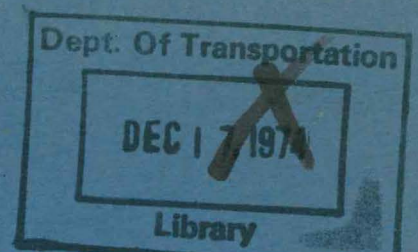


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# OSCOPIC AND X-RAY DIFFRACTION EXAMINATION OF ALT TO DETERMINE FACTORS AFFECTING DURABILITY

R.O. Van Atta and H. Ludowise



April 1974  
Final Report

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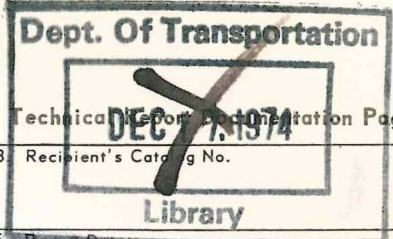
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| 16. Abstract<br>Similar mineralogy and textures exist in the basaltic rock studied from four quarries in the Nestucca River area of northwestern Oregon. However, durability of the aggregates manufactured from these quarries differs greatly.<br><br>This study, done by petrographic and X-ray analysis shows that no new minerals form during degradation. Existing clays such as nontronite, increase in percentage as degradation progresses. In contrast degradation did not occur in rocks containing analcite, a mineral which forms under conditions unfavorable to the formation of nontronite. It was also found that durability cannot be determined solely by percentages of weathering products found in the rocks as some studies have suggested.<br><br>Federal Highway Admin.<br>Technical Reference Center<br>6300 Georgetown Pike<br>McLean, VA 22101-2296 |  |  |  |   |           |
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PREFACE

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The authors wish to express their thanks to those above as well as to many others who contributed generously of their time and ideas to this project.

## TABLE OF CONTENTS

|                                    | <u>Page</u> |
|------------------------------------|-------------|
| Introduction                       | 1           |
| Purpose                            | 1           |
| History of Degradation Studies     | 3           |
| Definitions                        | 4           |
| Methods of Study                   | 6           |
| <br>                               |             |
| Petrography                        | 12          |
| Dovre Peak Quarry and Aggregate    | 12          |
| Bible Creek Quarry and Aggregate   | 23          |
| Bald Mountain Quarry and Aggregate | 27          |
| State Quarry and Aggregate         | 30          |
| <br>                               |             |
| Summary                            | 34          |
| <br>                               |             |
| Conclusions                        | 36          |
| <br>                               |             |
| References                         | 40          |

|  | <u>Page</u> |
|--|-------------|
| APPENDIX A - Aggregate Reports.  | 41          |
| APPENDIX B - Petrographic Analyses of<br>21 samples of quarry rock<br>from Western Oregon.                         | 46          |
| APPENDIX C - Results of Petrographic Analyses<br>of Dovre Peak, Bible Creek, Bald<br>Mountain, and State quarries. | 48          |
| APPENDIX D - Definitions of Minerals and<br>Other Components.  | 53          |

## ILLUSTRATIONS

| <u>Figure</u> |  | <u>Page</u> |
|---------------|--|-------------|
| 1.            | Index map, sample localities.  | 2           |
| 2.            | Dovre Peak quarry  | 9           |
| 3.            | Columnar jointing, Dovre Peak quarry.  | 9           |
| 4.            | Photomicrograph, lower unit, Dovre Peak quarry.  | 10          |
| 5.            | Photomicrograph, upper unit, Dovre Peak quarry.  | 10          |
| 6.            | Photomicrograph, upper unit, Dovre Peak quarry.  | 11          |
| 7.            | Photomicrograph, lower unit, Dovre Peak quarry.  | 11          |
| 8.            | Nestucca Access Road, pavement breaks.   | 14          |
| 9.            | Nestucca Access Road, grading deteriorated section.  | 14          |
| 10.           | Photomicrograph, aggregate from crusher site, Dovre Peak quarry.                           | 15          |
| 11.           | Photomicrograph, aggregate from crusher site, Dovre Peak quarry.                           | 15          |
| 12.           | Photomicrograph, degraded aggregate, Nestucca Access Road.                                 | 17          |
| 13.           | Photomicrograph, fibrous nontronite in degraded aggregate, Nestucca Access Road.           | 17          |
| 14.           | Photomicrograph, altered feldspar in degraded aggregate, Nestucca Access Road.             | 18          |
| 15.           | Photomicrograph, fibrous zeolite and chalcedony, degraded aggregate, Nestucca Access Road. | 18          |
| 16.           | Photomicrograph, degraded aggregate from paving, Nestucca Access Road.                     | 20          |
| 17.           | Photomicrograph, olivine gabbro, Bible Creek quarry.                                       | 20          |
| 18.           | Photomicrograph, base aggregate, Bible Creek Road.   | 24          |
| 19.           | Bible Creek Road.  | 24          |
| 20.           | Photomicrograph, Bald Mountain quarry rock.  | 26          |
| 21.           | Bald Mountain Access Road.   | 26          |

| <u>Figure</u> |   | <u>Page</u> |
|---------------|---|-------------|
| 22.           | Photomicrograph, base aggregate, Bald Mountain Access Road.                           | 28          |
| 23.           | Photomicrograph, State quarry rock.   | 28          |
| 24.           | Section of Nestucca Access Road above McMinnville reservoir.                          | 31          |
| 25.           | Comparative degree of alteration of quarry rocks and aggregates, Nestucca River area. | 33          |



## INTRODUCTION

### PURPOSE

This study is an outgrowth of problems incurred in the use of certain basaltic rocks as aggregate in the construction of roads in western Oregon. A large degree of uncertainty exists about the durability of these rocks since they often qualify as satisfactory according to numerous durability tests, yet they cause road failures in actual service.

All such basaltic rocks contain certain chemically and mechanically unstable components such as glass and the hydrothermal and weathering mineral products of the alteration of primary minerals and decomposed glass. Standard tests employed to rate rock and aggregate durability are almost entirely mechanical in nature, although some recently devised tests for swelling properties of rock components are chemical in part. Appendix A includes the tests which were employed on the rocks included in the present study and results of these tests. Since these mechanical tests are not conclusive for ranking durability, it is necessary that the mineralogy and texture of the rock be evaluated also. The purpose of this study is to examine in detail the mineralogical, compositional and textural characteristics of several basaltic rock bodies, and the aggregates derived therefrom in the Nestucca River drainage area of northwestern Oregon. Four such bodies which have been quarried, the aggregate in a former stockpile, a rock crusher site, and the aggregate from the base courses and asphalt paving of several roads were selected for study.

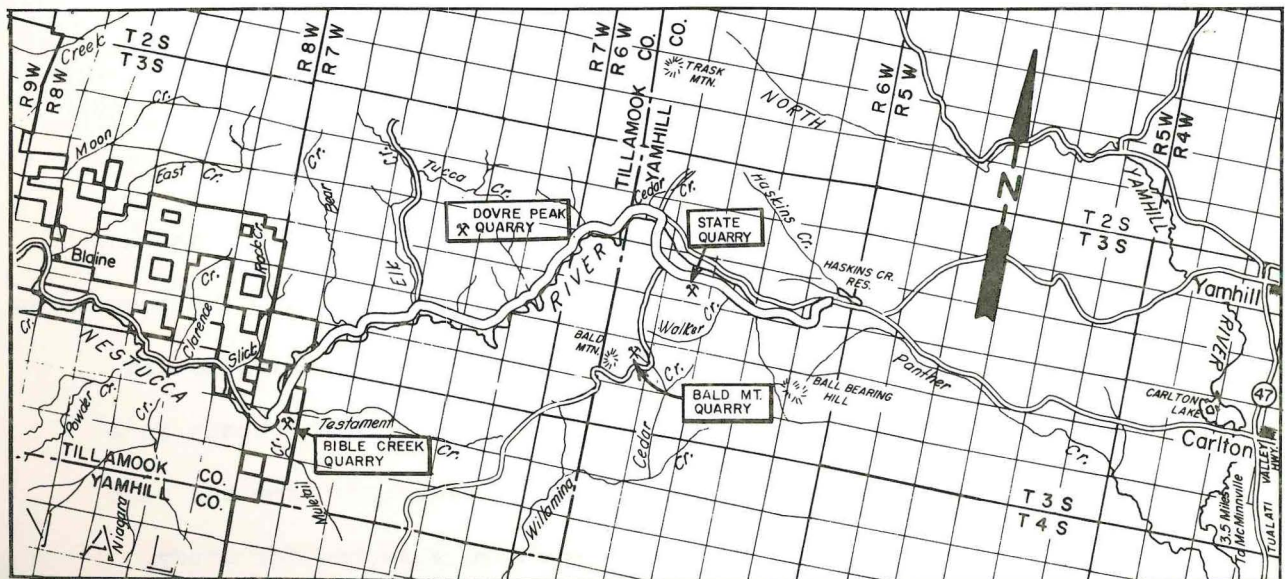
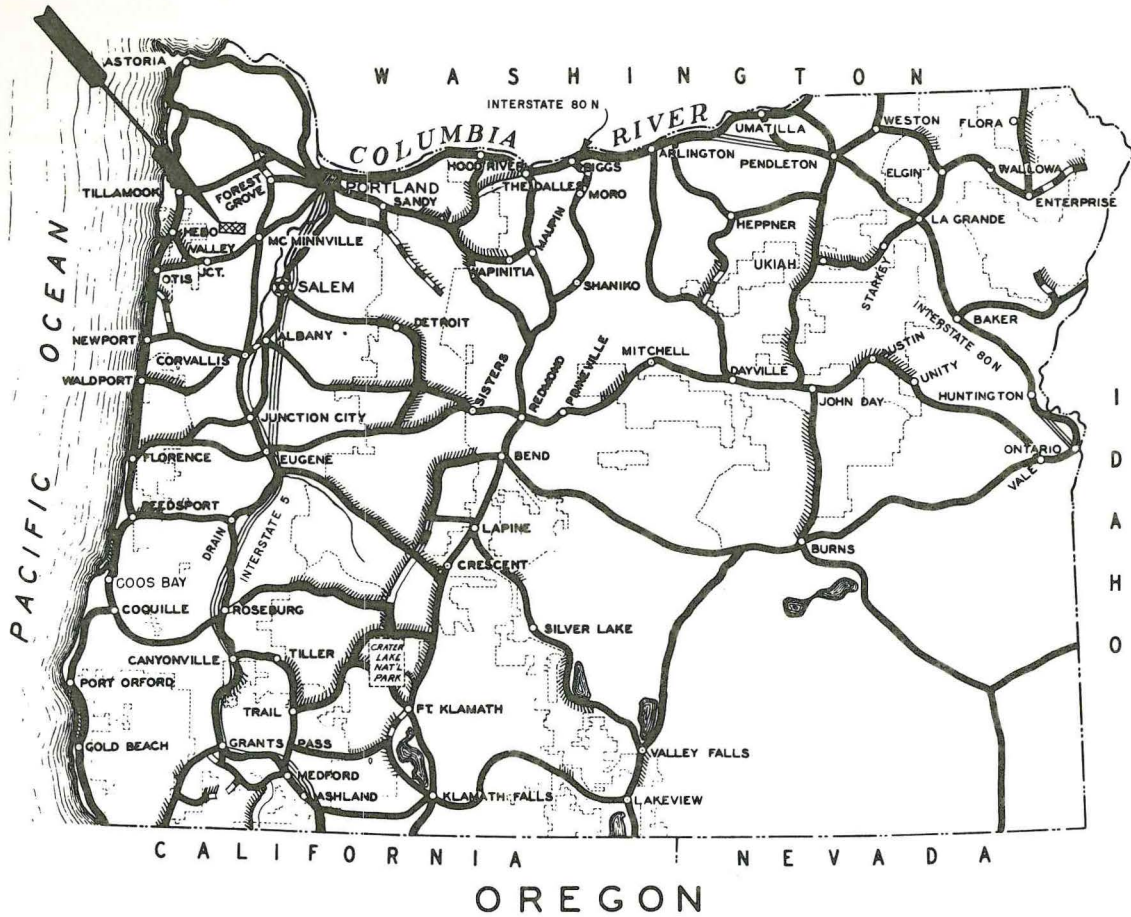


FIGURE 1

The aggregate source quarries are: Dovre Peak (35-29-0008), Bible Creek (35-29-0028), Bald Mountain (35-36-0001), and the "State quarry" (35-36-0007). For locations of the quarries, crusher site, stockpile and road sample sites involved in this study see Figure 1.

