed with clay it should make a satisfactory sand-clay road. As it is, it permits the wagon wheels to cut deeply. Its tenacity value is low, possibly due only to its coarseness.

Map Number 7. This sample was obtained from a ridge of gravel along the Columbia River, about 6 miles west of Clarkston. The ridge is about 50 feet high, 75 yards wide, and 300 yards long. But little sand occurs in the gravel and where material has been removed, the remaining portion will not stand with steep face, indicating that the cementing qualities are low. This was borne out by the tenacity test. The pebbles, however, are almost all firm, yielding a percentage of wear of only 4.2 per cent. If properly sized and graded and some clay added, it should prove satisfactory for road building.

Sand for Concrete

The sand of Map Number 5, from the Clarkston City pit, was washed and tested for its quality in concrete work, by making concrete briquets of the sand and comparing their tensile strength with that of the Ottawa Standard sand, according to the method described in Chapter IV.

Both the 7 and 28-day tests showed a tensile strength greater than that of the Ottawa Standard sand, the 7-day ratio being 133.2 per cent and the 28-day ratio 143.1

per cent. No organic matter was detected by chemical tests. This sand should therefore be entirely satisfactory for concrete, if washed, but the gravel is too fine for first-class concrete pavement.

The results of this test are given in tabulated form, together with those from other counties, in Tables III and IV.

BENTON COUNTY

GENERAL STATEMENT.

Benton county is located in the lower portion of the Yakima River Valley and within the bend of the Columbia River, where it turns westward to pass through the Cascade Mountain Range. The county has a maximum length of about 60 miles and a width of about 50 miles, but its area is 1671 square miles. Its population of 8,000 or more people is chiefly concentrated along the Yakima River Valley, which fact also centralizes the highway system and the necessity of immediate road surfacing. Prosser is the county seat, and Kennewick, Kiona, Hanford, and White Bluffs are other towns.

The main line of the Northern Pacific Railway and the branch of the O.-W. R. R. and N. Co. lie within the valley of the Yakima River, and the Inland Empire Highway closely parallels them. These facilities for transportation adequately care for the products of agriculture, horticulture, and stock raising of the county. Irrigation products are yielding good returns, and the promise of the future is for a much increased population. For the present, however, surfaced roads will meet the demands of the comparatively light traffic.

TOPOGRAPHY AND RAINFALL.

The northern part of the county is a part of the great plains of the Columbia, with the exception of a spur of the Rattlesnake Hills which, after attaining an elevation of 3500 feet near the west line, rapidly declines east-

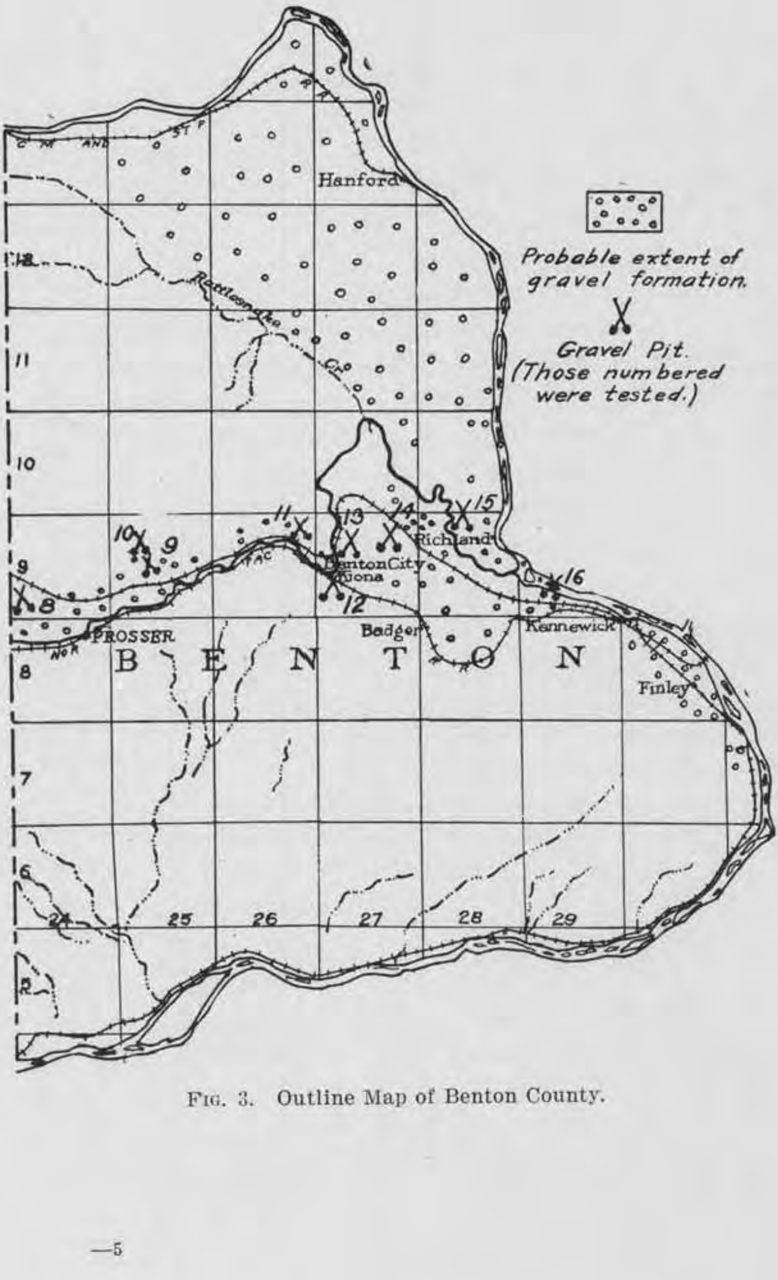


FIG. 3. Outline Map of Benton County.

ward. South of the Yakima River Valley is the north-facing escarpment of the Horse Heaven Hills, at the crest of which is a plateau sloping southward to the Columbia River. These higher hills and the plateau are composed of basalt, while the plain of the Columbia and broad flat of the Yakima River are underlain largely by clays, sands and gravels. The clays and sands afford little bearing power for traffic purposes and must be surfaced.

The annual precipitation averages about eight inches, a part of which is snowfall. The long dry summers deprive the earth-roads of their moisture so thoroughly that they not only become deeply covered with dust but rut badly. There is but little trouble from mud conditions during the rainy spells on account of the sandy nature of the soil in many places.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

The sketch-map in Fig. 3 shows by small circles the general area underlain by gravels and, by crossed shovels, the location of some of the pits which have been opened. Those from which samples were obtained and tested are numbered. It should not be assumed that suitable gravel can be obtained everywhere within the area mapped, for the character of the material varies widely from place to place and a choice must be made after test-pits have been opened. Along a given stretch of highway within the mapped portion it is likely, however, that satisfactory deposits may be found.

TESTS ON ROAD GRAVELS.

Map Number 8. This sample was taken from a deposit five and one-half miles northwest of Prosser, along the north line of Sec. 31, T. 9 N., R. 24 E. A large area is here underlain by gravels chiefly basaltic in composition but containing some fragments of lime-rock. The materials are well graded up to oversize, which is present in sufficient abundance to warrant crushing. About 90 per cent of the constituents are firm and have good wearing value. Binding material, however, is lacking in quantity, and clay will probably have to be added. The lack of a good quality of clay probably accounts for the low tenacity value. Only a test pit has been opened in this deposit thus far.

Map Number 9. In the N. E. ¼, Sec. 15, T. 9 N., R. 25 E., there is a deposit of gravel exposed along a ravine containing basaltic sand and pebbles mostly of the size of "pea-gravel," all of which are firm and would probably give excellent wearing results. Silt and lime have been filtrated down through the gravel. According to test this shows a fair tenacity value. Large quantities are available. This has had a practical test on the highway east from Prosser for two years and is giving excellent satisfaction, but at first was somewhat slow in packing.

Map Number 10. This sample was taken from a deposit ¼ mile north of Number 9. Here a large proportion of the material is coarse sand, sharp, well graded, and comparatively clean except in the lower part. The minor amount of gravel consists of basalt and quartzite pebbles, together with a few fragments of lime. It is too largely sand for surfacing unless used for dressing. A test was made of this for concrete uses and the results are given on a following page.

Map Number 11. This sample was obtained from a deposit on a high bench two miles northwest of Benton City, in the S. W. ¼, Sec. 12, T. 9 N., R. 26 E. Fifty per cent of the pebbles are basalt, 40 per cent quartzite, 6 per cent lime fragments, and 4 per cent granite. About 95 per cent of the pebbles are firm and have good wearing qualities. The materials are mostly well graded in size, but there is a large enough percentage of oversize to warrant crushing. By passing the material through a crusher pit-run, not only would there be a gain in proper grading, but binder would be contributed. As it is, the tenacity value of the binder is low. Some of the gravel has been used on the road for 1 mile east of this point and 2 miles west since 1915 and found satisfactory. Clays occur to the east, from which binding material may be secured.

Map Number 12. This sample was collected from a low bench at Kiona on the south side of the river. A fair percentage of the material is oversize but there is enough to make crushing advantageous. On the whole, the deposit is lacking in binding material in its natural state, and from the sample obtained not enough of the fine was available to test for quality. The pebbles include varieties of quartzite, basalt, and granite, and almost all are firm and hard and have good wearing virtues. Some are flat but there are not enough of them to hinder the binding of the gravel if clay is added.

Map Number 13. This sample was taken from a deposit on the high flat, 1¾ miles northeast of Kiona, and shows a variety of rounded pebbles of quartzite, basalt, granite, diorite and porphyry embedded in a matrix of fine sand. Ninety per cent of the pebbles show a firmness which warrants satisfactory wearing, but the fine sand is a poor binder. The cementation test gave a low value. Where used on the road this gravel has not packed well, and the cause seems to lie in the lack of good tenacious clay for binder and the presence chiefly of fine sand, and of flattened pebbles.

Map Number 14. This sample was collected near the eastern edge of the same flat about 4 miles northeast of Kiona. This deposit is light-colored and varies in texture from place to place. The pebbles are quartzite and basalt with much lime rock, embedded in a fine-textured, light powdery substance. The pebbles have such a high percentage of soft constituents that its wearing value is doubtful. The test for tenacity of the portion passing the 10-mesh gave a fair value. When the deposit was visited, the material was being used for surfacing the road in this vicinity and seemed to be packing fairly well, but the fine powdery matrix may yield dust.

Map Number 15. This sample was obtained from a gravel bar just east of the Fallon bridge, about 4 miles northwest of Richland. Although the materials are well-graded, round, and firm, the tenacity test of the binder gave a low value. Unless a good tenacious clay is added, there would probably be considerable difficulty in making the material pack.

Detailed results of the foregoing tests are given in Table I of Chapter III.

TESTS FOR CONCRETE.

Map Number 9, from a deposit described on a preceding page, was tested for its tensile strength for concrete use by making concrete briquets of the sand and comparing their strength with those from Ottawa Standard sand, according to the method described in Chapter IV. The seven-day briquets of the sand under test showed a strength of 98.7 per cent that of the Standard sand briquets, and the twenty-eight day briquets tested 130.3 per cent as strong. A slight amount of organic matter was detected by the colorimetric test, but not in sufficient quantities to be injurious.

Map Number 10, obtained from the deposit just north of Number 9, tested 114.0 per cent for the 7-day tensile strength ratio, i. e., 114.0 per cent as strong as the Ottawa Standard sand, and 119.9 per cent for the 28-day ratio. The colorimetric test showed no organic content.

Map Number 12, from the deposit at Kiona, was screened for its sand portion, and the 7-day briquets made from the washed sand tested in strength 87.1 per cent that of the Ottawa Standard sand, and the 28-day briquets 106.5 per cent. The colorimetric test showed a slight amount of organic matter present, but not in objectionable amounts.

The detailed results of these tests are tabulated with those of sands from other counties in Tables III and IV of Chapter IV.

CHELAN COUNTY

GENERAL STATEMENT.

Chelan county is located in the northern part of the state, on the east flanks of the Cascade Range, reaching to the Columbia River on the east. It is the third largest county in the state, its area including 2900 square miles. In 1916, the Census Bureau estimated its population to be 22,129. The larger part of this is concentrated along the Wenatchee River from Leavenworth down to Wenatchee and along the Columbia River Valley for a few miles below Wenatchee. A certain percentage, also, lives north along the Columbia River Valley as far as Chelan. Wenatchee is the county seat and most important city. Leavenworth, Peshastin, Cashmere, Chelan, Lakeside, and Entiat are important towns.

The large acreage of apple orchards and the reputation of the Wenatchee apple suggest at once to the visitor that apple growing is the chief industry. Besides this there is general farming, dairying, lumbering, and mining. A good system of highways is especially needed in the Wenatchee Valley and the county authorities have been devoting their efforts to perfecting it as rapidly as possible. One and one-quarter miles of paving were laid east of Monitor in 1917 and more is contemplated. The Sunset Highway, which is the main Seattle-Spokane automobile highway, enters the county at the southeast corner and passes through Wenatchee, where it crosses the river into Douglas County. State

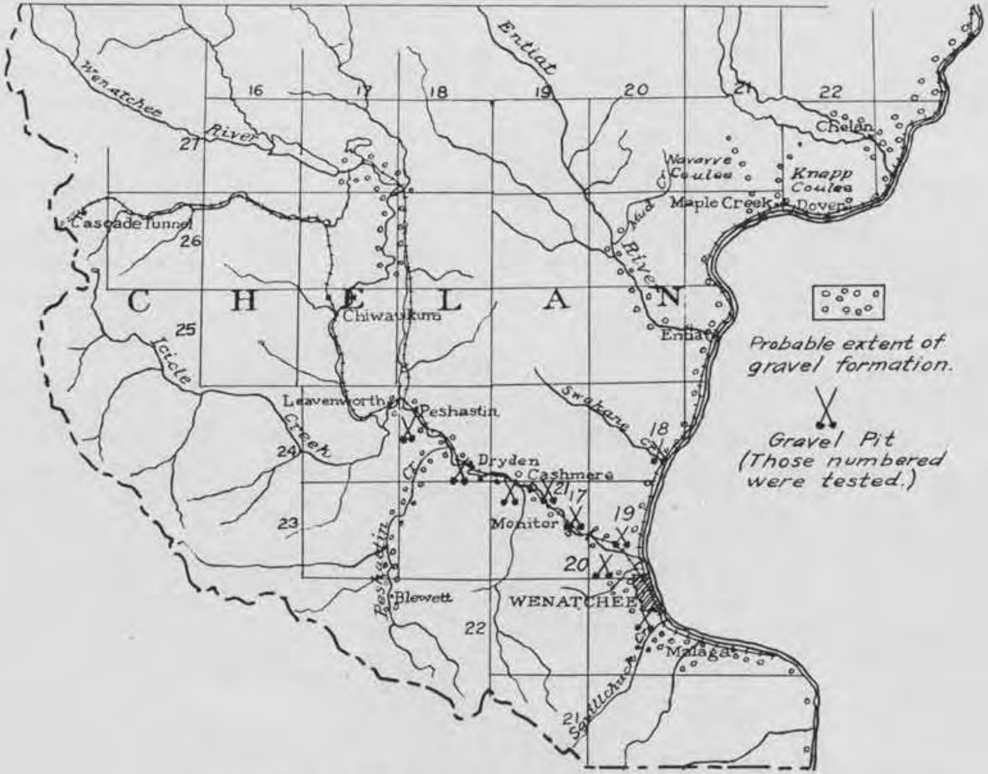


Fig. 4. Sketch Map of a portion of Chelan County.

Road No. 7 also furnishes an important outlet over the mountains by way of Wenatchee Valley and Peshastin Valley, over Blewett Pass. State Road No. 10 runs northward along the Columbia River into the Okanogan country. The main line of the Great Northern Railroad traverses the county from the Cascade Tunnel at the summit to the southeast corner, and has two branches, one to Oroville and one to Waterville.

TOPOGRAPHY.

The mountainous topography of the county makes road gradients a difficult and important item outside of the valleys. The Wenatchee, Columbia, and Entiat valleys serve as trunk lines for the larger part of the populace, but there must needs be some penetration of highways into both the tributary mountain valleys and ascension to the higher flats. The Blewett Pass road is an example of the former and the road to the Wenatchee Heights of the latter.

The importance of subsoil is well illustrated along the Columbia River. Where the highway passes over tracts of wind-blown sand and silt, as near Entiat, surfacing is essential, but where alluvial fans of granitic material between here and Chelan are traversed the road is always good. There are stretches of sand and light silt in the Wenatchee Valley which have comparatively little bearing power, especially in dry weather, and these must also be surfaced.

ROAD GRAVELS.

General Distribution

Terraces of road gravel of fresh and firm materials occur in the vicinity of Wenatchee near the mouth of the Wenatchee River, where there is perhaps the greatest demand for them. Gravels of varying texture and binding and wearing qualities also occur here and there further up the Wenatchee River as far as Leavenworth and along the Columbia River to Chelan and beyond. Along the Blewett Pass Road, or State Road No. 7, gravels are distributed in two sets of terraces for three miles or so in the lower portion of the valley, and then there seems to be a scarcity until the junction of Ingalls and Peshastin creeks is reached. Here a gravel flat, 100 yards broad, affords good material of suitable size. Ascending the high road no gravels are to be had for some distance, but there is an abundance of slide-rock of good quality from which materials of proper size can be chosen. In the vicinity of Old Blewett there is considerable gravel but its coarseness would require crushing.

An outline map of the county, showing the distribution of the gravel and the places from which samples were taken for testing, is given in Fig. 4.

Tests on Road Gravels

Map Number 17. This sample was taken from the flood-plain of the Wenatchee River, ½ mile east of Monitor, on the property of W. E. Taylor. The materials are well graded, with considerable oversize to warrant crushing. Pebbles of gneiss, granite, basalt, quartzite and diorite make up the deposit and almost all of them are firm and hard and would give excellent wear. The binding material, however, is of poor quality, there being scarcely enough of silt to make a plastic paste for the tenacity test. Clay would have to be added if this were used for surfacing. The deposit, however, was used as a source for the aggregate in the concrete paving of 1¼ miles in this vicinity. A crusher was installed and the materials were crushed and washed. The results of the sand tests for concrete use will be mentioned under "Tests for Concrete."

Map Number 18. This sample was taken from a deposit at the mouth of Swakane Creek, along the Columbia River, 9½ miles north of Wenatchee. The constituents are granite, schist, and quartzite. They range in size from 1½ inch down, with about 50 per cent passing the ¼-inch screen. Their wearing value is fair, but both the tenacity and cementation values tested low, suggesting that the materials will not pack readily or cement well without additional clay of good cementing quality. A 4-foot over-burden of coarser material shauld be stripped. The deposit in its natural state shows some incipient cementation.

Map Number 19. This sample was obtained from the high gravel bench 3¼ miles north of Wenatchee on the north side of Wenatchee River. The gravel bank here rises about 100 feet above the stream. A pit 100 feet long and 75 feet high has been opened, giving a good selection for examination. The material stands with vertical face, and is made up dominantly of gravel less than 2 inches in size, with a few large scattered boulders and scarcely any fine sand. By test, the wearing value is better than the average for the state. The tenacity and cementation tests show only fair values. It is believed that if clay of good tenacious value is available, its addition would be beneficial. Where used on the county roads in the vicinity of Sunnyslope, it has required sprinkling to keep it packed under the heavy traffic of dry weather. The results of the concrete briquet tests are given on a following page.

Map Number 20. This sample was taken from a deposit located 2½ miles northwest of Wenatchee, on the property of Mr. Larson. Most of the materials are firm, but there are some soft pebbles which, if this deposit were to be used for concrete paving, would have to be thrown out. The wearing quality of the material is shown by test to be good. No cementation test was made of the binder portion. For the results of the briquet tests the reader is referred to the discussion on the following page.

Map Number 21. This sample was obtained from a deposit 1½ miles southeast of Cashmere, in the N. W. ¼, Sec. 3, T. 23 N., R. 19 E. Here a pit has been opened in a bank of sand-clay containing fragments of rock, most of which are less than one inch in size and 76 per cent passes a ¼-inch screen. This high percentage of fine would be objectionable if it were not for the cementation value of the deposit. According to both the tenacity test and the cementation results on the road nearby this is very high. The road withstands the traffic of this important highway in remarkable fashion. Considerable quantities are available.

Tests for Concrete

Map Number 17. This sample was taken from a pit ½ mile east of Monitor, which has already been described, and from which the aggregate was obtained for the paved road nearby. Concrete briquets were made of the sand and tested and compared with concrete briquets made from Ottawa Standard sand, according to the methods given in Chapter IV. After seven days three of these briquets were tested for their tensile strength and found to have 110.0 per cent the strength of the briquets of the same age made from the Ottawa Standard sand. The 28-day briquets of the sand under test showed a strength of 127.9 per cent that of the standard sand. By the colorimetric test a slight amount of organic matter was found, but not in objectionable amounts.

Map Number 19. This sample was taken from the terrace of gravels, 3¼ miles northwest of Wenatchee, which is described on a foregoing page. Seven-day briquets made from this sand had a strength of 124.0 per cent that of the briquets made from the standard sand, and 28-day briquets gave a ratio of 133.1 per cent. No reaction for organic content was obtained by the colorimetric test.

Map Number 20. This sample was taken from the Larson pit, 2 miles northwest of Wenatchee. The 7-day briquet ratio of this sand was 144.0 per cent, and the 28-day ratio was 119.9 per cent. No organic matter was found to be present.

COMMERCIAL PITS.

The Columbia Engineering and Construction Co., of Wenatchee, operates a gravel pit to supply local demands across the river in Douglas county, in the south ½ of Sec. 11, T. 22 N., R. 20 E. The pit is located in a low ridge of gravel which is a cut 200 yards long and 75 yards wide. The material consists of granite, quartzite, and basalt pebbles of good quality and mostly under 2½ inches in diameter. The pit is operated by cable and clam-shell bucket to a platform from which the material is passed through a rotary screen down into bunkers.

CLALLAM COUNTY

GENERAL STATEMENT.

Clallam county is situated in the northwestern part of the state, bordering the Strait of Juan de Fuca on the north and the Pacific Ocean on the west. It has an area of 1,726 square miles and a population in 1916 of 7,479. Port Angeles is the county seat, and Forks, Sequim, Dungeness, and Neah Bay are other important towns.

The chief industries are lumbering and fishing. At the present time the county is contributing an enormous amount of spruce for the nation's aeroplane construction. Transportation facilities are afforded by a local line of the Chicago, Milwaukee and St. Paul Railroad and the county's highways. The Olympic High-

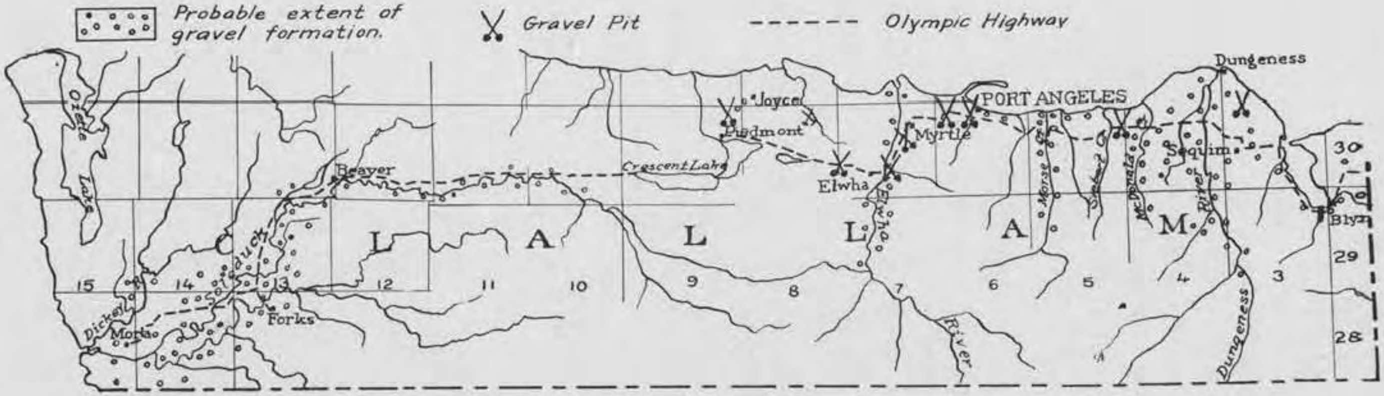


FIG. 5. Outline Map of Clallam County.

way enters the county northeast of Blyn, and except for an interruption at Lake Crescent, where ferries are used, it extends nearly to Mora, near the Pacific coast. It is improved over the entire distance.

The southern part of the county is mountainous, but the northern portion consists of a partially dissected table-land along the coast, which in places merges gradually to sea-level and in other places ends in wave-cut cliffs. Almost all of the population of the county live on the table-land, and consequently most of the roads are located here. A few high hills, such as occur on both sides of Morse Creek and the Elwha River, had to be overcome by careful locations, but moderate grades at these places are now the result.

All of the table-land, up to the mountain flanks, was glaciated, so that the subsoil over large tracts is pebbly clay, interspersed with gravels and sandy areas. The rainfall has a wide variation. In the Sequim district it amounts to but little over 20 inches, while in the higher mountains near the Pacific Coast, it is 120 inches or more. The average for the table-land is probably about 50 inches.

ROAD MATERIALS.

The chief road materials which have been used in the county are gravels. The general distribution of the gravels, together with the location of some of the gravel pits, is shown on the outline map of the county.

Sandy gravels occur at Blyn and to the east. The screening out of the excess portion of sand is necessary to their satisfactory use. A 50-foot section is exposed in a railway cut at Blyn. Along the west side of Sequim Bay gravels occur at intervals, and in places old beach gravels, now 15 to 20 feet above present sea-level contain quantities of fragile shells. This material makes a good dressing material but is not good road-metal in itself. Sequim is located on a large delta flat of the

Dungeness River, and gravel occurs abundantly for several miles westward to Carlsborg and for many miles in a north-south direction. East of Sequim they are bouldery, but west of Sequim there is a bench of finer gravel, well graded on the whole, with scarcely any oversize, but lacking, at least in part, clay for binder. On the east and west sides of Morse Creek, fresh gravel occurs in considerable thicknesses overlying tilted beds of highly colored gravel, sands, and clays. The latter are considerably softened by weathering. The former are mostly firm and are being drawn upon on the west side of the valley for surfacing.

Local occurrences of gravel are found in the vicinity of Port Angeles. About 2½ miles west and south of town, a large pit has been opened in gravels, the pebbles of which are coated with silt which seems to contribute good binder to the material. The composition of these is typical for the county, being composed mostly of basalt, quartzite, and veined metamorphics, with some granite and shale. The gravel here is not fit for concrete, but gives good service as a road-metal. Near the foot of the hill on the east side of Elwha River there is a conglomerate cemented with lime carbonate, which, if crushed, should make excellent surfacing. Similar material is now being crushed and used about 3 miles east of Joyce. From here to Lake Crescent the deposits are local.

Beginning about 2½ miles west of Lake Crescent a continuous belt of gravels occur all along the Soleduck River, practically to its mouth. On the whole the gravels are well graded and fairly firm, and pits can be put down alongside the road wherever materials are needed. The abundance and proximity of the gravels along this portion of the Olympic Highway is of especial value at the present time, since much spruce is being transported over the Highway.

Due to the fact that the Testing Engineer for the Washington Geological Survey had been called for war service, no samples were collected for testing.

SAND AND GRAVEL FOR CONCRETE.

As already noted, the sand in the gravel at Blyn is relatively fine, and the coarse aggregate is low in proportion to the sand content. Fairly good gravel can be obtained at various places on the gravel flat in the vicinity of Carlsborg.

The fresh gravel on the west side of Morse Creek, well up the grade, is exposed in a large pit. The materials are well graded from sand to 2 inches in size, with a small percentage above this size. The pebbles appear firm and resistant and the amount of clay present is small. If washed, this should make good concrete material. This deposit is not to be confused with the orange-colored gravel farther down the slope which would be unfit for concrete.

In Port Angeles, sand and gravel is being obtained from the cliff which fronts the Strait, in the west part of town. It appears to be of fair quality.

It was not possible to make tests of the material from this county, but through the courtesy of the Portland Cement Association some mechanical analyses were obtained of samples of sand taken at various points along the Soleduck River. These are given in Table III.

CLARKE COUNTY

GENERAL STATEMENT.

Clarke county lies within the bend of the Columbia River in the southwestern part of the state. Lewis River forms its northern boundary. It is one of the smaller counties of the state, having 634 square miles within its confines. In 1916, the Census Bureau estimated its population to be 3,639. Vancouver is the county seat and largest town, and Camas, Washougal, Yacolt, Battle Ground, Ridgefield, La Center, and Orchards are other thriving towns. The people are engaged mostly in diversified farming, dairying, lumbering, and fruit growing. With the increasing population and the extension of farming pursuits the demand for good roads is assuming a broader scope. The county has constructed and surfaced some excellent roads, including the Pacific Highway, which runs north from Vancouver, and State Road No. 8, which runs east. With these and the several railroad lines the transportation problems of the county are well in hand.

TOPOGRAPHY.

The larger part of the agricultural section of Clarke county is an undulating plain which lies about 200 feet above the Columbia River. A few streams have incised the upland with deep narrow valleys which necessitate the practice of modern engineering principles to secure moderate and economical grades. This is the case, for example, where the Pacific Highway crosses Salmon Creek Valley and the valley of the South Fork of Lewis River at La Center. The northeastern and eastern parts of the county are foothills which rapidly assume mountainous proportions near the eastern border.

CLIMATIC FACTORS.

About forty inches of rain falls each year. Most of this occurs during the winter season, so that the summers are dry. With such an abundant rainfall concentrated in one season, there can be but a limited amount of clay used in the road material or softening of the road-bed will take place during the winter; yet enough must be used to serve as an effectual binder

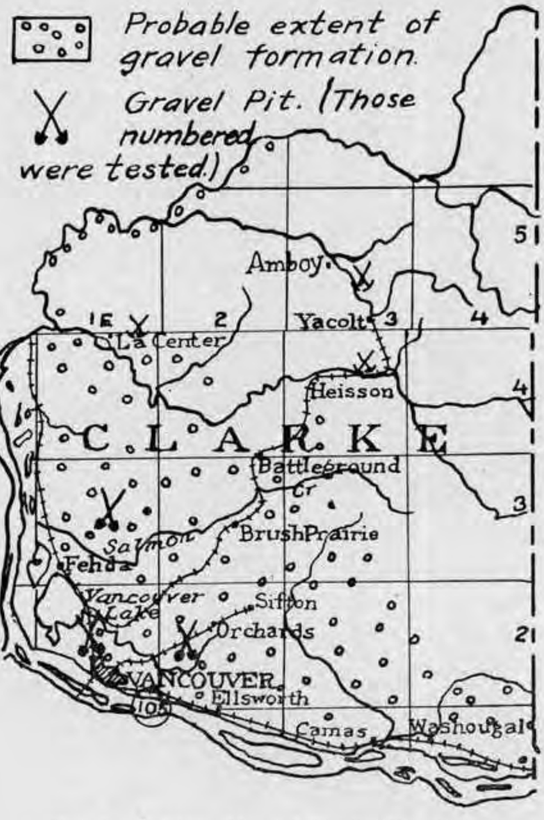


FIG. 6. Outline Map of Clarke County.

when the dry weather favors ravelling. The rains of winter also necessitate good side drainage. The temperatures are sufficiently moderate during the winter so that thawing and freezing have little effect in road-building.

ROAD MATERIALS.

Gravel beds underlie most of the well populated area of the county, but in spite of this the chief material which is used for road surfacing is crushed rock. This is due partly to the fact that the gravels in places are considerably weathered and partly to their lower cementation value than the rock material. In 1911, the Washington Geological Survey conducted an examination of the bedrock of the state which might be available for road-macadam. Samples from this county were collected for testing purposes from near Yacolt and Fisher. The results were published in Bulletin No. 2 of the Survey series. Regarding the rock near Yacolt the following statement is made:

"The rock is a fine-grained, dark greenish gray basalt. According to the test it has average hardness, rather high resistance to wear, and excellent cementing value. All of these qualities combine to make this rock an excellent road material. Basalt occurs very commonly along the south fork of the Lewis River, in this part of the county. In general the rock is quite uniform in character—hard, dark in color, fine-grained and compact, somewhat brittle, and breaking with a shelly fracture."

The sample of rock taken from the large quarry one mile east of Fisher is characterized as follows:

"The sample when tested showed that the rock is a basalt, with a color more grayish than usual. The rock is dense and compact, and fairly hard. It is tough, has a high resistance to wear, and possesses fair cementing value. As far as the tests can determine the matter the rock should make a satisfactory road material."

East of Camas a good grade of basalt outcrops at convenient points along the Washougal River for the surfacing of this portion of State Road No. 8. The county has opened a quarry at a few of these points and installed a portable crusher for obtaining material of suitable size.

For the roads in the western part of the county, crushed rock from St. Helens, Oregon, is shipped in. This is a firm type of basalt, offering resistance to wear, and when sufficient screenings are included with the larger size has good binding qualities. Where used on the highways, it has given satisfaction.

About two miles east of La Center an outcrop of basalt occurs at about the center of the E. ½ of Sec. 1, T. 4 N., R. 1 E., in a tributary to Lockwood Creek. The county is planning to open a quarry at this point and install a crusher to provide road metal for this part of the county. The rock has but little overburden, is but slightly weathered on the outside, and on fresh fractures is black, dense, and firm, thus promising good wearing value. According to test the rock has an excellent cementation value. The height to which the section can be quarried is over 40 feet, and the County Engineer estimates over 100,000 cubic yards are available.

Character of the Gravels

The distribution of the gravels is shown on the outline map of the county. About 1¼ miles northeast of Sifton, in the N. W. ¼, Sec. 12, T. 2 N., R. 2 E., is an old county gravel pit which exposes coarse gravels beneath 4 to 6 feet of soil and subsoil. The amount of coarse cobbles is so great that the material had to be crushed to be satisfactorily used. The pebbles include varieties of quartzite, basalt, andesite, tuff, chert, and clay pebbles. Ten to twenty per cent of them are too soft for use in any concrete work. The sand is sharp but the grains are coated with silt. A few years ago the county installed a crusher at this point and surfaced the road to Sifton with this material. The road is said to be satisfactory in winter, but is dusty in summer.

A part of the road from Vancouver to Fisher is surfaced with gravel which was obtained from pits in the side-slope along the highway. The gravel is better graded than in the pit near Sifton and the constituents are fresher and firmer. On the road it makes a smooth surface and with maintenance gives satisfaction.

Gravel beds are exposed for several miles in the bluff along the railway track northwest of Vancouver, up to an elevation of about 200 feet. Some of the gravel beds are interlaid with silt, and in places the material is dominantly silt. It appears that this gravel underlies the bordering upland for several miles to the eastward, for it is exposed along Salmon Creek and elsewhere. A pit has been opened in sandy gravel about 2 miles north of Vancouver along the Pacific Highway, and one in coarse gravel where the road crosses Whipple Creek about 7 miles north of Vancouver. This pit affords a section 150 feet long and 25 feet high, the bottom of the gravel not being exposed. Though coarse, it has a sand matrix, and it is believed that if crushed proper gradations could be secured. Most of the pebbles are firm, consisting of basalt, quartzite and andesite. Where used on the road north of this point, the surface shows roughness, probably due to including too coarse materials and adding too much clay. The gravel from the Armstrong pit east of Pioneer Church was sized before placing, and this has resulted in a smooth road surface. A gravel deposit containing considerable clay occurs in the hillside, 1 mile south of La Center.

TESTS FOR CONCRETE.

The only sand known to be used for concrete on any extensive scale is that which is secured from the Columbia River by dredging. Sand for concrete is thus obtained from near Ellsworth while masonry sand is gotten from the vicinity of the bridge near Vancouver. Briquet tests were made of the concrete sand according to the method described in Chapter IV, and compared with the strength of the Ottawa Standard sand.

Map Number 105. This sample of sand, which was collected from the Columbia River near Ellsworth by Minsinger Bros. of Vancouver, showed a tensile strength in the 7-day briquets equal to 95.6 per cent that shown by the briquets of the same age made from the Ottawa Standard sand and the same kind of cement, and the 28-day briquets 117.1 per cent of the standard sand briquets. By colorimetric test, some organic material was detected to be present but not in objectionable quantities. The sand was washed before tested, which may have eliminated a part of the organic content. Detailed results of this test are given in Tables III and IV, along with those from other counties.

The coarse aggregate, which is dredged from Willamette River and supplied to the concrete trade in this locality, was found by test to be very firm, yielding a loss by abrasion of only 3.2 per cent.

COLUMBIA COUNTY

GENERAL STATEMENT.

Columbia county is situated in the southeastern part of the state, south of the Snake River. Its area includes 858 square miles, the southern part of which is in the Blue Mountains. Dayton is the county seat and chief town, and Huntsville, Starbuck and Turner are also important trading centers. Stock-raising, wheat, and fruit-growing are the chief industries. The farms are large, making the population of the larger part of the area relatively small, with the concentration chiefly in the towns and also in the valley of the Touchet River, where fruit-growing is important. The chief roads to be surfaced in the immediate future are probably the trunk roads connecting the various towns. A good macadam road has already been constructed from Dayton to Huntsville, which is a part of the Inland Empire Highway. The road to Turner has also been surfaced, as well as a few miles of the highway east and west of Starbuck.

TOPOGRAPHY.