#### HISTORY OF DEGRADATION STUDIES

During the course of the past 62 years, 65 studies of the degradation of aggregates used in road building have been published (Highway Research Board, 1970). A review of this literature reveals that 31 studies are related to tests of durability, that 28 are concerned with factors and conditions affecting aggregate degradation and that only six are solely concerned with petrographic studies, most of which date after 1940.

Judging from the annotated bibliography cited above, studies on alteration of primary rock-forming minerals, other than weathering and on altered basalts were not undertaken before 1955. Apparently one of the first significant <sup>front</sup> petrographic studies in the United States is that by L. E. Scott (1955) concerning minerals which are formed by the alteration of primary components. In the past ten years, there has been an increasing number of references which cite the importance of petrographic studies of rocks being evaluated for aggregate suitability.

Nearly all of these studies show that petrographic study, including microscopic and X-ray identification of minerals and other components of rock, combined with durability tests, is more reliable than mechanical testing

alone for identifying rock likely to degrade. Except for a few studies, such as that by the California Division of Highways (Smith, 1967), little has been done with either the interrelationships between chemical composition, texture of primary minerals and alteration products, or the development history of the components in comparing rocks which have degraded and those that have not.

#### DEFINITIONS

Several terms employed in the designation of the rocks included in this study need to be defined since they are used by different writers in various senses.

Rock - An aggregate of minerals and other components in any stage of coherency. Badly decomposed rock grades into what is generally understood by the term "soil".

Mineral - A substance with a more or less definite chemical composition, orderly internal structural arrangement of constituents, naturally occurring, and inorganic. This excludes glass and certain other rock components which lack one or more of these properties.

Component - All constituent substances in a rock, whether they are mineral or not.

Glass - A substance formed by rapid chilling or quenching of molten rock. Glass has little if any internal ionic structure and

may vary widely in chemical composition.

Deuteric minerals - Those substances formed by hydrothermal (hot water and gaseous) alteration (chemical reactions) of primary minerals and glass as well as by other processes which take place during the crystallization history of igneous rock bodies (American Geological Institute, 1960).

Secondary minerals - Substances formed by weathering processes whereby primary minerals, glass, and deuteric minerals are altered under temperatures, pressures and chemical conditions at or very near the earth's surface.

Rock body - A unit or several genetically related units of rock. Lava flows, dikes or sills, or nondescript intrusive bodies of igneous rock would be included in this term.

Texture - The grain-to-grain relationship of rock components, irrespective of grain size, which is more or less uniform in any one part of a rock body.

Structure - Non-uniformly distributed, larger-scale features of rock bodies such as jointing (fracture systems), flow layering, vesicularity.

In addition to these terms, the minerals and other components of the rocks

under investigation in this present study need to be defined. A review of the literature dealing with degradation of aggregates used in road construction reveals that a number of rock component names, such as palagonite, chlorophaeite, and smectite are not always used in the same way by different workers. The terms "palagonite" and "chlorophaeite" are particularly susceptible to variant definitions. In Appendix D, definitions and descriptions of these minerals and other components are listed.

#### METHODS OF STUDY

Samples of rock and petrographic thin sections from 21 quarries in western Oregon were originally studied along with the laboratory reports of tests made on samples of quarry rock and aggregate from these sites. Complete microscopic petrographic analyses were made of 26 thin sections, including point counting with an automatic point counter to determine relative frequency of components. Point counting was done according to the method of Chayes, except that rather than a fixed number of points being counted, a grid was chosen so as to cover the entire thin section of rock. The number of points then varied from about 500 to 600. Since percentages of components are rounded to the nearest whole percent, this variation does not affect the relative abundance so determined. Rounding percentages to the nearest whole percent is wholly justified, since the frequency of counts for a given mineral always varies, depending upon the particular grid chosen for successive counts and upon operator error. For a listing of these samples and the relative abundance of components, see Appendix B.

From this reconnaissance survey of both serviceable and non-serviceable aggregate source rock, four sources of rocks in Tillamook and Yamhill counties, Oregon, were chosen for detailed study. These sources were selected because they had both good and bad service records of aggregate produced from them. Field sampling of quarries, a crusher site, a stockpile site, and roads constructed with aggregate from these sources was conducted. Grab samples, representative of each rock unit exposed, were taken from parts of rock bodies in place in the quarries. Grab samples were also taken from the crusher site, and from the floor of the stockpile site, since the original stockpiles have now been exhausted. Roads were sampled by coring and by grab samples from scarified sections. Rock thin sections of these samples were made and analyzed by petrographic microscopic methods. Point counts were again made on all the new thin sections to determine mineral and other component frequency. For location and results of analyses of these samples included in this study, see Appendix C.

In addition to petrographic analyses of thin sections, samples from the Tillamook and Yamhill county quarries were analyzed by X-ray diffractometer. Samples were prepared by crushing and grinding the rock to a minus 270 mesh. Since plagioclase feldspar and pyroxenes make up to 50% of the components in most of the samples, it is necessary to remove these minerals and concentrate the alteration products. This was accomplished by separating the components with specific gravities greater than 2.43 from those with lesser specific gravities by centrifuging twice in bromoform diluted with ethyl alcohol. The lighter fraction was then

mounted in a metal planchet by backloading (Zussman, 1967, pp. 282, 283). Care was taken to prevent preferred orientation of sheet-structured minerals, although this could not be wholly avoided. Alteration products were X-rayed untreated, treated with ethylene glycol for one hour at 60°C, and heated at 600°C for one hour.

In some cases, clean separation of feldspar and pyroxene from lighter density alteration products was not complete. This problem arises from the difficulties in separating components in a pulverized sample by using the centrifuge and from alteration minerals present in the feldspar lowering its specific gravity.

The use of bromoform to separate smectites, along with other alteration products, might be questioned because of the strong tendency of smectites to expand with certain organic compounds. One of the samples, known to have a high content of smectite, was run untreated with bromoform. There was no shift in the 14 to 15 angstrom diffractogram peak as compared to the same sample after it had been separated with bromoform. It is felt that the bromoform did not appreciably effect any swelling in these samples.

Precision of definition of smectite species, for purposes of this report, was limited because of complications inherent in this group of minerals. For a discussion of these complications and description of the extent definition, see Smectite in Appendix D of this report.





Figure 2. Dovre Peak quarry. Lower massive basalt unit exposed in lower half of picture, upper columnar basalt unit in upper half of picture.

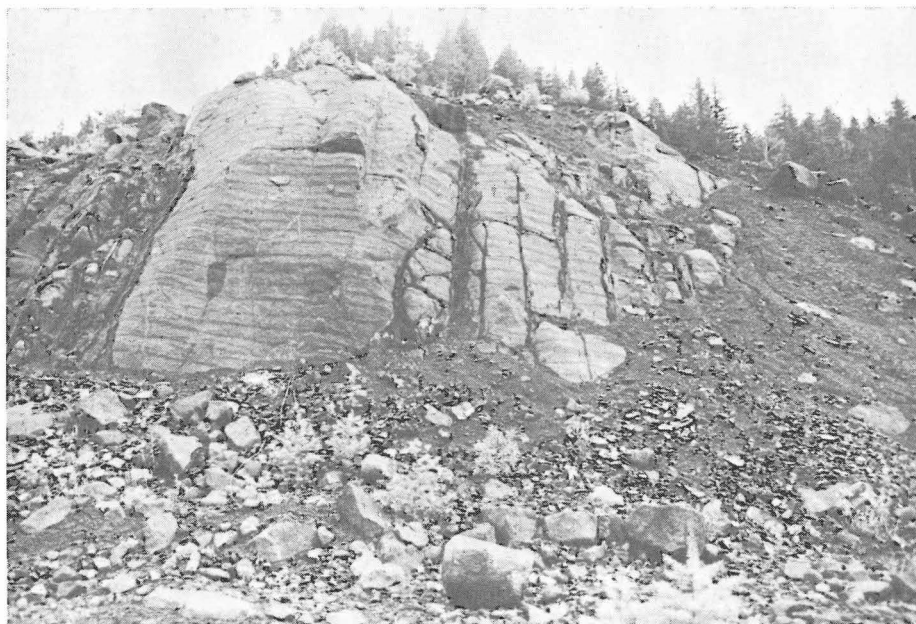


Figure 3. Dovre Peak quarry. Rude columns showing spheroidal weathering and cross-fluting.

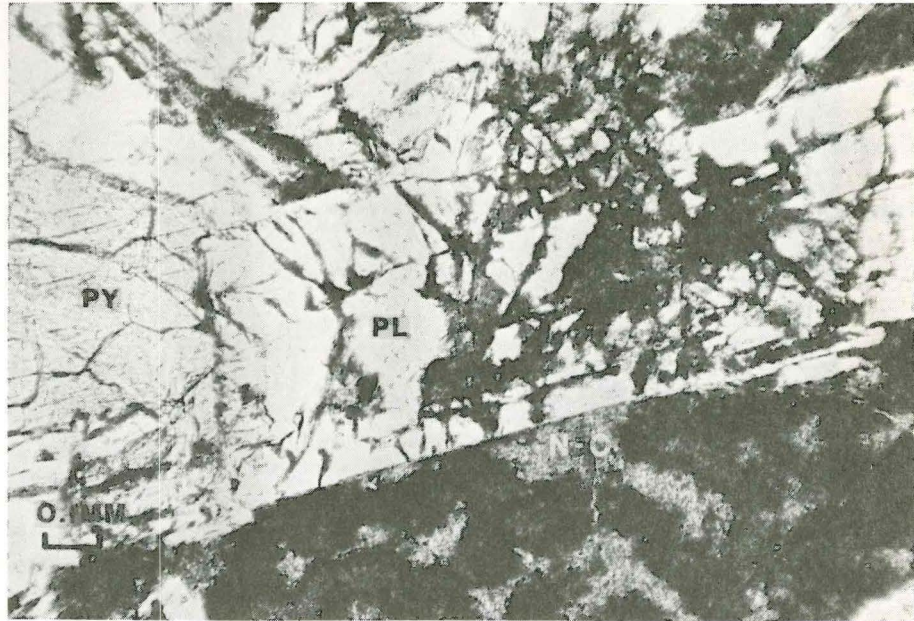


Figure 4. Photomicrograph, lower unit, Dovre Peak quarry showing nontronite vermicular aggregates in turbid opal (N-O), fractured plagioclase lath with hydrated iron oxide (PL) and pyroxene (PY), ordinary light.



Figure 5. Photomicrograph, upper unit, Dovre Peak quarry showing palagonite altered on margins to montmorillonite (P-M) microcrystalline plagioclase and pyroxene in glass and hydrated iron oxide (Mic), laths of plagioclase (PL), ordinary light.

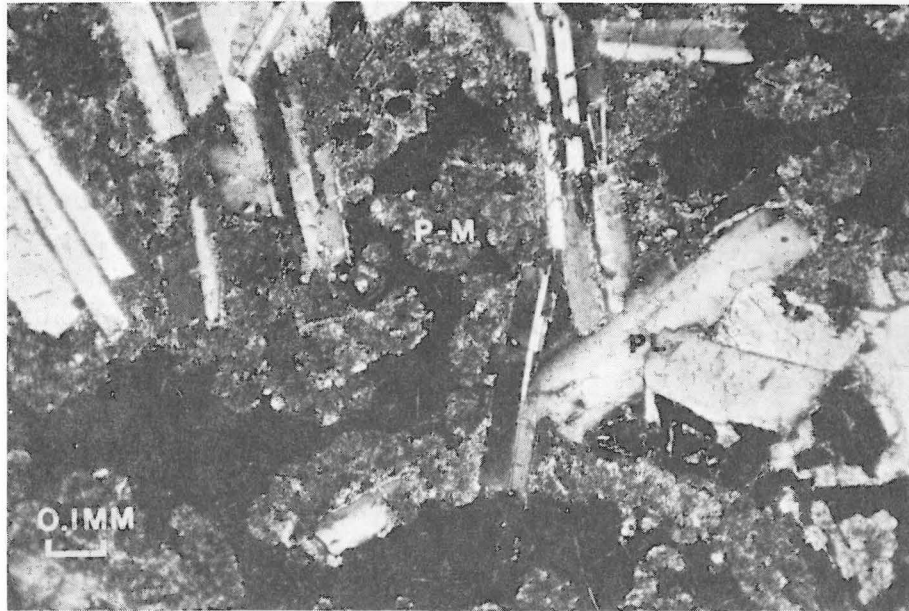


Figure 6. Photomicrograph, upper unit, Dovre Peak quarry showing interstitial palagonite with spherules of montmorillonite (P-M) and laths of plagioclase (PL). Polarized light.