The topography of the northern half of the county is a rolling plateau, with deep valleys near the Snake River. The contour of the land necessitates the location

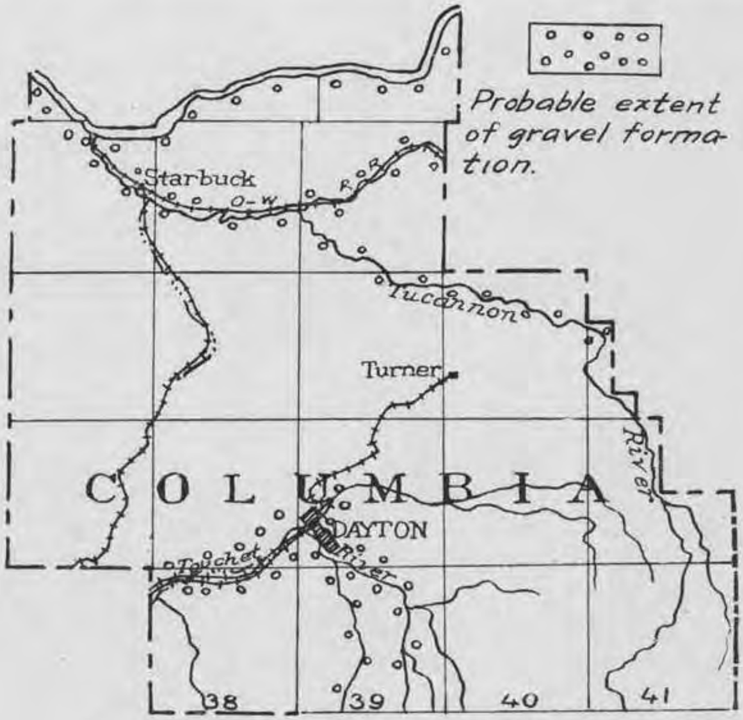


FIG. 7. Outline Map of a portion of Columbia County.

of the roads chiefly along the valleys, rather than along section lines. Some steep grades still remain to be moderated, such as the Marengo hill, but generally elsewhere admirable grades have been obtained. The upland is covered with a thick mantle of heavy clay which affords a good road a part of the year, but during the wet season is almost impassable and during very dry seasons becomes badly rutted. Along Tucannon River, Pataha Creek, and the valley south of Starbuck, there is a fine fluffy clay encountered in places which is worthless as a road foundation, and because of the frequent rutty places which it permits, the roads along these valleys should be surfaced.

ROAD MATERIALS.

Gravels occur in bars and benches along Tucannon River, west of Marengo, along Pataha Creek, along the Snake River, and along the Touchet River, including both forks. This is shown on the outline map of the county.

The benches along Tucannon River are made up of coarse fragments of basaltic rock, some rounded gravels, and much clay. A careful selection would be necessary to secure suitable material. As a whole, better gravel can be obtained from the bars along the stream, but these are commonly limited in quantity and clay would have to be added for binder. The location of the present road is such that wash from the side gulches fills the road with considerable debris from this bench.

Along Pataha Creek, much light, fluffy silt abounds, making a very bad road-bed. Except near Starbuck, most of the road-metal will have to come from the rock ledges along the valley slopes and occasional alluvial fans. Near Starbuck, considerable gravel can be gotten from the stream-bed and at certain places along the benches which rise 100 or more feet high. Where this has been used on the nearby road, it appears to be satisfactory.

Along the valley south from Starbuck to Alto, fine sand prevails. The basaltic ledges will be the only source for road material aside from the gravel which can be obtained from Pataha Creek at Starbuck. From about one mile north of Alto to within a few miles of Waitsburg, not even rock outcrops. Gravel, however, can be obtained for that portion of the road south from Alto, from the Touchet River.

The Touchet River southeast and southwest from Dayton carries large quantities of firm, well-rounded basalt gravel. Considerable oversize is present, necessitating either screening or crushing. Binding material is lacking and clay will have to be added. Where this has been used on the Inland Empire Highway, it makes a smooth, firm road-bed, and apparently has good wearing qualities, as the traffic between Dayton and Walla Walla is heavy.

For the first and latter parts of the Dayton-Starbuck road, gravel can be gotten from Touchet River and Pataha Creek respectively, but the basaltic bedrock will have to be drawn upon for the middle portion.

COWLITZ COUNTY

GENERAL STATEMENT.

Cowlitz county is one of the southwestern counties of the state, bordering the Columbia River and lying north of Lewis River. Eleven hundred and fifty-three square miles are included within its boundaries. In 1916, the Census Bureau estimated its population to be 15,506. Castle Rock is the largest town, and Kalama the county seat. Other towns are Kelso, Woodland, Ariel, and Silver Lake. Lumbering and dairying are the chief industries.

The greatest demands of traffic are along the Pacific Highway which enters the county from the south at Woodland, follows the Columbia River to Kelso, and then the Cowlitz River across the northern boundary. This road carries a great deal of the coast tourist travel. Unfortunately, this happens during the summer when the binding quality of any surfacing material is likely to be lowest. On account of this factor, special care in the selection of suitable materials is important. If the local demands were only to be considered, the present type of road probably would suffice, but the time is not far off when some kind of paving will necessarily be undertaken.

TOPOGRAPHY.

Cowlitz county has a rough topography on the whole. It is fortunate for reasons of transportation that the Cowlitz River Valley serves as a north-south gateway. In places, however, the valley is so narrow that the highway is crowded out of the valley by the railroad and river, and in several instances steep grades are encountered. In the eastern part of the county the hills rapidly increase in height to fair mountainous proportions.

CLIMATIC FACTORS.

The climate is very moist during the winter and dry during July and August. During the rainy season, about 55 inches of rain generally falls. Natural earth roads then become almost impassable. On the main arteries of travel, therefore, some sort of surfacing is necessary. But care must be exercised in choosing the material to avoid too much clay binder which will make the road soft in wet weather, or too little binder, which will permit ravelling during the dry summer months, when tourist travel is at the maximum. Frost action is of little consequence for the winters are usually mild.

ROAD MATERIALS.

Gravels have a limited distribution in the county when the whole area is considered, as shown by the accompanying outline map of the county. Commonly, silt terraces border the streams rather than gravel formations, especially in the lower part of the Cowlitz and Toutle river valleys, so that the occurrence of gravel is confined mostly to a few scattered bars along the stream, such as occurs at Castle Rock. Along the Columbia River, gravel outcrops on the side of benches, as south and west of Kelso. West of Kelso they are overlain in some places by silt so that the amount available is relatively small unless stripping can be done.

Where there is not a near source of gravel there is usually an abundant amount of tough and resistant

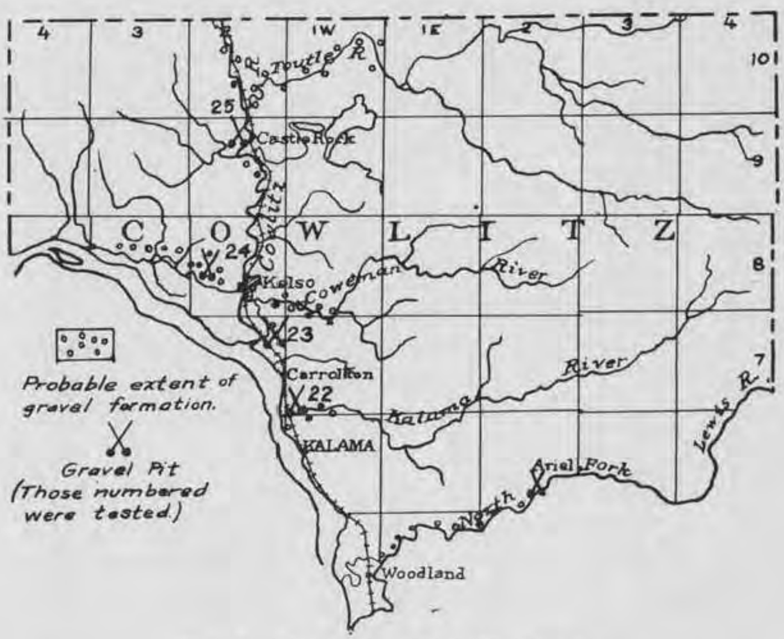


FIG. 8. Sketch Map of Cowlitz County.

basalt at hand. In 1911, the Washington Geological Survey examined and tested the rock formations of this and other counties of the state and the results are published in Volume No. 2 of the Survey's series, to which the reader is referred.

TESTS ON ROAD GRAVELS.

Map Number 22. This sample was taken from a bar or low terrace along the Kalama River, near its mouth, about 2¼ miles north of Kalama. Something like 70 per cent of the material passes a ¼-inch screen, so that the gravel would be called a sandy gravel. A few pebbles and cobbles range up to 6 inches in diameter, but these are not so abundant but that they can be screened or possibly raked out. The chief objectionable feature is probably the softness of the pebbles, most of them being andesite pumice and tuff, with some basalt. Nearly 68 per cent are soft and by test they showed a loss by abrasion of 32.8 per cent. They probably have their origin in the volcanic rocks of Mt. St. Helens, so that the materials which this stream carries are generally of the same nonresistant character. The absence of proper material for binder is also an objection. This gravel might be used for dressing purposes on crushed rock macadam, but for the body of the road it is not recommended.

Map Number 23. This sample was collected from the side of a high bench, about 2½ miles southeast of Kelso. This is a coarse gravel with a relatively low amount of material which would pass a ¼-inch screen. So much oversize is present that crushing would be warranted. If all of the material were passed through a crusher pit-run, not only would there be a better gradation but there would be a larger amount of binder secured. The quality of the binder already present is high as shown by both the tenacity and cementation tests. Forty per cent of the pebbles are andesite, 34 per cent basalt, 25 per cent quartzite, and 1 per cent granite. Of these 78 per cent are hard and offer strong resistance to wear. Only 6.1 per cent loss resulted from the abrasion test. For light traffic this material is considered satisfactory if properly prepared.

Map Number 24. This sample was collected from a side-hill pit about 5 miles northwest of Kelso. Here the gravel, which has a thickness of 12 feet, is overlain by about 15 feet of clay, which limits the amount of material that may be taken out at any one place. The gravel is well graded except that there is about 12 per cent of oversize. The pebbles are chiefly andesites and basalts with some quartzites, and about 85 per cent of them are firm. By test, the tenacity value is fairly good. Some of the gravel had just been put on State Road No. 19 when this locality was visited, and it appeared to be packing satisfactorily.

Map Number 25. This sample was obtained from the gravel bar of Cowlitz River at Castle Rock. The materials were too variable from place to place to warrant making a mechanical analysis, and there is so much oversize that crushing is an economic necessity. Eighty per cent of the pebbles, which consist of andesite, tuff, basalt, greenstone, and pumice, are fairly firm while the rest offer little resistance to wear. As is common to most stream gravels, the tenacity value is very low, and in this case the cementation value is also low. In actual practice a good, tenacious clay will have to be added.

TESTS FOR CONCRETE.

Two of the samples of gravel collected were screened and washed, and the sand was used in making concrete briquets for the tensile strength tests of the sand. The character of the test is described in Chapter IV. The briquets of the sand under test were compared with briquets of the same age made from Standard Ottawa sand and the same brand of cement.

Map Number 23, which has already been described as being obtained from the side of a high bench about 2½ miles southeast of Kelso, showed a tensile strength in the 7-day briquets equal to 53.4 per cent of that shown by the standard sand briquets of the same age, and the 28-day briquets gave a value 53.6 per cent as high as the standard sand briquets. The colorimetric test showed an absence of organic matter. It is evident from the mechanical analysis of the sand given in Table IV, that an addition of coarse sand is needed.

Map Number 25, collected from the gravel bar of the Cowlitz River at Castle Rock. In the 7-day test, this sand showed a strength 68.6 per cent as great as the Standard Ottawa sand, but in the 28-day test a greater strength was shown, namely 113.4 per cent. A considerable amount of organic matter was detected by the colorimetric test which would be a dangerous element unless this was removed by washing.

The results of these tests are given in some detail, along with those from other counties, in Tables IV and V.

DOUGLAS COUNTY

GENERAL STATEMENT.

Located in the big bend of the Columbia River, Douglas county is bounded on the north and west by this master stream and on the east by the ancient course of this stream, the Grand Coulee. Its area is 1,787 square miles. In 1910 its population was 9,227, most of which is rural. The northeastern portion is but sparsely inhabited. Waterville is the county seat and chief town, and others of importance are Mansfield, Bridgeport, Withrow, and Douglas.

Wheat is the chief product of the county. Some of the largest wheat fields of the country are to be seen here, and the large production calls for properly surfaced roads in order to market it. Foresight is being exercised by the county authorities for the coming of the motor truck. Considerable stock is also raised and dairying is of importance. In Moses Coulee, many acres are devoted to orchards.

TOPOGRAPHY.

In general the topography is a high rolling plateau, averaging 2,000 or more feet in altitude. The minor valleys in many instances lead to coulees of canyon propor-

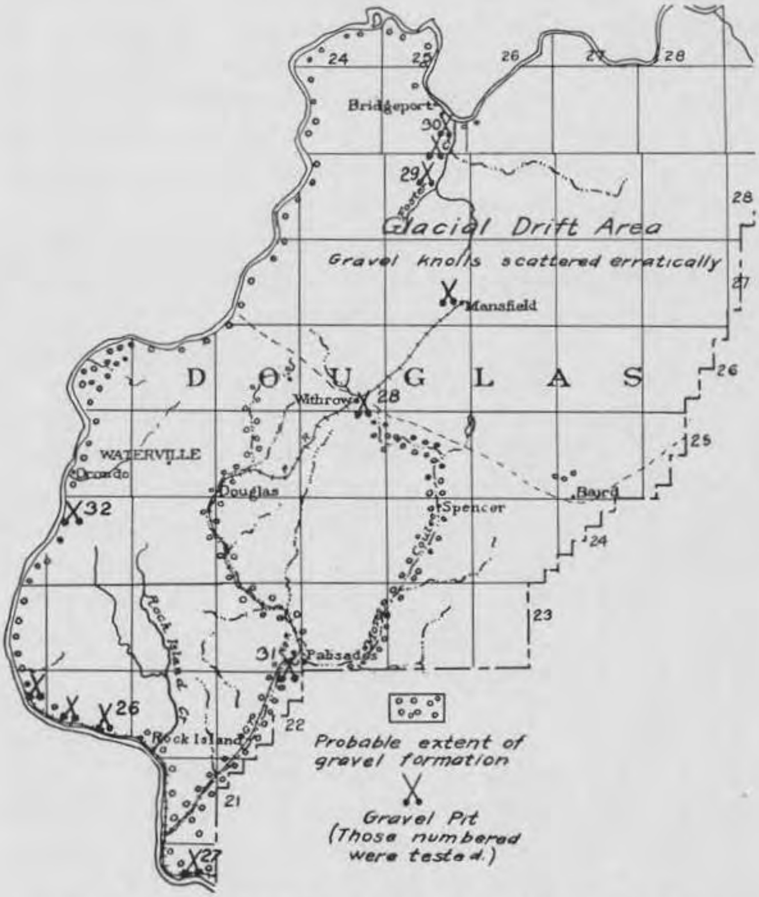


FIG. 9. Sketch Map of the main portion of Douglas County.

tions. At some points Moses Coulee is about 2,000 feet deep and very scenic. The Badger Mountains, an upwarp of the plateau, lie in the southwestern part of the county. The bedrock is mostly basalt. Some schists occur in the deep valleys west of Waterville. As a result of the deep coulees and canyons, the problem of obtaining moderate grades up their side slopes is imperative and frequently very difficult. The excellent grade and scenic "switch-backs" in the tributary canyon west of Waterville is an accomplishment of high order.

North of the dotted line drawn on the outline map of the county, the basalt is covered by a glacial formation whose topography consists of hillocks and depressions of erratic distribution. The soil is heterogeneous and stony, consisting of clay and rock material intimately mixed. Some localities are sandy. East of Mansfield huge boulders dot the landscape which were brought by the glacier which deposited the stony soil.

South of the dotted line the soil is very largely a clay which varies from heavy to light in character. In the valleys, this has been removed and the underlying basalt exposed. Along the Columbia River, from Orondo southward to the latitude of Wenatchee there is much sand. This requires a somewhat thicker surfacing to carry heavier loads than the clay. The clay muds to some extent during wet weather, but this condition usually does not remain for long. The heavy clay makes a very hard road during the summer, but the light becomes rutty. The variation from heavy to light may take place abruptly so that an otherwise splendid road may become bad by the occurrence of ruts at intervals.

CLIMATIC FACTORS.

Douglas county has a semi-arid climate. Its precipitation averages about 13 inches each year, one-third of which is snow. The drought of summer is particularly felt in harvest time when the moisture has been taken from the roads by evaporation, thus reducing their ability to support heavy loads. In consequence the wheat-hauling must be done over roads full of "chuck holes," unless the road has been properly surfaced with gravel. Strewing the road with straw is sometimes resorted to as a temporary emergency measure. Gradually the policy of road surfacing is being extended, either by gravel where it is available, or by crushed rock, where the gravel is not, so that in the near future most of the main highways will be improved.

The semi-aridity of the climate affects road maintenance and construction in another way. The fine material which ordinarily would serve as binder is loosened by traffic during the dry spells and carried away by the strong winds of this plateau. Its effect is seen in the ravelling of the road. Not only is the road metal deprived of much of what it had originally, but of practically all that would accrue from the wear of traffic.

If enough moisture is present in the soil when freezing of winter comes on, frost action in the early spring produces a soft roadbed and wheels are likely to cut deep courses. This is corrected by proper maintenance before dry weather comes.

DISTRIBUTION OF ROAD GRAVELS.

Within the area of glacial drift there are many knolls of gravel to be found. These cannot always be identified as gravel-bearing without making test-pits, but sometimes they can be detected by their smooth and rounded contour, their steepness of slope, and the character of the soil-covering. Their distribution is so erratic that their occurrence in any certain locality cannot be predicted, but they may be found most anywhere.

The drainage lines which lead away from the glacial drift area usually contain deposits of gravel which were transported and deposited there by the waters from the melting ice. Moses Coulee is an example, and the small valley east of Withrow another. The Columbia River Valley also represents such a relationship. The materials of the east side of the Columbia River, however, seem to contain too much fine sand until a point is reached a few miles below Wenatchee. The small valleys west of Waterville are barren of gravels because their sources were outside of the gravel-bearing waters of the glacier.

Tests on Samples

Map Number 26. This sample was taken from the deposit on the north side of the Columbia River, 4 miles northwest of Rock Island. Here a high bench attaining a height of nearly 500 feet above the river, contains immense quantities of gravel. The mechanical analysis shows that the material is mostly a mixture of "pea-gravel" and "torpedo-sand." The pebbles are fresh and firm and show good wearing value. The finer portion, which passed through a 10-mesh sieve, and which may be considered as the binder, tested rather low both in tenacity value and cementation value. In the lower terrace the gravels are much coarser and less satisfactory. The Wenatchee-Rock Island road was surfaced with the material from the higher terrace, and although it was slow in setting, the road is now a splendid one.

Map Number 27. This sample was obtained from a deposit 1½ miles west of Trinidad, and is very similar to the one just noted. The gravel is of essentially the same texture, although less of it passes the ¼-inch screen. Practically all of it is basaltic in composition. The binder of this sample tested moderately well both as to its tenacity properties and its cementation. This has been used on the Sunset Highway east of Trinidad, chiefly as a dressing over coarser gravel, and has given satisfaction, after the addition of more binder.

Map Number 28. This sample was taken from a deposit of gravel, 1 mile east of Withrow, by the railway track. This gravel is coarse and basaltic in composition to the extent of about 97 per cent. About 23 per cent is retained on a 2-inch screen and about 28 per cent passes the ¼-inch screen. Practically all of it is firm and excellent in wearing quality. The binder portion is very small in amount and too small to make a plastic paste for testing its tenacity value. The percentage of oversize would undoubtedly warrant running all of the material through a crusher pit-run. The binder would probably be increased by so doing. Much of this gravel is used for concrete purposes in Waterville. The results of the concrete briquet tests are given on a following page, as well as in Tables III and IV.

Map Number 29. This sample was taken to represent the average of the deposit in a low bench along Foster Creek, 6½ miles south of Bridgeport. The gravel formation is at least 100 yards long, but is overlain by 5 to 6 feet of light gray silts which must be stripped in order to secure the gravel. The materials are mostly basalt with some granite, and well graded save for some oversize. The pebbles are fresh and hard and show good wearing value. The binder is low in quantity and tested low in cohesiveness. A tenacious clay should be added to compensate for this lack in essential qualities.

Map Number 30. This sample was taken from the gravel pit near the mouth of Foster Creek, 2½ miles southeast of Bridgeport. The pit-face is 50 feet long and 30 feet high and stands vertically. The lower 10 feet contains material suitably graded up to 2 inches in size, while the overlying is coarser but also contains fine material. The sample was taken from the lower portion. Thirty-six per cent of the pebbles are basalt, 26 per cent granite, 23 per cent quartzite, and 15 per cent siliceous rock. About 88 per cent are firm. By test the gravel shows good wearing qualities, and the binder is fairly good in its cohesiveness and cementation. Where used on the highway it has given good satisfaction.

Map Number 31. This sample was taken from a deposit in Moses Coulee, about 1¾ miles north of the present Palisades Station. A 200-foot bench occurs here, containing immense quantities of gravel ranging in texture from coarse sand to 2-inch pebbles, with a few oversize constituents which can be easily discarded either in the excavation or in spreading on the road. The materials are rounded and consist mostly of basalt. Ninety-seven per cent are firm, and the loss they yield to abrasion is remarkably low, 3.9 per cent. The chief disadvantage is in its low binding qualities as indicated by its tenacity value. Not only is there an insufficiency of binder which passes the ¼-inch screen, but not enough passes the 200-mesh.

Map Number 31. This sample was obtained from a deposit along the Columbia River on the east side, 3 miles south of Orondo, where fragments of granite, quartzite, and schist have been washed out of a tributary canyon and deposited in the form of an alluvial fan. Nearly 20 per cent are oversize, but the rest are well graded. If crushed pit-run, it should make a desirable surfacing material. The schist constituents are soft, which reduces its wearing value, but this may be advantageous in one way in that binder is thereby contributed. In its natural occurrence the deposit is lacking in this essential element. The tenacity test gave a low value for the binder as it occurs naturally. Material from here was crushed and used on the road of this locality in 1915 and was found to pack readily, giving good service since.

Tests for Concrete

Map Number 26, heretofore described, was screened and washed and the sand used in making concrete briquets, whose tensile strength was tested and compared with the strength of briquets made from Ottawa Standard sand and the same brand of cement. The character of this test is recorded in Chapter IV. Three of the briquets of the sand under test were broken when seven days old and found to have a strength 100.8 per cent that of the briquets of Ottawa Standard sand of the same age, and the 28-day briquets tested 113.4 per cent as great. In actual practice the sand may be found to be a little too coarse and some fine may be needed. The colorimetric test showed no organic matter.

Map Number 28, from a deposit already described, yielded briquets which tested 129.5 per cent the strength-efficiency of Standard sand briquets in the 7-day briquets, and 109.9 per cent in the 28-day briquets. The sand is too coarse to give the proper density and fine sand or crusher dust should be added. No organic matter was found to be present.

Map Number 30, previously described, gave as the 7-day ratio, when compared with the Ottawa Standard Sand, 142.9 per cent, and as the 28-day ratio, 151.7 per cent. The sand was shown by the colorimetric test to be free of any organic content.

Map Number 31, from a deposit herein described, tested 114.3 per cent the strength-efficiency of Ottawa Standard sand in the 7-day briquets, and 129.1 per cent in the 28-day briquets. The sand should have some fine sand or fine crusher added to give the proper density. No organic matter was found by test.

FERRY COUNTY

GENERAL STATEMENT.

Ferry county is in the central part of the Okanogan Highlands, and is mountainous except for the Sanpoil-Kettle River Valley, which, fortunately, runs lengthwise through the county and provides a continuous passage for transportation and communication. The State Highway Department has established a state road, State Road No. 4, along this valley, beginning at Ferry on the northern boundary and connecting with the Sunset Highway at Wilbur in Lincoln county. A branch of State Road No. 4, running west from Republic, connects Ferry county with Okanogan county.

The population of the county, as estimated by the Census Bureau in 1916, was 4,951. The amount of traffic is accordingly light and the expenditure of money on roads cannot be large. Dairying, stock-raising, mining, lumbering, and diversified farming are the main industries.

The rainfall is not excessive for the proper maintenance of roads, the precipitation averaging about 17 inches, a certain amount of which is snowfall. In early springtime, frost action and moisture conditions are likely to make the road-beds soft and permit ruts from wheel-cutting.

DISTRIBUTION OF GRAVEL DEPOSITS.

Gravels are found along all of the chief valleys, such as the Sanpoil, Columbia, and Kettle River valleys, but they vary greatly as to gradation and sand content. Along the Kettle River Valley in the northern part of the county an abundance of good gravels may be had by screening out the over-size material. In fact, the roads in this part of the county have in part a natural gravel road-bed. In the lower portion of the Sanpoil River Valley and along the Columbia River, there is a great deal of fine sand and silt below an elevation of about 1700 feet which makes a poor sub-soil for a road-bed and in many cases necessitates the securing of good road-gravels at higher levels.

Tests on Samples

Map Number 33. This sample was taken from a deep road cut in the gravel formation, 3 miles east of

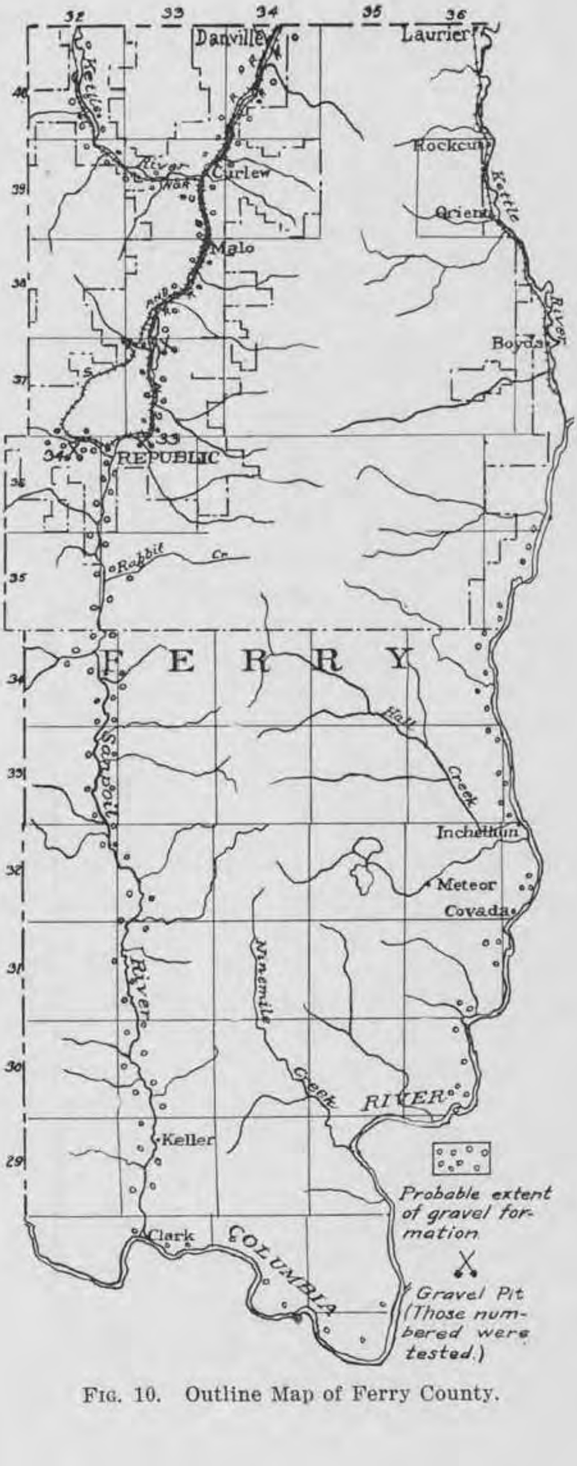


FIG. 10. Outline Map of Ferry County.

Republic. The gravels here form a bench-like feature along the lake, on which the road is located. They are well graded but contain considerable over-size. About 70 per cent are retained on a ¼-inch screen. The pebbles are composed chiefly of firm granites and andesites and have good wearing qualities. The cementing material, however, is lacking in sufficient clay to give it good binding qualities, as shown by the tenacity test, described in Chapter III. Crushing might aid this factor if a good tenacious clay is not available.

Map Number 34. This sample was collected from a road-side cut 3½ miles west of Republic. Its composition is much the same as Sample 33, as far as kinds of pebbles are concerned, but there is a greater percentage of soft, and the gradation in size is better. Where used on the road, it has proven satisfactory for light traffic.

OTHER ROAD-BUILDING MATERIALS.

Where gravels are not at hand or of suitable quality, there is an abundance of rock exposed that is suitable for road-building. Much andesite occurs along the Sanpoil Valley from Republic south and in the vicinity of Curlew. Granite and diorite also occur northeast of Curlew and along Kettle River from Orient to Laurier. These rocks were tested in 1911, and the results published in Bulletin No. 2 of the Survey series.

FRANKLIN COUNTY

GENERAL STATEMENT.

Franklin county is situated just north of the junction of the Snake and Columbia rivers, in the southeastern part of the state. Its area of 1206 square miles is but little populated in several of its townships, and all told its population in 1916 was estimated by the Census Bureau at 8,087, of which Pasco, the county seat, has about one-fourth. Connell, Eltopia, Mesa, and Kahlotus are the other chief towns.

The main line of the Northern Pacific Railroad passes northward through the county, a branch line of the same railway connects Connell and Kahlotus with northern points, and another follows the Snake River canyon to Lewiston, Idaho. The S., P. & S. Ry. also uses the track of the latter to Snake River Junction, and then by a line of its own ascends the canyon slope to the pass south of Kahlotus through which it reaches the Washtucna Coulee and thereby leaves the county.

The demand for good roads is quite prevalent, but they need not be planned for more than light traffic for perhaps several years. Surfaced roads should be provided over at least the sandy portions of the county, where the marketing of the wheat soon cuts the natural roads until they are almost impassable, and along the Central Washington Highway, which is the main automobile highway through the county.

TOPOGRAPHY.

In the eastern portion of the county is a rolling plateau, 800 to 1800 feet above sea-level, which is underlain mostly by clay and which is much cut up into hills and valleys. In the northwestern part of the county there are high-lying flats and in the vicinity of Pasco are bench lands which more or less gradually decline to the level of the Columbia River, at 350 feet above tide. The Washtucna Coulee, an ancient and imposing valley, now without a permanent stream, runs from Washtucna to Connell by way of Kahlotus and there joins the Esquatzel Coulee which trends southwestward and gradually becomes shallower until it merges into the bench land north of Pasco. The valley occupied by the Snake River is a very deep canyon from the eastern line to a short distance east of Pasco.

SUBSOIL.

The soil for some miles around Pasco is extremely sandy. Northeast this merges into a coarse sand and gravel of Esquatzel Coulee. The soil of the higher plateau to the east is mostly a heavy clay, but the dryness of the summers in this county is sufficient to deprive the clay of its moisture-binder and permit the roads to become very rutty when the season for heavy wheat hauling is at hand. The average precipitation for the whole year is only about 7 inches. This is reflected in the sagebrush vegetation of the area.

Progress is now being made in surfacing the main highways. Several miles were surfaced in 1917 northeast of Pasco, and a stretch of the Central Washington Highway, beginning at Pasco, is at present being metaled.

On the outline map of the county, the areas which are probably underlain by gravel are shown. It should not be understood that gravel occurs universally in these areas, for there is known to be some scab-land within these limits, as well as wind-blown sand. But the geological indications together with certain test-pits show that gravel may be found in many places within the areas mapped.

TESTS ON ROAD GRAVELS.

Map Number 35. This sample was taken from a deposit three miles northeast of Pasco, in the S. E. ¼ of Sec. 2, T. 9 N., R. 30 E. A pit in this deposit shows coarse rounded gravels of basalt, quartzite, and granite, most of which are firm and have excellent wearing value. The amount of oversize warrants putting the whole material through a crusher, thus giving not only well graded constituents but increasing the binder content. The tenacity test on the binder showed that its quality, as it occurs in the gravel, is fairly good, and the cemen-

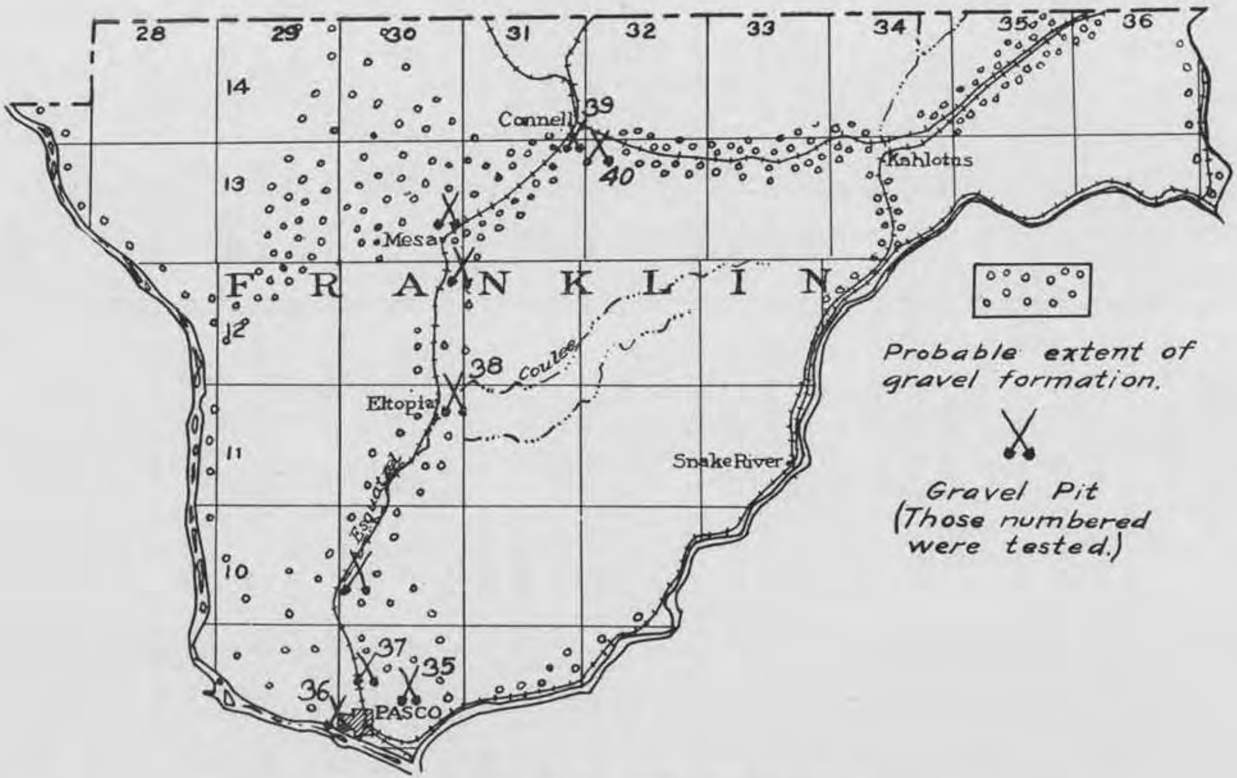


FIG. 11. Sketch Map of Franklin County.

tation test shows that after the material is ground up its cementing qualities will be high. Material was taken from this deposit for the newly gravelled highway northeast of the irrigation ditch.

Map Number 36. This sample was taken from the pit ¼ mile southeast of the passenger depot at Pasco. A great deal of gravel has been removed from this pit so that now it has a face about 150 yards long and 10 to 15 feet high. The material stands well in the pit, but this may be due partly to its coarseness. Such as is used for surfacing must be crushed. Seventy-four per cent of the pebbles in the sample were basalt, 15 per cent granite, and 11 per cent quartzite. Practically all of these are hard and have excellent wearing value. The sand is present in varying quantities, usually low in percentage, and so was not graded. Silt coats the pebbles in some horizons which increases their cementation value, but if the gravel were to be used for first-class concrete this feature would make washing necessary. Some of the quartzite pebbles are flattened, but their percentage is believed to be too small to affect the packing qualities of the gravel.

Map Number 37. This sample was collected from a deposit 4 miles northwest of Pasco, along the Northern Pacific Railway. A test pit had been opened, which exposed the characteristics of the gravel fairly well. The pebbles consist of basalt and quartzite, have excellent wearing value and are well graded, there being but little oversize. The cohesiveness of the binder is very high as shown by test, and the ultimate cementation is also high. This deposit may be drawn upon for the Washington Central Highway in this vicinity.

Map Number 38. This sample of gravel was taken from a deposit ½ mile northeast of Eltopia, in Smith's Canyon. The deposit is an eroded bench of considerable size, and the fact that it is a remnant of a bench shows that other deposits are likely to be found in this vicinity. The pit-exposure shows a little oversize but as a whole the gravel appears well graded. Most of the pebbles are basalt and have very good wearing value. The tenacity value tested low, indicating that an addition of clay is necessary. If this is done, it should make a very satisfactory road material. Five miles of the Smith Canyon road was surfaced with this material, and under heavy steel-tired traffic, such as prevails during the wheat-hauling season, the material has packed well. Some clay was added from the roadside.

Map Number 39. This sample was obtained from the deposit in the southern limits of Connell and is almost entirely a "torpedo sand" of basaltic composition, without any perceptible softening by weathering. So little silt material is contained in the coarse sand that a cohesive paste could not be made for the tenacity test. This material has been subjected to a practical test on the road for ½ mile north of town and found to pack and wear well. It would make excellent material for dressing purposes and should also prove satisfactory for use in a sand-clay road.

Map Number 40. This sample was taken from another deposit near Connell, located ½ mile southeast of town. This is a typical gravel in which but little oversize is present, the pebbles are hard and have average wearing value, but the binder is low in its content of clay. This was used on the highway for 1 mile west of town and with the addition of clay is reported to have packed promptly without rain.

In about the central part of Sec. 19, T. 13 N., R. 31 E., on the north side of the railway, the Northern Pacific Railroad has opened a large pit, 300 yards or more long in a deposit which stands 50 to 60 feet high. The pebbles are mostly small, the gravel being a true "pea-gravel." They are dominantly of basalt. Large quantities have been used for railroad ballast.