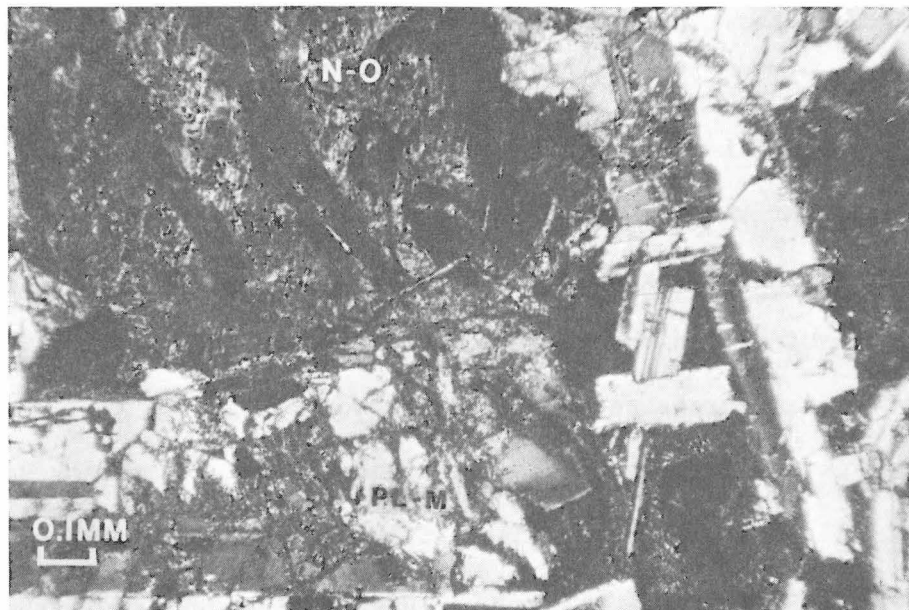


Figure 7. Photomicrograph, lower unit, Dovre Peak quarry showing fractured plagioclase with montmorillonite (PL-M) and large patch of nontronite with hydrated iron oxide along fractures (N-O). Polarized light.

## PETROGRAPHY

### Dovre Peak Quarry Rock and Aggregate

#### Quarry Rock

Rock exposed in the Dovre Peak quarry face occurs in two different basaltic units. The lower unit is more massive and generally structureless, while the upper unit displays well-developed columnar jointing. (Figure 2). The columns have a fluted structure normal to their long axis. The columnar upper unit is more subject to spheroidal weathering and exfoliates into spalls, giving a well-rounded appearance to the columns which have been exposed for some time. Jointing across the columns is related to their fluted character. (See Figure 3).

The lower basaltic unit consists of a coarse-grained aggregate of plagioclase feldspar and pyroxene with interstitial microcrystalline plagioclase feldspar set in a matrix of hydrated iron oxide and nontronite, or interstitial turbid brownish opal which has orange-brown nontronite in spherules or vermicular aggregates scattered through it (Figure 4). The upper basaltic unit is similar, except that instead of opal, prominent yellow palagonite fills vesicles or is interstitial between plagioclase and pyroxene crystals (Figures 5 and 6). The palagonite is partly altered to montmorillonite, which occurs as spherules at the margins of the glass. Hydrated iron oxide forms a significant part of microcrystalline interstitial

areas and is always present bordering the palagonite. Plagioclase is more fractured as compared to the lower rock unit in the quarry. The fractures are partly filled with montmorillonite (Figure 7). Deuteric alteration products account for 25 and 28 percent of the two samples of the upper unit and 30 and 33 percent of the samples of the lower unit studied. Relative percentages of other rock components are given in Appendix C.

The performance of the Dovre Peak quarry rock in durability and soundness testing is shown in Appendix A. The fact that this rock has, in general, passed such tests is probably due to the interlocking texture of plagioclase and pyroxene crystals. This texture provides a rigid framework, even though the interstitial glass, opal, hydrated iron oxides, and smectite are all either brittle or soft.

#### Aggregate

Crushed aggregate manufactured from the Dovre Peak quarry, however, is subject to remarkably rapid degradation, both in stockpile and in the base course. Dovre Peak aggregate has been used in the base course and paving of the Nestucca Access Road. The most recent paving of 22 miles of the road was completed in 1969, and failures caused by degradation of the base course began to appear in the spring of 1970. The Nestucca Access Road has been repaired a number of times in the past 4 years. During the past two years, parts of the road developed extensive chuck holes and suffered



Figure 8. Nestucca Access Road below McMinnville reservoir. Water-filled breaks in paving showing base aggregate failure. October, 1973.

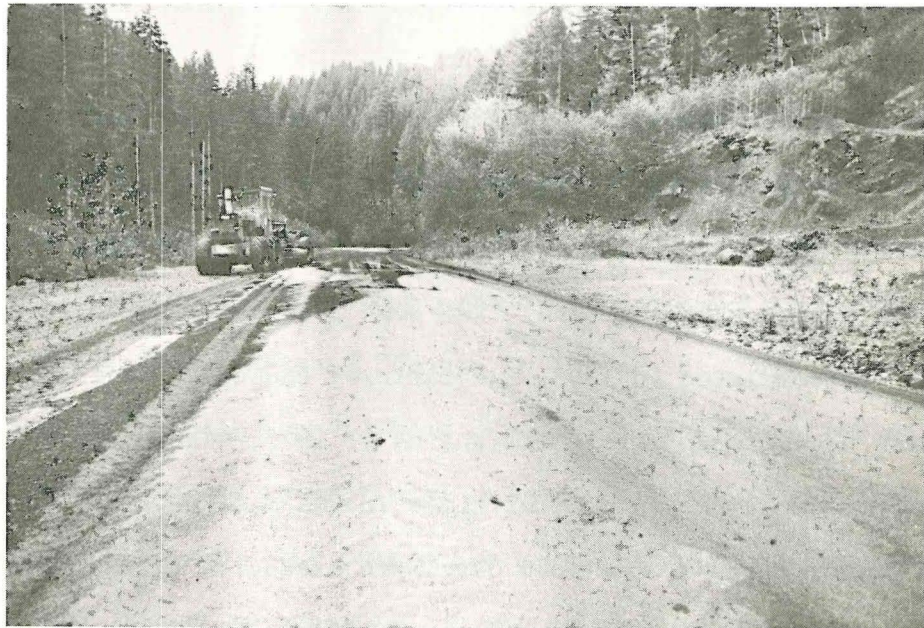


Figure 9. Nestucca Access Road at Davidson quarry. Grader scarifying and grading deteriorated section of road, October, 1973.

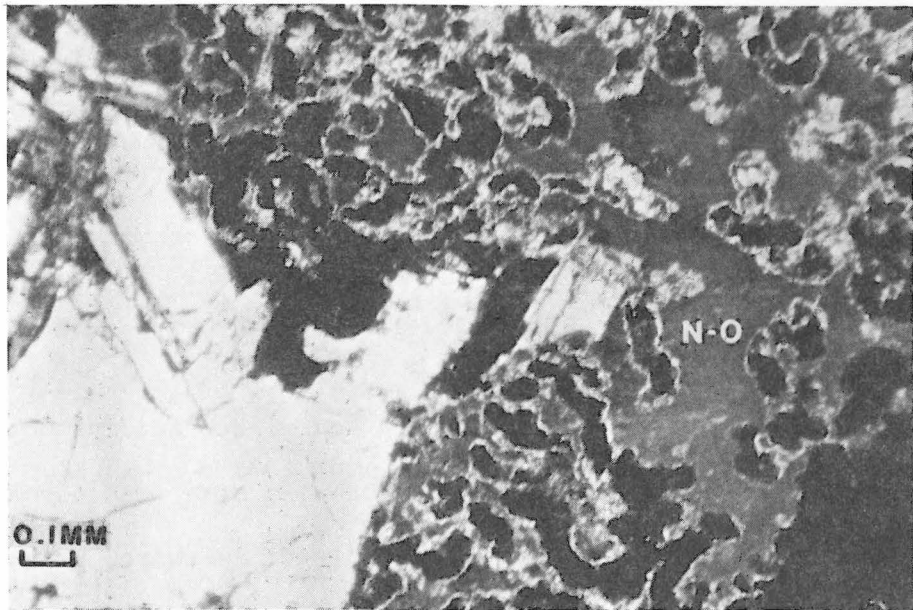


Figure 10. Photomicrograph. Aggregate from crusher site, Dovre Peak quarry, showing vermicular nontronite development in opal (N-O). Ordinary light.



Figure 11. Photomicrograph. Aggregate from crusher site, Dovre Peak quarry, showing nontronite in fibrous zeolite, (N-Z), in chalcedony (crossed polars).

general deterioration. In the summer of 1973, the worst stretches of road were scarified and regraded without resurfacing (Figures 8 and 9). At one of these sites, a sample taken from the scarified section (29-0008.8) revealed that the aggregate had degraded to the consistency of a pebbly, sandy soil.

A number of samples were taken of the Dovre Peak quarry rock to include aggregate from the crusher site, a stockpile site, and several parts of the base course of the Nestucca Access Road. Microscopic and X-ray examination of this aggregate in various stages of degradation reveals that smectite clay, mainly nontronite, has developed in the interstitial areas and vesicle fillings within the framework of plagioclase and pyroxene crystals. Except for minor alteration of plagioclase, this framework is generally fresh and unaltered. No palagonite remains and hydrated iron oxide is always more abundant in the degraded rock than in the quarry rock. Relative percentages of aggregate from various locations are given in Appendix C.

Aggregate taken from the crusher site at the Dovre Peak quarry showed extensive development of nontronite in the interstitial brownish opal and microcrystalline areas (Figure 10). Hydrated iron oxide is more abundant in the microcrystalline material. Some fibrous zeolite or chalcedony (Figure 11) is present in occasional patches which appear to be vesicle or fracture fillings. A little calcite fills some vesicles



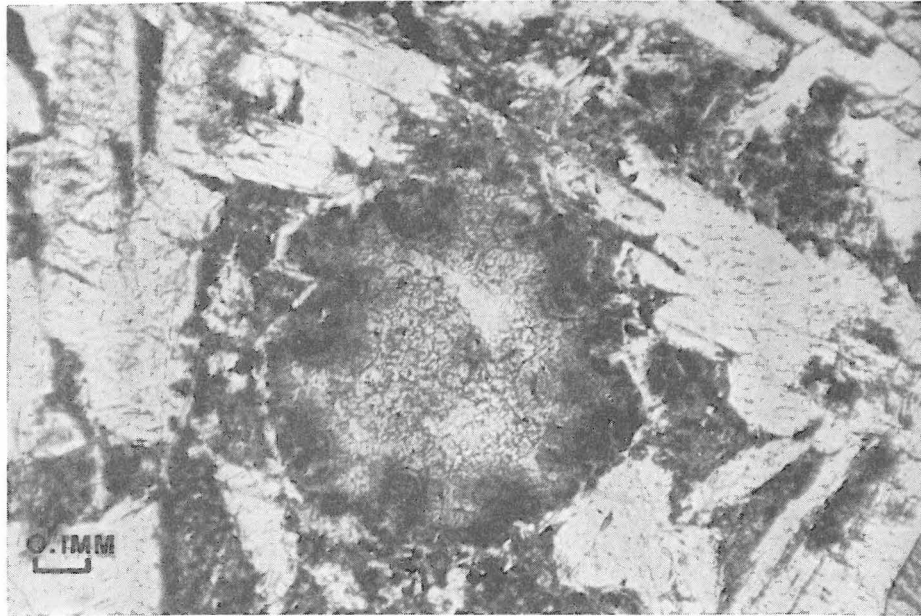


Figure 12. Photomicrograph. Degraded aggregate from scarified section of Nestucca Access Road. Vermicular and spherulitic nontronite, hydrated iron oxide, calcite and opal filling vesicle (center) and interstices between plagioclase laths (white). Ordinary light. (Site of sample 29-0008.8)



Figure 13. Photomicrograph. Degraded aggregate from base course of Nestucca Access Road. Extensive development of fibrous and scaly nontronite, (N), and hydrated iron oxide in what has been microcrystalline interstitial aggregates of feldspar (white laths), iron oxide and glass. No glass remains. Crossed polars. (Site of sample 29-0008.12)



Figure 14. Photomicrograph. Plagioclase laths, (P), (white) with smectite alteration throughout. Central area - fibrous nontronite, (N), surrounded by hydrated iron oxide (black). Same location as Figure 13. Crossed polars.



Figure 15. Photomicrograph. Fibrous zeolite and chalcedony, (Z-C), with plagioclase, (P), altered to smectite (white laths with dark central areas) and fresh pyroxene (gray crystals) (PY). Same location as Figure 12. Crossed polars.

also. Alteration products in the samples studied shown an increase of up to 100 percent over the amount of alteration present in the quarry rock. Most of this increase is due to the development of nontronite. X-ray diffractograms of the aggregate from the former stockpile site on Cedar Creek Road show that almost all of the newly-formed alteration material present is nontronite.

Samples of degraded base course aggregate from the Nestucca Access Road contain from 8 to 22 percent more alteration products, mostly nontronite. The major difference between the degraded base aggregate and the rock in Dovre Peak Quarry is due to the presence of well-crystallized nontronite. It is associated with and colored by hydrated iron oxides. Interstitial areas and vesicle fillings which have palagonite or opal in the quarry rock are altered the most. No palagonite is present in the degraded base aggregate. The nontronite has developed as a vermicular or spherulitic growth in the palagonite or opal (Figures 12 and 13). Smectite, probably montmorillonite, has developed along fractures and internally in some plagioclase feldspar (Figure 14). Pyroxenes are surprisingly fresh which is probably due to the relatively rapid rate of alteration in palagonite and opal as compared to slower chemical reactions necessary for alteration of plagioclase and pyroxene. Other alteration products, which may or may not be developed in the aggregate after quarrying and crushing, include fibrous zeolite and chalcedony. (Figure 15).

Selected rock fragments from the base aggregate were sound enough so that



Figure 16. Photomicrograph. Degraded aggregate from asphalt paving core, Nestucca Access Road. Spherulitic and vermicular nontronite (N), and hydrated iron oxide. Crossed polars.



Figure 17. Photomicrograph. Olivine gabbro, Bible Creek quarry. Fresh pyroxene (PY) and plagioclase (P) with nontronite and hydrated iron oxide (black central area). Two small crystals of olivine (O) are rimmed with hydrated iron oxide and chlorophaeite (black). Analcite (A)? occurs in one small irregular fracture. Crossed polars.

thin sections could be made from them. The degree of alteration would necessarily be much greater in thoroughly degraded rock than it was in these fragments so that percentages reported in Appendix C are minimal. In the case of Sample 29-0008.8, from the Nestucca Access Road, the base course degraded and developed a clay-layer under the paving. X-ray diffractograms reveal that this clay is nearly 100 percent nontronite, with minor chlorite. Samples of aggregate taken from the asphalt paving (29-0008.11A and Figure 16) show nearly as much nontronite and hydrated iron oxide alteration as that found in samples of base aggregate under the paving.

In summary, the chief deleterious alteration product in the rock taken from the Dovre Peak quarry is nontronite. However, it is probable that more than one smectite is present. It appears that the development of nontronite and perhaps, other smectite is accelerated by reducing the rock to a crushed aggregate and by alternatively wetting and drying it. A small amount of nontronite, initially formed by hydrothermal alteration of glass and opal, continues to form throughout the glassy or opaline portions of the rock. Unfortunately, little is known concerning the development of nontronite by the weathering processes. Williams and others (1954, p. 44) point out that sideromelane (and presumably palagonite) is altered to nontronite under conditions of poor drainage and pH greater than 7. Hay and Iijima, 1968, state that nontronite is formed with palagonite in Hawaiian basaltic tuffs. However, what needs to be known is the degree and nature of intermineral

chemical reactions which must take place within the rock during weathering and incipient degradation. A knowledge of these reactions will make it possible to devise tests for the presence of the mineral combinations which cause degradation and road failure.

## Bible Creek Quarry and Aggregate

### Quarry Rock

The quarry rock is an olivine gabbro, which in some parts contains near perfectly formed crystals of plagioclase and pyroxene. The olivine is mostly altered deuterically along fractures to chlorophaeite with much hydrated iron oxide, leaving remnant fragments of olivine separated by deep yellow-brown material (see Figure 17). Pyroxene and plagioclase are generally quite fresh and unaltered. There appears to be a small amount of fibrous zeolite. Some non-fibrous isotropic material is probably analcite (see Figure 17). The X-ray diffractograms of alteration products do show a small 3.43 angstrom peak, which is the strongest analcite peak.

Pale green lamellar to fibrous montronite is found in small patches associated with a small amount of chlorite and montmorillonite. Altogether, the rock does not show much alteration. Deuteric minerals, including 10 percent smectite, make up only 17 percent of the total volume. Most of the deuteric minerals form an intimate mixture.

### Aggregate

Aggregate pieces taken from under the paving on the Bible Creek Road are quite sound, with a little iron-oxide discoloration. Edges of these



Figure 18. Photomicrograph. Base course aggregate, Bible Creek Road. Large, dusty patch of analcite, fresh pyroxene (PY) and plagioclase (P) with a little nontronite. Ordinary light.

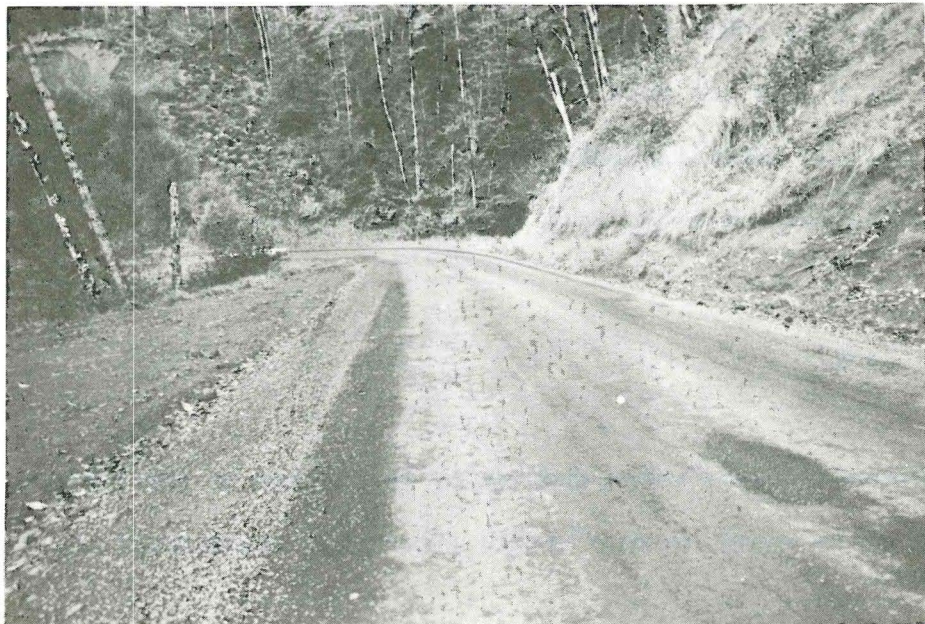


Figure 19. Bible Creek Road showing present condition.



pieces are sharp and angular to slightly rounded. At the point sampled, the base aggregate shows almost no sign of degradation. In coring the paving and base course, almost no clay-size material, other than cuttings, was generated, indicating the sound condition of the rock. In thin sections (Figure 18), the aggregate shows a large amount of a dusty brown or gray optically isotropic material filling interstitial areas and replacing some plagioclase feldspar. Point counting reveals that 29 percent of the rock is composed of this dusty brown or gray material, and X-ray diffractograms reveal a large percentage of analcite in the alteration products. It is probable that most of the dusty brown to gray material is analcite.

Aggregate pieces taken from the core cut in the asphalt paving have the same amount of alteration material (17 percent) as the quarry rock itself. Also, some nontronite and dusty brown to gray alteration is present. Some of this is probably analcite, although an X-ray diffractogram was not run on the sample to confirm this estimate. Small grains of olivine have been altered to iddingsite, nontronite and chlorite along fractures and around their borders. The Bible Creek Road, completed in 1969, is still in good condition and shows no signs of serious degradation of the base course (Figure 19). The paving has been spot repaired in 1971 and 1972.

The presence of analcite appears to bear some special relationship to the sounder condition of the base course aggregate, compared to the rock taken from the Dovre Peak quarry. The other deuteric and secondary alteration products are similar except in quantity to those of the Dovre Peak rock.



Figure 20. Photomicrograph. Bald Mountain quarry rock showing palagonite altered to nontronite, (P-N), and hydrated iron oxide (large black area near center). Note fresh laths of plagioclase, (P), and gray crystals of fresh pyroxene, (PY). Crossed polars.



Figure 21. Bald Mountain Access Road, October 1973.

The significance of analcite is discussed later in this report.

## Bald Mountain Quarry and Aggregate

### Quarry Rock

The rock in the Bald Mountain quarry, like that in the other three quarries, is a mixture of relatively fresh plagioclase feldspar, pyroxene, magnetite - ilmenite and more or less altered volcanic glass (Figure 20). The alteration of the glass, which is partly palagonite, includes considerable hydrated iron oxide and smectite, usually intimately mixed. Most of the smectite is nontronite which occurs as fibrous to lamellar aggregates. Alteration may vary from as much as 22 percent near the surface to 9 percent deeper in the rock unit. (Appendix C).

X-ray diffractograms reveal that analcite is a prominent mineral included in the deuteric alteration products. Analcite, not readily apparent in thin sections of the quarry rock, may be present as vesicle and fracture filling or included in the altered glass and masked by the iron oxide.

### Aggregate

Like the Bible Creek Road, the Bald Mountain Road has remained in generally good condition since completion in 1966 and sealing in 1971. Presently, the road is beginning to show a few signs of degradation of the base course

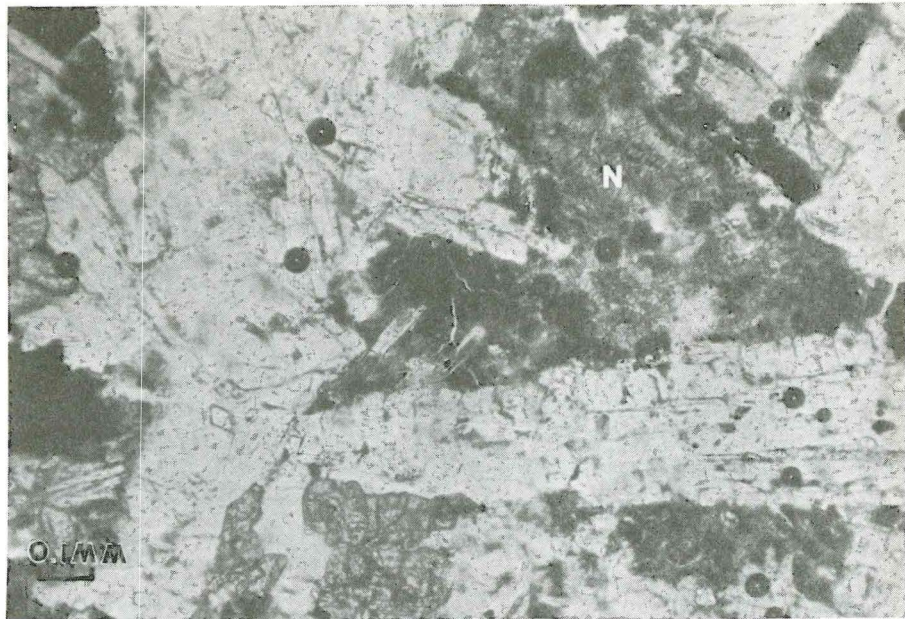


Figure 22. Photomicrograph. Base aggregate, Bald Mountain Access Road. Dark area is fibrous and spherulitic nontronite (N) with hydrated iron oxide alteration of original initial palagonite. Ordinary light.