In a high bench along the road north of Mesa, gravel of good quality is exposed. Where this forms the roadbed it seems to be entirely satisfactory. North of Kahlotus and elsewhere along Washtucna Coulee, gravel deposits occur in benches 100 to 150 feet high. Those at Kahlotus are well graded, with but little oversize and scarcely any sand. Where used on the highway in this vicinity it seems to have good binding and wearing qualities.

TESTS FOR CONCRETE.

The sand from Map Number 39, heretofore described, was washed and tested for concrete. The method used is described in Chapter IV and the results of the tests are tabulated with those from other counties in Tables III and IV. It tested in tensile strength 118.5 per cent as strong as Ottawa Standard sand, in the case of the 7-day briquets, and 142.1 per cent as strong in the case of the 28-day briquets. No organic content was found by the colorimetric test.

GARFIELD COUNTY

GENERAL STATEMENT.

This county is situated south of the Snake River in the southeastern part of the state. The extreme southern projection lies in the Blue Mountains, but most of the county is a high plateau, dissected by many deep canyons. The main canyons trend in a northwesterly to westerly direction. The existence of these, together with their trend, necessitates winding grades over high divides for roads leading from the northern part of the county to Pomeroy, the county seat. Pataha Creek, however, makes possible a grade for a railway branch of the O.-W. R. R. & N. Co. to enter the county and afford transportation facilities for the county's products and its needed imports. At the present time, much regrading is being done and extensive surfacing is planned for later. This will permit the use of motor trucks for the marketing of the large cereal yield of the farms. The First Division of the Inland Empire Highway, which passes through Pomeroy, is surfaced for several miles

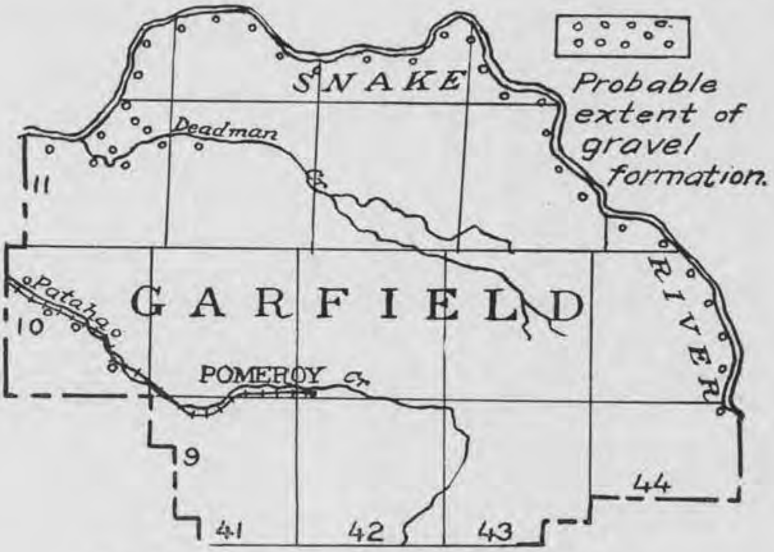


FIG. 12. Sketch Map of a portion of Garfield County.

both east and west of town. Along the Snake River, tramways are in use at some points for lowering and lifting produce to and from the Snake River canyon.

The traffic over most of the roads will be light for some time. In 1916, the Census Bureau estimated its population to be 4,374, or an average of about seven to the square mile. The road having the most traffic at present is the First Division of the Inland Empire Highway and the Pomeroy-Starbuck road.

SUBSOIL.

A heavy clay soil covers the upland areas to considerable depth north of Columbia Center. This makes a good earth road in the late spring and early summer, but during early spring and late fall such roads are usually almost impassable on account of mud. In the deeper canyons and gulches, below the 1200-foot level, a light fluffy clay abounds which is scarcely capable of making a good road at any season of the year. Another difficulty which must be contended with in the lower portions of the gulches is the great amount of debris which torrential rains wash down from the higher slopes. In some cases, roads are thus effectually blocked.

CLIMATE.

The average annual precipitation at Pomeroy is 18 inches. This amount is increased on the higher slopes of the Blue Mountains and decreased in the lower valleys near Snake River. The summers are dry, permitting the natural earth road to become almost entirely free of moisture and rutted in the marketing season when the traffic is fairly heavy.

DISTRIBUTION OF ROAD MATERIALS.

The gravels are confined almost entirely to the Snake River Valley and the lower reaches of Deadman Creek and Pataha Creek. The benches along the Snake River are not continuous but are remnants chiefly on the inner sides of the curves of the stream. They are commonly 50 to 75 feet high, and large quantities are available, but the difficulty of transporting them to the roads of the plateau is almost prohibitive. Along Deadman Creek and Pataha Creek, below the 1200-foot level, there are alluvial fans located at the mouths of tributary gulches composed of fragmental materials which have been washed down from the higher slopes. In a few cases suitable material may be secured, but usually the material is too coarse to use without crushing. Some small gravel bars are scattered along these streams, but these are commonly deficient in binding material.

Above the 1200-foot level, the bedrock is the chief source of road-metal. The rock is made up of basaltic lava-flows and is dominantly porous, fragmental and rather soft, with reddish horizons here and there. Indeed, its character is such that a most careful selection is necessary in order to locate a good quarry, and even after a quarry is once opened, objectionable rock may be encountered as the work progresses. This is illustrated in the case of the county quarry 3 miles west of Pomeroy. The quarry 1½ miles east of town is of somewhat better quality.

GRANT COUNTY

GENERAL STATEMENT.

This county, the fourth in size in the state, is situated in central Washington within the Big Bend of Columbia River. It is about 92 miles long in its longest dimension and 50 miles wide, and contains 2,720 square miles. This great area intensifies the difficulty of very extensive roadbuilding, for a county of its small population and low assessment value of the land. The population in 1910 was 8,698, or an average of 3.2 persons to a square mile. There is some concentration of the inhabitants along the Great Northern Railroad in the vicinities of Quincy, Winchester, Ephrata, Adrian, Wilson Creek, and Krupp, and also a fair percentage in the vicinity of Coulee City and Hartline, in the northern part of the county, and at Beverly, Smyrna, and Warden in the southern part. Thus the demands for good roads, while localized, are after all scattered over a wide territory.

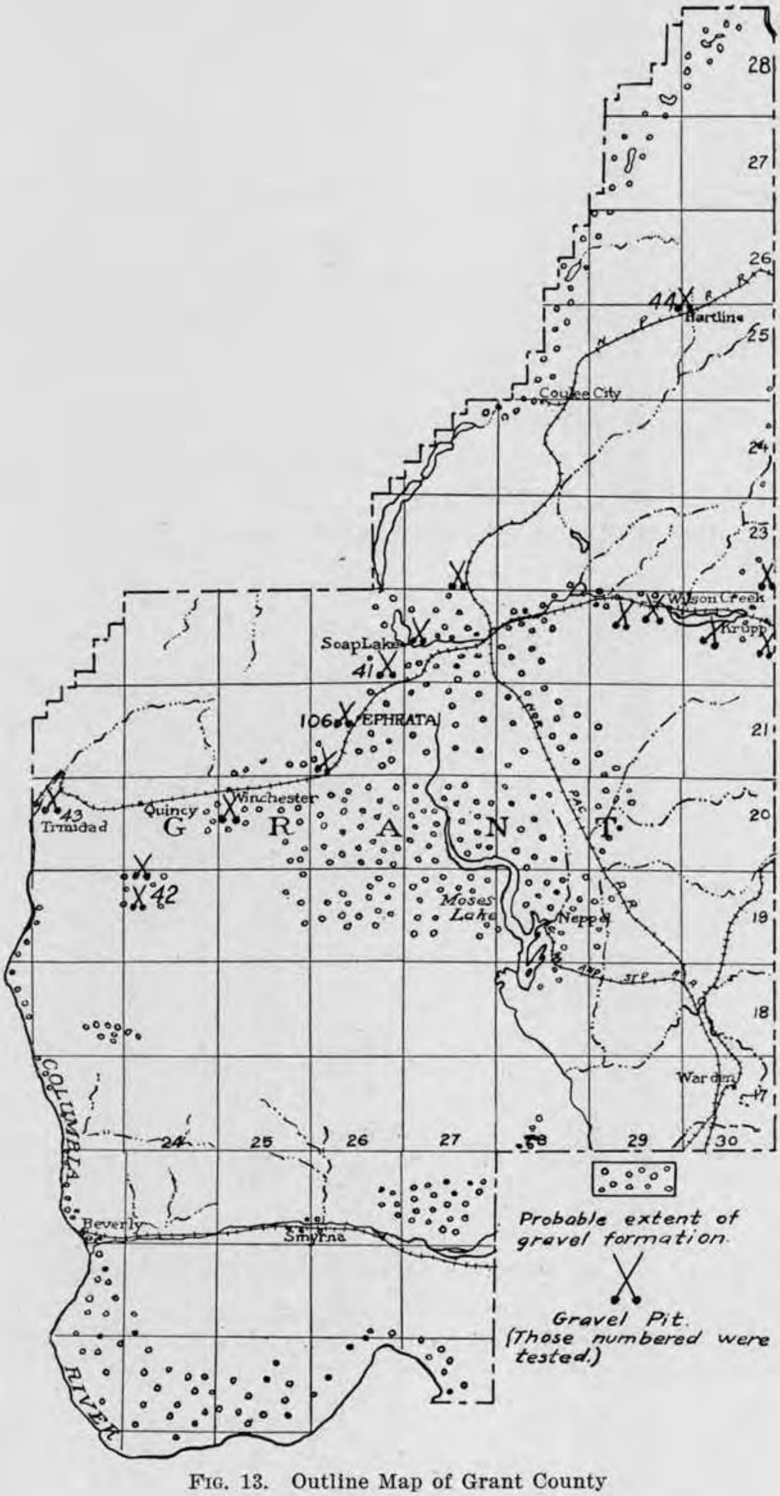


FIG. 13. Outline Map of Grant County

The chief industry of the county is wheat growing. Some alfalfa, rye, and fruit are also grown, and some mineral salts and diatomaceous earth are mined. The county is traversed by two transcontinental railways, the Great Northern through the central part and the Chicago, Milwaukee and St. Paul through the southern. A branch line of the Northern Pacific Railroad provides north and south connections.

The State Highway Department has established two roads, the North Central Highway from Quincy to Krupp, and the Sunset Highway from Vantage to Trinidad, and across the northern part through Coulee City and Hartline. Only a part of these roads has been surfaced.

TOPOGRAPHIC FACTORS.

The topography offers few difficulties in the way of roadbuilding. The county consists of flattish plains south of Soap Lake, with the exception of the Frenchman Hills and the Saddle Mountains, and a rolling plateau to the north. The latter is cut by the impressive Grand Coulee, which was occupied by the Columbia River during glacial times.

A large part of the plains have a sandy subsoil which causes abominable roads in dry weather. Some progress has been made in surfacing these. Along Crab Creek, in the vicinity of Redrock, there is a fine silt which is nearly as prohibitive to traffic in summer as sand. There are considerable areas, however, northeast of Ephrata where gravel underlies the surface, and the roads here are almost universally good.

CLIMATE.

Grant county must contend with a semi-arid climate in its construction and maintenance of roads. The rainfall is usually less than 8 inches each year. The long dry season taxes the binding qualities of the surfacing materials, especially when marketing is on or the tourist travel is large. In constructing roads it has been found that new surfacing made in the late spring packs less readily during the summer and makes a much less satisfactory road than if the surfacing were done in the fall and received the benefits of the winter's moisture.

DISTRIBUTION OF ROAD GRAVELS.

Due to the fact that the Columbia River was diverted from its present course during a part of the Glacial Period and made to flow through the Grand Coulee and by way of Moses Lake and Crab Creek, a large amount of sand and gravel was brought into the county and deposited over considerable territory in the vicinity of Soap Lake and Adrian and south beyond Moses Lake. The sketch map of the county shows by small circles the areas in which road gravel can likely be found, and by a symbol of crossed shovels some of the places where pits have already been opened.

The gravel seems to be coarser and more bouldery south of Soap Lake and Adrian and in the immediate vicinity of Moses Lake, but at the south end of the lake there is much wind-blown sand which has deeply buried the gravel and filled the old channel-way. Gravel occurs north of Corfu, but along Crab Creek from here to Beverly the deposits are patchy and consist mostly of fine sand and sandy silt. Along the outer border of the gravel area as mapped, as for example on the Morrison Flat, the materials are mostly coarse sand and pea-gravel.

Tests on Samples

Map Number 41. This sample was taken from a deposit in the N. E. 1/4 of Sec. 35, T. 22 N., R. 26 E., on the property of Mr. Robert Ingram. The material is chiefly pea-gravel and "torpedo sand," and mostly basaltic, over 90 per cent of which is hard and has very good wearing virtues. The tenacity test, however, showed that the material is likely to have a slow initial set, but the cementation test reveals that after the binder becomes ground up it will have a high cementing value. A remedy for the slow initial packing would be to add some tenacious clay. The deposit in its natural state would make good dressing material.

A coarser deposit occurs on the north side of the road, in which the pebbles range up to 3 inches in size. Gravel from these pits has been used on the road from Ephrata to Soap Lake, and was redressed in 1917 with the finer material. The traffic in summer is estimated at 200 vehicles per day, most of them fast tourist cars. In winter the travel is much less.

Map Number 42. This sample was taken from a deposit 5 miles south of Quincy. The materials are basaltic gravels, mixed with a considerable amount of lime fragments. A certain percentage is oversize which is screened and discarded. At a depth of about 6 feet clay beds are encountered. A little over 80 per cent of the constituents are hard, the remaining 20 per cent or less reducing the wearing virtues of the gravel but increasing its cementing qualities by yielding binder. The binder portion has a low tenacity value as shown by test, indicating that an addition of clay is needed.

Map Number 43. This sample was taken from the deep roadway cut, 2½ miles northeast of Trinidad. About 70 per cent of this sample consisted of pebbles and fragments over ¼-inch in size, and 10 per cent over 2 inches. A layer of lime-rock at the top of the gravel and beneath the soil yields a considerable amount of soft material which in the sample amounted to about 11 per cent. The remaining 89 per cent is hard, and would give good wear. The binder portion gave a low tenacity test, indicating that some clay is needed. This deposit was uncovered in the process of excavating for the cut, and the material was used on the road, with fine gravel from west of Trinidad for dressing. The result has been very satisfactory.

Map Number 44. This is a sample of the material from the Hartline Gravel Pit. This deposit, which has yielded so much road metal for the highways in this vicinity, has pebbles mostly under 1½ inches in size, fairly well rounded, and nearly 40 per cent of which passes the ¼-inch screen. About 95 per cent are firm, showing very good wearing qualities, but the binder portion tested low in its cohesiveness. This was borne out in actual practice by its slowness in packing and the considerable amount of maintenance necessary. After it is made to pack, it gives very good service. The slow initial set could probably be remedied by the addition of a good tenacious clay.

Tests for Concrete

Map Number 41. This sample, which was taken from Mr. Robert Ingram's pit previously described, was tested for concrete by making six concrete briquets according to the method described in Chapter IV. Three of these briquets were tested for their tensile strength when 7 days old and compared with briquets of similar age which had been made from Ottawa Standard sand and the same kind of cement. The 7-day briquets of the sand under test showed a tensile strength 141.0 per cent as great as those of the Ottawa Standard sand, and the 28-day briquets 131.4 per cent as great. The sand has no organic content, as shown by the colorimetric test. Due to the coarseness of the sand, fine sand or crusher dust should be added.

Map Number 106, taken from the Pruitt pit, ½ mile west of Ephrata. The 7-day briquets tested 94.6 per cent as strong as the Ottawa Standard, and the 28-day briquets 98.8 per cent, which indicate its unfitness for first-class concrete. Its inferiority is probably due to its fineness.

GRAYS HARBOR COUNTY

GENERAL STATEMENT.

This county is located on the Pacific Ocean and includes the bay which bears its name. Its area is 1927 square miles, and its population in 1916 was 48,457. Much the larger part of the population live in the southern half of the county, chiefly along the Chehalis River. Here is where the chief requirement for improved roads exists, and also in the lumbering region of the Olympics where the railroads have not as yet entered.

The county has a hilly topography except in the northeastern part where the uplands pass rapidly into the rugged topography of the mountains. Some wave-cut terraces border the narrow coastal plain. The irregular surface of the county necessitates the location of the highways chiefly along the valleys, where moderate grades facilitate travel. Here, too, the roads commonly lie on gravel benches and have excellent foundations while the uplands are covered with a heavy mantle of clay soil.

Situated close to the coast, this county receives a heavy rainfall. Most of it occurs during the winter, and the summers are fairly dry. Both extremes of climate are, therefore, present to affect road-building. The amount of clay which can be used in the binding portion of gravel is limited by the moisture of the winter season, but enough must be present to prevent ravelling during the summer. The temperature is so mild that severe frost action does not prevail. Good drainage is, of course, a prerequisite.

DISTRIBUTION OF GRAVEL DEPOSITS.

Before discussing the distribution of the gravel formations of this county, attention should first be called to the fact that there are two distinct gravel formations present which differ widely in their road-building qualities. One is a red or reddish brown gravel which is usually composed of soft, decayed pebbles, and is worthless as a road-metal, the other is a grayish to yellowish gravel, firm in character. The cause for the difference in character between the two is that the former is much older and has been weathered deeply, while the latter represents the outwash of the Puget Sound glacier and is comparatively recent in age. The former usually occurs on divides or in high terraces, while the latter forms relatively low benches along the Chehalis River.

Gravel of fresh character is found in benches along the Chehalis River from 20 to 40 feet above the flood-plain, practically the whole distance from where the river enters the county to Aberdeen. Similar gravels occur along the Cloquallam River, Wildcat Creek, Mock Chehalis Creek, and the eastern benches of the Satsop River.

The reddish brown gravel occurs in the higher bluffs at Cosmopolis, between Aberdeen and Montesano, near Rutherford, 1 mile west of Satsop village, and from Satsop to Elma. It also is found along the West Fork of the Satsop River, the Wynooche River, the Wishkah River, the Hoquiam River, and in bluffs along Grays Harbor nearly to the coast. Gravel of first-class quality cannot be expected to occur in any valley west of the West Fork of the Satsop River until the Humptulips River is reached. The soft, reddish gravel is found in some instances from near the bottom of these streams to the top of the divides. In practically all cases it occurs well above the valley-flat and can easily be identified by its reddish color. Some of the low benches, such as occur in the Wynooche, have been drawn upon for local uses, but while this is better than the gravel higher up on the slopes, its life is short.

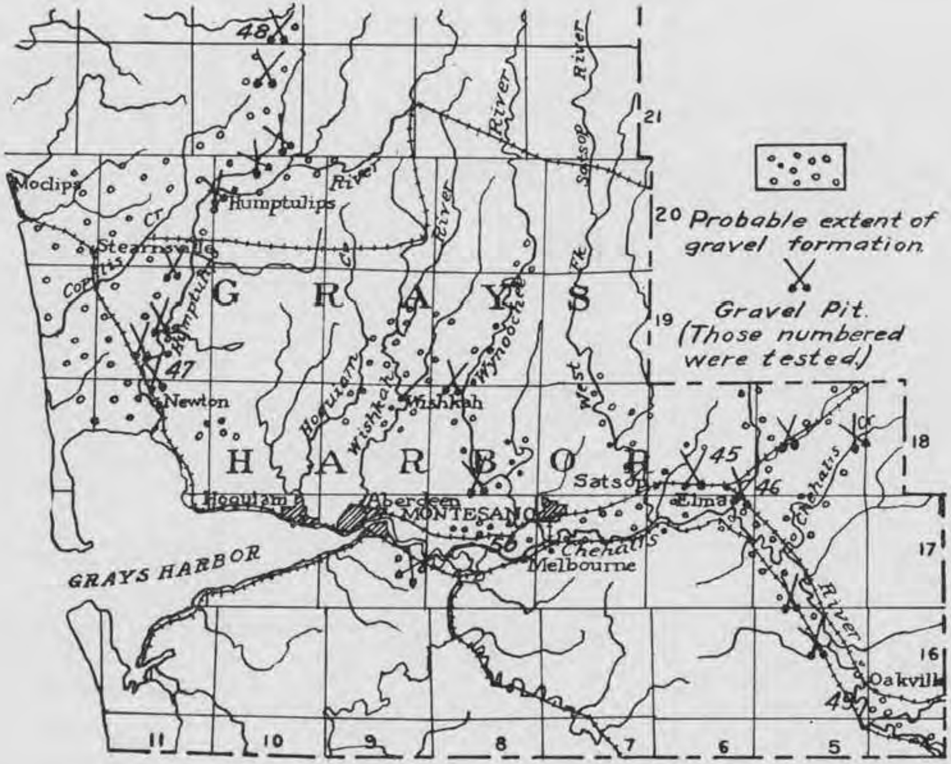


FIG. 14. Outline Map of Grays Harbor County.

The Humptulips River contains bars of fresher and firmer material than the streams immediately to the east, but not quite so firm as the Chehalis River gravel. The Humptulips River drained from a valley glacier in the Olympic Mountains during the last glacial epoch, whereas the Hoquiam River and others had no such source for fresh material. Benches occur upstream containing unlimited quantities of good material. Some of it is coarse, but a selection of properly graded gravel can usually be located.

Two classes of gravel characterize the coast of Grays Harbor County: a beach gravel and a reddish gravel. The beach gravel is made up of firm pebbles of rock with more or less sand, which has been washed and thrown up by the waves. Because of the wear and assortment by the waves, the gravel has very little binding material left in it. The reddish gravel is similar to that which has been mentioned, being usually soft and inferior. It occurs over broad benches and in wave-cut cliffs. The bars, which nearly enclose the mouth of Grays Harbor, are composed mostly of wind-blown sand, too fine for concrete.

Tests on Samples

In 1911, the bedrock of this county was studied to ascertain its adaptability for road macadam. The basalt north of Hoquiam and another outcrop one mile west of Oakville were tested and the results published in Bulletin No. 2, of the Washington Geological Survey. The present report has to do primarily with the gravels.

Map Number 45. This sample was taken from the Brady pit, 2¼ miles west of Elma. The gravel here occurs in a broad terrace, and is composed of basalt, 35 per cent; siliceous rock, 51 per cent; quartzite and sandstone, 14 per cent. Over 90 per cent of the pebbles are firm and have strong resistance to wear or rupture.

This sample gave the lowest percentage of wear of all the samples tested. They are well rounded and fairly well graded, with a considerable amount of oversize. The chief objection is the lack of good initial binding qualities, as shown by the tenacity test. The addition of tenacious clay would be beneficial, both as to its initial packing and to its ultimate cementation.

Map Number 46. This sample was obtained from a gravel bar of the Cloquallam River, 1 mile southeast of Elma. The bar is about 100 feet wide by 300 feet long. Material has been excavated to the depth of 3 feet. This gravel represents the re-working of the glacial outwash gravel which occurs in the banks of the stream. Sixty-six per cent of the pebbles are basalt, 14 per cent sandstone, 14 per cent siliceous rock, and 6 per cent granite. About 95 per cent are firm and of first-class wearing quality. It is lacking, however, in binding material, as might be expected in the case of a stream gravel.

Map Number 47. This sample was taken from a bar of the Humptulips River, 4 miles north of Newton, where the county was obtaining gravel with a sky-line drag. Most of the pebbles are basalt with some sandstone and metamorphic varieties. Over 90 per cent are firm and have good wearing value. By test the tenacity value is low, indicating that clay should be added. The material was being placed on the Olympic Highway at the time of this examination, but it was too early to note its practical value.

Map Number 48. This sample was collected from a pit located in a terrace, 8 miles northeast of Humptulips, in the N. E. ¼ of Sec. 14, T. 21 N., R. 10 W. The pit face shows a two-foot covering of brown soil, below which are fresh, light-colored gravels rather imperfectly assorted. Much clay occurs in the matrix which would enhance the binding virtues of the material. In the tenacity test, this showed a fairly good value. About 90 per cent of the pebbles are firm and sound, and have good resistance to wear and rupture.

Map Number 49. This sample was obtained from Black River, in the E. ½ of Sec. 33, T. 16 N, R. 2 W. In composition, the gravel runs as follows: basalt and andesite, 77 per cent; siliceous rock, 16 per cent; granite, 7 per cent. About 95 per cent of the pebbles are hard and sound and appear to have good wearing qualities. It lacks, however, in binding material, there being an insufficient amount in a 30-pound sample to test. The gravel, however, would be satisfactory for concrete pavement.

Map Number 50. This sample was dredged from the Chehalis River about 4 miles southeast of Montesano, by the Grays Harbor Construction Co., of Hoquiam. The gravel is well graded, contains 88 per cent of basalt and andesite, 9 per cent of siliceous rock, and 3 per cent of granite, and practically all of it is firm and hard. By test, it showed a loss due to abrasion of only 2.9 per cent. It is a first-class concrete gravel. It is unlikely that material from this source would be used for surfacing, but if it were, its cementing qualities would probably be found to be low, as much of the binder portion has been washed out.

The detailed results of the foregoing tests are tabulated with those of other counties in Table I.

Tests for Concrete

Map Number 45, from the Brady pit, 2¼ miles west of Elma, was screened, and the sand washed and used in making concrete test briquets, according to the method described in Chapter IV. These were tested for their tensile strength with the following results: The 7-day briquets showed a strength equal to 68.8 per cent that of the briquets made from Ottawa Standard sand,

and the 28-day briquets a strength equal to 64.6 per cent. The chemical test gave a blackish red color, showing an injurious amount of organic matter to be present. With this removed the strength would probably equal or exceed the Standard Ottawa sand, as the sand under test appears first-class.

Map Number 46, from the Cloquallam River bar, 1 mile southeast of Elma, was washed and tested with the following results: The 7-day briquets showed a tensile strength 132.0 per cent as great as the strength of the standard sand briquets, and the 28-day briquets a strength ratio of 153.2 per cent. By the colorimetric test, enough organic matter was found to be present to make washing desirable before using. Additional tests should be made from time to time as a precautionary measure while the sand is being used.

Map Number 49, from Black River, in the E. ½ of Sec. 33, T. 16 N., R. 2 W., gave a 7-day ratio of 98.7 per cent and a 28-day ratio of 124.3 per cent. A small amount of organic matter was detected by test, but apparently not in sufficient amounts to be injurious.

Map Number 50, from the bed of Chehalis River, 4 miles southeast of Montesano, dredged by the Grays Harbor Construction Co., of Hoquiam, gave the following results: The 7-day briquets had a tensile strength 108.0 per cent as great as the standard sand briquets, and the 28-day briquets a strength of 133.1 per cent as great. Some organic matter was detected by the colorimetric test, but not in injurious amounts. Careful washing probably would eliminate practically all that is present.

Map Number 107, from the Wynooche River bar, 1 mile southeast of Montesano, showed an efficiency test of 108.2 per cent as compared with Ottawa Standard sand in the 7-day test, and 137.1 per cent in the 28-day test.

The detailed mechanical analyses and other results of the tests are given in Tables III and IV.

ISLAND COUNTY

GENERAL STATEMENT.

Island county, as the name indicates, is made up of islands, the largest of which are Whidbey and Camano. They have a position within Puget Sound, between Admiralty Inlet and the mainland to the east. Their total area is 208 square miles, and in 1916 the population was 6,487. Langley is the largest town, and Coupeville the

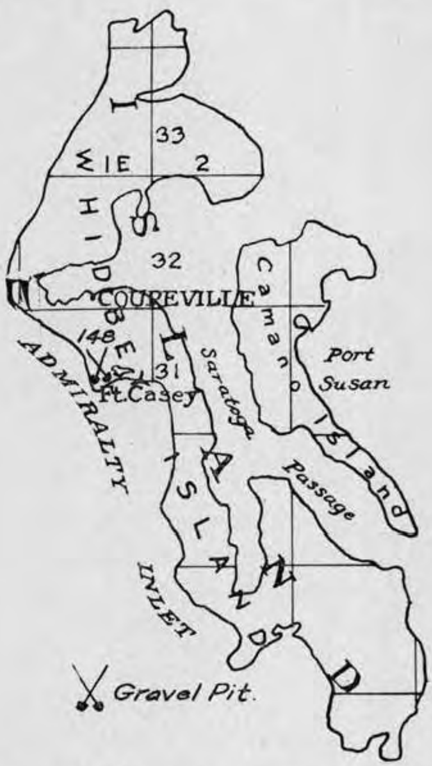


FIG. 15. Sketch Map of Island County.

county seat. These, together with several small villages, are all located on the coast. Dairying, fruit growing, vegetable raising, and salmon fishing are the chief industries. The topography is gently rolling, and the coastline is indented with many bays and harbors. In many places the coast is bounded by sea-cliffs. The rainfall averages about 21 inches, and the other features of the climate are characteristic of the Puget Sound country.

In view of the fact that all of the towns are located on the water's edge, water transportation is much more important than land transportation. The need for a well developed system of highways is, therefore, not so great as in most counties of the state. To meet such demands for surfacing as there are, the numerous local deposits of gravel can be drawn upon. All of the islands are covered with glacial deposits. Two important commercial pits have been opened at Ft. Casey. Samples of the sand and gravel from these were tested for their concrete making qualities. The results are given in tabulated form, with those from other counties, in Tables III, IV, V, and VI.

JEFFERSON COUNTY

GENERAL STATEMENT.

Jefferson county is a very long county passing through the heart of the Olympic Mountains, from the Pacific Ocean on the west to Hood Canal on the east, and thence north, ending in a point at Port Townsend. The total area is 1,747 square miles. Nearly all of the county's population live in the extreme eastern and northeastern portions. In 1916 the number of inhabitants was 9,987. Lumbering and fishing rank first in importance, but dairying and stock-raising are increasing in prominence. Port Townsend is the county seat and largest town, and Quilcene, Port Ludlow, and Chimacum are other towns.

A large part of the county is mountainous and not populated. The western part is a low plateau. Along Hood Canal, on the east side, the Olympic Mountains descend rapidly to sea-level, and most of the villages along here are situated at the mouths of streams. The Olympic Highway has been cut out of the precipitous slopes in many places, and for the most part follows closely the water's edge. The northeastern part of the county is a plain having rolling topography, and more or less forested. This part was covered by the glacier

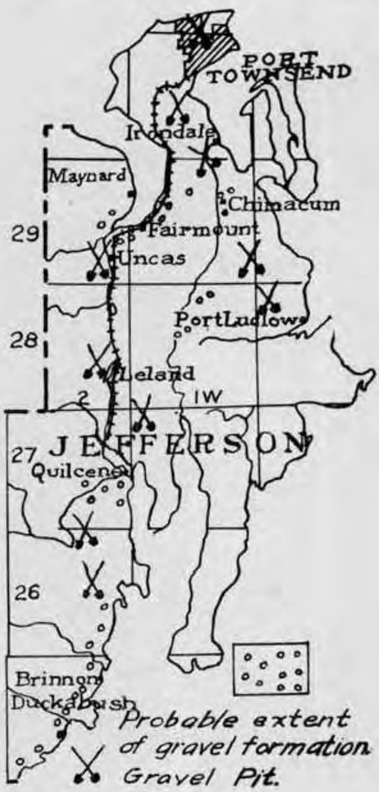


FIG. 16. Outline Map of a portion of Jefferson County.

during the Glacial Period, which also flanked the high slopes of the Olympics on the east and north.

CLIMATE.

Jefferson county has a variation in rainfall as great as, if not greater than, any other county in the state. Port Townsend receives an average of only 20 inches or less per year, while the western slopes of the Olympic Mountains are drenched with more than 120 inches. Otherwise, the climate is much like that of the rest of the Puget Sound country, save for the higher parts of the Olympics, which receive a heavy snowfall. The light rainfall of the northeastern portion makes possible the use of more clay binder in the road gravels than is possible for any other part of western Washington. In this respect it resembles parts of eastern Washington.

ROAD MATERIALS.

In 1911, the Washington Geological Survey made a study of the bedrock formations of the state to ascertain their adaptability for macadam roads. Several samples were collected from this county and tested, the results of which were published in Bulletin No. 2 of the Survey's series. The present investigation was devoted chiefly to a study of the gravel deposits.

DISTRIBUTION OF THE GRAVEL DEPOSITS

Along practically the whole length of Hood Canal to north of Brinnon, gravel deposits are abundant. Few highways in the state are as economically situated with respect to available gravel for surfacing as the Olympic Highway for this portion of its course. In its construction, excavations were made in the side slope of the mainland and gravels of good quality exposed. There is scarcely an instance where the material must be hauled over a greater distance than a half mile. The manner of occurrence of the deposits is illustrated in

—7

Plate VIII. The pebbles are mostly hard and firm varieties of granite, basalt, quartzite, and other siliceous metamorphics. All gradations, of course, occur, but materials suitably graded can be obtained without difficulty. There are some deposits of small sized gravel suitable for dressing purposes.

In passing over the high point of land north of Brinnon, the road rises above the gravel plain. Road cuts in places expose angular basalt talus which is used to good effect. It appears to contain about the right amount of clay for binding. At Quilcene another gravel deposit is encountered, but from here north the area is notable for its lack of gravels. There are instances where the material must be hauled several miles to the place where it is to be used. Indeed, from Quilcene northward to Port Discovery, the Olympic Highway passes through territory which is unfortunately almost barren of good material. Not only is there a paucity of road gravel but of good bedrock. Chiefly soft sandstones and shales are exposed from beneath the mantle of glacial debris.

Chimacum is located on a gravel flat. From Chimacum southeastward along the Port Ludlow road, a few deposits are to be found, as in the S. E. 1/4 of Sec. 25, T. 29 N., R. 1 W. This deposit, however, is so surrounded and overlain with clay and fine sand that but little can be taken out. Fairly good gravel occurs near the junction of the Center Road with the Port Ludlow road. At Irondale and Hadlock, the deposits are sandy. Northwest from Chimacum to Port Townsend, good gravel is somewhat more abundant.

About two blocks north of the high school at Port Townsend, on the south side of the road, a gravel pit has been opened in a sideslope exposing materials of variable quality. On the north side the gravel is coarse, containing some large boulders and fragments of clayey till, which make the gravel unfit for concrete. On the south side of the pit sand appears to be satisfactory for concrete. Except for the included fragments of clay the gravel is firm. An overburden of 2 to 3 feet of clayey soil, filled with roots of vegetation, should be stripped before the material is used, either for surfacing or concrete.

Along the Port Discovery road a few small patches of gravel occur. At Maynard there is a high bank of gravel 60 feet high, and 200 yards long. The materials vary greatly in size. Very coarse and bouldery gravel occurs at the top, north of the railroad viaduct, but a few yards further north finer material is to be had. The chief objection is the absence of binder. The presence of many fragments of soft shale and sandstone make the deposit undesirable for concrete aggregate.

On account of the Survey's Testing Engineer being called for war service, no samples of material were collected for testing.

KING COUNTY

GENERAL STATEMENT.

King county is situated in the west central part of the state, extending from the crest of the Cascade Mountains to the shores of Puget Sound. Its area is 2,111 square miles. This is the most populous county in the state, its population in 1916 being 394,397, as given by the U. S. Census Bureau. Much the larger part of this is concentrated in Seattle and the adjoining valleys, although settlement is fairly widespread in the mountain valleys. The concentration in the western part, however, produces traffic demands which are too great in many cases for ordinary macadam roads and many miles of paving have been laid. These are so planned that they carry most judiciously the traffic of the various lumber mills, shipyards, factories of all sorts, feed and cereal mills, packing plants, canneries, condensaries, machine shops and other industries of Seattle and vicinity, including the products of the nearby farms and truck gardens.

Besides the various continental railway lines, all of which converge at Seattle, certain state highways have been established. The Pacific Highway passes through the county in a north-south direction, entering the county south of Auburn and leaving it at Bothell. The Sunset Highway enters at Snoqualmie Pass, with the convergent travel from eastern Washington, and terminates at Seattle. And the McClellan Pass Highway will, when finished, cross the Cascade Mountain Range at McClellan Pass and join the Pacific Highway at Au-

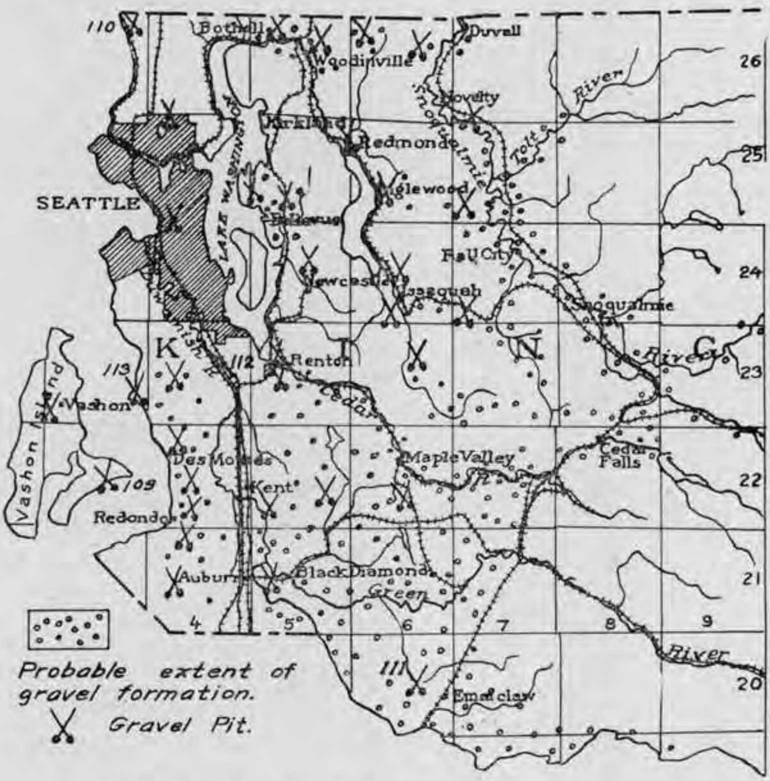


FIG. 17. Outline Map of a portion of King County.

burn. In addition to these the county has devised a system of highways to meet the demands in the various parts.