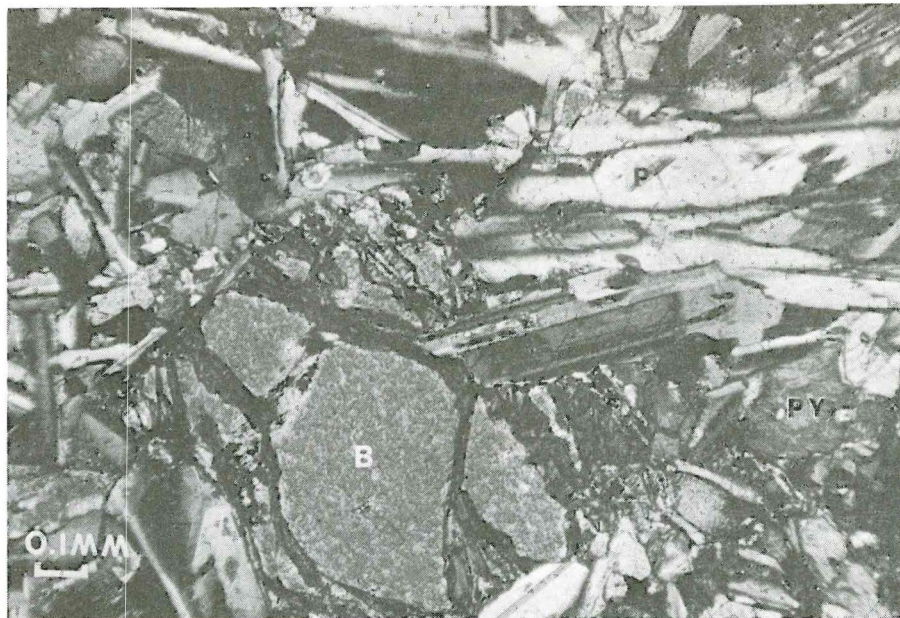


Figure 23. Photomicrograph. State quarry rock. Large olivine crystal altered completely to bowlingite (B) (dark gray), nontronite and chlorite (fibrous and granular surrounding material). Laths of plagioclase (P) and crystals of pyroxene (PY) are unaltered and fresh. Crossed polars.

aggregate (Figure 21). Thin sections of base aggregate rock reveal that hydrated iron oxide and fibrous green nontronite are more abundant than in the quarry rock. (Figure 22 and Appendix C).

Curiously, the X-ray diffractograms of the base aggregate do not show any analcite, although it is the most conspicuous component in the diffractograms of the alteration products in the quarry rock. This lack is not easy to understand, unless analcite was selectively leached from the base aggregate. The fact that analcite is present in the quarry rock and that the base aggregate manufactured therefrom has not shown any extensive degradation may still, however, be significant.

## State Quarry and Aggregate

### Quarry Rock

Rock taken from the "State" quarry has degraded severely in service as base course aggregate. Parts of the Nestucca Access Road east of McMinnville reservoir developed extensive failure of the base aggregate and had to be resurfaced in 1971. The quarry rock shows as much as 24 percent deuteric alteration products, including celadonite, nontronite chlorite, hydrated iron oxide and a very small amount of fibrous zeolite. Less than one percent of bowlingite is present, having almost completely replaced the olivine (Figure 23). Plagioclase and pyroxene are relatively fresh. Joint surfaces are coated with a few mm of shiny to dull black, extremely brittle material which is mostly smectite. This material bears a superficial resemblance to serpentine, including some slickensiding. Very dark yellow brown, faintly fibrous, and pleochroic, this mineral appears to be a mixture of hydrated iron oxide and montmorillonite or saponite. It is an alteration product after palagonite which, also, is present in thin sections of the rock. X-ray diffractograms of the quarry rock reveal a large amount of nontronite.

### Aggregate

A core was taken from the paving and base aggregate of a section of the



Figure 24. Section of road above McMinnville Reservoir,  
site of sample 36-0007.1.

Nestucca River Access Road east of the McMinnville Reservoir. The amount and type of alteration evident in this section did not, however, differ significantly from that present in the quarry rock. (See Appendix C, Sample No. 36-0007.1). There is some doubt that the core was representative of aggregate from the State quarry because recent resurfacing in 1971 may have been done with aggregate from some other quarry. Also, this section of road is in good condition at the present time. (Figure 24).



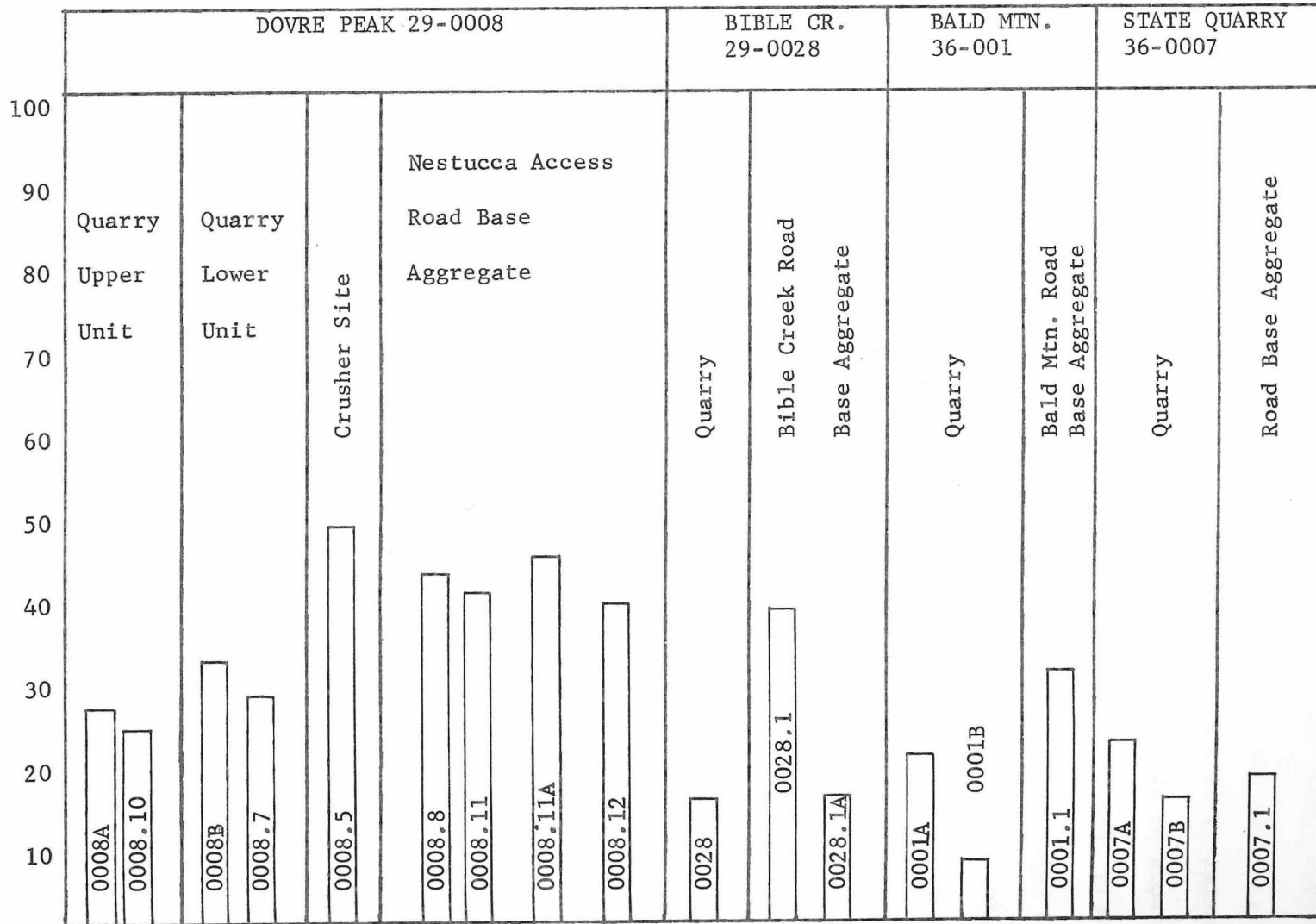


Figure 25. Comparative degree of alteration of quarry rocks and aggregates Nestucca River Area

## SUMMARY

The mineralogy of the four quarry rocks is quite similar. Relative percentages of alteration in all rocks studies is shown in Figure 25. Relatively fresh calcic plagioclase feldspar makes up from 35 to 50 percent of most samples studied. Generally fresh pyroxene, which may be augite, pigeonite, or both, accounts for 21 to 29 percent. Iron and titanium oxides (magnetite-ilmenite) account for 2 to 12 percent. Unaltered volcanic glass forms as much as 8 percent of the rock or may be absent. Alteration products, formed chiefly from interstitial microcrystalline aggregates of glass, feldspar and pyroxene, accounts for 9 to 25 percent of the volume of the rocks.

Hydrated iron oxide is ubiquitous, as is smectite clay. The smectite is mostly nontronite, sometimes accounting for as much as 12 percent of the volume of the rock. Notable variations in this general composition are due to the presence of fibrous zeolite in all quarry rocks but the Bald Mountain quarry which contains analcite. Opal is also present in some quarry rocks but not in others.

Aggregates manufactured from the four quarries studied were similar in composition in terms of plagioclase feldspar. It made up as little as 18 percent of the aggregate from the Dovre Peak quarry crusher site to as much as 29 to 48 percent in aggregate from the base course of the roads sampled. In general, feldspar seems to survive weathering quite

well, except for aggregate from the Dovre Peak crusher site. Pyroxene also resists weathering well. It is present in about the same percentages in both the quarry and in the base rock. (See Appendix C for specific percentages in quarry rock and aggregate).

Secondary alteration minerals are also generally the same in each aggregate manufactured from the four quarries (see Appendix C). The only essential difference in mineral content from that of the quarry rocks is that glass (palagonite or sideromelane) does not survive but is almost totally altered to smectite and hydrated iron oxides. Otherwise, the differences between alteration in the aggregate, as compared to that in the source rocks, is simply in quantity of secondary minerals. The common alteration products of these aggregates studied include hydrated iron oxides, nontronite, chalcedony, chlorite, opal, and, in the case of the Bible Creek Road, analcite.

## CONCLUSIONS

It is clear that the alteration of the aggregate in stockpile or in service on these three roads is a further development of certain combinations of secondary minerals already present in the respective quarry rocks. These minerals are smectites, chiefly nontronite, and hydrated iron oxide, formed by further alteration of volcanic glass and/or opal.

The increase in secondary minerals is especially evident in the case of the aggregate manufactured from the Dovre Peak quarry. Nontronite, for example, amounted to only 4 percent of the volume of the lower basaltic rock unit in the quarry, whereas, it can make up as much as 39 percent of the volume of the aggregate sampled from the base course of the Nestucca Access Road. However, the total percentage of alteration by itself is not a sufficient indicator of potential durability, as has been suggested by some workers (Smith, 1967). There is little difference in the total volume percentage of deuteric and secondary alteration products, as compared with that from the Dovre Peak quarry, in the base course aggregate from the Bible Creek quarry. (Figure 25). Nor is the relative percentage of a single deleterious mineral such as nontronite a clear cut indicator of potential durability. This can be easily seen by comparing the volume percentage of nontronite in quarry rock and aggregate from the Bible Creek, Bald Mountain and State quarries. In these rocks, nontronite is actually present in lower relative percentages in the aggregate in road base courses

as compared with rock in the quarry (see Appendix C).

Little degradation occurred in the rock of the Bald Mountain quarry and in the aggregate from the Bible Creek quarry which contain abundant analcite. In contrast, the Dovre Peak quarry aggregate, which degraded, contained no analcite. In the base aggregate from the Bible Creek Road, which did not degrade, analcite makes up 72.5 percent of the total alteration. The balance of the alteration products is mostly nontronite, which is present in about the same percentages in both the aggregate and the quarry rock.

Analcite (See Appendix C) is a sodium and aluminum silicate which is quite commonly formed in several different types of rocks. Analcite is very common in hydrothermally altered volcanic rocks, such as the basalts involved in this present study. It commonly forms from the alteration of volcanic ash deposits, both by heated waters and by cold ground waters involved in chemical reactions which attend weathering.