TOPOGRAPHY.

The county has almost every type of topography within its boundaries, from mountains and canyons on the east to plains and broad valleys on the west. This incurs many problems of grade in which the principles of modern highway engineering have been well carried out. The Sunset Highway, for example, crosses the Cascade Mountain Range on a maximum grade of 5 per cent. The mountains leave off rather abruptly west of Duvall, Fall City, Kanasket and Enumclaw and give way to more or less broad plateau-like areas incised by river valleys. In the western part these valleys have broad flood-plains. The shores of Puget Sound on the west are marked by wave-cut cliffs.

CLIMATE.

The rainfall of King county averages about 60 inches, but this includes the heavy rainfall of the higher portions of the Cascades. At Seattle the precipitation is about 35 inches per year. Most of the rainfall occurs in the winter season and July and August usually have but little rain. This gives the two extreme conditions of moisture and aridity, according to which the highways must be surfaced and maintained. Caution is exercised to avoid using too much clay-binder on account of the moisture conditions of winter, and yet enough must be used, if possible, to provide proper cementation for the dry months. Dressing material is in some places resorted to, to prevent excessive ravelling during the summer.

Snowfall is generally light and of short occurrence in the western part of the county, on account of marine influences, but in the higher portions of the Cascades the snowfall is so heavy that the Sunset Highway is closed for several months of the year. Snowslides and floods wash much material from the higher slopes in places, and expensive maintenance must be carried on, especially in the spring.

DISTRIBUTION OF ROAD GRAVELS.

The gravel of the county has a wide distribution in the western portion. West of the foot of the mountain range, glacial gravel is generally abundant. This is especially true west of Cedar Falls and Black Diamond. Much glacial wash covered this region, and material for surfacing can be procured at most any point along the highways, or at least within short hauling distances. The county operates scores of pits, one of the largest being at Auburn. Large commercial pits have been opened in the cliffs of Puget Sound at Three Tree Point, on Vashon Island, and Richmond Beach, which supply much of the trade material used for concrete purposes. At present the deposit at Richmond Beach is not being worked. The general distribution of the gravels and the locations of various gravel pits are given on the outline map of the county. There are numerous other local pits, most of which are of local character, which are not given.

BRIQUET TESTS OF THE SANDS.

Briquet tests were made of some of the sands of the county to indicate their quality for concrete use. Many of the tests in the county had been made by the Portland Cement Association, who have kindly placed the results at the Survey's disposal.

Map Number 109. This sample taken from a pit of the Vashon Sand and Gravel Co., on Maury Island, showed a tensile strength in the 7-day briquets 121.3 per cent as strong as the briquets of the same age made from Standard Ottawa Sand, and the 28-day ratio was 121.7 per cent.

Map Number 110. This sample from Richmond Beach gave a 7-day ratio of 110.1 per cent and a 28-day ratio of 119.1 per cent.

Map Number 111. This sample from a deposit between Enumclaw and Auburn, which was used in the concrete pavement of this locality, was found to have a 7-day ratio of 114.2 per cent and a 28-day ratio of 113.4 per cent.

Map Number 112. This sample taken from a local pit between Duwamish and Renton Junction, gave a 7-day ratio of 128.5 per cent, and a 28-day ratio of 103.7 per cent.

Map Number 113. This sample obtained from Three Tree Point, gave a 7-day ratio of 118.8 per cent and a 28-day ratio of 103.3 per cent.

More detailed information concerning the character and the chemical analyses of the sands is given in Tables III and IV, of Chapter IV.

STRENGTH TESTS OF FIELD CONCRETE CYLINDERS.

According to the method described in Chapter IV, concrete cylinder tests were made of the mix which went into two of the pavements laid in King county in 1917. These cylinders were cured as far as possible under the same conditions as the pavements. These were later tested for their compressional strength at the Engineering Testing Laboratory of the University of Washington.

Four cylinders which were made of the material in the Duwamish-Renton Junction pavement averaged 4,043.15 lbs. per square inch. The source of the aggregate which was used in the concrete was the Steilacoom deposits. A sample of these gravels showed them to be composed of pebbles of granite, diorite, quartzite, andesite and siliceous rock, most of which were of firm and durable character. The abrasion test was made on these gravels and the results show an excellent value. The percentage of wear was only 2.4 per cent.

On the Houghton-Medina Road the four test cylinders averaged in compressional strength 3,572.6 lbs. per square inch. The source of the aggregate in this case was also the Steilacoom deposits. More detailed information concerning the character of the aggregate and the strength tests is given in Tables V and VI.

KITSAP COUNTY

GENERAL STATEMENT.

Kitsap county is located in the central part of the Puget Sound Basin. It has an area of 371 square miles and a population of 24,487, according to the 1916 census. Lumbering and the manufacturing of wood products are the most important industries, while others are fishing, poultry raising, truck farming, stock raising, and shipbuilding. Bremerton is the largest town and Port Orchard the county seat.

On account of the indented coast-line and the nearness to good harbors from any part of the interior of the island, the roads are short. As the logged-off land is prepared for farming purposes, the surfacing of the roads is extended. The average rainfall is about 41 inches per year, with the greater part occurring in the winter season. The other factors of climate are also like those of the rest of the Puget Sound country.

DISTRIBUTION OF ROAD MATERIALS.

This county has a thick covering of glacial drift, in which the materials range from a pebbly clay to a good quality of gravel. Deposits of gravel are widely distributed and in most cases are first-class. Because of their similarity in quality to the other gravels of the

Puget Sound region, and of the light traffic which the highways of the county carry, no samples were collected for testing.

KITTITAS COUNTY

GENERAL STATEMENT.

Occupying nearly a central position in the state, this county reaches from the crest of the Cascades on the west to the Columbia River on the east, the entire width of the east flank of the mountains. The Yakima River Valley forms a trunk route through the county from northwest to southeast, and it is along this valley, particularly in its very broad portions, that the larger percentage of the population lives. In the Kittitas valley, east of Ellensburg, and in other parts, fruit interests, the growing of hay, and stock-raising support a large number of people. In the vicinity of Roslyn, many are employed in coal mining, and in the northern mountainous area gold mining is carried on to some extent.

TOPOGRAPHY AND ITS INFLUENCE.

The existence of the broad Yakima Valley simplifies the road system of the county, and for many lineal miles affords an excellent grade. Steep grades are encountered only where detours are made around canyon passes, or in the mountainous topography of the northern, western, and southwestern parts. The Sunset Highway runs the entire length of the county from Snoqualmie Pass to Vantage. The amount of tourist travel which this highway carries adds much to the expense of maintenance. Up to the present much of the tourist auto travel has taken the short-cut of State Road No. 7 over Blewett Pass to Wenatchee, instead of going by way of Vantage. At Ellensburg the Inland Empire Highway begins and runs southwestward over Manastash Ridge into Yakima county. Railway transportation facilities are offered by two transcontinental lines, the Northern Pacific Railway and the Chicago, Milwaukee and St. Paul Railway.

CLIMATE.

The precipitation of the county varies greatly and affects road-construction and maintenance accordingly. At Lake Kachess the precipitation averages about 47 inches, at Cle Elum 25 inches, at Ellensburg about 10 inches, and in the eastern part of the county about 8 inches or less. Washouts and slides are usual accompaniments of heavy continued rainfall in the western mountainous section, while in the eastern part the dry summers cause ravelling of the graveled roads or rutting of the earth roads. Heavy snowfall in the vicinity of Snoqualmie Pass closes the Sunset Highway for several months in the winter and spring. During this time avalanches bring down much debris from the higher slopes which later must be cleared away.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

Most of the gravels which are available for road-building in this county are situated along the Yakima River, in the broad portions of the valley and on high rock benches. Kittitas Valley, east and west of Ellensburg, is underlain by a thick deposit which varies in coarseness from place to place. These extend up the river to the canyon northwest of Thorp. East of Thorp there is a ridge of silt, sand and gravel 400 to 500 feet high which extends northwest nearly to Horse Canyon. Much of the gravel is coarse and would require crushing. Similar gravel occurs at a similar height on the west side of the river north of the mouth of Taneum Creek.

In the vicinity of Cle Elum, benches of gravel occur along the stream and from here to Lake Keechelus, along the Yakima River, and to Cle Elum Lake, along the

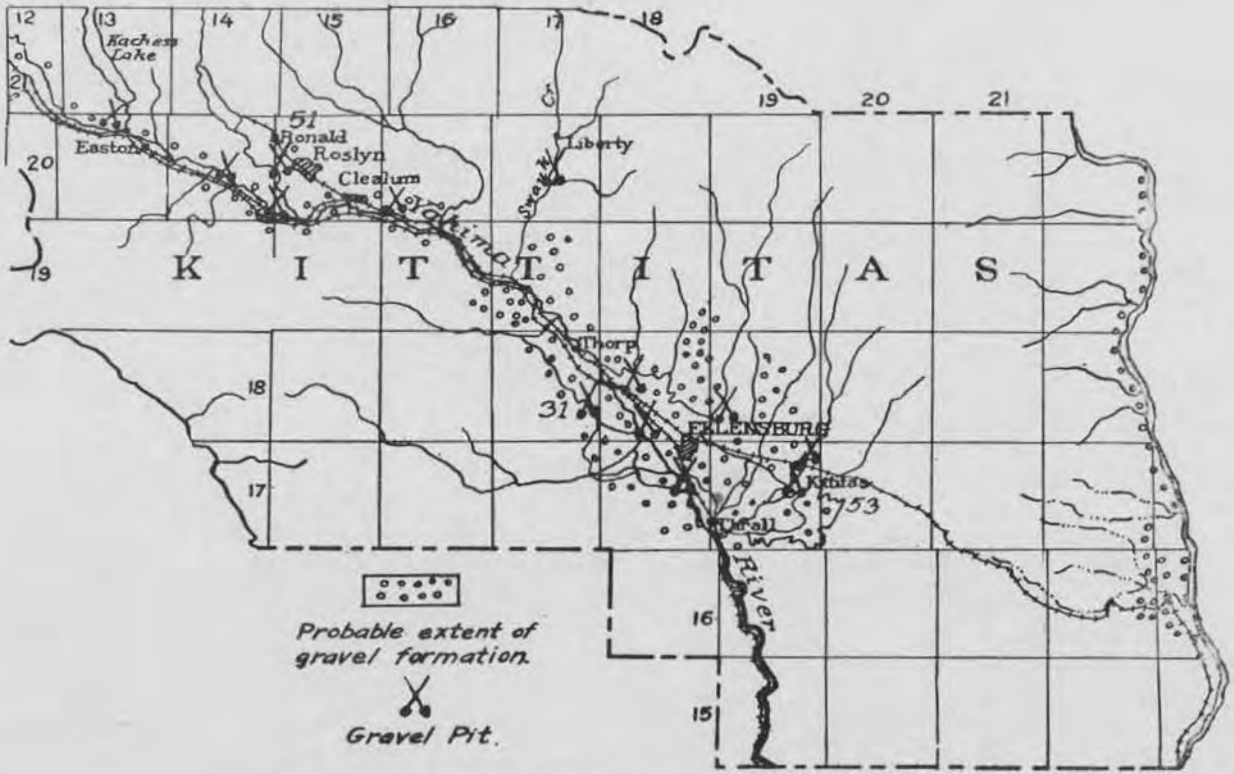


FIG. 18. Outline Map of the main portion of Kittitas County.

Cle Elum River, the same situation prevails. Most of these gravels are fresher and firmer than those mentioned near Thorp.

Tests on Road Gravels

In 1911, an examination was made of the rock of this county which would be suitable for crushed rock macadam. Some samples were tested and the results published in Bulletin No. 2 of the Washington Geological Survey series. The present study was therefore confined to the gravel formations. Tests were made of representative deposits both for uses as road surfacing material and for concrete. Those which were tested for road surfacing material will be first considered.

The sketch map of the county attempts to show the general distribution of the gravel deposits, and the location of some of the pits by the conventional symbol of crossed shovels. The deposits which are numbered are those tested. The results are given in tabulated form, with those of other counties, in Table I.

Map Number 51. This sample was taken from a deposit about 2 miles west of Roslyn, which here forms a rather high bench above the Cle Elum River. A considerable percentage of this gravel is oversize, but that which is under 2½ inches is well graded. A variety of pebbles occur, most of which are hard and have good wearing value. Granite, basalt, rhyolite, quartzite, and diorite are among the varieties represented. The tests for tenacity and cementation showed that the binder material has a fair value. One and one-quarter miles of the Roslyn-Ronald road were surfaced with this in 1917, the coarse material being screened out. Clay was added for binder. No conclusion regarding the satisfaction of this material in actual practice can be made at this early date.

Map Number 52. This sample was secured from a deposit of iron-stained gravel, 3 miles southeast of Thorp, in the south central part of Sec. 24, T. 18 N., R. 17 E. The materials are well graded from clay and sand for binder to oversize, of which there is a considerable amount, enough to warrant crushing. By pebble count, 85 per cent of the pebbles are basalt, 11 per cent schist, and 4 per cent granite. The tenacity and cementation tests showed that the binder is first-class. The results of the abrasive test, however, gave a high percentage of wear. In 1915, this material was drawn upon for metalling the highway nearby. The gravel was crushed and put on in two courses, each sprinkled and rolled. The result has been a hard surfaced road, having splendid binding qualities and thus far good wear.

Map Number 53, collected from a deposit 1½ miles south of Kittitas on the farm owned by M. M. Wheeler. A pit has been opened here exposing well graded material up to oversize, which is present in large enough quantities to warrant crushing all of the material pit-run. One to one and one-half feet of the gravel beneath the soil is infiltrated with lime, which yields considerable soft material when excavated. These soft lime fragments increase the percentage of wear, as reflected in the abrasive test, so that the gravel is hardly suitable for other than light traffic roads. The tenacity value of the binder is rather low, partly due at least to the lack of enough tenacious clay.

Tests for Concrete

Map Number 51, which has already been described as taken from a deposit 2 miles west of Roslyn, was screened, and the sand washed and used in making concrete briquets. These were tested for their tensile strength and compared with briquets made from Ottawa Standard sand and the same kind of cement. The details of the test are described in Chapter IV. The 7-day briquets showed a tensile strength 97.2 per cent the strength of those made from the Standard sand, and the 28-day briquets a tensile strength equal to 117.1 per cent that of the Standard sand. A small amount of organic material was detected by the colorimetric test, but not enough is present to be injurious.

Map Number 52. This sample from the deposit 2 miles west of Roslyn tested 97.3 per cent as strong as the Ottawa Standard sand in the 7-day test, and 114.0 per cent as strong in the 28-day test. No organic reaction was obtained by test.

Map Number 53, collected from the deposit 1½ miles south of Kittitas, showed a tensile strength 68.8 per cent as strong as the Standard sand in the 7-day briquets, and 65.7 per cent as strong in the 28-day briquets. This sand, according to this test, should therefore not be used for concrete.

More detailed results of these tests, together with those from other counties, are given in Tables III and IV.

KLICKITAT COUNTY

GENERAL STATEMENT.

This county is situated just east of the Columbia River gorge, on the east flanks of the Cascade Range. The county is 84 miles long, and averages about 25 miles wide. In 1910 its population was 10,180, or an average of 5.6 persons per square mile. Goldendale is the county seat and largest town, and White Salmon, Bickleton, Lyle, Guler, Centerville, Glenwood, Maryhill, Trout Lake, and Roosevelt are important. Agriculture and horticulture are the chief industries, and considerable lumbering is carried on. The S., P. & S. Ry. follows the Columbia River throughout the length of the county, with a branch running from Lyle to Goldendale. The steamers along the river also provide means of trans-

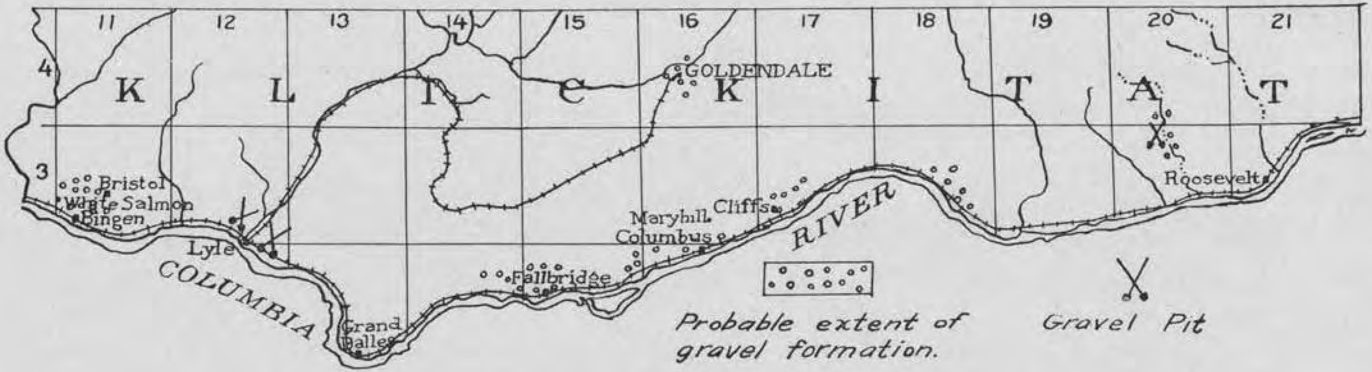


FIG. 19. Outline Map of a portion of Klickitat County.

portation. A state road, known as State Road No. 8, has been established, which when completed will connect with the Pacific Highway at Vancouver and the Inland Empire Highway near Mabton in Benton County. This road will pass through White Salmon, Lyle, Grand Dalles, Maryhill, and Goldendale. Practically all of the traffic within the county may be classified as "light traffic."

TOPOGRAPHY.

Klickitat County has a topography that is mountainous in the western part and a plateau in the eastern, with slopes that in places descend gently to the Columbia River and in places precipitously. Deep valleys and small canyons trend north and south, giving the county a very rough surface with high grades for east-west roads. Along the Columbia River, where sheer cliffs come to the water's edge, expensive blasting is necessary to locate a road. From Maryhill to Goldendale the steep grades of the old road have been admirably overcome by location according to modern highway engineering.

CLIMATE.

The western part of the county has a much greater rainfall than the eastern. According to government reports the average annual precipitation in the western part is 25 inches and upward, while in the eastern it is as little as 6½ inches. If the county were uniformly populated, this would mean that there would be more difficulty in retaining the binder and in keeping the metaled roads from ravelling in the eastern part than in the western, but fortunately the larger percentage of the people live in the western part.

ROAD MATERIALS.

The scarcity of gravel along the main highways and the prevalence of basalt rock necessitates the use of the latter for most road-surfacing. In 1911, the Geological Survey made a study of the bed-rock formations of the state with respect to their suitability for road-building. The results of the tests made on the samples collected were published in Bulletin 2 of the Survey series.

Gravel deposits occur in patches along the Columbia River, as at White Salmon, Lyle, Fallbridge, Maryhill, east of Cliffs, and northeast of Roosevelt along a creek valley. (See outline map of the county.) Gravels also occur in the vicinity of Goldendale, but here they seem to be inferior to the rock which is available. The deposit at Fallbridge was drawn upon by the S., P. & S. Ry. for construction of the concrete piers of their bridge across the Columbia River.

Tests for Road Surfacing

Map Number 54. This sample was taken from the deposit 7 miles northwest of Roosevelt from what is known as White's pit. The gravel occurs in a high bench which forms the south slope of the creek valley. About 15 per cent of the material is oversize, the largest of which are cobbles up to 6 or 8 inches. The pebbles include varieties of basalt, andesite, and quartzite, some of which have been softened by decay, but as a whole have fair wearing value. The amount of oversize would warrant crushing, which would give not only a better gradation for the whole but would do away with some of the flattened pebbles, give angularity to the rounded, and increase the amount of binder. The tenacity test of the binder as it occurs naturally showed the material to be good and the cementation test of the binder after being ground up indicated that it would ultimately have high cementing value. This material has been used on the nearby road and found to be satisfactory.

Map Number 55. This sample was collected from the deposit in the northeastern part of the town of White Salmon. This material consists of fine gravel and coarse sand, the constituents of which are basalt with some quartzite. The materials are fairly well rounded. The natural cohesiveness of the binder portion tested low, due chiefly to the lack of enough clay. The ultimate cementation value, however, is high. As a dressing material for roads it is of the proper size and would be excellent, but if used for the body it would be less satisfactory on account of the absence of pebbles over 1 inch and the high proportion of sand.

Map Number 56. This sample obtained from the deposit ¾ mile northwest of Lyle, on the east side of the road, was found to be very similar to Map Number 55 in gradation, size, and kinds of pebbles. The binder content, however, is in greater abundance, giving it a higher tenacity value. Where used on the highway in this immediate vicinity it has made an excellent surfacing. Great quantities are available, the material forming a high bench for a quarter of a mile or more to the eastward.

The detailed results of the foregoing tests, with those of other counties, are given in Table I.

Tests for Concrete

Map Number 55, which was taken from the deposit in the northeast part of White Salmon, and which has already been described, was screened and the sand washed and used in the making of concrete briquets. These were tested for their tensile strength, and compared with the strength of briquets of the same age made from Standard Ottawa sand and the same brand of cement. The briquets of the sand under test, which were seven days old, showed a tensile strength of 91.6 per cent as great as the briquets of the Standard sand,

and the 28-day briquets a strength 150.9 per cent as great.

More detailed results are given in Tables III and IV, with those from other counties.

LEWIS COUNTY

GENERAL STATEMENT.

Lewis county extends from near the crest of the low Coast Range, or Willapa Hills, on the west to the summit of the Cascade Mountains on the east, a distance of 96 miles. When the construction of State Road No. 5 is completed in the Cascades, there will then be a continuous highway demanding maintenance from one end of the county to the other, having a length considerably greater than 100 miles. This, together with the responsibility of maintaining the Pacific Highway, which carries heavy traffic in a north-south direction across the county, will entail large responsibilities on the County Engineer.

The population of the county in 1916 was 42,795, according to the Census Bureau. Centralia is the largest town and Chehalis the county seat. Other important towns are Winlock, Napavine, Pe Ell, Doty, Dryad, Littell, Vader, Mendota, Morton, Mossy Rock, Mineral, and Silver Creek. Lumbering is the chief industrial resource of the county, although agriculture and coal mining are important. Besides having to carry the traffic incident to the county's industries, the Pacific Highway has a large tourist traffic, and the National Park Highway over the Coast Range is the main artery of travel to and from the Willapa Bay country. A considerable portion of the Pacific Highway has been paved as an economic necessity, ordinary surfacing being incapable of withstanding the traffic.

TOPOGRAPHIC CONDITIONS.

That part of the county traversed by the Pacific Highway and the main line railways is the lowest part

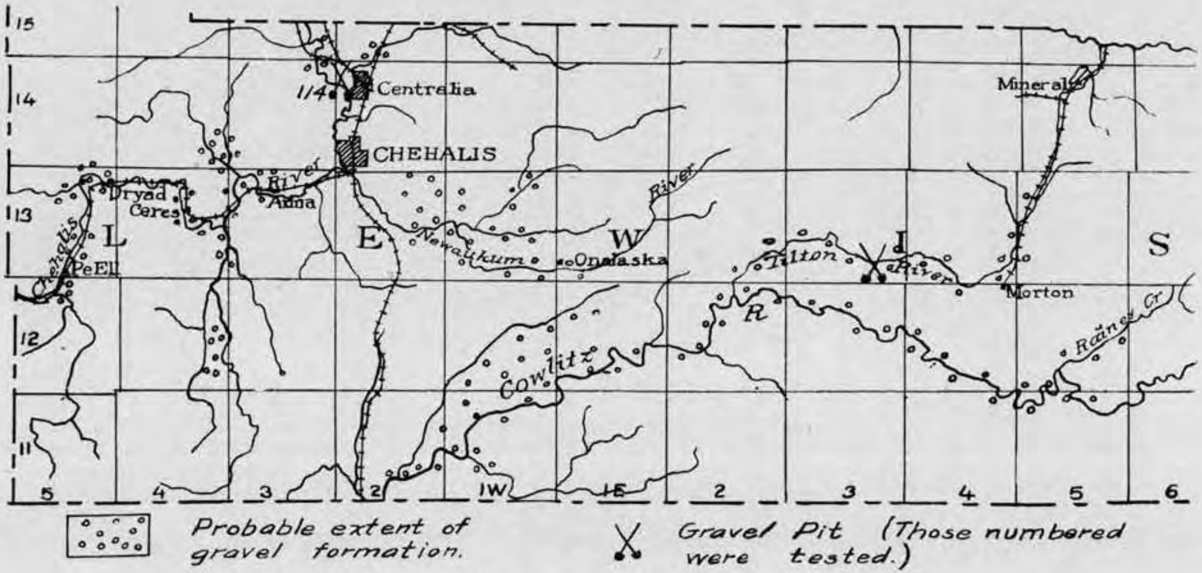


FIG. 20. Outline Map of the main portion of Lewis County.

of the county, being a continuation of the down-warp of the Puget Sound trough. This geologic feature makes moderate grades possible. In crossing the Coast Range at Pluvius a good grade has been obtained by following the Chehalis River Valley. Rolling uplands exist east of Centralia and Chehalis, and usually in less than a half score of miles assume semi-mountainous proportions and rapidly become mountainous. State Road No. 5 has been projected along the Cowlitz River in order to obtain the best natural grade to the summit of the Cascades. The subsoil which overlies most of the county is a heavy clay which makes an almost impassable road in wet weather. Hence, the necessity for surfacing.

CLIMATE.

The climate of the county is an important factor in road-building and maintenance. From 50 inches to 70 inches of rain falls each year in the low lands and higher hills respectively, and much of the larger part of this occurs during the winter. Materials for road surfacing, therefore, must be limited in the content of clay for binder, to prevent excessive softening during the winter. On the other hand, there must be enough binder for the dry season when the moisture of the roads is taken up by evaporation and the binding quality is reduced to the minimum. Some ravelling is prone to be common at this period in spite of precautionary measures. Frost action is of little consequence, because of the mild temperatures that usually prevail.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

A small area of excellent road gravels occurs north of Centralia along the Skookumchuck River and the Chehalis River. Here it forms benches along the streams. South of Centralia the gravel gives way to a broad flat of silt along the Chehalis and Newaukum

Rivers until the vicinity of Forest is reached. East of the latter point gravels may be found along several forks for some distance upstream.

West of Chehalis, gravels appear along the stream near Adna, partly in bars and partly in high benches. Gravels and basalt bedrock alternate for most of the distance to the west border of the county. The gravels here, as well as along the upper reaches of Newaukum River, are only of fair grade. The Cowlitz Valley east and northeast of Vader contains large quantities of gravel of varying qualities from place to place. The sketch map of the county shows the areas of gravel of the county so far as was possible to ascertain by reconnaissance study and geological relations. The great variation in coarseness and quality of the gravel for road purposes within short distances require open test pits to determine their adaptability.

Test for Concrete

Map Number 114. This sample was taken from the pit of the Centralia Sand and Gravel Co., at Centralia. The gravel underlies the broad flat bordering the river and continues northward along the Chehalis and Skookumchuck rivers. At the pit of the company, the sand and gravel has been obtained to a depth of 50 feet without change in the general character of the material. Scattered bits of wood float are sometimes incorporated with the gravel which make it objectionable for concrete paving unless removed. The sample collected was screened and washed and the sand used in making concrete briquets, which were tested for their tensile strength and compared with the strength of briquets of the same age made from Ottawa Standard sand and the same brand of concrete. The 7-day briquets of the sand under test had a strength 107.1 per cent that of the briquets made from the Standard sand, and the 28-day briquets 116.2 per cent.

The results of this test with those from other counties are given in Tables III, IV, and V.

LINCOLN COUNTY

GENERAL STATEMENT.

This county is situated in the east central part of Washington within one tier of counties of the Idaho line. It is approximately quadrangular in form and comprises 2,302 square miles. It is a part of the great Columbia plateau. In 1916 the Census Bureau estimated its population to be 21,042. Davenport is the county seat and the chief town, with a population of 1,229 in 1910. Other important towns are Reardan, Wilbur, Creston, Almira, Edwall, Sprague and Harrington.

TRANSPORTATION FACILITIES.

The county is one of the greatest wheat producing sections of the state. Other cereals are also grown, together with some fruit. The marketing of the products calls for an improved system of roads, and the county and state are making rapid strides in providing them. The Sunset Highway crosses the county from east to west, passing through Almira, Wilbur, Creston, Davenport, Reardan, and other towns. The North Central Highway enters from the southwest at Krupp and passes through Odessa, Lamona, and Harrington, and ends at Davenport. The Central Washington Highway, which is the main road of travel from Spokane to Pasco, passes through the southeastern part of the county, thus giving Sprague and the surrounding country the advantages of direct outside connections. The Sunset Highway is improved over much of its mileage east of Creston, and the Central Washington Highway is metaled from Sprague southwest nearly to Ritzville. The North Central Highway is splendidly surfaced from

Davenport to Harrington and work is in progress on parts of the remaining portion.

Railway facilities are also good. The main line of the Great Northern Railway serves the southern part, and a branch line of the Northern Pacific the northern portion. The main line of the Northern Pacific Railway is the chief one which carries the exports and imports of the southeastern district.

TOPOGRAPHY.

Lincoln county is a rolling plateau, broken here and there by deep valleys and coulees. The higher upland ranges from about 2,000 feet above sea-level south of Almira to about 2,500 feet in the vicinity of Reardan. Crab Creek Valley, where it leaves the county, is about 1,300 feet above sea, which gives an average maximum relief of approximately 1,200 feet. When the highways were first laid out they were made to correspond as nearly as possible with section lines, but the new locations are being adapted to the topography, following the contour of the land sufficiently to give good gradient for heavy and comparatively rapid hauling. The present valleys appear to be an inheritance of an epoch of more humid conditions in the past, for at present but few of them are occupied by permanent streams, and such streams as there are are small. The humid epoch may have belonged to the Glacial Period, for at this time there was drainage across the county in a north-south direction, caused by the movement of a glacier from the Okanogan Highlands into the northern part of the county. An abundance of gravels were distributed along these old drainage lines and now are important sources of road-building material.

SUBSOIL.

Practically all of Lincoln county is underlain by basalt, save for a few occurrences of granite in the

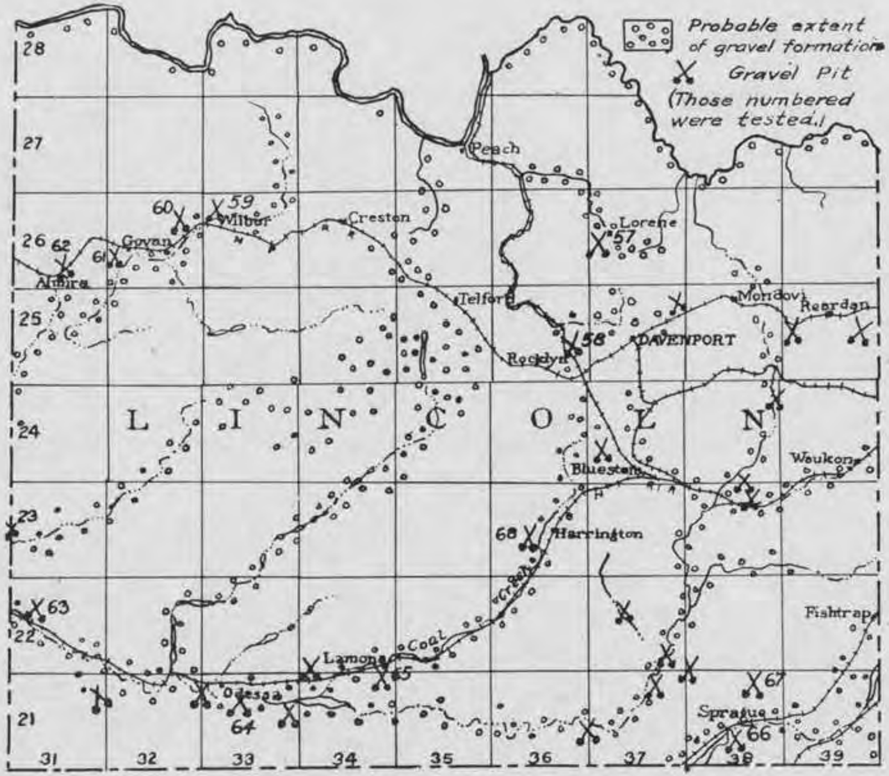


Fig. 21. Outline Map of Lincoln County.

northern part. The basalt is in turn overlain by a thick mantle of clay except where it has been eroded off along the old stream courses. Where the latter has taken place there is much "scab-land". Over the northern part this clay formation is partly covered by glacial material which is usually quite stony.

The clay varies from a heavy to a light fluffy texture. The heavy clay makes a good, hard road in dry weather, but muds heavily in wet seasons. The light fluffy clay makes a poor foundation for a road at most any season, for it not only muds up during moist times, but produces a very rutty and dusty road during the latter part of the summer and early fall, when the season of marketing is on.

In some places the clay is interlaid with 1½ feet to 2 or 3 feet of lime substance which outcrops on the hillside. Where the road passes over this nonresistant layer a rut is bound to ensue. Such occurrence may be cited on the hill slopes of the higher upland east of Lamona. These ruts are frequently so deep that they are particularly dangerous for automobiles in descending the hills and are obstructive in going up. To correct this, the whitish lime material might be thoroughly cut out for a few feet back and clay, like that above and below, put in its place.

CLIMATE.

The semi-arid climate of Lincoln county has a direct bearing on the maintenance of the roads and the choice of materials for surfacing. In the southwestern part of the county the rainfall averages less than 10 inches per year, but this increases northward to 13.7 inches at Wilbur and eastward to 16.3 inches at Reardan. One-third of this precipitation is snow. Very little rain falls during the summer months of June, July, and August; and the moisture which aids so much in binding a road material is nearly all evaporated by harvest time. In consequence, the bearing-power of the materials is at a minimum when the heavy hauling is at the maximum, and the smooth roads give way to deep ruts and thick dust. This is so general that the demand for good gravel surfacing is equally general, and the county has become a road-building one. The moisture of winter and early spring aids in the packing of new road-metal which has just been put on. For this reason a special effort is made to do as much road-building as possible late in the fall and early spring.

GENERAL DISTRIBUTION AND CHARACTER OF ROAD GRAVELS.

The sketch map of the county shows by small circles the general areas where road gravel can probably be found, and by crossed shovels where pits have been opened. Those which are numbered represent places from which samples were taken and tested and which will be considered hereafter. In general the gravel areas follow the old drainage courses from north to south and southwest, and the east-west valley of Crab Creek. Over the northern part of the county there are mounds of gravel having an erratic distribution which can be definitely identified as gravel-bearing only by test-pits. These were deposited irregularly by the ice-sheet during its retreating stages.

Samples Tested

Map Number 57. This sample was taken from the gravel deposit ½ mile west of Lorene, at the cross roads. This gravel occurs in the east bank of the ravine, about 25 feet deep and 50 yards long, with an overburden of 2 to 3 feet of clay soil. The materials are dominantly torpedo sand and angular fragments, chiefly of basalt, with some granite, greenstone, and quartzite. Some seams of silt occur, which with the overlying clay furnish binder. About 93 per cent of the material is firm and has good wearing quality. According to the tenacity test, the gravel will pack slowly, due to lack of enough tenacious clay for binding.

Map Number 58. This sample was taken from a deposit along the Sunset Highway, 4 miles west of Davenport, along the north line of the N. E. 1/4 of Sec. 26, T. 25 N., R. 36 E. About 60 per cent of the pebbles in this deposit are rounded pebbles of clay, making the gravel worthless for road surfacing. The material has been used on the Sunset Highway between Davenport and Rocklyn since 1916, and the poor quality of the pebbles shows in the roughness and irregularities of the road.

Map Number 59. One-fourth mile north of Wilbur, on the west side of the road on the hillside, a gravel pit has been opened in a large deposit of gravel which consists of well graded material with enough oversize to warrant crushing pit-run instead of screening, thereby improving the binder as well as the gradation. There is an occasional quartzite or other foreign rock and some coating of lime in the upper four feet, but otherwise the local basalt is the chief constituent. The constituents have good wearing qualities, 91 per cent of them being firm. The low tenacity test indicates that an addition of tenacious clay to the binder would be beneficial. A short stretch of road east of Reardan was surfaced from this pit in 1908. Barring too large rock for easy riding, the road is in excellent condition without any repair since placing.

Map Number 60. This sample was taken from the deposit 2½ miles west of Wilbur, in the S. E. 1/4 of Sec. 11, T. 26 N., R. 32 E. The gravel is almost entirely basalt, partly dense, partly porous, yet firm in character. Enough oversize is present to warrant running all of it through the crusher. Some of the pebbles have a slight coating of lime. Not enough of the fine was present in the sample to make a paste to test for tenacity. This gravel has been used on the road east for nearly one mile for eight years without repair and shows wonderful wearing qualities. Its readiness to pack when first put on could not be learned but the laboratory test would indicate that it would set slowly. The addition of a tenacious clay would probably be helpful. This deposit seems to extend north for at least one-eighth to one-fourth mile, and to have a width of 100 to 150 yards.

Map Number 61. This sample was taken from a deposit ½ mile southwest of Govan. The material consists mainly of "torpedo sand" with a few larger fragments scattered through the material. There is an absence of fine which would do for binder, but on the road it seems to be giving good service and has for six years. This would probably make an excellent dressing material.

Map Number 62. About 1¼ miles northeast of Almira, and about 100 yards southeast of the road, there is a bench of gravel rising 50 feet above the draw, containing basaltic gravels ranging in texture from fine to boulders 1½ feet in diameter and dominantly firm. By test, the percentage of wear is about average. The bottom portion seems to be mostly torpedo sand, while the coarse gravels occur above. On account of an insufficient amount of the fine binder, no tenacity test could be made. Some clay should probably be added when it is placed on the road.