Hay (1966, p. 77, 78) points out that the formation of zeolites, including analcite, depends upon the ratio of base cations (e.g.,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ) to hydrogen ions. Analcite has formed at the expense of montmorillonite in some environments, such as Searles Lake, California, the lake deposits of the Eocene Green River Formation of Wyoming and the Olduvai Gorge of central East Africa. It must be noted, however, that these

environments were probably more alkaline than the environment of hydrothermally altered basalt.

Although, at this point of investigation, specific chemical reactions and environmental conditions cannot be stated, it is very probable that the presence of analcite in these basaltic rocks either inhibits the further development of smectites, as in the Bald Mountain Quarry rock, or it forms at the expense of smectite, as may be the case in the Bible Creek aggregate.

Apparently, the combination of alteration products present in the quarry rocks continues to develop at the expense of any volcanic glass, generally palagonite. (Compare percentages of nontronite in quarry rock samples with percentages of nontronite in aggregate manufactured from Dovre Peak Quarry in Appendix C table.)

With a more precise knowledge of the relative abundance of particular species of smectites, hydrated iron oxide and zeolites, it would be possible to devise tests to assess potential durability of rock such as these. Cation exchange capacity (CEC), for example, could very likely be used as a basis for a simple test because the CEC of specific smectite minerals and of zeolites is different so that their relative abundance could be measured. Additional knowledge of relative abundances of specific minerals could be gained by chemical analysis of whole rock samples and by calculation of normative minerals.

The mode of occurrence of a particular rock body, determined by its relationship to surrounding rock units in the field, is an important indicator of the origin of the rock and its probable mineralogy. Basaltic rock bodies in the Nestucca River area are either submarine lava extrusions, subaerial lava flows or intrusives formed at some time after the deposition of the Nestucca Formation sediments (upper Eocene). Submarine lava flows are subject to extensive hydrothermal alteration and subsequent development of deuteric alteration products. In addition, sudden chilling produces volcanic glass, often palagonite, in vesicles and interstices between framework mineral crystals. Subaerial lava flows and intrusive igneous rocks may not be so extensively altered. Thus, the mode of occurrence can be an important clue as to the extent of rock alteration and potential durability. Additional field investigation could establish the mode of origin of rock bodies used for aggregate.

Correlation of these findings with similar aggregate source rocks in other regions of western Oregon and Washington should be attempted to establish general criteria for recognition of potentially bad materials. Then specific tests could be devised to detect deleterious mineral combinations.

It is evident from this initial investigation that chemical reactions produce minerals which cause the degradation of aggregate and base course failure. Therefore, tests which assess chemical durability are as important as tests which evaluate mechanical durability.

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APPENDIX A

AGGREGATE REPORTS

AGGREGATE REPORT

DOVRE PEAK QUARRY 35-29-0008

| Field Sample No.            | 2         | 10       | 1        | 6     | 5        | 4        | 3        | 2        | 1        | Crush.   | Rd. Bd. | Rd. Bd. | Rd. Bd. | Rd. Bd. |
|-----------------------------|-----------|----------|----------|-------|----------|----------|----------|----------|----------|----------|---------|---------|---------|---------|
|                             | AG        | AG       | AG       | AG    | AG       | AG       | AG       | AG       | AG       | 1        | 2       | 3       | 4       | 5       |
| Depth                       | GRAB      | 0-52'    |          | 0-81' | 0-80'    | 0-80'    | 0-79'    | 0-90'    | 0-50'    | 0-4"     | 0-4"    | 0-4"    | 0-4"    | 0-4"    |
| Plasticity Index            | Nat. Mfg. | NP       | NP       | NP    | NP       | NP       | NP       | NP       | NP       | NP       | NP      | NP      | NP      | NP      |
| Liquid Limit                | Mfg.      | 21       | NP       |       | NP       | NP       | NP       | NP       | NP       | NP       | NP      | NP      | NP      | NP      |
|                             | Nat.      | .        | .        | .     | .        | .        | .        | .        | .        | 22       | NP      | NP      | NP      | NP      |
| Sand Equivalent             | Mfg.      | 48       | 52       | .     | 56       | 49       | 53       | 58       | 55       | 64       | .       | .       | .       | .       |
|                             | Nat.      | .        | .        | .     | .        | .        | .        | .        | .        | .        | 35      | 37      | 30      | 45      |
| Durability Coarse           |           | 60       | 57       | 23    | 60       | 48       | 54       | 50       | 50       | 50       | 67      | .       | .       | .       |
| Durability Fine             |           | .        | .        | 29    | .        | .        | .        | .        | .        | .        | 30      | .       | .       | .       |
| Specific Gravity            | LE. CHL.  | 2.86     | 2.82     | .     | 2.86     | 2.82     | .        | 2.84     | 2.86     | 2.86     | .       | .       | .       | .       |
| Asphalt Strip Pct.          |           | Above 95 | Above 95 | .     | Below 95 | Above 95 | Above 95 | Above 95 | Above 95 | Above 95 | .       | .       | .       | .       |
| Sulfate Soundness Pct. Loss |           | 27       | 12       | .     | 12       | 25       | 6        | 10       | 21       | 20       | .       | .       | .       | .       |
| L.A. Abrasion Pct. Loss     |           | 26       | 24       | 29    | 24       | 24       | 23       | 23       | 25       | 30       | .       | .       | .       | .       |
| Design R Value              |           | .        | .        | .     | .        | .        | .        | .        | .        | .        | 73      | 71      | 78      | 71      |
|                             |           | .        | .        | .     | .        | .        | .        | .        | .        | .        | .       | .       | .       | 72      |

AGGREGATE REPORT

BIBLE CREEK QUARRY 35-29-0028

|                          |          |          |           |          |          |          |         |           |               |          |        |   |         |         |                |
|--------------------------|----------|----------|-----------|----------|----------|----------|---------|-----------|---------------|----------|--------|---|---------|---------|----------------|
| Field Sample No.         | : 2      | : 3      | : AG<br>4 | : 1      | : 2      | : 5      | : 4     | : 3       | : RIB         | :        | : ATE  | : | :       | : RB    | : ATE          |
|                          | :        | :        | :         | :        | :        | :        | :       | :         | : 17-V        | : D-1    | : 36-3 | : | : D-6-V | : D-5-V | : 70-V : 36-13 |
| Depth                    | : 0-120' | : 0-120' | : Surf.   | : 14-53' | : 10-95' | : 12-91' | : 7-16' | : 95-173' | :             | :        | :      | : | :       | :       | :              |
| Plasticity Index Nat.    | :        | :        | :         | :        | :        | :        | :       | :         | : NP          | :        | :      | : | : NP    | : NP    | : NP           |
| Plasticity Index Mfg.    | : NP     | : NP     | : NP      | : NP     | : NP     | : NP     | : NP    | : NP      | :             | :        | :      | : | :       | :       | :              |
| Liquid Limit Nat.        | :        | :        | :         | :        | :        | :        | :       | :         | : NP          | :        | :      | : | : NP    | : NP    | : NP           |
| Liquid Limit Mfg.        | : NP     | : NP     | : NP      | : NP     | : NP     | : NP     | : NP    | : NP      | :             | :        | :      | : | :       | :       | :              |
| Sand Equiv. Nat.         | :        | :        | :         | :        | :        | :        | :       | :         | : 28          | :        | :      | : | :       | :       | :              |
| Sand Equiv. Mfg.         | : 70     | : 66     | : 70      | : 32     | : 75     | : 65     | : 72    | : 66      | : SE as Recd. | : Moist. | : 51   | : | : 48    | : 54    | :              |
| Durability Coarse        | : 82     | : 82     | : 74      | : 23     | : 70     | : 71     | : 78    | : 70      | :             | :        | :      | : | :       | :       | :              |
| Durability Fine          | : 65     | : 63     | : 64      | : 27     | : 54     | : 42     | : 59    | : 51      | :             | :        | :      | : | :       | :       | :              |
| Specific Gravity Le.Chl. | : 2.87   | : 2.65   | : 2.73    | : 2.69   | : 2.86   | :        | : 2.88  | : 2.79    | :             | : 2.92   | :      | : | :       | :       | :              |
| Asphalt Strip Pct        | : Below  | : Below  | : Above   | : Below  | : Below  | : Below  | : Below | : Below   | :             | :        | :      | : | :       | :       | :              |
|                          | : 95     | : 95     | : 95      | : 95     | : 95     | : 95     | : 95    | : 95      | :             | :        | :      | : | :       | :       | :              |
| Sulfate Sound Pct. Loss  | : 11     | : 15     | : 9       | :        | :        | :        | :       | :         | :             | :        | :      | : | :       | :       | :              |
| LA, Abras. Pct. Loss     | : 17     | : 18     | : 19      | : 49     | : 19     | : 21     | : 18    | : 21      | :             | :        | :      | : | :       | :       | :              |
| Vol. Swell Pct.          | :        | :        | : 0.8     | : 0.1    | :        | :        | : 0.1   | :         | :             | :        | :      | : | :       | :       | :              |

AGGREGATE REPORT

| BALD MOUNTAIN QUARRY     |       |        |          |       |       |          |          |      |            |      | 35-36-0001     |  |
|--------------------------|-------|--------|----------|-------|-------|----------|----------|------|------------|------|----------------|--|
| Field Sample No.:        | 10    | 11     | 12       | 13    | 17    | 1A       | 2A       | 1    | 5          | 1    | From Stockpile |  |
| Depth                    | 8-72' | 22-69+ | 0-80'    | 0-50' | 0-46' | GRAB     | GRAB     |      | Roadwy. 5" |      |                |  |
| Plasticity Index Nat.    |       |        |          |       |       |          |          | NP   | NP         | NP   | NP             |  |
| Plasticity Index Mfg.    | NP    | NP     | NP       | NP    | NP    | NP       | NP       |      |            | NP   |                |  |
| Liquid Limit Nat.        |       |        |          |       |       |          |          | NV   | NV         | NP   | NP             |  |
| Liquid Limit MFG.        |       |        |          |       |       |          |          |      |            | NP   |                |  |
| Sand Equivalent Nat.     |       | 34     |          |       |       |          |          | 51   | 33         | IM   | 51             |  |
| Sand Equivalent Mfg.     | 47    | 69     | 27       | 37    |       | 42       | 44       |      |            | 61   |                |  |
| Durability Coarse        | 62    | 63     | 62       | 68    | 66    | 41       | 82       |      |            | 62   | 66             |  |
| Durability Fine          | 46    | 34     | 36       | 46    | 38    | 43       | 40       |      |            | 39   | 45             |  |
| Specific Gravity Le.Chl. | 2.82  | 2.82   | 2.80     | 2.80  |       | 2.69     | 2.83     | 2.87 |            | 2.87 |                |  |
| Asphalt Strip Pct.       |       |        | Above 95 |       |       | Above 95 | Above 95 |      |            |      |                |  |
| Sulfate Snd. Pct. Loss   |       |        |          |       |       | 36       | 14       |      |            |      |                |  |
| LA. Abras. Pct. Loss     | 26    | 29     | 20       | 24    | 23    | 48       | 31       | 30   |            | 32   |                |  |

AGGREGATE REPORT

STATE QUARRY 35-36-0007

| Field Sample No.      | N-1A     | N-1B     | N-1C     | N-1D | N-1E | N-1F     |
|-----------------------|----------|----------|----------|------|------|----------|
| Depth                 |          |          |          |      |      |          |
| Plasticity Index Mfg. | NP       | NP       | NP       | NP   | NP   | NP       |
| Liquid Limit Mfg.     | NV       | NV       | NV       | NV   | NV   | NV       |
| Sand Equiv. Mfg.      | 60       | 50       | 42       | 53   | 62   | 35       |
| Durability Coarse     | 67       | 70       | 53       | 52   | 68   | 68       |
| Durability Fine       | 41       | 44       | 40       | 37   | 44   | 33       |
| Spec. Grav. Le.Chl.   | 2.89     | 2.89     | 2.85     | 2.94 | 2.89 | 2.84     |
| Asphalt Strip Pct.    | Below 95 | Below 95 | Above 95 |      |      | Above 95 |
| Sul. Snd. Pct. Loss   | 13       | 8        | 18       | 16   | 14   | 17       |
| LA. Abras. Pct. Loss  | 29       | 33       | 35       | 33   | 34   | 33       |

APPENDIX B

PETROGRAPHIC ANALYSES OF 21  
SAMPLES OF QUARRY ROCK FROM  
WESTERN OREGON

Explanation:        35 - volume percentage of whole rock.  
                      (15) - volume percentage included in total alteration.  
                      x - present, percentage not determined.  
                      ? - not positively identified.  
                      T - trace; one or two counts.