Map Number 63. This sample was taken from a deposit about 3½ miles southeast of Krupp, in the north central part of Sec. 21. T. 22 N., R. 31 W., and about 100 yards northeast of the main road, in the side of a high bench. This is dominantly a "pea gravel" and "torpedo sand", basaltic in composition, and firm in character. The tenacity test gave a low value on account of insufficient clay. This is to be used for surfacing from Krupp to Irby when the permanent grade is made and should prove satisfactory if some tenacious clay is added.

Map Number 64. One-half mile southeast of Odessa, on the side of the road there is a sand-clay deposit, which contains a few larger fragments but in the main is a mixture of coarse sand and clay in such proportion that it is suitable for making a sand-clay road. The tenacity test gave a high value for its initial setting qualities. This was placed on the highway for 1½ miles east of Odessa in 1914 and is in good condition today without maintenance. It does not mud in wet weather and yields scarcely any dust when dry and makes a firm, smooth surface.

Map Number 65. This sample was taken from a deposit 5 miles southwest of Lamona, along the north line of the N. W. ¼ of Sec. 5, T. 21 N., R. 34 E. The formation occurs as a low ridge on the north side of the new road. It is well graded from coarse sand to about 14 per cent oversize. When the pit is opened it may seem advantageous to run the gravel through a crusher. Ninety-five per cent of the pebbles are hard and the percentage of wear is low. The binder portion lacks tenacity to set readily on account of the absence of clay.

Map Number 66. This sample was collected from a deposit 1½ miles west of Sprague, along the Central Washington Highway. Gravel may be found along this highway for several miles in scattered patches. This sample showed 89 per cent of the pebbles to be hard, the wearing quality is known to be good by test, but its readiness to pack would be slow without the addition of a good quality of clay. If used without crushing, a top course of fine should be added.

Map Number 67. This sample was taken from a deposit along the new Sprague-Harrington Road, three miles northwest of Sprague. It consisted chiefly of the fine material which had been crushed and screened and used on the top course of the road. The constituents are hard and though the amount of binder is small its packing quality is indicated by test to be good. The material packed readily on the road after a few weeks of traffic.

Map Number 68. One and one-fourth miles southwest of Harrington, in the N. E. ¼ of Sec. 21, T. 23 N., R. 36 E., is the Witt gravel pit. The material is mainly a "pea-gravel" with some larger materials. Basalt pebbles make up the great mass of the deposit, and of these about 93 per cent were found to be firm and hard, insuring good wearing results. The deposit, however, is lacking in good binding material, and good tenacious clay should be added.

The reader is referred to Table I for the detailed results of the foregoing tests.

Some disintegrated granite occurs along the Sunset Highway about 3½ miles southeast of Creston, which has been used in a short stretch of the road and promises excellent results as a dressing material.

Concrete Briquet Tests

According to the method described in Chapter IV, concrete briquets were made of several samples of sand from this county, the results of which are tabulated in Tables III and IV. These will be briefly reviewed here.

Map Number 59. Seven-day briquets made from this sand showed a tensional strength 95.6 per cent as great as the briquets made from Ottawa Standard sand, with the same kind of cement. The 28-day briquets, however, showed a strength 134.3 per cent as great as the 28-day briquets made from the Ottawa Standard sand. No organic content was found by the colorimetric test. Fine sand should be added to give the desired density.

The sand from sample No. 60 gave briquets which in the 7-day test were 100.7 per cent as strong as the briquets made from Standard Ottawa sand. By oversight the 28-day test was not made. A colorimetric test showed no organic content. On account of the coarseness of the sand, fine sand or crusher dust should be added.

Map Number 62, from the deposit 1¼ miles northeast of Almira, tested 113.5 per cent as strong as the Ottawa Standard sand in the 7-day test, and 101.7 per cent as strong in the 28-day test. No organic content was found by test. This sand also has a deficiency of fine material.

Map Number 65, taken from 5 miles southwest of Lamona, tested 114.8 per cent and 123.7 per cent as strong as the Standard Ottawa sand in the 7-day and 28-day tests, respectively. Analyses showed this sand to be so coarse that an addition of fine sand or crusher dust should be made. A very slight and unobjectionable amount of organic impurity was detected.

In Sample No. 68, which was taken from the Witt pit, 1¼ miles southwest of Harrington, the 7-day briquets were 108.7 per cent as strong as those made from the Standard Ottawa sand, and the 28-day briquets were 109.4 per cent as strong. This sand should have fine sand or crusher dust added to give the desired density in concrete.

MASON COUNTY

GENERAL STATEMENT.

Mason county is located in the west central part of Washington, just west of the southern limits of Puget Sound. It has an area of 930 square miles. Due to the ramifying arms and inlets of the Sound and Hood Canal it has a long coast line. The population in 1916 was 6,001. Shelton is the county seat and largest town. Lumbering, general farming, and oyster growing are the chief industries. Local logging railways bring the forest products down to the water's edge, from whence they are shipped by boat. No other railways enter the county. The Olympic Highway enters at the southeastern part, passes through Shelton to the northward and follows at the foot of the bluffs along Hood Canal. The county has established main roads leading to Matlock, Cloquallam, Allyn, Clifton, Union, and Lake Cushman, besides various minor roads.

TOPOGRAPHY.

The northwestern portion of the county is mountainous, while the southeastern part is a rolling plain. It is the latter which contains practically all of the population. The plain has considerable stretches of flat upland, but where the streams have incised deeply the steep valley slopes introduce some problems of grade. The subsoil over much of the plain is gravel, but in the southern part there is considerable heavy clay. Originally a heavy forest covered the area, and most of the area is still forested, but the land is gradually being cleared.

CLIMATE.

Mason county has an abundant rainfall. The average precipitation is 83 inches per year, and much of it comes in the winter season. This necessitates the surfacing of the main roads, in spite of the fact that almost all of the traffic, except on the Olympic Highway, would be classified as "light traffic". The other features of the climate are similar to the rest of the Puget Sound Basin.

DISTRIBUTION OF THE GRAVEL FORMATIONS.

There are comparatively few areas in the plain portion of the county which are not underlain with gravel, and these are chiefly among the high hills in the southern part. The rest of the plain area has abundant gravel extending in a broad belt from Clifton and Allyn to Matlock and the East and Middle forks of the Satsop River. In gravelling the Olympic Highway northwest of Shelton, the material was obtained from pits put down at short intervals along the roadside. This is in the main also true of the Shelton-Matlock Highway and of the highway running southwest from Matlock. West of Shelton there are a few small local areas where

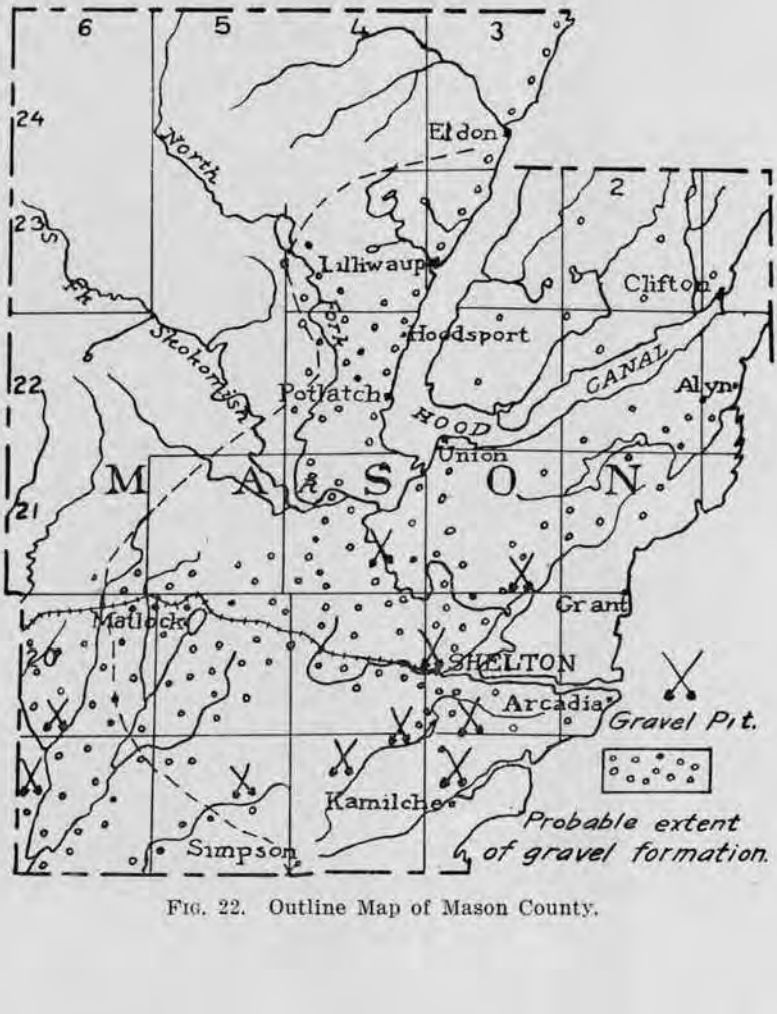


FIG. 22. Outline Map of Mason County.

pebbly clay prevails instead of gravel. Along the Hood Canal, abundant material can be obtained from the roadside at the foot of the high slopes. The general distribution is shown on the outline map of the county.

Character of the Gravels

The gravel is a part of the great deposit left by the last glacier which invaded the Puget Sound region during the Glacial Period. For a considerable length of time the glacier had a position approximately along the dotted line shown on the outline map, and immense quantities of gravel were washed from the front of the glacier down all of the forks of the Satsop River, except the west fork. As the ice was gradually melted back the outwash was extended more and more to the northwest, thus fortunately providing the area of the County with large quantities of gravel.

The gravels in the main are fresh and firm, and consist of pebbles of granite, basalt, quartzite, and other siliceous metamorphic rocks. The gradation varies from place to place, but in only a few places are there very coarse materials. Some of it is lacking partly in binder, so that if none is added the gravel is slow to pack. Along the north side of Isabella Lake gravels of fine quality abound, with but little oversize. Their results on the road in this vicinity have been highly satisfactory, producing one of the best roads in the county. Only the first few miles of the highway from Shelton to Allyn and Clifton have been improved, but when the improvement is undertaken, there will be no lack of good gravels to draw upon for practically the whole distance.

In view of the fact that the Testing Engineer of the Geological Survey had been called for war service, no samples were collected for testing.

OKANOGAN COUNTY

GENERAL STATEMENT.

This county is in the north central part of the state, bounded on the north by the International Boundary. Its area includes 5,221 square miles, which makes it the largest county in the state. In addition to its size affecting the work of the County Engineer, is the factor of its mountainous topography. The Okanogan Valley on the east and the Methow Valley on the west, both of which are fairly well populated, are separated by a mountain range across which there are but few roads. The problems of road-building are further enhanced by steep grades and also by sandy subsoil which requires surfacing. Fruit-growing is one of the chief industries and marketing comes at the dry time of year when the roads are least able to stand heavy loads. The roads must be built and maintained, therefore, with this in view.

A branch of the Great Northern runs from Wenatchee to Oroville, thus serving the towns along the Columbia and Okanogan rivers, and indirectly the towns along the Methow Valley by stage-line from Pateros.

State Road No. 10 has been established along the Okanogan Valley and graded and surfaced a considerable part of the distance. State Road No. 12 runs along the Methow Valley, beginning at Mazama and joining State Road No. 10 at Pateros. Much of it has been graded and surfaced.

CLIMATIC FACTORS.

The average annual precipitation of Okanogan county is 15 inches, of which one-third is snow-fall. Cloudbursts occur occasionally which work havoc to bridges and highways. During the summer, the dry spells are frequently prolonged enough to deprive the road-beds of moisture and reduce their wearing power below the

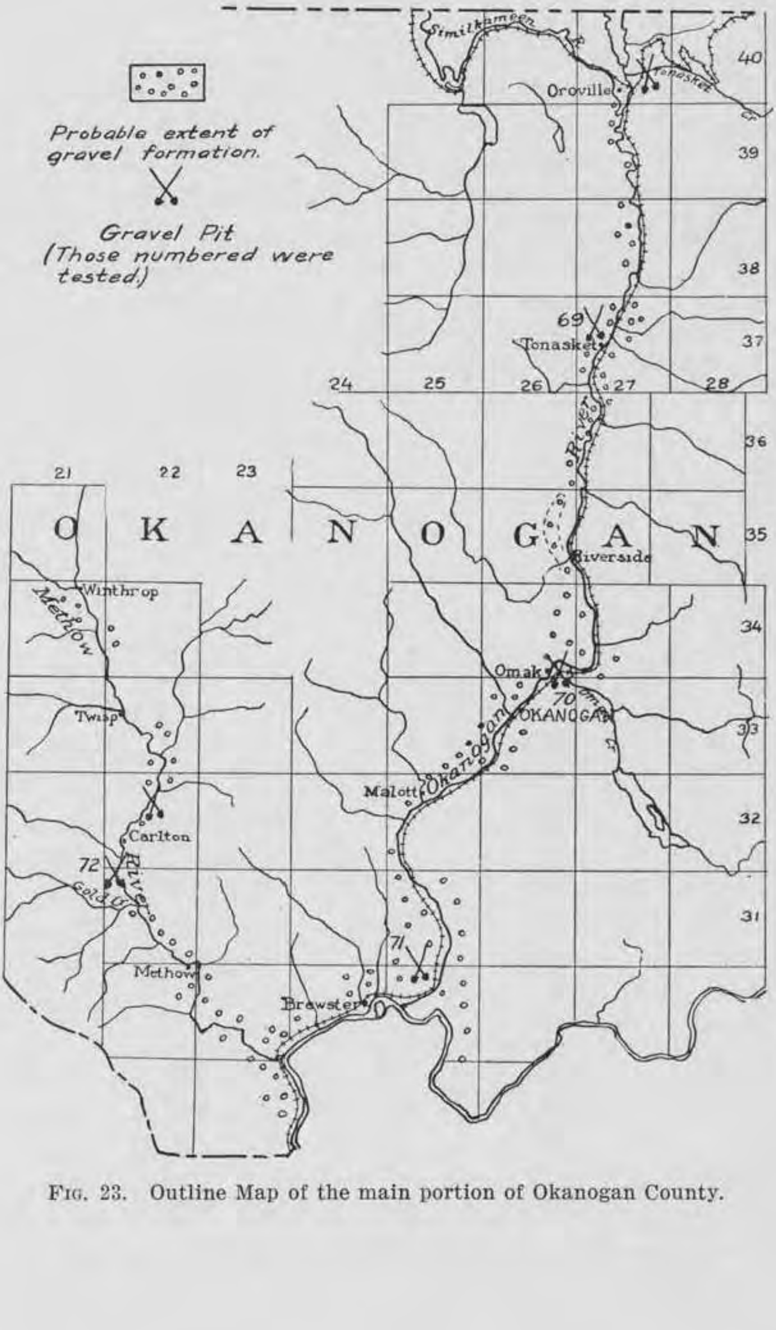


FIG. 23. Outline Map of the main portion of Okanogan County.

minimum required. As a result the heavy hauling during the fruit-marketing season cuts up the roads except where the surfacing is of the proper quality and thickness.

Frost action during early spring also loosens and softens the road-bed so that careful maintenance is required to keep the roads in good condition.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

The Okanogan Valley

Terraces of sand and gravel are found here and there along the Okanogan Valley from Whitestone Mountain southward. They rise several hundred feet above the river to an altitude of about 1,300 feet. During glacial times the valley was filled to this level with silt, sand, and gravel, and subsequently the stream removed all except the remnant benches which now exist. Some of these are from one to three miles wide.

It is unfortunate, however, that the material consists so dominantly of fine silt and sand. Pockets or thin layers of gravel occur at varying horizons in most any section, but they are usually so interstratified with the valueless silt that they cannot be economically excavated except in a very few cases. Fortunately, talus deposits of good "shell rock", andesite and rhyolite, flank the rock cliffs at various places, as for example, 1½ miles south of Oroville, at Whitestone Mountain, northeast of Omak and north and northeast of Okanogan. Granite has been quarried and crushed for road-metal 4½ miles northeast of Brewster.

The Methow Valley

In this valley the situation is somewhat different. Gravels are found in remnants of benches up to 600 feet high, which have less of the objectionable fine material than occurs in the Okanogan Valley. On the whole fairly good materials can be found here within hauling distance. Southeast, east and north of Twisp, there is abundant slide-rock to be had which, when crushed, is satisfactory on the roads.

The outline map of the County shows the general distribution of road gravels.

Tests on Road Gravels

Map Number 69. This sample was taken from the Pheasant Pit at Tonasket, on the west side of the river. The face of the pit in the side slope of the bench is 25 feet high and stands vertically, showing good binding power. At the top is 4 to 5 feet of light gray silt, then 3 feet of cobbles below and 8 feet of coarse gravel, below which is 10 feet of fine gravel, well graded up to 2½ inches in size and showing incipient cementation. About 50 per cent of the pebbles are retained on a ¼-inch sieve and about 5 per cent are larger than 2 inches. About 87 per cent of the pebbles are firm and by test show average wearing quality. The gravel has been used on State Highway No. 10 for 1 mile north of Tonasket and wears nicely. In obtaining the material from the pit, if sand pockets are encountered, clay is mixed in. The pit is owned by Olaf Lauraguard.

Map Number 70. This sample was taken from an alluvial fan at the mouth of Omak Creek, across the river from Omak. The gravel contains considerable oversize material but the rocks are almost all firm. The sample, which was taken from below the surface, tested low in cohesiveness, showing that it has insufficient clay to pack readily. If it had been taken from the surface portion, the cementation value would probably have been higher, for it contains more clay. This gravel has been used on the main street in Omak and care was used in obtaining it and spreading it. The results are highly satisfactory.

Map Number 71. This sample was taken from a gravel pit on top of Brewster Flat, and about 5½ miles northeast of Brewster, on the right-of-way near the land owned by Ray Perkins. In the natural state, the gravel is rather sandy and lacks enough binding material without the addition of clay. In the test for tenacity, the sand would not adhere sufficiently to make the necessary cylinders. Obviously, a good tenacious clay is needed. The wearing quality of the pebbles, however, is believed to be good, as 94 per cent of them are firm and they consist of 43 per cent granite, 36 per cent basalt, 13 per cent rhyolite, and 7 per cent quartzite. These gravels have not had an extensive practical test on the road.

Map Number 72. This sample was collected from a deposit of gravel 3½ miles southwest of Carlton, about ¼ mile west of the highway. The gravel occurs in a bench which rises about 300 feet above the valley flat. The materials consist of a considerable amount of clay mixed with the pebbles, which consist of basalt, andesite, rhyolite, granite, and diorite. About 69 per cent of the material passes the ¼-inch screen, and only about 5 per cent are oversize. Ninety-one per cent of the pebbles are firm. The tenacity test gave a high value, indicating that the binder is good and the material will pack readily.

This gravel deposit was being drawn upon for surfacing the adjacent section of the highway in the fall of 1917. The pit was located in the side-slope of the terrace so that gravity would aid in bringing the material down to the bunkers. The hauling was being done by trucks. The terrace seems to run consistently in kind and quality of materials, and appears to be a fortunate deposit for machine handling.

The detailed results of tests on the foregoing samples are given in Table I, along with those from other counties.

OTHER DEPOSITS EXAMINED.

About 1¾ miles northeast of Oroville there is a bank of angular gravel which contains much clay. This pit is known as the Carroll pit. The materials show little wear by water and consist largely of local material which accumulated here from the higher ledges. They have been used for road metaling and found to be satisfactory.

About on the north line of the city limits of Omak, the Omak Cement Products Co. has opened a gravel pit on the slope of a terrace. The materials are firm and mostly of good quality. They are used by the company in the manufacture of concrete irrigation- and culvert-pipe.

About ½ mile below the mouth of Benson Creek, in the S. W. ¼ of Sec. 10, T. 32 N., R. 22 E., there is a gravel pit in the side of a terrace, 100 feet high, in which the materials are chiefly coarse sand with a fair percentage of pebbles. Where used on the road, this material packs fairly well.

OTHER KINDS OF ROAD METALS.

On the west and northwest sides of Whitestone Mountain, north of Tonasket, there is a great talus deposit of white calcareous volcanic tuff, and andesite and basalt flows. A selection of proper sized materials can be made very easily and immense amounts secured. The white rock would probably make an excellent binder, while the andesite and basalt would give firm rock for wear.

About 1½ miles southwest of Oroville, a large talus apron borders a high point of rock, the talus reaching to a height of 100 to 150 feet and containing thousands of cubic yards of andesitic material. Some of the material has been used on the roads near here and in Oroville with satisfactory results.

About 2¼ miles northeast of Okanogan, a point of rock is flanked by "shell rock" of felsite, which in places is of suitable size for road metal, and where used on the road has given satisfaction except where it was put on too thin. Some of it has borne heavy fruit hauling for four years.

Quite similar material is also found in the talus deposit which flanks the rocky point about 4 miles northeast of Omak, and which occurs along the rock bluff west of Pogue Flat.

Tests for Concrete

Sand from the Pheasant Pit, at Tonasket, was used in making concrete briquets for comparison in tensile strength with Ottawa Standard sand. Three 7-day briquets of the former averaged 155 per cent as strong in tensile strength as those of Standard Ottawa sand, and the 28-day briquets of the former averaged 149.1 per cent greater. No organic content was found. See Tables III and IV for detailed results and comparison with other sands.

PACIFIC COUNTY

GENERAL STATEMENT.

Situated in the extreme southwest part of the state, on the Pacific Ocean, Pacific county has a heavy rainfall generally averaging about 75 inches per year. This necessitates the surfacing of at least the main highways of traffic. Most of the National Park Highway east of South Bend to the eastern limits of the county has been metaled, and much of the highway southwest from South Bend. The subsoil in most cases is a heavy clay, which, if not surfaced, makes an almost impassable road during many months of the year.

In 1916, the population of the county was estimated by the Census Bureau to be 16,649. South Bend is the county seat and largest town, with Raymond a close second according to the 1910 census. Ilwaco, Nahcotta, Tokeland, Lebam, Chinook and Long Beach are the other towns. The chief industry of the county is lumbering, with oyster and salmon fishing, dairying, and truck farming subordinant.

Two branch railroads serve the area, the Northern Pacific Railway and the C. M. & St. P. Railway. A large amount of produce is carried by boat, and hauling by motor truck promises to be another important means in the future. If such is the case it will increasingly tax the efficiency of the surfaced National Park Highway until eventually paving may be necessary.

Pacific county is unfortunate in its lack of good road building materials. The bedrock formations were ex-

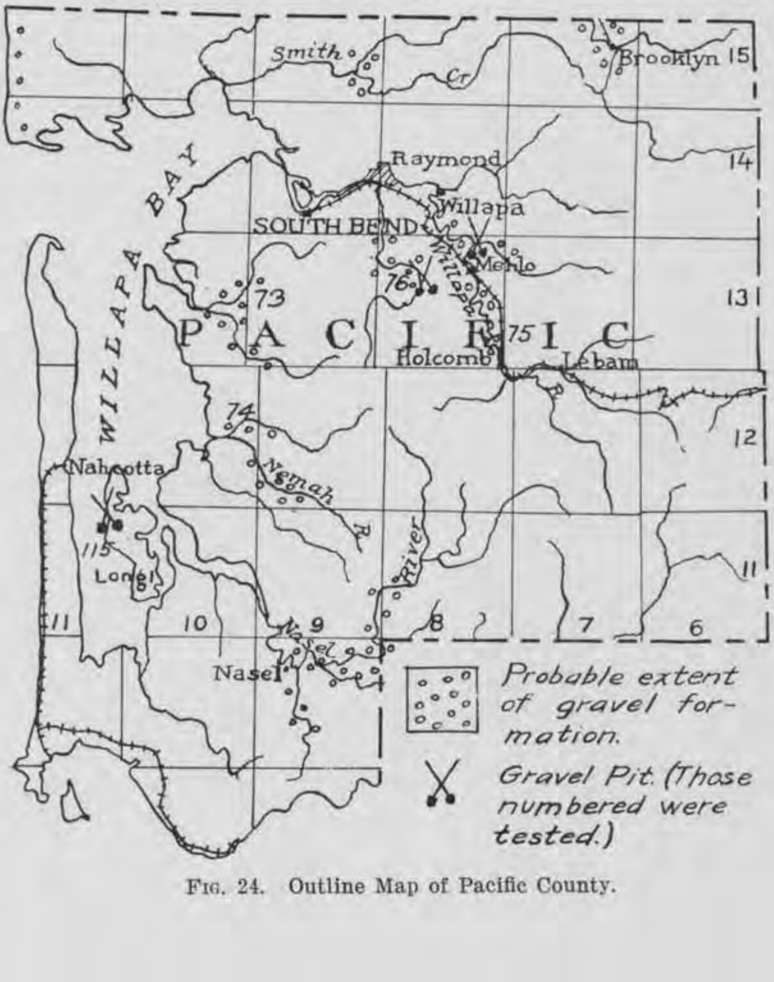


Fig. 24. Outline Map of Pacific County.

amined and tested by the Washington Geological Survey in 1911, and some outcrops were located which would seem to yield satisfactory material, but in most cases the rocks are too soft and so much weathered that after crushing the fragments "slack" and break into smaller pieces and eventually become so fine as to make mud. The rock of the area consists chiefly of basalt, sandstone, and shale. The results of the study were published in Bulletin No. 2 of the Survey's series.

The present investigation was confined chiefly to the possible occurrence of gravels for road surfacing and concrete.

GRAVEL DEPOSITS.

Pacific county lies outside of the glaciated area, and apart from any drainage lines which carried glacial wash. As a consequence its gravel resources are very limited. Some gravel bars occur along the Willapa River for some distance upstream from Raymond, along the lower part of Mill Creek, in the bed of the North Fork of Palux River, and along Nasel River. The general distribution is shown on the outline map of the county. Gravel also occurs on the west side of Long Island, and along a part of the coast, although much of this is sand.

In view of the soft character of the sandstone and shale formations and of the weathered condition of the basalt, it might be expected that such gravels as have been derived from these formations would be inferior in quality. This is borne out by field inspection. Nowhere was there found a gravel deposit along a stream that could be called first-class material. Some of the pebbles are hard, but there is such an intermixture of weathered constituents that their wearing value is considerably below par and their use in concrete is not recommended. The gravel along the west side of Long Island is firmer than the river gravel, but there is a deficiency of pebbles as compared to the sand content.

Tests on Samples for Road Surfacing

Map Number 73. This sample was obtained from a quantity of gravel which had been brought from a few miles up Palux River for surfacing the National Park Highway in the vicinity of Bay Center. The gravel is well graded, has but little oversize, is composed chiefly of basalt with some sandstone, and the pebbles are fairly well rounded. About 30 per cent of them, however, are soft and by test the whole gravel gave high values, indicating that the material will pack readily and have good ultimate cementation. In actual use on the road this is found to be true. The road is also smooth and will serve the light traffic of this region fairly well.

Map Number 74. This sample was obtained from a deposit near the mouth of Williams Creek, a tributary to Nemah River, near the National Park Highway. This gravel is much like the one just described in composition, but its sand content is very low. A small percentage is oversize. About 25 per cent of the pebbles are soft, which gives the whole gravel rather inferior wearing qualities. So little binder was present that no tenacity test could be made. This would indicate that some binder should be added in order to facilitate packing and cementation, although caution must be exercised on account of the wet climate.

Map Number 75. This sample was collected from a bar along the Willapa River, 1 mile north of Holcomb. The bar is about 200 feet wide by 300 feet long, and contains much coarse material of semi-rounded to rounded character. The pebbles consist of over 90 per cent basalt, some of which are decomposed, but in the main are firm enough to give good wearing results in the abrasion test. The amount of binder is very small, not enough being present in a 40-pound sample to make the tenacity test. Crushing, pit-run, would not only give a better gradation but would increase the binder portion. Some additional binder might also be required. This should make the gravel fairly satisfactory for road metal.

Map Number 76. This sample was secured from a bar along the South Fork of Willapa River, about 6 miles south of Raymond. The pebbles are dominantly of basalt, with some sandstone. About 90 per cent are firm and, according to test, have fair wearing quality. There is an insufficiency of the fine below one-quarter inch in size for binding, but the amount present gave good results in the tenacity test. This gravel would likely prove satisfactory for road-metal, if good binder can be added.

The detailed results of the foregoing tests are given with those from other counties, in Table I.

Tests for Concrete

Map Number 115. This sand was obtained from the bunkers of the Nahcotta Sand and Gravel Co., of Raymond, and was secured by them from the west side of Long Island. The sand was washed and used in making concrete briquets to be compared in tensile strength with briquets made from Standard Ottawa sand and the same kind of cement. The method followed is described in Chapter IV.

The 7-day briquets of the sand under test showed a tensile strength 102.9 per cent as great as the 7-day briquets made from Standard sand, and the 28-day briquets of the former tested 104.5 per cent as strong as the 28-day briquets of the latter. A chemical test showed enough organic matter to be present to require other tests to be made from time to time if this sand is to be used for any sort of concrete. The reader is referred to Tables III and IV for the details of this test and comparison with tests from other counties.

Unfortunately, the gravel from Long Island is insufficient in quantity of coarse aggregate without wasting much of the sand, but it would seem that coarse aggregate might be secured by crushing the rock from the sandstone quarry about 1 mile northwest of Raymond, on the property of the Raymond Sand and Improvement Company. The rock seems to be firm in quality. It occurs in a high bluff, and could be brought down to the river by gravity and transported by scows.

PEND OREILLE COUNTY

GENERAL STATEMENT.

Pend Oreille county is in the extreme northeast corner of the state, next to the Canadian and Idaho boundary lines. Its area includes 1,472 square miles. The valley of the Clark Fork enters the county at Newport, and at Dalkena trends northward for the remaining length of the county and joins the valley of the Columbia River a short distance north of the Canadian line. Along this valley are located the chief towns of the county. The population of the county is comparatively small, and the amount of the traffic correspondingly light. Grazing and lumbering are the chief industries, but farming and mining are rapidly developing.

Two railway lines serve the county. The transcontinental line of the Great Northern crosses the southeastern portion and the Idaho and Washington Northern Railway follows the Clark Fork from Metaline Falls to Newport, and crosses into Idaho by way of Penrith.

State Road No. 23 serves all vehicle traffic from Newport to Spokane. This is now improved the entire distance. The chief county road parallels the Clark Fork along the west side, providing good transportation facilities between Newport, Dalkena, Usk, Cusick, Locke, Ruby, Blueslide, and Ione. Another highway parallels the Clark along the east side. Tributary roads branch from these to the various communities in the tributary valleys.

TOPOGRAPHY.

Although this is a rolling to mountainous county, the valley of the Clark Fork and the pass southwest from Newport provide remarkably good conditions of grade for the main highways. The valley of the Clark Fork is broad most of the distance south from Jared and between Blueslide and Ione, and throughout this distance has a low gradient.

North of Cusick, nearly to Jared, the subsoil is a lake-deposited clay which makes a muddy road during wet seasons and a rough, hard, and dusty road when dry, especially after a period of heavy hauling. Elsewhere, as a general rule, the subsoil is a sandy or gravelly formation. Both types have been much improved by surfacing.

CLIMATE.

The average precipitation is about 25 inches per annum, of which about one-fourth is snowfall. Government records show that July, August, and September are the driest months, but nevertheless the rainfall is usually sufficient to prevent such a thorough drying out of the roads, with consequent rutting, as occurs in the interior of the Columbia Plateau. Thawing and freezing during the winter make a soft road for early spring and necessitates maintenance.

DEPOSITS OF ROAD GRAVELS.

The distribution of gravel formations and the location of some of the pits are shown on the outline map of the county. Gravel is found in abundant quantity southwest of Newport and in benches along the Clark Fork as far north as Usk. From Usk southward it is scarce, except in the vicinity of Ione. Granite is being

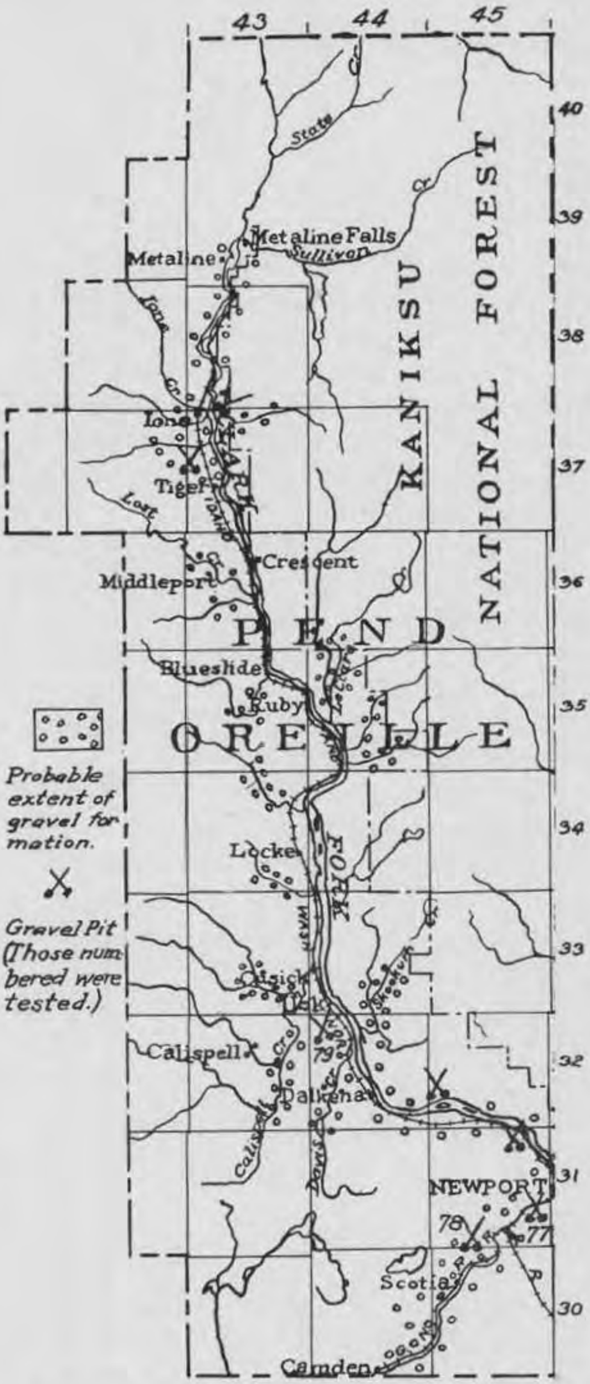


FIG. 25. Outline Map of Pend Oreille County.

crushed and used along the road south from Ruby, and slide rock and tailings at various places on the north side of the river, east of Dalkena. In the southwest quarter of Sec. 30, T. 32 N., R. 45 E., there is a talus deposit of calcareous slates and schists, angular in form, and well graded in size, which has been used with success on the Usk Road for two years. The material was transported across the river by barges. River gravel has been used on the road on the north side of the river from Newport, but its binding qualities are still poor after three years' service.

Tests for Road Surfacing

Map Number 77. This sample was taken from the gravel pit, located 1½ miles southwest of Newport, on the south side of the I. & W. N. Ry., in the S. E. ¼ of Sec. 23, T. 31 N., R. 45 E. The gravel formation here forms a bench about 60 feet high. The gravel is well graded, composed of pebbles of durable rock, such as quartzite, granite, and schist, of which 94 per cent are firm. By test these are known to have an average wearing value. The gravel has been in use on that portion of State Highway No. 23, known as Permanent Highway No. 1, and found to be a most excellent road gravel, ranking among the best gravels of the state. Besides having good wearing qualities its property of natural cementation is high. A small section was cut out from the roadbed for an examination of the factors involved in its cementation. The section showed that the material was well graded so as to give compactness and the pebbles of the natural deposit are coated with a clay which after wetting possesses good binding qualities.

Map Number 78. This sample was taken from the gravel pit located about 1 mile west of Penrith. The materials consist of stratified granite debris, angular and fairly well graded from fine to oversize, with a probable excess of sand. Upon examination, about 28 per cent of the fragments are soft or partially disintegrated, and their percentage of wear is high, as shown by test. The binding material which passed a 10-mesh sieve, tested low in its power to pack readily, but its ultimate cementation is good. This material should not be used on roads except those having light traffic.

Map Number 79. This sample was taken from a gravel pit 4 miles southeast of Cusick, in the S. W. 1/4 of the S. E. 1/4 of Sec. 5, T. 32 N., R. 44 E. The gravel deposit forms a low bench on the broad flat. The materials are only fairly well graded, with some oversize, and have average wearing qualities, as shown by test. Enough decomposed granite seems to enter into the binder portion to give it a good cementation value. The tenacity test shows that it would pack fairly readily. In actual practice it packs well and seems to be very satisfactory.

The foregoing results are given in detail in Table I, with those from other counties.

Other Gravel Pits Examined

N. E. 1/4, Sec. 33, T. 31 N., R. 45 E. This pit occurs in the side of a high terrace. The materials are dominantly fine sand and small pebbles, with a few cobbles and boulders up to 2 or 3 feet. They consist of quartzite, argillite, granite, dolerite, basalt, and slate and schist. Although of a good wearing quality, the materials do not seem to be properly graded to pack well. Some of the sand should be eliminated.

S. W. 1/4, Sec. 1, T. 31 N., R. 45 E. This is a side-road pit on a high bench, exposing a pea-gravel. The material has been used on the road for two years, giving good wearing service and packing well.

S. E. 1/4 of S. E. 1/4, Sec. 7, T. 37 N., R. 43 E. This pit is located on a low terrace, made up of lenses of silt, sand and gravel which are discontinuous and variable. Some of the layers are iron-stained. It was being drawn upon for use on Permanent Highway 4 A, south of Ione, and where it has been put on, it seemed to be packing well.

N. W. ¼, Sec. 5, T. 37 N., R. 43 E. This gravel pit is located on the east side of the river across from Ione, near the ferry. The gravel stands with a vertical face, 30 to 40 feet high, and 70 to 80 feet wide, and is made up of pebbles of all sizes up to oversize material, some of which consists of two-foot boulders. The matrix is a fine sand and silt; "torpedo" sand is lacking. When screened this material should make an excellent road gravel as the pebbles are hard and resistant and the whole body shows good natural cementation.