-47-

|                                  | 35<br>03-0007 A | 35<br>03-0007 B | 35<br>06-0016 | 35<br>06-0021 A | 35<br>06-0021 B | 35<br>06-0028 | 35<br>10-0001 | 35<br>10-0250 | 35<br>10-0257 | 35<br>10-0265 | 35<br>15-0065 A | 35<br>20-0009 | 35<br>29-0006 | 35<br>29-0040 | 35<br>36-0043 |
|----------------------------------|-----------------|-----------------|---------------|-----------------|-----------------|---------------|---------------|---------------|---------------|---------------|-----------------|---------------|---------------|---------------|---------------|
| Primary Minerals                 |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               |               |               |
| Plagioclase                      | 38              | 32              | 45            | 27              | 26              | 21            | 20            | 24            | 33            | 26            | 43              | 47            | 37            | 42            | 38            |
| F-Fresh, A-Alt.                  | F,A             | F,A             | F,A           | F               | (F)A            |               |               |               |               |               | A               |               | A             | F(A)          |               |
| Pyroxene                         | 24              | 11              | 26            | 39              | 35              | 26            | 5             | 25            | 8             | 35            | 9               | 10            | 24            | 22            | 21            |
| Augite                           |                 |                 |               |                 |                 |               |               | x             |               |               |                 |               |               |               |               |
| Hypersthene                      |                 |                 |               |                 |                 |               |               | x             |               |               |                 |               |               |               |               |
| Pigeonite                        | x               |                 |               |                 |                 |               |               |               |               |               |                 |               | x             |               |               |
| F-Fresh, A-Alt.                  |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               |               |               |
| Ilmenite - Mag.                  | 7               | 20?             | 4             | 4               | 4               | 7             | 1             | 5             | 5             | 7             | 3               | 5             | 6             | 14            | 6             |
| Olivine                          |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               | 2             |               |
| Glass                            |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               |               |               |
| Palagonite                       | 3               | --              |               |                 |                 |               |               |               |               |               |                 |               |               |               | ?13           |
| Other                            | 28              | 6               |               |                 |                 |               |               | 38            | 33            |               |                 |               | 4             |               |               |
| Altered Microcryst. Interstitial |                 |                 |               |                 |                 |               |               |               |               |               |                 |               | x             |               |               |
| Other Deuteric and Secondary     |                 | 30              | 25            | 28              | 35              | 47            | 26            | 9             | 20            | 33            | 45              | 35.5          | 30            | 20            | 23.5          |
| Hyd. Fe-ox.                      |                 | x               | x             |                 |                 |               |               |               | x             | x             |                 | 3             |               |               |               |
| Smectite                         |                 | x               |               |                 | x               | (29)          | (26)          | (6)           | (8)           | (20)          |                 | (15)          | (24)          |               |               |
| Nontronite                       |                 | ?               | x             |                 | ?               | (1)           |               | (1)           |               |               |                 |               |               | (20)          | (23)          |
| Montmorill.                      |                 |                 |               | x               |                 |               |               |               |               |               |                 |               |               |               |               |
| Saponite                         |                 |                 | ?             |                 | (24)            | ?             |               |               |               |               |                 |               |               |               |               |
| Chlorite                         |                 | x               | x             | x               | (11)            | (15)          |               |               |               | (13)          | xx              | (9)           | (1)           | ?             |               |
| Zeolite                          | ?               | (9)             | <1            |                 |                 | (3)           |               |               |               |               | x               |               |               | ?             | (0.5)         |
| Analcite                         |                 |                 |               |                 |                 |               |               |               |               | ?             | (2)             |               |               |               |               |
| Chalcedony                       |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               |               |               |
| Quartz                           |                 |                 |               |                 |                 |               |               | (2)           |               |               | (9)             | (1.5)         |               |               |               |
| Opal                             |                 |                 |               |                 |                 |               |               |               |               |               |                 |               |               |               |               |
| Calcite                          |                 |                 | <1            |                 |                 |               | (2)           |               | (1)           |               |                 |               |               |               |               |
| Pyrite                           |                 |                 |               | 1               |                 |               |               |               |               |               |                 |               |               |               |               |
| Devitrif. Glass                  |                 |                 |               |                 |                 |               | 48            |               | x             |               |                 |               | (5)           |               |               |
| Kaolinite                        |                 |                 |               |                 |                 |               |               |               | (9)           |               |                 |               |               |               |               |
| Actinolite                       |                 |                 |               |                 |                 |               |               |               |               |               | (34)            |               |               |               |               |
| "Other"                          |                 |                 |               |                 |                 |               |               |               |               |               |                 | (10)          |               |               |               |

APPENDIX C

Results of petrographic analyses of quarry rocks and aggregates manufactured therefrom:

| <u>Name</u>             | <u>Number</u> | <u>Location</u>   |
|-------------------------|---------------|---|
| 1. Dovre Peak quarry    | 35-29-0008    | Tillamook County, Oregon<br>Sec. 15, T.3S., R.7W.                     |
| 2. Bible Creek quarry   | 35-29-0028    | Tillamook County, Oregon<br>N.E.1/4, S.E.1/4, Sec. 7,<br>T.4S., R.7W. |
| 3. Bald Mountain quarry | 35-36-0001    | Yamhill County, Oregon<br>N.E.1/4, S.E.1/4, Sec. 29,<br>T.3S., R.6W.  |
| 4. State quarry         | 35-36-0007    | Yamhill County, Oregon<br>N.E.1/4, S.W.1/4, Sec. 16,<br>T.3S, R.6W.   |

Explanation:

35 - volume percentage of whole rock.

(15) - volume percentage included in total alteration.

x - present, percentage not determined.

? - not positively identified.

T - trace; one or two counts.



|                    |   | QUARRY           |                  |                  |                    | Crusher Site | Stock-pile Site | Nestucca Access Road Bed Aggreg. |                 |        |                 |          |            |                  |          |          |                  |   |
|--------------------|---|------------------|------------------|------------------|--------------------|--------------|-----------------|----------------------------------|-----------------|--------|-----------------|----------|------------|------------------|----------|----------|------------------|---|
|                    |   | Upper Unit       |                  | Lower Unit       |                    |              |                 |                                  |                 |        |                 |          |            |                  |          |          |                  |   |
| DOVRE PEAK ROCK    | 35-29-0008                                      | 0008A            | 0008.10          | 0008.10<br>X-Ray | 0008B              | 0008.7       | 0008.7<br>X-Ray | 0008.5                           | 0008.5<br>X-Ray | 0008.9 | 0008.9<br>X-Ray | 0008.8   | 0008.11    | 0008.11<br>X-Ray | 0008.11A | 0008.12  | 0008.12<br>X-Ray |   |
| Primary Components | Plagioclase A-Altered F-Fresh                   | 39%<br>An55<br>F | 35%<br>An47<br>A | x                | 39%<br>An69<br>F,A | 43%          |                 | 18%<br>x                         |                 |        | x               | 37%<br>F | 35%<br>F,A | x                | 29%<br>F | 32%<br>F | x                |   |
|                    | Pyroxene  | 22%              | 22%              |                  | 21%                | 23%          |                 | 27%                              |                 |        |                 | 17%<br>F | 21%<br>F,A |                  | 22%<br>F | 15%<br>F |                  |   |
|                    | Augite  | x                | x                |                  | x                  |              |                 |                                  |                 |        |                 |          |            |                  |          |          |                  |   |
|                    | Pigeonite                                       | x                | x                |                  | x                  |              |                 |                                  |                 |        |                 |          |            |                  |          |          |                  |   |
|                    | Ilmenite-Magnetite                              | 4%               | 9%               |                  | 4%                 | 4%           |                 | 5%                               |                 |        |                 | 2%       | 2%         |                  | 2%       | 12%      |                  |   |
|                    | Glass: Palagonite                               | 6%               | 8%               |                  | 2%                 |              |                 |                                  |                 |        |                 |          |            |                  |          |          |                  |   |
|                    | Micro-Crystalline Interstitial Plag, Pyr, Fe-ox | x                | x                |                  |                    | x            |                 |                                  |                 |        |                 |          |            |                  |          | x        |                  |   |
|                    | Deuteric and Secondary Components - Total       | 28%              | 25%              |                  | 33%                | 30%          |                 | 50%                              |                 |        |                 |          | 44%        | 42%              |          | 47%      | 41%              |   |
|                    | Hydrated Iron-Oxide                             | x                | x                |                  | x                  | (7%)         |                 | x                                |                 |        |                 |          | (4%)       | x                |          | (14%)    | (15%)            |   |
|                    | Smectite Nontronite Montmor.                    | x                | x                | x                | x                  | (7%)         | x               | x                                |                 |        |                 |          |            |                  |          |          |                  |   |
|                    |   | x                |                  |                  | x                  | (4%)         |                 | (39%)                            | xx              |        | xx              |          | (39%)      | (14%)            | xx       | (19%)    | (26%)            | x |
|                    |   | x                | (2-3%)           | x                | x                  |              | x               |                                  |                 |        |                 |          |            |                  |          |          |                  |   |
|                    | Chalcedony Opal                                 |                  |                  |                  |                    |              |                 |                                  |                 |        |                 |          |            | (22%)            |          |          |                  |   |
|                    |   |                  |                  |                  |                    | (12%)        |                 | (10%)                            |                 |        |                 |          |            | (6%)             |          |          |                  |   |
| Zeolite Chlorite   | (1%)  |                  |                  | (2%)             |                    |              | x               |                                  |                 |        |                 | (1%)     |            |                  |          |          |                  |   |
|                    |   |                  | x                |                  |                    |              | ?               | x                                |                 | x      |                 |          |            |                  |          |          |                  |   |
| Calcite Leucoxene  | (1%)  | T                |                  |                  |                    |              | T               |                                  |                 |        |                 |          |            |                  |          |          | x                |   |
|                    |   |                  |                  |                  |                    |              |                 |                                  |                 |        |                 | x        |            |                  |          |          |                  |   |

| BIBLE CREEK                               |                   | QUARRY |           | BIBLE CR. ROAD BED AGGREG. |          |          |
|---|-------------------|--------|-----------|----------------------------|----------|----------|
| QUARRY ROCK                               |                   |        |           |                            |          |          |
| 35-29-0028                                |                   |        |           |                            |          |          |
|   |                   | 0028   | 0028      | 0028.1                     | 0028.1   |          |
|   |                   | X-Ray  | X-Ray     | X-Ray                      | X-Ray    |          |
| Primary Components                        | Plagioclase       | 50%    | x         | 31%                        | x        | 48%      |
|   | A-Altered         |        |           |                            |          |          |
|   | F-Fresh           |        |           | F,A                        |          | F,A      |
|   | Pyroxene          | 29%    |           | 24%                        |          | 24%      |
|   | Augite            | x      |           |                            |          |          |
|   | Pigeonite         | ?      |           |                            |          |          |
|   | Olivine           | 2%     |           |                            |          | 7%       |
|   | Ilmenite-Magn.    | 3%     |           | 5%                         |          | 3%       |
|   | Glass             | T      |           | T                          |          |          |
|   | Microcrystalline  |        |           |                            |          |          |
|   | Interstitial      |        |           |                            |          |          |
|   | Plag.-Pyrox;Fe-Ox |        |           |                            |          |          |
| Deuteric and Secondary Components - Total |                   | 17%    |           | 40%                        |          | 17%      |
|   | Hydrated          |        |           |                            |          |          |
|   | Iron-Oxide        | x      |           | x                          |          | x        |
|   | Smectite          | x      |           |                            |          | x        |
|   | Nontronite        | (10%)  | x         | (8%)                       | x        | (5%)     |
|   | Montmor           | x      |           |                            |          | x        |
|   | Chlorophaeite     | x      |           | (3%)                       |          | ?        |
|   | Iddingsite        |        |           |                            |          | x        |
|   | Zeolite           | (2%)   | Analcite? | (29%)                      | Analcite | Analcite |
|   | Chalcedony        |        |           |                            | xx       | x        |
|   | Opal              |        |           | ?                          |          |          |
|   | Chlorite          | (5%)   |           |                            |          |          |
|   | Calcite           |        |           | x                          |          |          |