Tests for Concrete

Tests were made on Samples 77 and 79, whose locations are given on a preceding page. In the case of Map Number 88, the 7-day briquets showed a tensile strength 125.0 per cent as great as the briquets made from Standard Ottawa sand, and the 28-day briquets 145.9 per cent as great. The colorimetric test showed the sand to be practically free of organic content.

The 7-day briquets of Map Number 79 tested 102.8 per cent as strong as the briquets of Standard Ottawa sand, and the 28-day briquets 141.2 per cent as strong. Some organic matter was shown to exist in the sample. Care will need to be exercised in stripping the pit, to keep out all humus and other organic material.

The detailed results of these tests are given in Tables III and IV.

PIERCE COUNTY

GENERAL STATEMENT.

This county is situated in the west central part of Washington, southeast of Puget Sound. It reaches from the summit of the Cascades to the southern shores of the Sound and includes an area of 1,701 square miles. In 1916, the population amounted to 161,863 inhabitants. The larger portion of this occurs in the northwestern part of the county. Manufacturing, lumbering, coal mining, and fishing are important industries, together with berry raising, dairying, stock raising, truck farming, and poultry raising. Tacoma is the county seat and largest city.

The transportation requirements of the county are served by several of the transcontinental railway lines, together with certain state highways and the county system of roads. The Pacific Highway enters the county north of Sumner, passes through Tacoma, and leaves the county at Nisqually. The National Park Highway leads from Tacoma to Mt. Rainier. Both of these highways are improved, the Pacific Highway being paved throughout its whole course in the county. Most of the important county highways are surfaced.

TOPOGRAPHY.

The topography of Pierce county includes mountains and plains, this combination giving a wide range of problems to be contended by the highway engineers. The mountains give way rather abruptly to the plains along a line drawn through LaGrande, Eatonville and Orting. The plains consist of broad table-lands, more or less rolling in character and incised by a few valleys, the most notable of which is the Puyallup River Valley. The subsoil in the valleys consists chiefly of loam and sand, but much of the plain area, especially south of Tacoma, is underlain by gravel.

CLIMATE.

Pierce county is situated in the humid region of western Washington and has abundant rainfall. The average for the plain area of the county is about 42 inches, while the mountains receive much more. Most of this occurs during the winter season and the summer

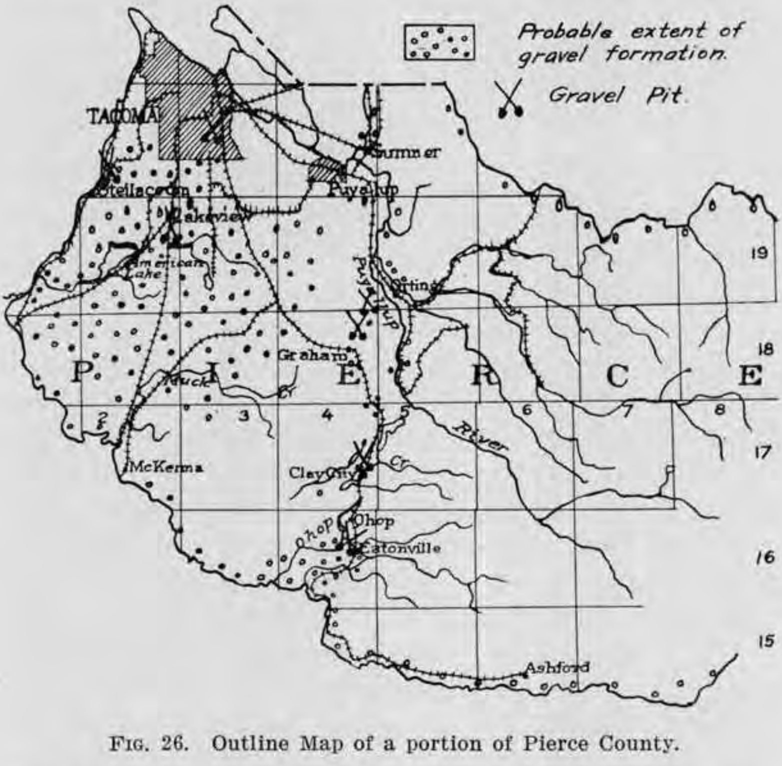


FIG. 26. Outline Map of a portion of Pierce County.

months have very light rainfall. This provides two extremes of moisture conditions which must be met in constructing and maintaining the highways. Careful attention is paid to the amount of clay material in a gravel due to the wet winters on the one hand and dry summers on the other. The snowfall on the plains is usually light and of short duration, but in the mountains it is much heavier and remains for the winter season. As a result of avalanches and flood conditions the highways which enter the mountain valleys must be maintained at considerable expense.

DISTRIBUTION OF THE GRAVELS.

The western part of Pierce county is almost entirely underlaid with gravel, the chief exception being the flood plain of the Puyallup River, the materials of which are chiefly silt. The gravels belong to the last glacial epoch and were deposited under glacial conditions. During the melting of the ice a large amount of gravel was washed out of the ice and deposited in extensive outwash plains.

Along the cliffs of Puget Sound, southwest of Tacoma, extensive gravel deposits occur at Steilacoom and at the mouth of Sequalitchew Creek. The gravels at Steilacoom are known throughout western Washington for their firm quality and use for concrete. They occur in a cliff which rises about 160 feet above the Sound. This position makes possible the use of gravity in bringing the material down to the bunkers where it is washed, screened and loaded onto cars or scows. The Pioneer Sand and Gravel Co. and the Tacoma Sand and Gravel Co. operate pits here. Large deposits also occur in the southern part of Tacoma.

The general distribution of the gravels is shown on the outline map of the county. The gravels are dominantly of siliceous composition, being composed of granites, basalts, andesites, rhyolites, quartzites, and other igneous and metamorphic rocks. As a rule but few soft pebbles are found among them. Abrasion tests which were made on the gravels occurring at Steilacoom showed them to have a remarkably low percentage of wear, the amount being about 2.4 per cent.

Briquet Tests of the Sands

Briquet tests were made of some of the sands in order to determine their quality for concrete use. Many of these tests were made by the Portland Cement Association and to them the Survey is indebted for much of the data. All of the tests made averaged higher than 100 per cent in strength ratio as compared with Standard Ottawa sand, for both the 7-day and 28-day briquets. Detailed results of analyses of these sands and of the strength of the briquets are given in Tables III and IV, of Chapter IV.

Tests on Field Concrete Cylinders

Field concrete cylinders were made of the concrete mix which was used in the pavements of the Pacific Highway near Nisqually, designated by the county as Permanent Highway No. 8 A. Four of these cylinders, after being cured under as nearly as possible the same conditions as the pavement, were tested for their compressional strength in the testing laboratory of the University of Washington. They were found to have an average compressional strength of 4,312.87 lbs. per square inch.

Three concrete cylinders of the mix which went into the concrete dock at Dash Point averaged 2,880.31 lbs. per square inch. In the case of the Pacific Highway the proportions of mix were 1:2:3, while in the latter the proportions were 1:2:4. The aggregates for the Pacific Highway pavement were from Steilacoom and those for the concrete dock from Maury Island. More detailed information concerning the character of the aggregates used and of the concrete cylinder tests is given in Tables V and VI.

A rather extensive series of tests were made by Mr. R. J. Borhek of Tacoma on the concrete making qualities of the gravel at Lakeview and at Steilacoom. The cylinders which were made in these series of tests were tested in the Engineering Laboratory of the University of Washington by Mr. Everett G. Snell, Instructor in Civil

Engineering. The physical properties of the fine and coarse aggregates used in the tests, together with the results of the compressional tests of the cylinders, are given in Tables VII and VIII of Chapter IV.

SKAGIT COUNTY

GENERAL STATEMENT.

Skagit county is in the northwestern part of the state, in the second tier of counties from the Canadian line. It fronts the waters of the Strait of Juan de Fuca on the west, and reaches eastward to the crest of the Cascade Range. The greater part of the population live in the west one-third, the remaining portion of the county being mountainous. A certain percentage of the population, however, live along the valley of the Skagit River where lumbering is an important industry, and the manufacture of cement is being conducted on an increasing scale at Concrete. Farming and dairying are the important occupations in the western plain portion, especially on the broad delta flat of the Skagit River. In 1916, the number of inhabitants was estimated by the Census Bureau to be 38,652. Mount Vernon is the county seat and Anacortes the largest town. Some of the other towns are Sedro Woolley, Burlington, La Conner, Biglake, Clearlake, Concrete, and McMurray.

Railroad transportation facilities are afforded by the Great Northern Railway and the Pacific Northwest Traction Company. The Pacific Highway, which passes through the western part of the county, is the chief thoroughfare.

CLIMATE.

Skagit county has an abundant rainfall, most of which occurs during the winter. The average each year is about 60 inches. Occasionally flood conditions ensue on the broad delta flat of the Skagit River. This heavy rainfall prohibits the use of excess clay materials in the gravels for road surfacing. In places on the delta flat, the subsoil consists of bog deposits which necessitate a goodly amount of crushed rock or gravel fill in order to provide a good foundation for pavement. The increased heavy hauling of the farming section west of Mount Vernon is creating demands for paved highways. Several miles have already been laid by the county. Concrete cylinder tests of one section were made and the results are given on a following page.

DISTRIBUTION OF ROAD GRAVELS.

Gravel formations are found generally along the Skagit River in benches and bars, and along the East Fork of the Samish River. Those along the latter stream, especially near Prairie, are very high. For the paving along the McLean Road, Permanent Highway 3 B, the sand was gotten from the Skagit River near Mount Vernon and the gravel from the Keystone Pit at Fort Casey on Whidbey Island. The aggregate which entered into the paving of Bennett Street in Sedro Woolley in 1917 was obtained from a bar of the Skagit River south of town. Local deposits for road gravelling are to be found on the hill-slopes of western Skagit county outside of the delta flat.

In almost all cases the gravels are firm and of good quality. Those along the Skagit River contain some pumice material which the waters have transported from Mt. Baker. For road surfacing the river gravels are not so good as the bench gravels, the former lacking good binding quality.

Tests on Samples for Concrete

Map Number 120. This sample was obtained from the Skagit River one mile southwest of Mount Vernon. Six briquet tests were made of the washed sand which passed the ¼-inch screen. At the end of 7 days the ten-

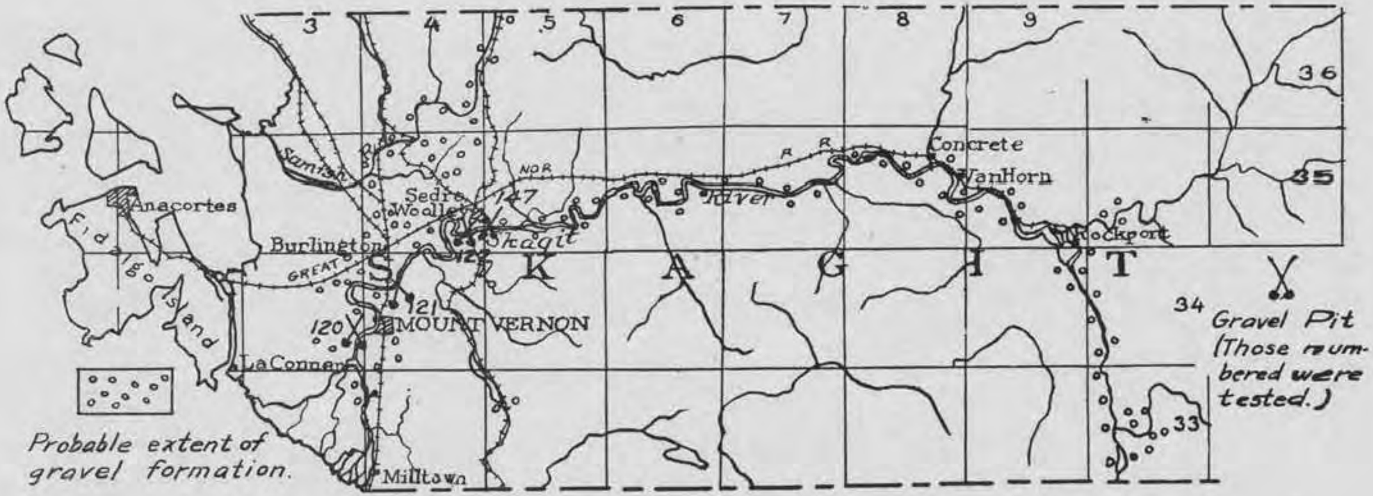


FIG. 27. Outline Map of a portion of Skagit County.

sile strength of three of these were made and compared with the strength of briquets which had been made from Standard Ottawa sand, according to the manner described in Chapter IV. The results showed the sand under test to have a strength 91 per cent as great as the Standard sand. At the close of 28 days, the remaining three briquets averaged 104.6 per cent the strength of those made from the Standard sand. By the colorimetric test, organic matter was found to be present to an extent which shows that this factor would need to be controlled if first-class concrete paving were desired.

Map Number 121. This sample was taken from the Skagit River, near the Burlington bridge, by the Portland Cement Association and tested for its tensile strength in concrete briquets. Their results show that the 7-day briquets had a strength 145.3 per cent as great as the briquets of the same age made from Standard Ottawa sand, and the 28-day briquets 142.6 per cent as great. No test was made for organic content.

Map Number 122. This sample was obtained from the Skagit River, west of the bridge, near Sedro Woolley. Six separate tests by the Portland Cement Association showed the 7-day briquets to have a tensile strength averaging 112.3 per cent as great as those made from Ottawa Standard sand, and the 28-day briquets 111.5 per cent as great. The colorimetric test to ascertain the presence of organic matter was not made.

The detailed results of the above tests are given in Tables III and IV.

Field Concrete Tests

On the McLean Road, Permanent Highway 3 B, concrete cylinder tests were made of the material which was put into the pavement at Station 306+25 to 306+55. The material was taken at random as it came from the mixer and poured into three cylindrical molds, 6 inches in diameter and 12 inches in length. Care was exercised in puddling to obtain the same approximate density as would be obtained in the pavement proper. After twenty-four hours the cylinders were covered with earth in the same way as the pavement and for thirty days were cured under approximately the same conditions as the pavement. When 254 days old, their compressional strength was tested in the Engineering Testing Laboratories of the University of Washington. The three cylinders were found capable of sustaining a maximum load of 3,662.95 lbs., 2,976.32 lbs., and 3,593.31 lbs. per square inch, respectively.

Four similar tests were made of the concrete paving which was laid on Bennett Street in Sedro Woolley, between Township and Third streets. When 260 days old these showed a maximum compressional strength of 3,203.34 lbs., 4,050.98 lbs., 3,064.07 lbs., and 3,543.60 lbs. per square inch, respectively.

The reader is referred to Tables V and VI for a tabulation of results and comparison with other pavements.

SKAMANIA COUNTY

GENERAL STATEMENT.

This county lies along the Columbia River gorge, in the southern part of the state. Having a most rugged mountain topography, the inhabited portion is confined to the Columbia River Valley. In 1916 the Census Bureau estimated its population to be 3,639. The chief industries are fruit and berry raising, dairying, poultry raising, lumbering and fishing.

The need for surfaced roads is limited almost entirely to State Road No. 8, which follows the Columbia River to Vancouver and there connects with the Pacific Highway. In the eastern part of the county, the cliffs of the Columbia River gorge have delayed the extension of this highway on account of the great expense involved in blasting a road out of the solid rock. An early completion by the state is contemplated. Frequent train service on the S., P. & S. Ry. and shipping facilities on the Columbia River do much to alleviate transportation problems.

The suitability of the bedrock of this county is discussed in Bulletin No. 2 of the Washington Geological Survey. The gravel deposits are scattered, one being

FIG. 28. Outline Map of a portion of Skamania County.

found about one mile east of Carson, another on the west side of Wind Mountain, and one northeast of Cook. These occur from 100 to 500 feet or more above the Columbia River. Some quartzite and basalt gravels are found on the high upland west of Cape Horn.

Tests on Samples

Map Number 80. This sample was taken from the deposit west of Wind Mountain and about 4 miles east of Carson. The county has opened a pit here which has a face about 150 feet long, and a maximum height of 50 feet. The materials are mostly less than one inch in diameter and composed chiefly of firm basalt. No test could be made of the binder because of an insufficiency of fine material to make a plastic paste, but where used on the road it gives excellent satisfaction. One street in Stevenson has been surfaced with this gravel since 1908. The county has purchased 20 acres from which material will be drawn for metalling in this part of the county. The location is close to the S., P. & S. Ry. so that a spur can readily be built.

Somewhat similar materials are exposed about one mile east of Carson, but here they are somewhat finer. They would serve as excellent dressing material but are too fine to form the body of the road.

In the western part of the county, local basalt will probably have to be used. A crusher has been installed about 2 miles southwest of Skamania.

Tests for Concrete

Map Number 80. This sample was screened and the sand washed and used for testing its quality for concrete uses. Briquets were made of the material according to the process described in Chapter IV, and at the end of seven and twenty-eight day periods their tensile strength was ascertained and compared with the tensile strength of briquets of the same age which were made from Standard Ottawa sand and from the same kind of cement. The tensile strength of the 7-day briquets of the sand under test was 66.3 per cent as great as the strength of the briquets made from the standard sand, but the 28-day briquets showed a marked increase, showing a strength of 110.3 per cent of that of the standard sand. No organic material was detected by the colorimetric test. Due to the coarseness of the sand, fine sand or crusher dust should be added to give the necessary density. Tables III and IV give the details of these tests, together with those of samples from other counties.

SNOHOMISH COUNTY

GENERAL STATEMENT.

This county is situated in the northwestern part of the state, in the third tier of counties south of the International Boundary and fronting Puget Sound on the west. It is 24 miles wide and reaches from the shores of Puget Sound to the crest of the Cascades, comprising 2,664 square miles of territory.

In 1916 its estimated population was 81,375. Everett is the county seat and one of the important smaller cities of the state. Other towns are Snohomish, Monroe, Marysville, Arlington, Edmonds, Stanwood, Gold Bar, Granite Falls, Index and Sultan. By far the larger part of the population live in the western one-third of the county, and it is here where the traffic demands for good roads are great. A wide range of occupations are engaged in, including lumbering, dairying, agriculture, horticulture, manufacturing, fishing and mining. The imports and exports of the county are handled by railways, steamships, and highways. The main line of the Great Northern Railway follows the Skykomish and Snohomish river valleys to Everett and the Puget Sound beach southward to Seattle. A branch line of the Great Northern, Northern Pacific, and the Chicago, Milwaukee & St. Paul railways traverse the western part from north to south. The excellent harbor at Everett provides ample shipping facilities by water. The Pacific Highway passes through Everett, Marysville, Silvana, and Stanwood in its north-south course. Besides this the county has constructed a remarkable system of highways of its own which marks an advanced step in highway provision in the state. The paving of 140 miles of trunk highways has been nearly carried to completion. tion.

TOPOGRAPHY.

The surface is affected by a rolling plain in the western one-third and rugged mountains in the remaining eastern portions. Passage into these mountains is made possible by the valleys of the Skykomish River, the South Fork of the Stilaguamish River and the North Fork of the Stilaguamish River. Within the mountain fastnesses are immense quantities of timber and considerable mineral ore. The trout streams and magnificent scenery attract many tourists.

The western plains portion has a rolling surface with smooth contours which were shaped chiefly by the Puget Sound glacier during the Ice Age. The river valleys are comparatively shallow and broad and among the hills are scattered lakes and ponds. Except along a stretch north of Marysville the highways are winding to avoid steep hill-grades.

SUBSOIL.

Along the main rivers and most of the smaller streams the subsoil is of gravel which serves as an excellent foundation for all types of roads. In many places, however, where the highways descend the side slopes, clay formations are crossed, which in wet weather cause slides. This factor is a difficult one to overcome in obtaining a good location for a pavement. Bog areas are encountered on certain upland areas and on the tidal flats, particularly near the mouth of Snohomish River. Here a considerable fill has been made necessary by the soft subsoil and high waters during flood-time.

CLIMATE.

Snohomish county is in the humid area of Washington. Its precipitation averages from 40 to 100 inches or more, the latter figure applying to the high, mountainous portion. Since the larger percentage of this occurs during the winter season, and since the ground

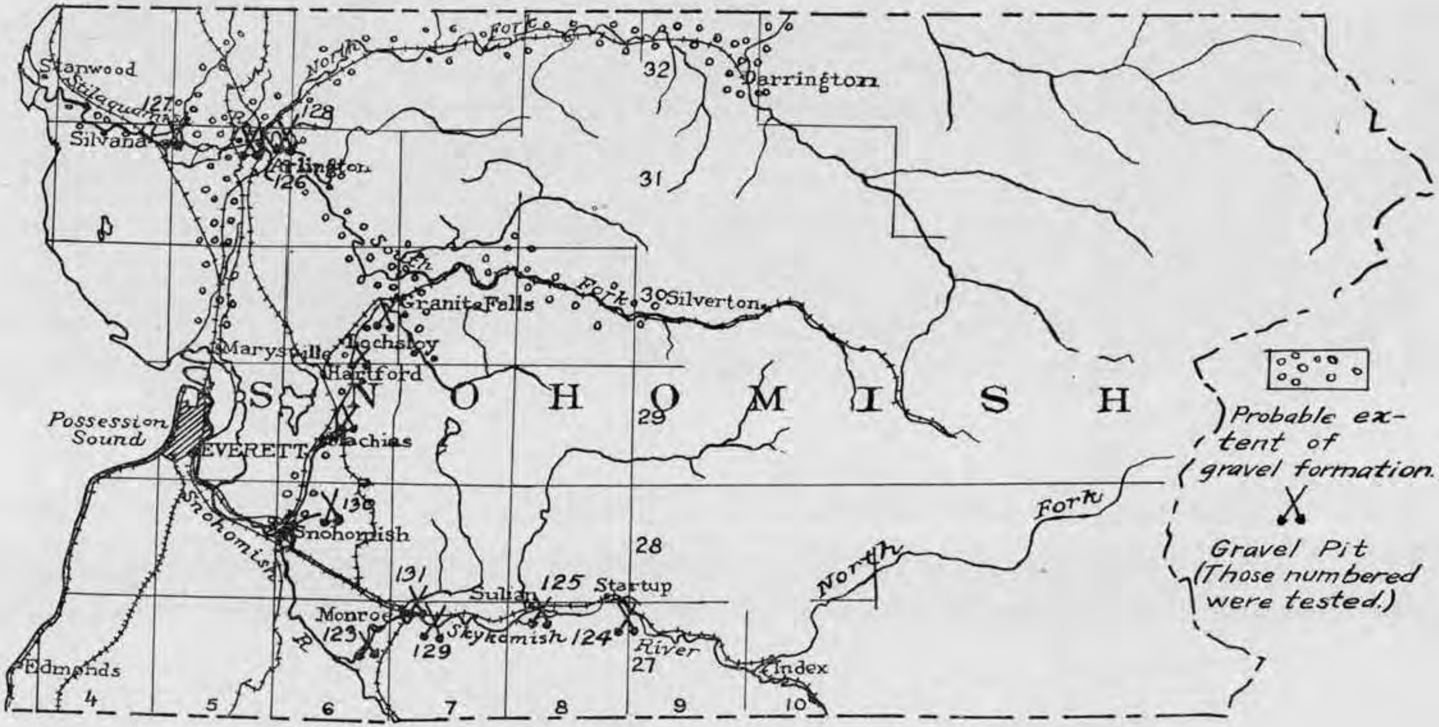


FIG. 29. Outline Map of Snohomish County.

remains unfrozen throughout most of the time, the subsoil becomes saturated and the bearing power is greatly reduced. Clays in particular absorb so much of the moisture that a clayey gravel will soften and be unfit for even moderate traffic. During some winters extra heavy rains or the rapid melting of snow in the mountains by warm winds or a combination of these two factors may result in devastating floods in the lower portions of the valley.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

The road gravels of Snohomish county are found in three situations: first, in gravel bars along the streams close to the water's edge; second, in benches or terraces along the streams; third, in local and usually small deposits scattered over the upland in hillocks. The sketch-map of the county shows the general distribution of the gravels. From Arlington to Marysville there is a rather exceptional area of gravel in that it covers a continuous area about 3 miles wide across the divide between the Stilaguamish River and the Snohomish River. This strip represents the course of a glacial stream when the mouth of the Stilaguamish River was blocked by the glacier.

Tests on Samples

During the construction of the concrete pavements of Snohomish county a careful check of the character of the sands which were being used in the concrete was kept by the Portland Cement Association in order to insure a first class quality of pavement. The number of the samples collected and tested were so much larger than could be permitted by the time allotted to the present survey that a duplication was not attempted. Through the generosity of the Association their results are herewith published. A full tabulation of the tensile strength of the briquets and the mechanical analyses of the sands is given in Tables III and IV.

Map Number 123. This sample was taken from the Skykomish River, between Monroe and Duval. The 7-day briquets which were made from this sand showed a tensile strength 104.7 per cent as great as the briquets of the same age made from the Ottawa Standard sand, and the 28-day briquets tested 123.6 per cent as strong.

Map Number 124. This sample was taken from the Skykomish River, 2 miles south of Startup. The average of three separate tests gave 117.1 per cent for the 7-day ratio and 129.8 per cent for the 28-day ratio.

Map Number 125. This sample was obtained from the Skykomish River, at the Sultan pit, and tested 108.9 per cent as strong as the Ottawa Standard sand in the 7-day briquets, and 127.9 per cent as strong in the 28-day briquets.

Map Number 126. This sample was obtained from the Stilaguamish River at Arlington. Three separate tests were made and the following averages were deduced: 130.5 per cent for the 7-day ratio, and 128.5 per cent for the 28-day ratio.

Map Number 127. This sand from the Stilaguamish River, 1½ miles east of Silvana, was tested in four different instances and averaged 122.5 per cent for the 7-day ratio, and 122.5 per cent for the 28-day ratio.

Map Number 128. This sample was secured from the Stilaguamish River, 1 mile east of Arlington, and gave 108.7 per cent for the 7-day ratio, and 154.2 per cent for the 28-day ratio.

Map Number 129. This sample, obtained from the Snoqualmie River, 2 miles east of Monroe, averaged the following in two separate tests: 109.0 per cent for the 7-day ratio, and 123.7 per cent for the 28-day ratio.

Map Number 130. This sample which represents the sand obtained from the Snohomish city pit, gave 91.4

per cent as the 7-day ratio, and 99.5 per cent for the 28-day ratio.

Map Number 131. This sample was taken from a sidehill pit 2 miles east of Monroe, tested 131.0 per cent for the 7-day ratio, and 111.2 per cent for the 28-day ratio.

SPOKANE COUNTY

GENERAL STATEMENT.

Spokane county has a position in the east central part of the state, bordering the Idaho line. Its area is 1,756 square miles. Spokane, its county seat, is the second largest city in the state, having a population of 190,870 people, according to the estimate of the Census Bureau, July 1, 1916. Manufacturing and diversified agriculture are the important industries, with apple growing and dairying as important phases.

Spokane is the great market center of eastern Washington and nearly all of the transcontinental lines of the Northwest converge here. The county has an excellent system of highways, many miles of which are paved and the rest of the mileage of the important ones surfaced. The Inland Empire Highway enters the county from the south at Rosalia, the Central Washington Highway from the southwest, the Sunset Highway from the west and State Road No. 23 from the north. The Pacific Highway passes on into Idaho through the eastern part of the county, and the Inland Empire Highway runs through into Stevens county by a northern route.

TOPOGRAPHY.

The eastern part of the county is affected by the foothills and subsidiary ranges of the Rocky Mountain system, while the western part is typical of the Columbia basalt plateau of eastern Washington. The mountains reach an altitude of 3,500 to 4,500 feet above the sea, Mt. Spokane, the chief peak, ascending to a height of 5,808 feet. The mountains are composed chiefly of old granites, gneisses, schists, and quartzites.

The plateau portion has a level to rolling surface with an occasional high hill rising above the general surroundings. The extreme southeastern portion is maturely dissected into hills and valleys, and covered by a deep mantle of soil. The plateau is underlain by basalt, and north of Cheney is mantled with glacial drift.

The Spokane River enters the county from the east in a broad capacious valley, which is deeply underlain with gravel. At Spokane it turns northwestward and flows through a deep narrow valley quite unlike that east of the city. Latah Creek with its tributaries, Rock Creek, Spangle Creek, and Lake Creek, drain the southeastern section; Deep Creek and Coulee Creek the northwestern part; and Little Spokane River the northern portion. All of these with the exception of the latter have cut deep valleys throughout a large part of their course.

There are few roads in the northeastern part because of the mountainous topography. The broad valley of the Spokane River east of Spokane and the flattish area on the western basalt plateau permit roads to be established along section lines, but in the hilly area of the southeastern part there are many curving and diagonal roads which must be angling in order to obtain proper grade. This is true to a certain extent in the northern part, also.

SUBSOIL.

The natural subsoil conditions are extremely varied. The gravel flat of the broad Spokane Valley affords a most admirable foundation for roads of all descriptions. In the Dennison area of the north there is much sand, and on the western plateau there is a mantle of glacial drift composed of much stony material. In the Rock-

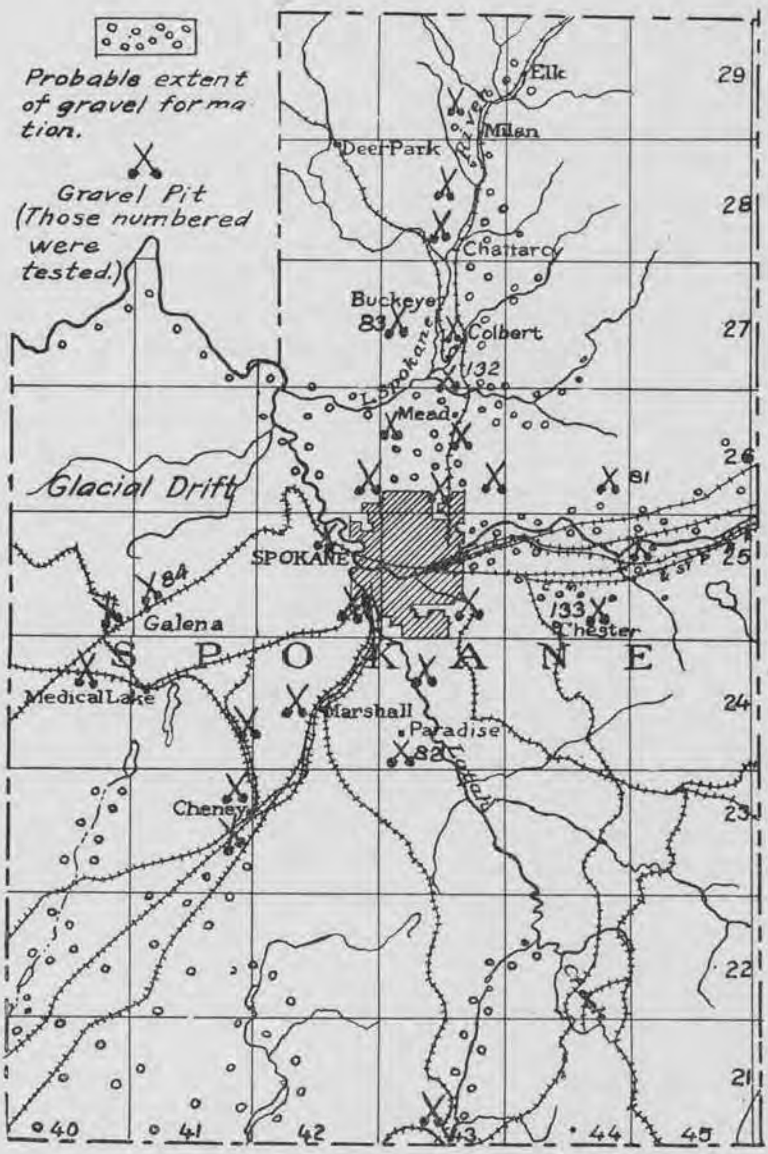


FIG. 30. Outline Map of Spokane County.

ford-Fairfield section the subsoil is a fine clay, and southwest of Cheney there is much "scab-land."

CLIMATE.

Although the county is but 36 miles wide, there is a considerable increase in rainfall from west to east. This is reflected in the vegetation. Near the western border, the landscape is unbroken by trees while in the vicinity of Cheney the coniferous type begins to increase markedly in numbers, and on the higher hills and mountains of the eastern border they clothe the landscape. The precipitation at Spokane averages about 17 inches per year. One-fourth of this is snow-fall. June, July and August are usually dry months and it is at this time that the binding quality of the road-metal is severely tested. Much of the heavy hauling also occurs at this time. Thawing and freezing in the latter part of the winter also has some effect in softening the road-bed and making it susceptible to cutting.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

Unlimited quantities of road gravel occur in the Spokane Valley and in the vicinity of Hillyard. These are in the main fairly coarse. Some also are found in scattered deposits in the locality of Colbert, Chattaroy, and Milan, and near Fairview, Four Lakes, and Dykes. On Pleasant Prairie, Five Mile Prairie, and other table-lands of similar height deposits of excellent dressing material are to be had. "Pea-gravel" commonly occurs in the side of such table-lands above the 2,000-foot contour. The gravel pits at Marshall and along the N. P. Ry. in the western part of Spokane are mostly of this type.

The gravels near Moran and on the western plateau are scattered and in many cases occur in hillocks. This is due to their glacial origin, they having been deposited promiscuously at the front of the glacier during the several stages of its retreat. This, therefore, means that no specific prediction can be made as to just where these are likely to occur or what hillocks and knolls contain gravel but that they are likely to be found in various places as far south as the vicinity of Cheney.

The southeastern part of the county is almost entirely devoid of gravels for the reason that the drainage of the glaciers did not reach this district. Where gravel can not be economically hauled or shipped, basalt will have to be relied upon. The nearest known point from which gravels may be obtained is in the area northwest of Spangle or from the Pine Creek Valley near North Pine.

The outline map of the county shows the general distribution of the gravel formation.

Tests on Samples

Map Number 81. Five miles northeast of Trent, on Pleasant Prairie there is a deposit of stratified gravel consisting chiefly of small, angular particles of granite and gneiss. Most of the material is less than 1 inch in size and on the road cements nicely, producing a smooth and nearly dustless surface. It is an admirable dressing material for automobile roads. Several exposures of this occur here and at the western edge of the Prairie showing that a large quantity is available.

Map Number 82. A somewhat similar deposit occurs 1 mile southeast of Paradise, in the N. E. 1/4 of Sec. 32, T. 24 N., R. 43 E., except that the materials are chiefly quartzitic instead of granitic. These have high wearing value; the percentage of loss by the abrasion test was remarkably low. The constituents are angular and mostly 1 inch and less in size. Some clay lenses are interstratified which add to the binding elements of the material. The chief value of this deposit is for road-dressing purposes and its efficiency has been well tested on the nearby road. The surface of the roadbed is hard, and dragging easily keeps it in condition. The county owns 3 acres at this point.

Map Number 83. This sample was taken from a deposit on Half Moon Prairie, about 4 miles north of Dartford, in the N. E. ¼ of Sec. 18, T. 27 N., R. 43 E. The material is chiefly a fine pea-gravel and "torpedo sand," made up of particles of quartzite, granite, and basalt. Most of it is firm but it is low in packing qualities, there being insufficient binder to make a paste for the tenacity test. Its chief use is for road-dressing purposes. A large quantity is available.

Map Number 84. This sample was collected from a deposit located ¾ mile north of Galena. The gravel is mostly under 3 inches in size and consists chiefly of angular to subangular fragments of basalt, with a few granites, quartzites and schists intermingled. The soil covering is about 1½ to 2 feet thick. About 94 per cent of the constituents are firm and show very good wearing value by test. The binder, however, is of rather low quality, partly due to the lack of clay. If run through a crusher, pit run, as the County Engineer recommends, the binding qualities should be enhanced. The county has purchased 2 acres for pit operations.

The detailed results of the foregoing tests are given in Table I, with those from other counties.

Other Deposits Examined

One-quarter mile south of Hillyard, a pit has been opened on the 2,000-foot flat in well-graded and nearly clean gravels. Some of the pebbles are coated with silt, but washing would easily remove this. Some of the pebbles are cemented together in lumps, which is an objection for concrete paving, for if these came to the surface they would likely work loose and cause pits.

In the western part of Spokane the Northern Pacific Railway is excavating gravel from the face of the high bluff by steam shovel. The materials are mostly coarse sands, horizontally to cross-bedded, containing erratic bowlders and angular blocks of large size scattered promiscuously throughout. The greatest height exposed is about 200 feet. The material is being used for fill and ballast by the company.

In the southeast corner of Sec. 22, T. 25 N., R. 41 E., a large gravel mound has been opened for road material on the Pacific Highway. This exposes an angular basaltic gravel intermixed with reddish brown gumbo-like clay in chunks and thin seams. There is an overburden of 2 to 4 feet of pebbly soil. The amount of the overburden and the presence of the gumbo-like clay reduces the value of the material.

About ¾ mile west of Dykes, in about the S. W. ¼ of Sec. 1, T. 23 N., R. 41 E., there is a deposit of coarse sand and fine gravel with a few scattered fragments of larger material. With the natural clay soil of this region the coarse sand should make a good sand-clay road. From here south to Cheney there are several similar gravel knolls which should serve as a source for road material. About one and one-half miles southwest of Cheney a knoll similar to the foregoing has been opened and the gravel used with success on the nearby road. There is enough coarse material to warrant crushing, which should also increase the binding virtues of the material.

The materials for the Cheney road from Meadow Lake to the Sunset Highway were obtained from a large pit east of the Interurban line and about 1 mile southwest of Meadow Lake. The presence of considerable oversize necessitated screening, but with this portion eliminated the gravel seems to be well graded and to have satisfactory binding qualities.

About ¾ mile northwest of Pantops, the Interurban Railway has opened a large pit in a fine gravelly material which in reality is composed of small pea gravel and coarse sand with large angular bowlders scattered here and there throughout. About half of the small pebbles are quartzite and the rest are granite, gneiss, and schist. Most of the large bowlders belong to the local gneiss and schist series, and there are some quartzites and granites. The material is being used by the Interurban company for ballast.

The Hawkeye Fuel Co. of Spokane operates a pit at Irvin, 9 miles east of Spokane on the south side of the Spokane River. The pit is on the gravel flat, and at present is about 300 feet long by 250 feet wide by 25 to 30 feet deep. Excavation is by bucket with skyline cable. They have gone nearly 50 feet deep in places and found the material satisfactory all the way. The oversize is crushed, and all of the material is screened into several sizes: sand, pea gravel, 1-inch gravel, 1½-inch gravel, and 2¾-inch gravel. Down to about 35 feet in depth the sand runs in proportion to the gravel about 1 to 7. The sand is sharp and clean but is a little coarse. The pebbles are first class for all kinds of high grade concrete work. Bunkers, consisting of compartments for the various sized material, are situated along the tracks for loading, and there are also attachment bunkers for loading trucks, and a bin for the oversize rock which is to run into the crusher. Ten acres are owned by the company.

The Ross Holding Company owns a gravel plant ½ mile east of the city limits of Spokane and ¾ mile south of Sprague Avenue. The gravel occurs in a little rise above the general flat of the valley and the material obtained is sand and pebbles not over ½ inch in size. They consist of basalt, quartzite and granite. The present pit covers about an acre, and has been found to be fairly consistent with depth. Ten acres are owned by the company.

A large pit is operated by the Union Sand and Gravel Co. at Ft. Wright, in the N. W. ¼ of Sec. 14, T. 25 N., R. 42 E. The pit is being operated in the face of a high bench about 200 feet above the river by drag-line to a conveying elevator belt and thence to the bunkers where it is washed and screened on stationary screens by a flow of 750 gallons of water per minute. The water is pumped by their own plant from the river. The equipment provides for screening to seven sizes. Each of the seven compartments of the bunkers have a capacity of 180 to 200 cubic yards. A sidetrack about ½ mile long and capable of holding 13 loaded and 16 empty cars at one time, run alongside the bunkers. The gravel consists very largely of basalt, there being an occasional foreign bowlder of granite and other rocks.

The A. J. Smith Sand Co. operates a pit in a low rise at the south foot of Five Mile Prairie, on land owned by Mrs. Elizabeth McKenzie. The sand is chiefly basaltic and relatively fine, and is used almost altogether for masonry work. Hauling is done from a loading platform by motor trucks and teams.

Tests for Concrete

Map Number 132. The sand from the pit located 1½ miles north of Mead, which was the source of the sand for the Mead Road pavement, was tested by making six concrete briquets, three for a 7-day test and three for a 28-day test. Their tensile strength was ascertained and compared with briquets of the same age made from Standard Ottawa sand and the same kind of cement. The reader is referred to Tables III and IV for detailed results and comparison with other sands from other parts of the state. The 7-day briquets of the sand under test showed a strength 92.8 per cent as great as that of the Standard Ottawa sand briquets, while the 28-day briquets showed a strength 144.1 per cent as great. The colorimetric test showed an absence of organic matter.

Map Number 133. This sample was taken from the Shelley pit 4½ miles southeast of Dishman, and was the source of the aggregate of Apple Way. The 7-day briquets of this sand showed a strength 85.6 per cent as great as the briquets made from the Standard Ottawa sand and the 28-day briquets had a strength 171.4 per cent as great. This sand gave no reaction for organic content.

Concrete Field Tests

According to the description given in Chapter IV, four concrete cylinders were put down on Apple Way, Permanent Highway 4B, at Station 188+00 to 188+50, and cured under the same conditions as the pavement. When 200 days old, each cylinder was tested in the Engineering Testing Laboratory at the University of Washington and found capable of sustaining a weight of 3,841.5 lbs., 3,714.2 lbs., 3,310.9 lbs., and 4,156.3 lbs. per square inch, respectively. The aggregate used in the first two was a mixture of gravel and crushed rock, while in the last two it was only gravel. Their average strength, however, is nearly the same.

Two cylinder tests were made on the Mead Road pavement by Mr. A. L. Strong, of the County Engineer's staff, for this survey, at Station 258+70. At the age of 197 days, these showed a compressional strength of 3,735.5, and 4,909.8 pounds per square inch respectively, or an average of 4,332 pounds per square inch. C-30 was taken from a "wet" mix and C-31 from a "dry" one. This is suggestive of the efficiency of the different consistencies of mix, but it is unsafe to draw definite conclusions on this slender amount of data.

STEVENS COUNTY

GENERAL STATEMENT.

Stevens county is in the northeastern part of the state in the second tier of counties from the Idaho line and bordering the International Boundary on the north. It is 84 miles long, averages 32 miles wide, and includes 2,394 square miles. It ranks fifth in size in the state and in 1910 had a population of 25,297, which is widely distributed along the valleys of the Colville and Columbia rivers.

The chief industries are lumbering, fruit raising, agriculture, and mining. Only locally and along comparatively short stretches of road is the traffic, resulting from these industries, greater than would be classed as "light" traffic.

A branch of the Great Northern enters the county at Clayton and follows the Colville Valley to its mouth. At Marcus it forks, one going to Northport and Canadian stations, the other to Republic and Oroville by way of Canada. The Columbia Valley below Marcus has no railroad, and the various towns depend chiefly on the highways for exporting their products and importing their necessaries. The county's greatest traffic, however, is along the Colville Valley.

The State Highway Department has planned two systems of highways: the Inland Empire Highway which enters the county at Clayton and follows the Colville Valley to Meyers Falls and thence the Kettle River Valley to Laurier, and State Road No. 22 which runs north from Davenport, crosses the Spokane River at Detillion Bridge, and follows the Columbia River to Meyers Falls. Only small portions of these highways have been improved, but gradually the work is being extended.

TOPOGRAPHY.

The county has a diversified topography. The Huckleberry Mountains, between the Colville Valley and the Columbia Valley, range from 3,200 feet to 6,200 feet in height. The western slope is considerably steeper than the eastern, due to the greater depth of the Columbia Valley than the Colville Valley. This range is crossed by highways in three or four different places. The mountain range between the Kettle River Valley and the Columbia, in the northwest part of the county, is an extension of the Huckleberry Mountains. East of the Colville Valley and forming the high divide between Stevens county and Pend Oreille county, is the Calispell Range. The average elevation is between 5,000 and 5,500 feet. With this type of topography, trunk highways were necessarily established along the Colville and Columbia valleys, with lateral branches reaching into the tributary valleys.

SUBSOIL.

Along the Colville Valley from Gray northward to beyond Colville, the Inland Empire Highway in many places is located on a light gray silt which is very dusty during dry spells, and soft and muddy in wet weather. In the vicinity of Meyers Falls this changes to a sandy subsoil, which makes an excellent road as long as it is damp, but an abominable one when dry. A sandy subsoil is characteristic of the Columbia River Valley for most of its extent in this county.

CLIMATE.

Stevens county receives an average precipitation of about 18 to 20 inches per year. Of this, over one-third falls in the summer and less than two-thirds in the winter, part of which is snowfall. Muddy roads are characteristic during the spring, fall, and part of the winter. Sometimes during August and September the roads be-

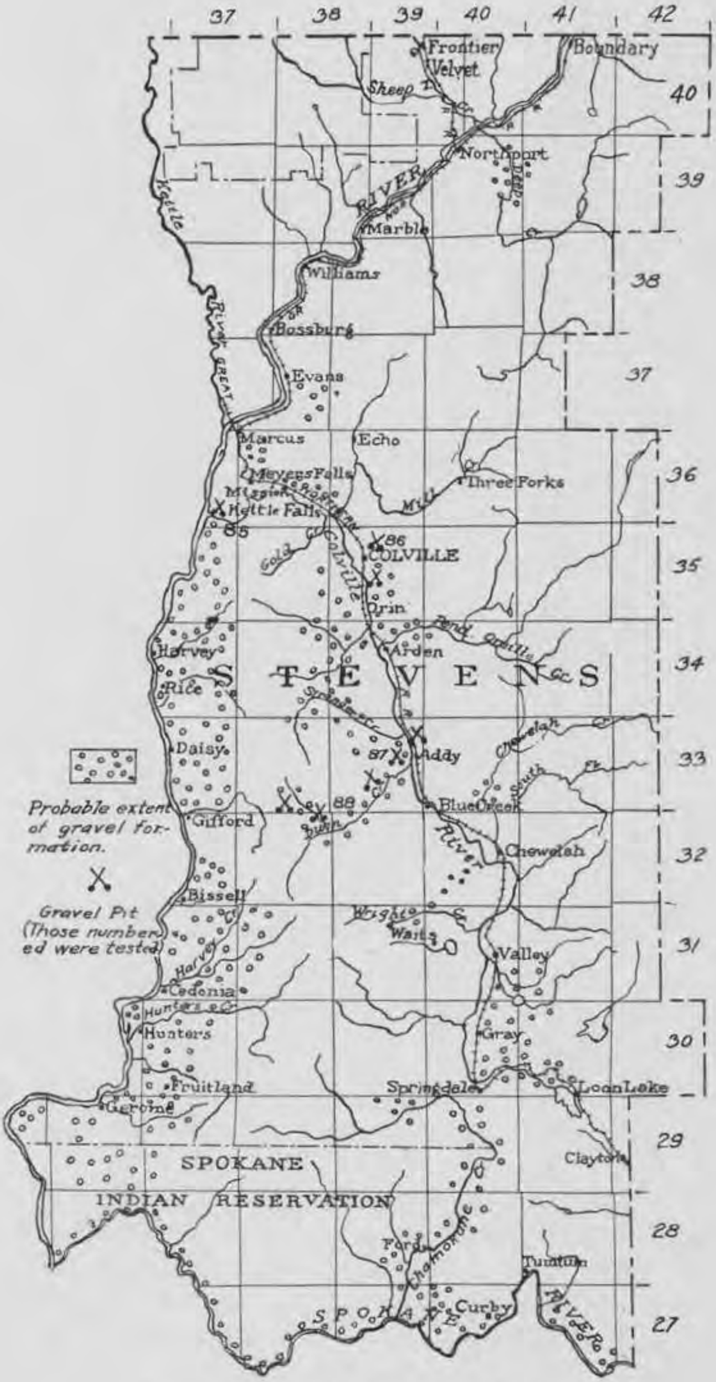


Fig. 31. Outline Map of Stevens County.

come so dry as to offer little bearing power and under heavy loads become very rutty and dusty. Thawing and freezing during the late winter and early spring loosens the subsoil and makes the roads soft.

DEPOSITS OF ROAD GRAVELS.

Deposits of good gravel occur in many places along the Colville Valley. It varies from a sandy gravel to a "pea-gravel." Along the Columbia River the gravel contains much fine sand and little if any binder. This is true particularly of most of the benches below the elevation of 1,700 feet. All but the high points of Stevens county have been glaciated and local deposits of gravel may be found in high benches on the sides of the valley slopes. The outline map of the county shows the general distribution.

Tests on Samples

Map Number 85. This sample was taken from an exposure of gravel ¾ mile south of Kettle Falls, where the road descends into the immediate valley of the river. The gravel is well graded, as shown by the mechanical analyses, has but a small percentage of oversize, is composed of durable pebbles of granite, quartzite, diorite, greenstone, and slate, shows very good wearing qualities, but lacks binding material. In using this for surfacing, a tenacious clay should be added.

Map Number 86. This sample was collected from the Colville City pit, located ½ mile east of town, at the western edge of Church Flat. The face of the gravel pit at the time of inspection stood vertically for nearly 50 feet in height. There is an excess of sand and a deficiency of building material, but if properly screened and some clay were added the gravel would be good for road surfacing. The pebbles consist of granite and quartzite, with some schist, and some are coated with lime. The abrasion test showed a high percentage of wear. The materials were used pit-run on the road for a few miles south and north of town, but the large amount of fine sand retarded packing.

Map Number 87. This sample was obtained from a gravel deposit in the north side of a hill west of Addy. The pit is 25 feet deep and 150 feet long, with 3 to 5 feet of clay overburden. The gravel is dominantly a pea gravel and coarse sand, with a fair amount of pebbles up to 3 inches in size. About 97 per cent of the pebbles are firm, and show excellent wearing quality, but the binding qualities are low for road surfacing. Some clay could be added to advantage. This gravel has been used on the Addy-Gifford Permanent Highway No. 1 for 5 years, for a distance of 1 mile, and where it was put on in sufficient thickness it has given satisfaction.

Map Number 88. This sample was taken from a pit 9 miles southwest of Addy, in the south part of Sec. 1, T. 32 N., R. 38 E., near the top of the gravel bench. The gravel body contains some pockets of sand and silt, indicating that some variation is to be expected. About 94 per cent of the pebbles are firm and appear to have good wearing qualities. The tenacity of the binder was shown by test to be low, probably due to an insufficient amount of tenacious clay. This gravel was put on the adjacent road during 1917.

The detailed results of the foregoing tests are given in Table I of Chapter III.

Other Deposits Examined

Just north of the center of Sec. 21, T. 35 N., R. 39 E., at the side of the road and in the adjoining field, is a gravel deposit, containing considerable slate, shale, and schist, with very little oversize and a goodly amount of clay for binding. There is some evidence of cementation by lime.

In the S. E. ¼ of Sec. 31, T. 35 N., R. 39 E., a gravel pit occurs on the east side of the road, 20 to 25 feet high and 150 feet long. The pebbles are coated with a fine powdery clay which in dry weather does not bind the gravel, making the road a little rough and dusty. The constituents are of a good quality of rock. Sand streaks are few.

In the N. W. ¼ of Sec. 12, T. 33 N., R. 39 E., a small gravel pit shows the body of gravel to vary from fine to coarse, with some granite and clay balls. The variation in quality and size would require careful selection to obtain satisfactory material.

In the N. W. ¼ of Sec. 23, T. 33 N., R. 39 E., a gravel deposit just north of Darringer's saw mill, on the north side of the road, contains firm gravel, but there is too high a percentage of sand, and some oversize.

In the S. W. ¼ of Sec. 27, T. 33 N., R. 39 E., a gravel deposit forms a bank 30 to 40 feet high, in which a pit has been opened. The exposure shows an admixture of fine and coarse in such a way that a very careful selection would be necessary to get material that is properly graded. Some of the material has been used on the road here for a couple of miles and has been found to have poor binding qualities in dry weather and to yield dust.

In the N. W. ¼ of Sec. 35, T. 33 N., R. 38 E., a gravel bench occurs 50 to 60 feet above the road, on the property of Mr. Grinnell. This will probably be drawn upon for surfacing the road west from here. The gravel as exposed in a test pit shows proper grading and sufficiently durable rocks for the traffic of the road in question. Many of the pebbles are coated with lime and should cement well.

In the S. W. ¼ of Sec. 34, T. 33 N., R. 38 E., a high, level-topped ridge, at an altitude of about 3,200 feet, contains gravel in immense quantities and well graded with little oversize. Many of the pebbles are impure limestone, although there is a good percentage of granite and quartzite. The material appears to have suitable binding qualities.

Tests for Concrete

The sand from the pit ¼ mile west of Addy, Map No. 87, was used in making concrete briquets, the tensile strength of which was compared with the strength of briquets made from the Standard Ottawa sand. The 7-day briquets of the Addy sand showed a strength 153.1 per cent as great as the briquets of Standard Ottawa sand, and the 28-day briquets 151.4 per cent as great. The test for organic content showed but a slight discoloration.

The detailed results are given in Tables III and IV, in Chapter IV, with those of other counties.

OTHER ROAD-SURFACING MATERIALS.

One-half mile east of Meyers Falls, along a cliff, there is an immense deposit of "shell-rock" or "slide-rock," of basaltic composition which is mainly of the proper size and gradation to make good road material. The material has been used on the road west of Meyers Falls for a distance of 2 miles, for 8 years. The writer was told that it was put on without preparation of any kind and had no maintenance, but made a good road for 5 years.

In the S. W. ¼ of Sec. 15, T. 35 N., R. 39 E., by the roadside, is a pit in shaly and slaty rock which has been drawn upon for the Minor Street road. The material is brittle and soft, and would ordinarily be classed as unsatisfactory, but in actual practice it packs readily and has given excellent satisfaction for 3 years without maintenance. It does not mud up in wet weather and yields but comparatively little dust in dry weather.

In the north part of Sec. 5, T. 35 N., R. 39 E., along the hillside, there is a talus deposit of shale and slate rock, which has been used on the road north and northwest of Colville with satisfaction. The material is so soft that it breaks readily and would ordinarily be classed as unfit for surfacing, but after 3 years' wear on the road it proves to wear well, provides a smooth roadbed, and makes but little mud in wet seasons or dust in dry seasons.

THURSTON COUNTY

GENERAL STATEMENT.

Thurston county is located at the southern end of Puget Sound. Its area includes 709 square miles and its population in 1916 was 22,393. Shell fishing and lumbering are its chief industries, and dairying, fruit, stock, and poultry raising are also important. Building stone is quarried at Tenino. Olympia is the county seat and largest town, and also the state capital.

The transportation needs of the county are met by the several transcontinental lines of railway which run between Portland and Seattle, and their branch lines, and also by steamboats and highways. The Pacific Highway crosses the county in a north-south direction, and the Olympic Highway enters the county in the northwestern part. Besides these there are the various county highways. Most of them are surfaced, and the Pacific Highway east of Olympia is paved.

TOPOGRAPHY.

The county has a glacial topography of rolling to flat plains. The rolling portion is in part underlain with bedrock, as near Tenino, and in part made up of glacial moraines, as in the vicinity of Lacey. Flat and undulating plains of outwash gravel occur in various parts of the county, such as Mound Prairie, northeast of Grand Mound, Rocky Prairie, southeast of Maytown, Chambers Prairie, southwest of St. Clair, Tenalquat

Prairie north of Rainier, and Yelm Prairie near Yelm. No difficult grades are encountered.

The subsoil is a pebbly to sandy clay over the rolling portion and a gravel with a minor quantity of clay over the prairies. Forests are confined chiefly to the rolling portion.

CLIMATE.

Thurston county receives an average of 55 inches of rainfall per year. Much the larger portion falls from

FIG. 32. Outline Map of the main portion of Thurston County.

October to May. This necessitates the surfacing of the roads where the subsoil is clayey, or the removal of the soil loam where the subsoil is gravel. The dry summers affect the binding qualities of the gravels considerably, especially on the Pacific Highway and the Olympic Highway where there is much tourist travel. Caution must be exercised in this county in giving a surfaced road the right amount of clay binder which will do for both winter and summer seasons. Where the gravels are coarse, this is especially true.

ROAD MATERIALS.

Distribution

The chief road materials of this county are gravels. During the last glacial epoch, the ice-sheet which invaded the Puget Sound region extended over nearly all of Thurston County, save for a small strip in the southern and western parts. As a result, great quantities of gravels were deposited by the outwash, constituting the various prairies named Mound Prairie, Rocky Prairie, Chambers Prairie, Tenalquat Prairie, Yelm Prairie, and others. (See outline map of the county in Fig. 32.) In many places on these prairies, all that is necessary in constructing a gravel road is to remove the soil loam, crown the roadbed and provide drainage ditches, and remove the cobbles, bowlders, and other coarse material. An illustration of this type of road is shown in Plate IX.

Quality of the Road Gravels

The gravels of the county are of first class quality with respect to hardness. They are composed of granite, basalt, andesite, quartzite, and other siliceous metamorphic rocks. Generally they are very well rounded. They vary largely in size and gradation, some deposits being very coarse, while others are mostly sand. The amount of binder which they contain is seldom enough to bind the gravels well for summer traffic. Either some tenacious clay, free from humus material, should be added, or a dressing material used on the wearing course.

Tests Made

Due to the fact that the Survey's Testing Engineer had been called for war service when this county was studied for its road gravels, no samples were collected for testing. Some tests, however, were made earlier on the cement concrete pavement which was laid down east of Olympia. These were compressional strength tests of cylinders which were made in the field of the mix as it went into the pavement. The details of these tests, together with the results, are given in Chapter IV.

WALLA WALLA COUNTY

GENERAL STATEMENT.

Walla Walla county includes over twelve hundred square miles of territory just east of the junction of the Snake and Columbia rivers. Its population in 1916 was estimated by the Census Bureau to be 40,262. Walla Walla, one of the important cities of the state, and the county seat of the county, has a population of 25,136.

The chief industries are general farming, dairying, stock-raising, manufacturing, and horticulture. Most of the traffic takes place along the Inland Empire Highway from Wallula to Walla Walla and thence to Waitsburg, and along the Waitsburg-Lamar highway. These are surfaced most of their distance. Besides these there are county roads over which much of the farm products must be hauled to market but which have not been surfaced.

TOPOGRAPHY.

The topography of the county is made up mostly of hills and valleys, having an average relief of about 200 feet or more. The Eureka Flat in the northwest part of the county and the flat along the Walla Walla River east of Touchet are the chief exceptions. The rough type of topography forbids the location of roads along the section lines as a general rule, if moderate grades are to be obtained.

A heavy mantle of clay covers the bedrock in the eastern part of the county. Toward the west this becomes more and more sandy until the sand plain of the Columbia River is reached. There are three horizons of clay formations which vary in their properties for use as a road foundation. The clays which cover the hills above the 1100-foot elevation are compact, heavy clays which generally make a hard road in dry weather and heavy, muddy roads in wet weather. Below the 1100-foot level is a light, fluffy clay which drys out quickly, ruts badly, and yields much dust. Below the 500-foot level is another clay formation, chiefly exposed in the stream cuts of the Touchet River, which behaves under traffic much like the clay just mentioned. Roads on at least the last two must be surfaced if they are to sustain travel the year round.

CLIMATE.

The precipitation is light in the western part of the county and increases toward the eastern. At Wallula, it averages about 7 or 8 inches per year, at Touchet

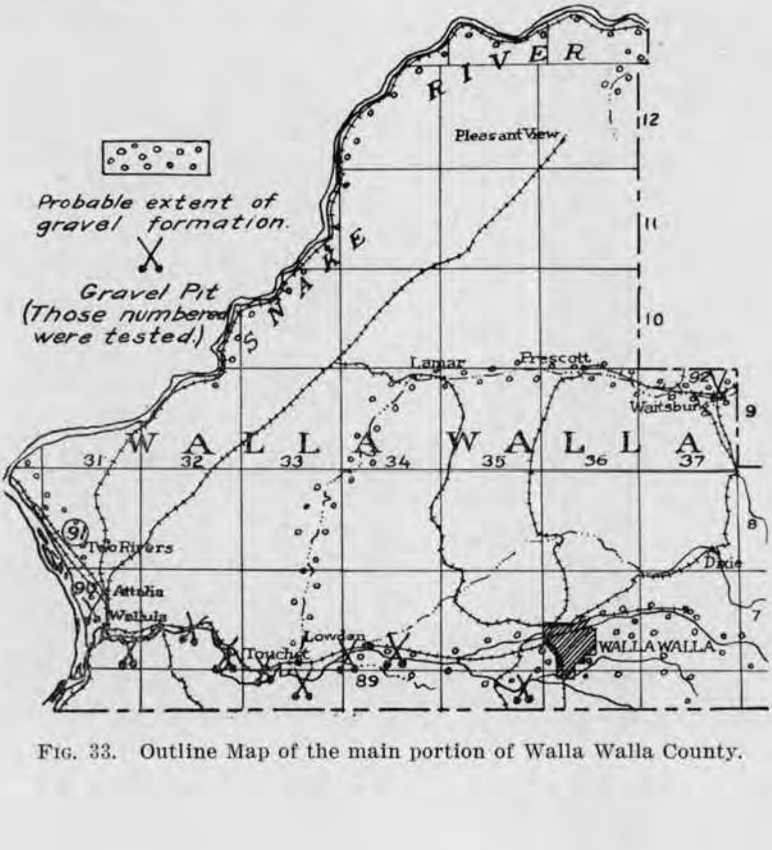


FIG. 33. Outline Map of the main portion of Walla Walla County.

about 10 inches, and at Walla Walla 17 inches. The summers are usually long and dry, thus taxing the cementing power of any surfacing material and increasing its tendency to ravel under traffic, which unfortunately is heaviest at this season.

DISTRIBUTION OF ROAD MATERIALS.

The bedrock of this county was examined and tested for its road-making qualities in 1911, and the results published in Bulletin No. 2 of the Washington Geological Survey series. The gravels, therefore, claimed chief attention in this study.

The gravel deposits are confined almost entirely to the Snake, Columbia, Walla Walla, and Touchet rivers, as shown in the outline map of the county. Because the larger portion of the traffic is in the vicinity of the Walla Walla and Touchet rivers, the deposits along these streams are of the most importance. From the outline map, the interesting fact will be observed that these two drainage lines have east-west courses through the most thickly populated portion of the county and will be important sources for materials to surface the Lamar-Walla Walla and Prescott-Walla Walla roads, just as they are important sources today for the highways paralleling these valleys.

The city of Walla Walla is located on a large gravel flat which has been deposited at the confluence of the various forks of Walla Walla River. This deposit extends eastward and northeastward up the forks, and westward along the river to the Columbia. The Inland Empire Highway west from Walla Walla was surfaced from the various bars which occur along the stream. Similarly the deposits along the Touchet River were drawn upon for the highway west of Waitsburg.

Gravel along the east side of the Columbia occurs not only on the flat which is but little above high-water, but also in benches which rise 100 to 150 feet above the lower flat, about two and a half miles northwest of Two Rivers Station. In both occurrences, the matrix is frequently a fine sand which would probably offer difficulties to ready packing, but in places near the top of the high bench, this objectionable feature does not appear to exist. From here, it is believed that suitable road metal can be obtained. The gravels on the lower flat are well exposed in a railway cut of the O.-W. R. R. & N. Co., just south of the center of Sec. 29, T. 8 N., R. 31 E.

In the extreme northeastern part of the county, about five miles northeast of Pleasant View, scattered deposits of gravel occur along a tributary to the Snake River. These appear to be firm and well graded, and where the road passes over them, they appear to serve excellently as road metal. From Pleasant View, extending southeast along the Northern Pacific Ry., there is a broad depression with a wide flat, which has the appearance of having once been the valley of Snake River. The Eureka Flats lie within the confines of this feature. The soil is a sandy loam in which an occasional pebble is found. This, together with the valley-like aspect of the flat and bordering slopes, suggests that possibly a few feet below the level of the flat, gravel may be found, but its presence cannot be positively predicted.

Tests on Road Gravels

Map Number 89. This sample was selected as being representative of the kind of material taken from the Walla Walla River for use on the Inland Empire Highway. As shown on the sketch-map, it came from one mile southwest of Lowden. The pebbles are entirely of basalt, well rounded, and well graded. About ninety-five per cent of them are firm, and their wearing value is good. The tenacity test gave a satisfactory value for the binding portion. In practical use on the highway, where the oversize was eliminated, the gravel is giving satisfaction.

Map Number 90. This sample was taken from the deposit on the lower flat of the Columbia River, about one-half mile northwest of Wallula. It was difficult to obtain a representative sample as regards gradation, as the gravel varies greatly in coarseness from place to place. Indeed, it may be found wise, if this material is used, to pass all of it through a crusher. The sample, however, shows the other qualities well. Granite, quartzite, diorite, and basalt are all present and ninety per cent or more are firm and appear to have good wearing value. Much fine sand is generally present, which is responsible for the low tenacity value. Without the addition of clay, which is not conveniently at hand in this locality, this material would probably bind slowly and imperfectly.

Map Number 91. This sample was obtained from the gravel exposed in the railway cut of the O.-W. R. R. & N. Co., about one-fourth mile northwest of Two Rivers Station. This material consists chiefly of basalt pebbles, with a few granites and quartzites scattered through. Almost all of them are firm and have very good wearing value. The sand-matrix is coarser than in Sample No. 90, and the materials are well graded, with some oversize. By test, the binding material has a low tenacity value, which would make the gravel slow in packing, but its ultimate cementation after the materials are ground up is fairly high. If this material were to be used in road-building, the addition of a tenacious clay would enhance its packing qualities.

Map Number 92. This sample was taken from the gravel bar at Waitsburg, just east of the bridge, and is believed to be representative to a fair degree of the Touchet River gravel. The constituents are basaltic in composition, rounded, fresh, and fairly well graded with some oversize. About ninety-five per cent of them are firm, and show good resistance to abrasion. Not enough binder could be secured from a forty pound sample to make a tenacity test, which indicates that it has poor cementing qualities of its own. In use, clay would have to be added, which in this part of the county occurs abundantly along most any road. This source of gravel was drawn upon for surfacing three miles of the Inland Empire Highway, south from Waitsburg, in 1914. Without maintenance it ravelled rather badly during the dry summer of 1917.

The detailed results of these tests, together with those from other counties, are given in tabulated form in Table I, of Chapter III.

Tests for Concrete

Map Number 89. The sand from this sample which came from the Walla Walla River, one mile southwest of Lowden, was washed and tested for concrete use by making concrete briquets, according to the method described in Chapter IV. The seven-day briquets had a tensile strength of 97.0 per cent as great as briquets of the same age, made from Standard Ottawa sand. This ratio was considerably increased in the twenty-eight day briquets, to 140.9 per cent. No organic matter was detected by the colorimetric test.

Map Number 90. This sample from the gravel flat, one-half mile northwest of Wallula, tested 72.0 per cent efficiency in the twenty-eight day briquets as compared with Standard Ottawa sand. The seven day test was omitted. This sand, by mechanical analysis, is shown to be too fine for concrete use.

Map Number 91. This sample from the O.-W. R. R. & N. Co.'s cut, one-fourth mile north of Two Rivers Station, gave a sand which, when washed, tested as follows:

The seven day ratio, of the sand under test as compared with Standard Ottawa sand, was 102.1 per cent, and the twenty-eight day ratio, 134.1 per cent. The colorimetric test showed no organic content.

Map Number 92. This sand, which came from the Touchet River at Waitsburg, was washed and tested and found to have a strength of 102.1 per cent as great as the standard sand in the seven day briquets. The results of the twenty-eight day test were lost and another test could not be made.

The results of these tests are given in Tables III and IV, of Chapter V, together with those from other counties.

WHATCOM COUNTY

GENERAL STATEMENT.

Whatcom county is in the extreme northwestern part of the state, just south of the Canadian boundary line. It has a width of about 25 miles and an average length of nearly 90 miles. According to the estimate of the Census Bureau it had a population of 40,262 in 1917. Bellingham, a city of nearly 33,000, is the chief market center of the county and accordingly the highways of the county in general converge towards it. Other important towns are Blaine, Sumas, Lynden, Ferndale, Kendall, and Custer. Farming, lumbering, manufacturing, coal mining and dairying are the chief industries.

Branch lines of the Great Northern Ry. and of the Northern Pacific Ry. enter the county from the south and give direct transportation to Seattle and Tacoma and eastern points, and also with Vancouver and other Canadian points on the north. The Bellingham & British Columbia Ry. runs from Bellingham to Glacier, and the electric line of the Pacific Northwest Traction Co. connects Bellingham and Mt. Vernon.

The Pacific Highway enters the county at the southwestern corner, follows the Sound to Bellingham and then takes a northwesterly direction to Blaine. A portion of this, from Bellingham to Ferndale, is paved. Other paved roads radiating from Bellingham are the Geneva Road, extending along Lake Whatcom for 2½ miles, the Northeast Diagonal Road to Lawrence and Deming, the Laurel Road, the Blaine-Ferndale Road, which is paved as far as Pleasant Valley, and the Whatcom-Marietta Road.

TOPOGRAPHY.

Whatcom county has a mountain and plain topography. That portion in which the greater part of the population lives and where the demands of traffic are greatest is naturally the plain area. The surface is gently rolling in the main, with rounded hills and ridges scarcely reaching an elevation higher than 300 or 400 feet, and with slopes that grade gently to the broad valleys. Along the coast wave-cut cliffs border the Sound. The Nooksak River heads in the mountains to the east in three forks and on the plains these forks join to form the major stream which empties into the Sound at Bellingham Bay. The Sumas River heads in the vicinity of Lawrence, close to the Nooksak River, and flows northward, leaving the state at Sumas. Only to a minor degree do the hills and ridges of the plain cause departures from straight roads for the sake of obtaining the proper grade.

SUBSOIL.

Whatcom county is in the glaciated area of Puget Sound, and its soils as well as the curving profiles of its plain area are largely due to glaciation. Generally the subsoil is a clay containing scattered pebbles and bowlders which becomes very sticky when wet and in some instances impassable, but in summer usually makes a good road. However, there are variations from this type to sand ridges which are good in wet weather but have scarcely any bearing power in dry and therefore are usually rutty and obstructive to most types of vehicles. On the other hand, there are muck and bog places which require filling to make a stable road, especially if the road is to be paved.

CLIMATE.

The chief factor of climate which affects road conditions in Whatcom county is the rainfall. The average rainfall at Bellingham according to government reports, is 30.5 inches, at Blaine 42.5 inches, and at Clearbrook 50.7 inches. The concentration of the rains during the winter produces difficult conditions for the highway engineer to deal with. The subsoil becomes thoroughly soaked with little chance for drying out and the ground remains unfrozen most of the winter. Sur-

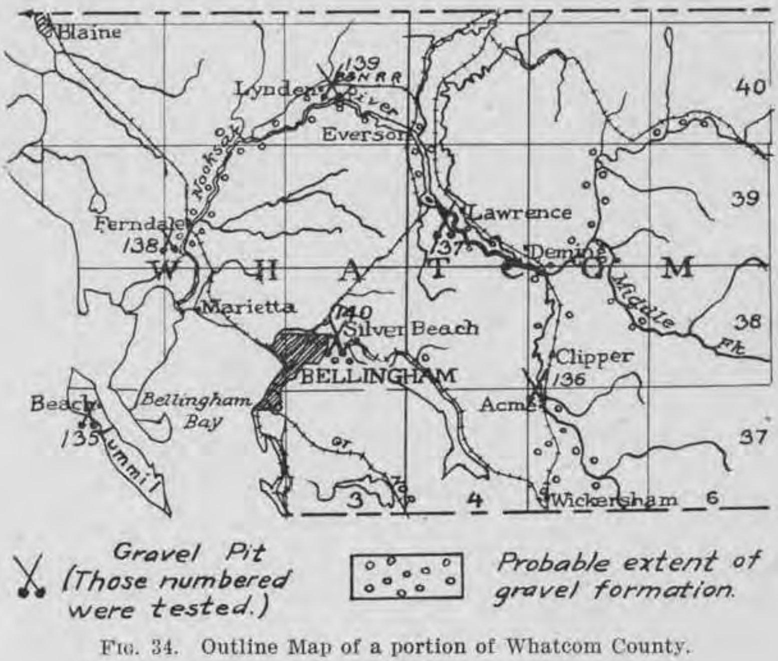


FIG. 34. Outline Map of a portion of Whatcom County.

facing is a necessity and the gravel must contain only a limited amount of clay.

Occasionally the rains in the winter produce slumping or slides and unless the side drainage is perfect the foundations of pavements may become soft and yielding and the pavement in sections destroyed. To some extent flood conditions have to be dealt with also. The summers are comparatively dry. In some years, the dry spells are of long enough duration that the moisture content of the gravel-surfaced roads is evaporated, and when this happens the road ravels and becomes rutted.

DISTRIBUTION OF THE GRAVEL FORMATIONS.

In 1911 the Washington Geological Survey investigated the rock formations of the state and collected samples for testing to determine their adaptability for crushed rock macadam. The results were published in Bulletin No. 2 of the Survey's series.

The present study, therefore, deals chiefly with the gravel formations. In Whatcom county gravel beds occur along Lake Whatcom, along the Nooksak River, and in glacial knolls scattered indiscriminately over the upland. The general distribution is shown on the outline map of the county. The gravel knolls on the upland are local in their occurrence and their quality in each case must be determined by test-pits. The materials occurring in bars along the streams are mostly firm, but have been deprived of their binder by stream action. Where these materials are used for surfacing clay must be added for binder.

Tests for Concrete

In view of the extensive paving program which the county has adopted samples were collected of the sand and gravel which was being used as aggregate in the concrete pavements.

Map Number 135. This sample was taken from the pit near Village Point on Lummi Island. As will be seen by the mechanical analysis in Table III of Chapter IV, the sand from this place is well graded, composed of hard materials, and showed a tensile strength in the 7-day briquets 138.9 per cent as great as the Standard Ottawa sand, and in the 28-day briquets 162.8 per cent as great. No organic content was detected by the colorimetric test.

Map Number 136. This sample collected from the Acme pit along the Nooksak River, was found by the Portland Cement Association to have the following ratios: the 7-day ratio (obtained by dividing the strength of the briquets made from the sand under test by the strength of the briquets made from Standard Ottawa sand) was 86.7 per cent, and the 28-day ratio 105.5 per cent.

Map Number 137. This sample was obtained from the gravel bar of the Nooksak River at Nugent's bridge. The average of four separate tests gave a value of 124.0 per cent for the 7-day ratio, and 144.2 per cent for the 28-day ratio.

Map Number 138. This sample was taken from the Clarkson pit, 1 mile southwest of Ferndale. This test, made by the Portland Cement Association, gave a value of 130.5 per cent for the 7-day ratio, and 126.3 per cent for the 28-day ratio.

Map Number 139. This sample was secured from the county pit at Lynden. This sand gave a value of 113.1 per cent for the 7-day ratio, and 112.2 per cent for the 28-day ratio.

Map Number 140. This sample was collected from the Lind pit at Bellingham, and averaged in four separate tests, made by the Portland Cement Association, 114.5

per cent for the 7-day ratio, and 115.7 per cent for the 28-day ratio.

The mechanical analyses of these sands are given in Table III.

Abrasion Test of the Coarse Aggregate

Map Number 136, from the Nooksak River bar at Nugent's bridge, and which is a sample of the material used in the Deming-Lawrence pavement, showed a loss due to abrasion of 5.2 per cent. Although slightly higher than for most other Puget Sound gravels, this percentage indicates that the gravel has good wearing value.

Map Number 149, which was taken from the pit leased by Mr. Chas. Lind in the N. W. ¼ of Sec. 27, T. 39 N., R. 2 E., and which represents the material used in the Blaine-Ferndale pavement showed a percentage of wear of 4.4 per cent.

The lithologic composition and mechanical analyses of these gravels are given in Table V of Chapter IV.

Strength Tests of Concrete Field Cylinders

Three concrete cylinders, which were made of the concrete mix which went into the Geneva Road southeast of Bellingham, were tested for their compressional strength in the Testing Laboratories of the University of Washington and found to have an average strength of 4110.90 lbs. per square inch. The coarse aggregate and sand which was used came from the Eureka pit of the Lind Gravel Co. The contractors who laid the pavement were Riddle & Hawkins. On the Deming-Lawrence road, three concrete cylinders averaged in compressional strength 4645.03 lbs. per square inch. The sand and coarse aggregate came from the Nooksak River bar at Nugent's bridge. The Washington Paving Co. were the contractors.

Two cylinders were tested of the mix which went into the Blaine-Ferndale road and found to have an average compressional strength of 4133.15 lbs. per square inch. The sand and coarse aggregate came from the Lind pit near Ferndale, and the pavement was laid by Ledingham & Cooper.

Three cylinders of the mix which went into the street pavement near the Bellingham Normal School averaged 4316.6 lbs. per square inch in compressional strength. The aggregate came from the Hesselgrave pit.

WHITMAN COUNTY

GENERAL STATEMENT.

This county has a position in the eastern part of the state, north of the Snake River and bordering the Idaho line. It includes a total area of 2,108 square miles. This, the Palouse country, is one of the most noted grain-growing districts in the state. Wheat, oats and barley are the chief cereals. Dairying and stock raising are also important industries. In 1916, the Census Bureau estimated the population of the county to be 38,260. Colfax is the county seat and the largest town, but Pullman, Tekoa, Palouse, Garfield, and Rosalia are also important.

The productiveness of the soil calls for transportation facilities of every kind. The O.-W. R. R. & N. Co. operates several of their branch lines through the fertile districts, the main line of the C. M. & St. P. Ry. crosses the northern part, and a branch of the Northern Pacific Ry. traverses the county from north to south. The State Highway Department has established two trunk highways through the county from north to south, the main Inland Empire Highway running from Central Ferry to Rosalia and the Second Division from Clarkston to the same point where they both unite and pass northward into Spokane. The county has laid out certain trunk highways of its own between the principal towns and has begun the task of regrading and surfacing them. The Colfax-Pullman road is now complete and is a splendid example of modern highway engineering.

TOPOGRAPHY.

The effect of the topography on the course of the highways is distinct. The county is a rolling plateau having an average elevation over its upland of about 2500 feet. The valleys thoroughly ramify the former upland, producing a very hilly country. The adaptation of the roads to these valleys, therefore, rather than their location along section lines, gives a network of winding roads which economize grade and tractive

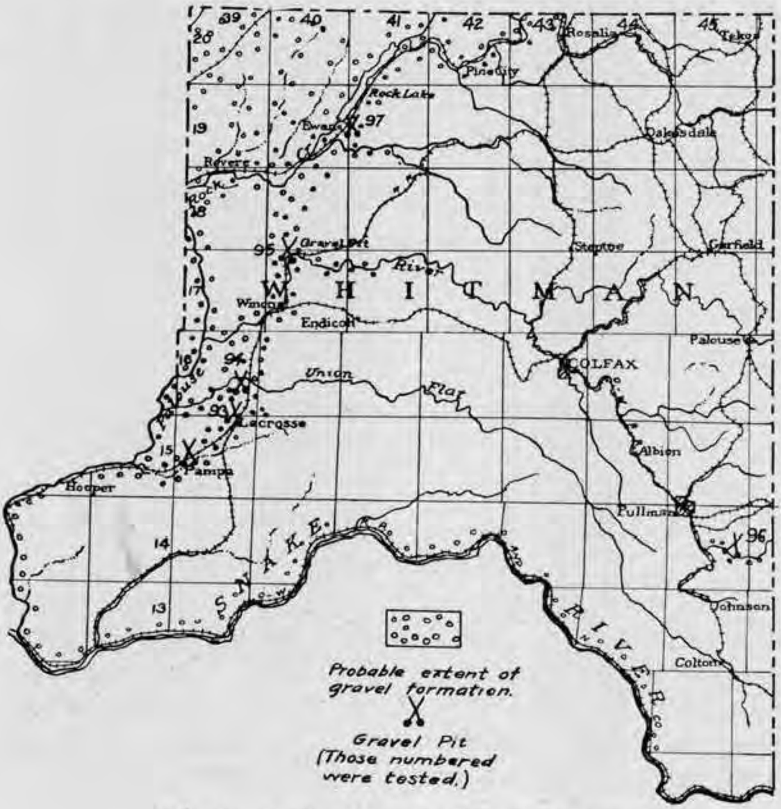


FIG. 35. Outline Map of Whitman County.

force. Along the south boundary of the county the Snake River has cut a canyon over 2,000 feet deep which constitutes a barrier between this county and those lying to the south. Some smaller though considerable canyons have been cut by the Palouse River and some of its tributaries which involve problems of grade for the highway engineer in ascending their walls. A few buttes rise above the general plateau level, but these enter very little into the question of road-building.

SUBSOIL.

Except in the northwest part, the subsoil of the county is a thick clay which varies from light to heavy in different places. The heavy soil in dry weather makes a firm hard road, but the light soil ruts badly, especially in the latter part of the dry season. Both give muddy roads in moist seasons. In a few places there are earth roads which are generally good the year round, and these are on the so-called alkali flats. Rebel Flat, east of Endicott, is perhaps the best example. The reason for this is a subject for investigation.

The formation below the thick clay is generally basalt, as shown in the deeper valleys and exposed over the "scab-land" areas of the northwest district. The buttes, however, are not basalt, but either granite or gneiss or quartzite. The scab-land of the northwest part is due to the removal of the clay formation by the glacial waters which deposited the gravels of that area.

CLIMATE.

Whitman county receives an average of 22 inches of precipitation each year, a part of which falls as snow. Most of the rains come during the fall, winter, and early spring, leaving the summer with comparatively little moisture. The results of these conditions on the clay formation have already been mentioned. The work of frost during the latter part of winter and early spring also affects the roads by softening them and requiring maintenance in order to prevent them from cutting up.

DISTRIBUTION OF ROAD GRAVELS.

In 1911, the Washington Geological Survey conducted an investigation of the bedrock of the county to ascertain its adaptability for crushed rock macadam. The results were published in Bulletin No. 2, of the Survey series. The present study has had to do chiefly with the gravels which could be utilized.

Most of Whitman county is devoid of sands and gravels. The outline map of the county shows that the general area in which deposits of any extent are found is in the northwestern part of the county. This limited distribution is due to the fact that only those valleys in that part were drainage lines from the ice-sheet which lay to the north in Spokane county during the Glacial Period, and which were therefore the only ones that carried glacial gravels. The removal of the clay formation from over the basalt was also accomplished at this time and this resulted in rather extensive areas of "scabland." While the gravels cannot fully compensate for this loss of agricultural soil, yet there is some compensation in the fact that this area carries these valuable deposits.

Tests on Road Gravels

Map Number 93. This sample was taken from the deposit ¾ mile northeast of LaCrosse. The gravel underlies the flat in the northwest outskirts of town and is exposed in a pit about 100 yards square and 10 to 12 feet deep. A great deal of oversize is present, indeed so much that there is much waste in screening and it would seem the point of economy to run the material through a crusher pit-run. They consist chiefly of basalt rock, some of which are porous and the remainder dense. About 90 per cent appear firm and have fair wearing value as shown by the abrasion test. The amount of binder is comparatively small and more is needed but what there is has good tenacity and will pack readily. Crushing would add somewhat to the binder content. The county owns five acres. The new road east of LaCrosse was surfaced with this in 1917.

Map Number 94. This sample was taken from a gravel bench along Union Flat Creek, 3 miles north of LaCrosse where a new bridge was being constructed. The material here is also basalt but is better graded than the deposit at LaCrosse. Ninety per cent and more are firm and have good wearing value. No tenacity test was made because of the lack of clay to make a plastic paste. With the addition of clay for binder this should make a satisfactory road metal. A test was made of the sand for concrete uses which will be considered in a later connection.

Map Number 95. This sample was obtained from the high bench at Gravel Pit Station on the O.-W. R. R. & N. Company's line. The gravel is on the whole comparatively fine but ranges in size up to 2 inches. There are some silt layers at different horizons which will add to the binding portion of the gravel. The pebbles are chiefly basalt fairly well rounded, about 90 per cent are firm and have average wearing value. The cementation test showed that the binding material is somewhat deficient in quality and quantity. The county has purchased 52 acres which insures unlimited quantities. The gravel is loaded directly into railroad cars or motor trucks by a Jarmine loader which operates by gasoline power. If freight rates permit, much will be shipped to other parts of the county for use on the highways. The sand was tested for concrete uses, and the results are given on a following page.

Map Number 96. This sample was taken from a deposit along the stream bed of the South Fork of Palouse River, 5 miles southeast of Pullman. There are some pebbles but most of the material is a coarse to fine sand, which, when mixed with the clay of the roadbed, makes a good sand-clay road. The materials have been washed from one of the higher buttes which is situated near the headwaters of the stream, and consist of granite, quartzite and basalt. Where used on the road it has rendered good service and withstands heavy wheat hauling.

Map Number 97. This sample was taken from the ridge of gravel located on the north side of the railway track at Ewan. The ridge is about ¼ mile long and 30 to 40 feet high, and contains immense quantities. The C. M. & St. P. Ry., which owns the deposit, has excavated thousands of cubic yards for road ballast, and has offered a portion of the rest for the surfacing of the roads in the vicinity of Ewan. About ten per cent are oversize, but the rest are well graded. The material is basaltic, some of the pebbles are porous, but practically all of it has very good wearing value as shown by the abrasion test. A test of the binder showed it to be fairly tenacious and to have good ultimate cementation value. It would seem advisable from the standpoint of grading and increasing the binder content to run the gravel through a crusher pit-run.

About ¾ mile east of LaCrosse there is a ridge of gravel considerably finer than that at LaCrosse. No pit has yet been opened in this. Between Union Flat Creek and Winona there is a broad sag with gravels scattered at different places along the way. A pit has been opened in a gravel bench in the N. W. ¼ of Section 17, T. 17 N., R. 40 E.

Detailed results of the foregoing are given in Table I, of Chapter III, together with those from other counties.

Tests for Concrete

The sands of the samples which have already been described, were washed and tested for their tensile strength in concrete briquets, according to the method described in Chapter IV.

Map Number 93. Three briquets made from this sample, which was collected from the deposit ¾ mile northeast of LaCrosse, were found to have a tensile strength at the end of 7 days 88.5 as great as the briquets made from Standard Ottawa sand. This percentage, however, was increased to 136.1 per cent in the 28-day test. By the colorimetric, only a slight content of organic matter was found.

Map Number 94. This sample of sand is from the deposit 3 miles north of LaCrosse at Union Flat Creek. The 7-day briquets of this sand showed a strength-ratio of 93.8 per cent, and the 28-day briquets a strength-ratio of 145.9 per cent. The sand is free of organic matter, as shown by the colorimetric test.

Map number 95, taken from the deposit at Gravel Pit Station, on the O.-W. R. R. & N. Co. line, gave a strength ratio of 72.8 per cent for the 7-day briquets and 101.7 per cent for the 28-day briquets. No organic content was found by test.

Map number 97, obtained from the deposit at Ewan, on the north side of the railway, tested 74.7 per cent for the 7-day ratio and 124.4 per cent for the 28-day ratio. Some organic material was indicated to be present by the colorimetric test, but not in objectionable quantities.

All of the foregoing sands are too coarse to give the desired density without the addition of fine sand or crusher dust. Otherwise they are believed to be satisfactory. More detailed results are given in Tables III and IV of Chapter IV.

YAKIMA COUNTY

GENERAL STATEMENT.

Ranking the second in size in the state, this county includes over 5,000 square miles of territory on the east flanks of the Cascades, in the south central part of the state. In population it ranks sixth, according to the census of 1910, at which time the inhabitants numbered 41,709. Since then its population has probably increased notably.

The high slopes of the Cascades gradually descend to the broad floor of the Yakima Valley which crosses the eastern part of the county in a southeasterly direction. It is in this trunk valley where most of the population is concentrated and where the demand for good roads exists. As the result of irrigation parts of this valley are intensively cultivated for agricultural and horticultural products and the productivity supports a large population. Some roads, therefore, carry heavier traffic than surfaced or macadam roads can bear with economical maintenance, and these are now being paved. Yakima, the county seat, is one of the ranking cities of the state. Other towns are Toppenish, Sunnyside, Zillah, Mabton, Granger, Grandview, Wapato, Outlook, Selah, and Moxee City.

TOPOGRAPHY.

In leaving the county on the north, over Umptanum Ridge, and south over Horse Heaven Hills, the topography entails some problems of grade. Northward the road at present crosses the Umptanum Ridge, the canyon of the Yakima River being too narrow for a highway location without much expensive rock cutting. Southward, State Road No. 8 leaves the county by ascending the slopes and crossing the summit of Horse Heaven Hills, which attain an altitude of nearly 3,000 feet. Aside from this the capacious Yakima River Valley and the Naches Valley provide excellent natural grades.

The natural subsoil of the Yakima Valley on which the roads are located consists largely of silt and sand. The bearing power of these materials is easily exceeded by most conveyances and hence, this necessitates surfacing of some sort on even the secondary roads. The prevalent dry air of summer reduces the strength and binding power of any loose material to a minimum. In consequence the silt or sand roads become almost impassable with ruts, and the crushed rock macadam or gravelled highways are prone to ravel, especially during the market season of heavy hauling.

There is every encouragement for a maximum production by the county in the various facilities of transportation which it possesses. Besides the Inland Empire Highway which traverses the full length of the county, the main line of the Northern Pacific Ry. and the O.-W. R. R. & N. Co. offer ready means for foreign marketing. In the near future the McClellan Pass Highway will probably be open with suitable grade across the Cascades at McClellan Pass.

GENERAL DISTRIBUTION OF ROAD GRAVELS.

Two classes of road gravels are found in Yakima county. Fresh gravels occur in bars and islands along the Yakima and Naches rivers, and more or less weathered gravels occur erratically here and there at varying elevations on the slopes above the valley floor. The general distribution is mapped on the outline map of the county by a symbol of small circles. Where pits have been opened some of these are shown by the conventional sign of crossed shovels, and those which were tested are given a map number.

It should not be taken for granted that the mapped area includes only the gravel deposits suitable for road building. A very detailed survey necessitating many test-pits and several months of time would be required to make such a map, but it is thought that a generalized sketch of the area from which satisfactory material is likely to be found and selected will be helpful.

Tests on Road Gravels

Two series of tests were made on the gravels of this county according to the uses to which they would likely be put, namely, gravels to be used for road surfacing, and samples of sand from gravel deposits which are conveniently situated for concrete uses. The discussion of the latter will be considered later on succeeding pages. The results of the tests on gravels for surfacing are tabulated with those of other counties in Table I, of Chapter III. Herewith is given a brief discussion as to their occurrence, abundance and general value.

Map Number 98. This sample was taken from a deposit of gravels on the upland ¾ mile southwest of Selah, from a rock known as the Ellensburg formation. This sample showed good gradation, with a small percentage of oversize. By determination of 100 pebbles taken at random, 29 per cent were found to be basalt, 29 per cent andesite, 28 per cent quartzite, and 3 per cent rhyolite. About 10 per cent of them are soft, the remainder being hard to very hard and having fair wearing value. Most of them are coated with a light silt which, with the other fine material of the deposit, was found to have fair tenacity value, thus indicating that the gravel would pack fairly promptly. At this point a large pit has been opened by the county, in the hillslope, and several miles of road in this vicinity surfaced with the materials, with fair to good results. Locally this formation is known as the "cement gravel."

Map Number 99. This sample was obtained from a test-pit in a deposit occupying the position of a sloping

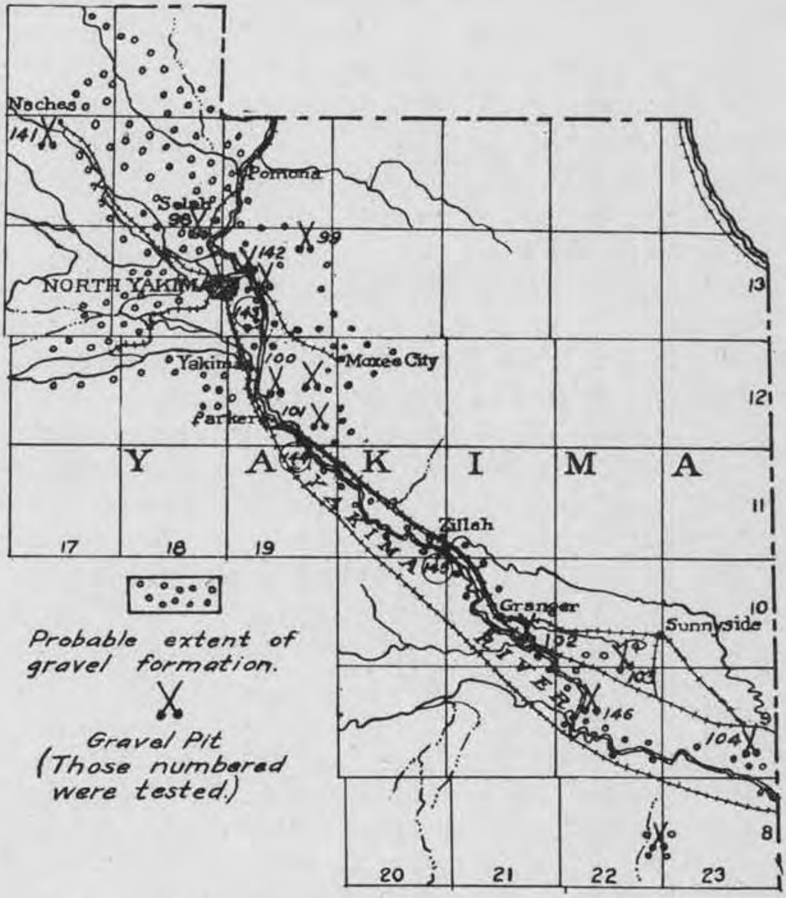


FIG. 36. Outline Map of the main portion of Yakima County.

bench above the Yakima River flat, 4½ miles northeast of Yakima. The pebbles are chiefly andesite and basalt, are coated with silt like those in Sample 98, but a larger percentage are soft and have poor wearing qualities as shown by the abrasion test. A mechanical analysis was not made on account of the uncertain variation of the deposit. The tenacity test, however, showed that the binder has a high value, which suggests that the material will pack readily. The percentage of oversize seemed to be large enough to warrant crushing all of the material pit-run.

Map Number 100. This sample was obtained from a deposit on the north side of the Atanum Ridge, ¾ mile east of Union Gap. These gravel beds are tilted southward at an angle of 70 degrees, and contain lenses and seams of sand and silt. About 42 per cent of the pebbles are basalt, 46 per cent andesite, and 12 per cent quartzite. Somewhat less than 90 per cent of them are firm and have fair wearing qualities. The gravel varies too much to warrant giving a mechanical analysis. By test the tenacity value is low, indicating that the addition of clay would be beneficial. One mile of road is to be surfaced from this deposit in 1918. Crushing is recommended.

Map Number 101. About 4 miles northeast of Wapato a gravel pit has been opened in a deposit very similar in appearance to the one described as Map Number 99. It has a position on the slopes north of the flat of Yakima River. The composition is mostly pink and gray andesite, with a few quartzites and diorites; about 80 per cent are firm enough for road gravel, and about 12 per cent are oversize. By test the percentage of wear is so high that its use is recommended only for light traffic, and if so used it should be crushed.

Map Number 102. This sample, taken from a deposit along the south side of Snipe's Mountain, 2½ to 3 miles southeast of Granger, is a gravel coated with light silt, composed of pebbles of andesite and rhyolite, and decayed to the extent that nearly 20 per cent of the pebbles are soft. The percentage of wear, according to test, is high and the binder shows a low value in cohesiveness. This gravel would be suitable only for a road having light traffic.

Map Number 103. This sample was collected from the Patch Gravel pit, about 3½ miles southwest of Sunnyside. The materials, as exposed in the pit, occur in stratified layers tilted about 80 degrees to the south and consist of interbedded gravels and greenish gray and whitish silts. Fifty per cent of the pebbles are quartzite, 46 per cent basalt, and 4 per cent granite. The variability of the gravels prevent any dependence being made on a mechanical analysis. Some of the pebbles, especially the quartzites, are flattened, the rest are rounded. About 20 per cent are hard and firm, with good wearing quality. The binder tested low in tenacity, and fair in cementation. This gravel is considered only fairly satisfactory for road purposes on account of the flattened pebbles, and its low tenacity.

Map Number 104. This sample is largely a "torpedo sand" taken from a deposit 1½ miles south of Grandview. Most of it is basaltic, which gives it the black color, but there are a few fragments of lime rock scattered through it. By test the tenacity value is low, but where it has been used on the road, as north of Grandview, it makes a smooth, firm road, permitting a minimum of wear on motor tires. It is an excellent dressing material.

Sand for Concrete

Samples of sands were collected at various points along the Yakima and Naches rivers and after being washed were used in the making of concrete briquets whose strength was tested and compared with that of briquets of the same age made from Ottawa Standard sand and the same brand of cement. The character of this test is described more fully in Chapter IV. Besides the following general results which are noted for each sample the full results are tabulated with those from other counties in Tables III and IV.

Map Number 103. This sample which was taken from the Patch gravel pit, 3½ miles southwest of Sunnyside, was screened and the sand used for the briquet test. The briquets which were made from this sand, when 7 days old, showed a tensile strength 45.5 per cent that of the briquets made from the Ottawa Standard sand, and when 28 days old, 92.6 per cent. The mechanical analysis shows that the sand is too fine for concrete purposes. It is almost free, however, from any organic content, as shown by the colorimetric test.

Map Number 104, a sample from the deposit, 1½ miles south of Grandview, which has been described, tested 89.8 per cent as strong as the Standard sand in the 7-day test, and 142.9 per cent as strong in the 28-day test. This sand is too coarse to give the proper density without the addition of fine sand or crusher dust. No organic matter was detected by the colorimetric test.

Map Number 141. This sand was screened from the sample of gravel which was collected from a bar of the Naches River at Naches, just below the bridge. The 7-day briquets had a strength 105.2 as great as the briquets of the Standard sand, and the 28-day briquets 156.7 per cent as strong. This sand seems to be a desirable one for concrete. The amount of organic matter detected is very small and unobjectionable.

Map Number 142, taken from a bar along the Yakima River, northeast of Yakima, on the Marble Spur of the Northern Pacific Railway, showed a tensile strength in the 7-day briquets equal to 106.2 per cent that of the

Standard sand, and a strength in the 28-day briquets equal to 116.4 per cent that of the Standard sand.

Map Number 143, collected from a bar on the west side of the Yakima River, just south of the Lower Moxee bridge, 2½ miles southeast of Yakima, showed a strength 109.3 per cent as great as that of the Standard sand in the 7-day briquets, and 114.1 per cent as great in the 28-day briquets. The mechanical analysis indicates that the sand is lacking in coarse constituents.

Map Number 144. This sample is from the bar along the Yakima River, on the west side, just below the Donald-Wapato bridge. The 7-day ratio in this case was 102.1 per cent and the 28-day ratio 155.9 per cent. By the colorimetric test organic matter was indicated to be present in amounts that are somewhat objectionable, and this feature should be watched and tested for from time to time if the material is used.

Map Number 145. A bar along the Yakima River, ½ mile southeast of Zillah, was sampled. This sand gave an efficiency test of 103.1 per cent of the strength of Standard sand in the 7-day briquets, and 135.6 per cent in the 28-day test. Some organic matter was found to be present by test.

Map Number 146, taken from a bar of the Yakima River, 7 miles southwest of Sunnyside, on Ole Levold's place, tested 93.8 per cent for the 7-day ratio, and 106.5 per cent for the 28-day ratio. A small inconsequential amount of organic matter was found by chemical test. The mechanical analysis of this sand indicates that some coarse sand should be added.

The coarse aggregate of the river gravels is of good quality and fairly clean, but in the case of the Patch gravel pit the pebbles are coated with silt. The gradation varies in size even in the same bar, but with caution proper materials can be obtained.

APPENDIX I.

BIBLIOGRAPHY.

1880. Willis, Bailey. 10th Census of United States. Vol. XV, 759-771. "Report on the Coal Fields of Western Washington." Mainly a summarizing report so far as the southwestern Washington fields were concerned.

1888. White, C. A. Am. Jour. of Sci. 3rd Series, Vol. 36, 443-450. "On the Puget Group of Washington Territory."
A review of the work of Willis and Newberry with the suggestion of possible correlation of the Puget Sound rocks with the Laramie, Tejon, etc.

1889. White, C. A. Bull. 51, U. S. Geol. Survey. "On Invertebrate Fossils from the Pacific Coast."
First applies the name Puget to the coal-bearing series of Washington.

1891. Clark, Wm. B. Bull. 83, U. S. Geol. Survey. 100-110. Correlation Papers: Eocene.

1892. Ruffner, W. H. Science, Vol. 19, 58. "Some Recent Mineral Discoveries in the State of Washington."

1893. Corey, T. B. Jour. Ill. Mining Inst., May, 1893, Vol. 11, No. 1, 14-30. "Coal Fields of Western Washington."

1898. Lawson, A. C. Am. Geologist, Vol. 13, 436-437. "Note on the Chehalis Sandstone."
Notes the finding of marine fossils—Tertiary—in sandstones apparently associated with the lignite beds.

1901. Landes, Henry. Annual Report of State Geologist, Vol. I, Pt. IV, 61-65. "Coal Deposits of Washington."
Discusses briefly the Bucoda-Tenino field in Thurston county; the Centralia-Chehalis field in Lewis county, and the Kelso-Castle Rock field in Cowlitz county, and mentions higher grade coals in Upper Cowlitz valley.

1902. Landes, Henry. Annual Report of State Geologist, Vol. II, 238-257. A somewhat more detailed account (than that of 1901) of the known fields, viz.: Bucoda-Tenino, Chehalis-Centralia, Alpha, Cinnabar, Morton, Packwood, Davis, Kelso-Castle Rock.

1902. Smith, Geo. Otis. 22nd Ann. Report U. S. Geol. Survey, Pt. III, 473-513. Coal horizon placed in Eocene, but no specific details of the Southwest Washington fields. Base of Puget series in southern Puget Sound fields not known. In the northern part it rests on schists.

1905. Diller, J. S. Bull. 260, U. S. Geol. Survey, 411-412. "Coal in Washington, near Portland, Oregon."
A brief discussion of some of the occurrences in Cowlitz county.

1906. Arnold, Ralph. Prof. Paper 47, U. S. Geol. Survey. "The Tertiary and Quaternary Pectens of California."
Mentions the occurrence of certain fossils in the vicinity of Little Falls (Vader) and places the age of these beds as probably Upper Eocene, possibly above the Tejon.

1911. Smith, E. E. Bull. 474, U. S. Geol. Survey. "Coals of the State of Washington."
Gives 3 from Cowlitz county, 32 from Lewis county, 9 from Thurston county. Analyses of section secured and discussion as to rank of coal, mining methods and character of samples.

1912. Weaver, Chas. E. Bull. 15, Wash. Geol. Survey. "A Preliminary Report on the Tertiary Paleontology of Western Washington."
A general statement of the geologic history of Western Washington with faunal lists and description of eighty-four new species.

1913. White, David, and **Thiessen, Reinhardt.** Bull. 38, Bureau of Mines, Department of Interior. "The Origin of Coal."
A technical discussion of the subject introducing the most recent material as to methods of examination and results.

1913. Arnold, Ralph, and **Hannibal, Harold.** Proc. Am. Phil. Soc., Vol. 52, 566-571. "Stratigraphy of the North Pacific Coast of America."
The Tejon is subdivided into the Chehalis, Olequa and Arago formations, of which the first two are present in southwestern Washington. On the basis of fossil flora it was concluded that colder climatic conditions obtained during Chehalis than during Olequa times.

1913. Bretz, J. Harlan. Bull. Wash. Geol. Survey, No. 8. "Glaciation of Puget Sound Region."
The origin of the Pleistocene deposits in southern Thurston county is discussed in connection with the Puget Sound deposits.

1915. Dickerson, Roy E. Cal. Acad. Sci. Proc., 4th Series, Vol. 5, 35-51. "The Fauna of the Type Tejon, Its Relation to the Cowlitz Phase of the Tejon Group in Washington."
The writer concludes that the Cowlitz phase of the Washington Tejon appears to represent the same faunal facies as the fauna of the type Tejon.

1916. Weaver, Chas. E. Bull. 13, Wash. Geol. Survey. "The Tertiary Formations of Washington."
A report on the geology and paleontology of the Tertiary of Western Washington with maps, structure sections and faunal lists.

1916. Weaver, Chas. E. Cal. Acad. Sci. Proc., 4th Series, Vol. 6, 1-40. "Eocene of Lower Cowlitz Valley, Wash."
"Post Eocene Formations in West. Wash."
A description of strata and fossil zones with inferences as to geologic history.

INDEX.

PUBLICATIONS

OF THE

WASHINGTON GEOLOGICAL SURVEY

ADDRESS
STATE LIBRARIAN
OLYMPIA, WASHINGTON

Volume 1.—Annual Report for 1901. Part 1, Creation of the State Geological Survey, and An Outline of the Geology of Washington, by Henry Landes; part 2, The Metalliferous Resources of Washington, Except Iron, by Henry Landes, William S. Thyng, D. A. Lyon and Milnor Roberts; part 3, The Non-Metalliferous Resources of Washington, Except Coal, by Henry Landes; part 4, The Iron Ores of Washington, by S. Shedd, and the Coal Deposits of Washington, by Henry Landes; part 5, The Water Resources of Washington, by H. G. Byers, C. A. Ruddy and R. E. Heine; part 6, Bibliography of the Literature Referring to the Geology of Washington, by Ralph Arnold. Out of print.

Volume 2.—Annual Report for 1902. Part 1, The Building and Ornamental Stones of Washington, by S. Shedd; part 2, The Coal Deposits of Washington, by Henry Landes and C. A. Ruddy. Out of print.

Bulletin 1.—Geology and Ore Deposits of Republic Mining District, by Joseph B. Umpleby. Bound in cloth; price 35 cents.

Bulletin 2.—The Road Materials of Washington, by Henry Landes. Bound in cloth; price, 60 cents.

Bulletin 3.—The Coal Fields of King County, by Geo. W. Evans. Bound in cloth; price, 75 cents.

Bulletin 4.—The Cement Materials of Washington, by S. Shedd. Bound in cloth; price, 75 cents. Paper cover; price, 40 cents.

Bulletin 5.—Geology and Ore Deposits of the Myers Creek and Oroville-Nighthawk Districts, by Joseph B. Umpleby. Bound in cloth; price, 50 cents.

Bulletin 6.—Geology and Ore Deposits of the Blewett Mining District, by Charles E. Weaver. Bound in cloth; price, 50 cents.

Bulletin 7.—Geology and Ore Deposits of the Index Mining District, by Charles E. Weaver. Bound in cloth; price, 50 cents.

Bulletin 8.—Glaciation of the Puget Sound Region, by J. Harlen Bretz. Bound in cloth; price, 60 cents. Paper cover; price, 35 cents.

Bulletin 9.—The Coal Fields of Kittitas County, by E. J. Saunders. Paper cover; price, 40 cents.

Bulletin 10.—The Coal Fields of Pierce County, by Joseph Daniels. Bound in cloth; price, 60 cents. Paper cover; price, 40 cents.

Bulletin 11.—The Mineral Resources of Washington, with Statistics for 1912, by Henry Landes. Paper cover; price, 25 cents.

Bulletin 12.—Bibliography of Washington Geology and Geography, by Gretchen O'Donnell. Paper cover; price, 25 cents.

Bulletin 13.—The Tertiary Formations of Western Washington, by Charles E. Weaver. Paper cover; price, 40 cents.

Bulletin 14.—The Quincy Valley Irrigation Project, by Henry Landes, A. W. Mangum, H. K. Benson, E. J. Saunders, and Joseph Jacobs. Paper cover; price, 20 cents. Out of print.

Bulletin 15.—A Preliminary Report on the Tertiary Paleontology of Western Washington, by Charles E. Weaver. Paper cover; price, 20 cents.

Bulletin 16.—Geology and Ore Deposits of the Covada Mining District, by Charles E. Weaver. Paper cover; price, 25 cents.

Bulletin 17.—A Geographic Dictionary of Washington, by Henry Landes. Paper cover; price, 75 cents.

Bulletin 18.—The Country About Camp Lewis, by Morris M. Leighton. Paper cover; price, 50 cents.

Bulletin 19.—The Coal Fields of Southwestern Washington, by Harold E. Culver. Paper cover; price, 75 cents.

Bulletin 20.—The Mineral Resources of Stevens County, by Charles E. Weaver. Paper cover; price, one dollar. In press.

Bulletin 21.—The Mineral Resources of Washington, with Statistics for 1917, by Henry Landes. Paper cover; price, 50 cents. In preparation.

Bulletin 22.—The Sand and Gravel Deposits of Washington Suitable for Road Building, by Morris M. Leighton. Paper cover; price, 75 cents.

PUBLICATIONS OF THE U. S. GEOLOGICAL SURVEY, IN CO-OPERATION WITH THE WASHINGTON GEOLOGICAL SURVEY.

(For copies of these publications address the Director, U. S. Geological Survey, Washington, D. C. Water-Supply papers may also be obtained, upon request, from the U. S. Geological Survey district office, 406 Federal Building, Tacoma, Washington.)

Topographic Maps of the Following Quadrangles.

Arlington, Beverly, Cedar Lake, Chehalis, Connell, Coyote Rapids, Hoquiam, Lake Crescent, Malaga, Moses Lake, Mount Vernon, Ocosta, Pasco, Port Angeles, Port Crescent, Priest Rapids, Prosser, Quincy, Red Rock, Samish Lake, Van Zandt, Walla Walla, Wallula, Wenatchee, Wickersham, Winchester.

Power Reports.

Water-Supply Paper No. 253: Water Powers of the Cascade Range, Part I, Southern Washington.

Water-Supply Paper No. 313: Water Powers of the Cascade Range, Part II, Southwestern Washington, Puget Sound Region.

Water-Supply Paper No. 369: Water Powers of the Cascade Range, Part III, Yakima basin.

Water-Supply Paper No. 486: Water Powers of the Cascade Range, Part IV, Wenatchee and Entiat basins. In preparation.

Water-Supply Paper No. 487: Water Powers of the Cascade Range, Part V, Chelan, Methow and Similkameen basins. In preparation.

Water-Supply Paper No. 488: Water Powers of the Cascade Range, Part VI, Snoqualmie, Skykomish, and Stilaguamish basins. In preparation.

River Profiles.

Water-Supply Paper No. 346. Profile Surveys of Clark Fork of Columbia River.

Water-Supply Paper No. 366: Profile Surveys of Snoqualmie, Sultan and Skykomish rivers.

Water-Supply Paper No. 368: Profile Surveys of Wenatchee River and tributaries.

Water-Supply Paper No. 376: Profile Surveys, Chelan and Methow basins.

Water-Supply Paper No. 377: Profile Surveys, Spokane and John Day basins.

Water-Supply Paper No. 419: Profile Surveys in Skagit River Basin.

Annual Stream-Flow Reports.

Water-Supply Paper No. 272: Surface Water Supply of the United States, North Pacific Coast, 1909.

Water-Supply Paper No. 292: Surface Water Supply of the United States, North Pacific Coast, 1910.

Water-Supply Paper No. 312: Surface Water Supply of the United States, North Pacific Coast, 1911.

Water-Supply Paper No. 332: Surface Water Supply of the United States, North Pacific Coast, 1912.

Water-Supply Paper No. 340: Gaging stations and publications on water resources 1885-1913.

Water-Supply Paper No. 362. Surface Water Supply of the United States, North Pacific Coast, 1913.

Water-Supply Papers Nos. 392, 393, and 394: Surface Water Supply of the United States, North Pacific Coast, 1914.

Water-Supply Papers Nos. 412, 413, and 414: Surface Water Supply of the United States, North Pacific Coast, 1915.

Water-Supply Papers Nos. 442, 443, and 444: Surface Water Supply of the United States, North Pacific Coast, 1916. Government Printing Office.

Water-Supply Papers Nos. 462, 463, and 464: Surface Water Supply of the United States, North Pacific Coast, 1917. Completed for publication.

Water-Supply Papers Nos. 482, 483, and 484: Surface Water Supply of the United States, North Pacific Coast, 1918. In preparation.

Qualitative Report.

(Principally in cooperation with State Board of Health.)

Water-Supply Paper No. 339: Quality of Surface Waters of Washington.

PUBLICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE, BUREAU OF SOILS, IN COOPERATION WITH THE WASHINGTON GEOLOGICAL SURVEY.

(For copies of these publications address one of the members of congress from Washington.)

Reconnoissance Soil Survey of the Eastern Part of Puget Sound Basin.

Reconnoissance Soil Survey of the Western and Southern Parts of the Puget Sound Basin.

Reconnoissance Soil Survey of Southwestern Washington.

Reconnoissance Soil Survey of the Quincy Area.

Reconnoissance Soil Survey of Stevens County.

Reconnoissance Soil Survey of Franklin County.

Reconnoissance Soil Survey of Spokane County. In press.