|   |                    | QUARRY      |         |            | BALD MTN. ROAD |        |
|---|--------------------|-------------|---------|------------|----------------|--------|
|   |                    | QUARRY ROCK |         |            | BED AGGREGATE  |        |
| 35-36-0001                                |                    | 0001A       | 0001B   | 0001       | 0001.1         | 0001.1 |
|   |                    |             |         | X-Ray      |                | X-Ray  |
| Primary Components                        | : Plagioclase      | : 52%       | : 59%   | : x        | : 49%          | : x    |
|   | : A-Altered        | : An 63     | : An 65 |            | : An 65        |        |
|   | : F-Fresh          | : F         | : F     |            | : F            |        |
|   | : Pyroxene         | : 18%       | : 20%   |            | : 12%          |        |
|   | : Ilmenite-        |             |         |            |                |        |
|   | : Magnetite        | : 7%        | : 8%    |            | : 6%           |        |
|   | : Glass            |             |         |            |                |        |
|   | : Palagonite       | : 0.5%      | : 1%    |            |                |        |
|   | : Apatite          | : 0.5%      |         |            |                |        |
|   | : Microcrystalline | : --        | : --    |            | : --           |        |
| : Interstitial                            |                    |             |         |            |                |        |
| : Plag-Pyr-Fe-Ox                          |                    |             |         |            |                |        |
| Deuteric and Secondary Components - Total | : Total            | : 22%       | : 11%   |            | : 33%          |        |
|   | : Hydrated         |             |         |            |                |        |
|   | : Iron Oxide       | : (2%)      | : (2%)  |            | : (18%)        |        |
|   | : Smectite         |             |         |            |                |        |
|   | : Nontronite       | : (20%)     | : (9%)  | : x        | : (15%)        | : xx   |
|   | : Montmor.         |             |         |            |                |        |
|   | : Zeolite          |             |         | : Analcite |                |        |
|   |                    |             | : xx    |            |                |        |

|   | STATE         | QUARRY |       |       | NESTUCCA ACCESS  |
|---|---------------|--------|-------|-------|------------------|
|   | QUARRY        | QUARRY |       |       | ROAD BED AGGREG. |
|   | ROCK          |        |       | 0007  | 0007.1           |
|   | 35-36-0007    | 0007A  | 0007B | X-Ray | 0007.1           |
| Primary Components                        | Plagioclase   | 47%    | 45%   | x     | 44%              |
|   | A-Altered     | An 54  | An 55 |       | An 52            |
|   | F-Fresh       | F      | F     |       | F                |
|   | Pyroxene      | 25%    | 33%   |       | 29%              |
|   | Augite        |        | x     |       | x                |
|   | Pigeonite     |        |       |       | x                |
|   | Olivine       |        | 2%    |       |                  |
|   | Ilmenite -    | 5%     | 4%    |       | 7%               |
|   | Magnetite     |        |       |       |                  |
|   | Glass         | --     | --    |       | x                |
| Deuteric and Secondary Components - Total |               | 24%    | 17%   |       | 20%              |
|   | Hydrated      |        |       |       |                  |
|   | Iron Oxide    | x      | x     |       | x                |
|   | Smectite      | x      |       |       | x                |
|   | Nontronite    | (12%)  | (6%)  | xx    | 9%               |
|   | Montmorillon. | (10%)  |       |       |                  |
|   | Zeolite       |        | x     | ?     |                  |
|   | Chlorophaeite | x      | (1%)  |       | x                |
|   | Bowlingite    |        | x     |       | x                |
|   | Celadonite    |        | (10%) |       | x                |
|   | Chalcedony    | x      |       |       | x                |
|   | Opal          |        |       |       |                  |
|   | Chlorite      | 2%     |       | x     | (11%)            |
|   | Calcite       |        |       |       |                  |

APPENDIX D

DEFINITIONS OF MINERALS

## APPENDIX D

### Definitions of Minerals

#### Analcite

A mineral with formula  $\text{Na}(\text{AlSi}_2\text{O}_6) \cdot \text{H}_2\text{O}$ . Analcite is considered to be closely related to feldspars in terms of structure, composition and modes of origin. It can, however, be included as a member of the zeolite group of minerals. (Deer et al., Vol. 4, p. 338). The occurrence of analcite in the rocks of this study is not well understood, but it is apparently present interstitially.

#### Augite

A mineral of the pyroxene group, formula  $(\text{Cu}, \text{Na}, \text{Mg}, \text{Fe}^{+2}, \text{Mn}, \text{Fe}^{+3}, \text{Al})_2 [(\text{Si}, \text{Al})_2\text{O}_6]$  (Deer et al., Vol. 2, p. 109). Under the microscope, augite is pale brown and stands out more prominently than does plagioclase. Augite is a common pyroxene and is present in all of the rocks of this study as a primary mineral. It appears to be somewhat more resistant to alteration than the type of plagioclase feldspar found in these rocks. It can be altered in severely weathered specimens to hydrated iron oxides and clay, but in most of the rocks studied, augite is quite fresh, even in severely degraded base course aggregate.

### Calcite

Calcium carbonate,  $\text{Ca CO}_3$ . A mineral formed in rocks studied in this report by deuteric alteration of minerals such as olivine, calcic plagioclase and, probably calcium-bearing glass. It tends to be found as vesicle fillings, but may also be included as one of the alteration minerals formed from interstitial glass.

### Celadonite

A bright-green, blue-green or yellow-green alteration product found in some of these basaltic rocks; formula -  $\text{K}_2 \text{Al}_2 \text{Mg}_2 \text{Si}_8 \text{O}_{20} (\text{OH})_4$  or  $\text{K}_2 \text{Mg}_2 \text{Fe}_2^+ \text{Si}_8 \text{O}_{10} (\text{OH})_4$  (Deer et al., 1962, Vol. 3, p. 217). Celadonite is essentially equivalent to glauconite, which is formed in marine sedimentary environments. It is a member of the illite group of clay minerals, celadonite has no swelling properties. Commonly, aggregate celadonite may have a narrow border of saponite.

### Chalcedony

The name "chalcedony" is used in this report to distinguish a fibrous variety of quartz found as interstitial or vesicle fillings or linings. Deer et al. (1963, Vol. 4, p. 209) use the name "chalcedony" to designate all the compact minutely crystalline varieties of quartz, including agate, chert and flint. Other workers, such as Kerr, (1959, p. 240), restrict

the term chalcedony to the fibrous variety of quartz. Chert is a microgranular variety of quartz which is not found in any of the rocks of this study.

### Chlorite

The chlorite group of minerals consists of several solid-solution series for which the formula  $(\text{Mg}, \text{Al}, \text{Fe})_{12} (\text{Si}, \text{Al})_8 \text{O}_{20} (\text{OH})_{16}$  is considered descriptive (Deer et al., 1962, Vol. 3, p. 131). Chlorites are very fine-grained and may be green, brown, or sometimes yellow. Chlorite minerals are not especially abundant as deuteric alteration products in the basaltic rocks included in this study. Chlorite may also be formed in weathering. The so-called "swelling chlorites" are actually interstratified smectite and chlorite minerals (see smectite, below). The chlorite minerals found in rocks of this study are always associated with smectite.

### Chlorophaeite

This name is used to designate a bright orange to deep green alteration product of olivine (Deer et al., 1962, Vol. 1, p. 18, Williams et al., 1954, p. 44). Chlorophaeite is generally reported to be isotropic but may show some birefringence when it consists of a mixture of chlorite, goethite and, possibly, calcite (Deer, et al., 1962, op. cit.). Uncommon in the rocks of this study,



chlorophaeite is present only in the olivine-bearing rocks where it is deep green.

#### Hydrated Iron Oxides

This general terminology has been employed in this report to include the following minerals (Deer et al., 1962, Vol. 5, p. 118 - 127).

Goethite -  $\text{FeO}\cdot\text{OH}$

Lepidocrocite -  $\text{FeO}\cdot\text{OH}$

Limonite - Amorphous  $\text{FeO}$ ,  $(\text{OH})\text{nH}_2\text{O}$

All of this material has a deep yellow-brown to red-brown color. Hydrated iron oxides often occur intimately associated with other alteration products, such as smectites, where it causes a yellow or orange-brown coloration. Hydrated iron oxides often occur with and color chlorophaeite and iddingsite. Deer et al, (Vol. 5, p. 118) point out that limonite consists of cryptocrystalline goethite and lepidocrocite.

#### Ilmenite - Magnetite

In this report, ilmenite-magnetite refers to an intimate mixture of two oxides,  $\text{FeTiO}_4$ , ilmenite, and  $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ , magnetite. In the rocks studied, these minerals are quite common in large (0.5 to 0.1 mm.) crystals which

are often skeletal. Hydrated iron oxides are almost invariably associated with them, having been formed either deuterically (in fresher quarry rock) or secondarily (in weathered road aggregate). Ilmenite is very deep purplish-black in reflected light, whereas, magnetite is black.

#### Leucoxene

An alteration product formed from ilmenite. It is generally considered to be finely crystalline rutile,  $TiO_2$ . It is opaque and has a dull-white color in reflected light. Leucoxene is found in some of the badly degraded aggregate studied in this report.

#### Olivine

A general name for a solid solution series, formula  $(Mg, Fe)_2 Si O_4$ , ranging from  $Mg_2 Si O_4$ , forsterite, to  $Fe_2 Si O_4$ , fayalite. Olivine is not especially common in the basaltic rocks included in this study since it apparently was converted to pigeonite when the magmas crystallized. Olivine group minerals are especially liable to alteration, either deuterically or by weathering. The possible alteration products of olivine are quite numerous. Many of them have been given specific names, such as bowlingite or chlorophaeite, although recent studies show that these are not specific minerals but are, in reality, mixtures of several common minerals. (Deer, et al., 1962, Vol. 1, pp. 18-20). Most of the olivine present in some of the rocks of this study is completely altered

to deuteritic minerals.

### Opal

Opal is an amorphous mineraloid of hydrated silica, formula  $\text{Si O}_2 \cdot \text{H}_2\text{O}$ , with the water content about 6 to 10 percent. Because opal is without crystalline structure, it often contains clay minerals such as nontronite, hydrated iron oxides, and other fine-grained alteration products. It is relatively difficult to identify under the microscope since it is isotropic zeolites, such as analcite. Most of what is identified in these rocks as opal is a turbid brownish or grayish interstitial material between framework crystals of pyroxene and plagioclase.

### Palagonite

This name is used for brown to yellow or orange hydrated basaltic volcanic glass such as sideromelane or tachylite (Gary et al., 1972, p. 509). Palagonite is also reported to be green (Kerr, 1959, p. 424). It occurs in basaltic rocks as rinds on pillows, amygdule linings, and as interstitial material within the rock fabric (Gary, loc. cit., Williams et al., 1954, p. 39). It is generally believed that palagonite is formed syngenetically by reactions of still-hot rock or volcanic ejectamenta with water (Williams et al., 1954, p. 152). Hay and Iijima (1968, p. 368) have shown that palagonite is also formed by cold percolating ground water in normal weathering of volcanic glass.

These authors further point out (loc. cit., p. 372) that palagonite may include crystalline constituents, namely goethite, nontronite and montmorillonite. (Williams loc. cit., p. 153) reports fibropalagonite which is somewhat birefringent.

Palagonite occurs in the rocks of this study as vesicle and interstitial fillings. In both occurrences, palagonite may be somewhat altered. Much of the thoroughly altered interstitial material so common to all the rocks of this study may have originally been palagonite. It is a deep yellow brown and is isotropic, remaining black with crossed polarizing filters.

#### Pigeonite

A mineral of the pyroxene group, formula  $(Mg, Fe^{+2}, Ca) (Mg, Fe^{+2}) Si_2 O_6$ . Often present with augite, another pyroxene, as a primary mineral of rocks in this study. In most cases, it appears to have been formed at the expense of original olivine. Pigeonite is pale brown and stands out more prominently than does plagioclase feldspar.

#### Plagioclase

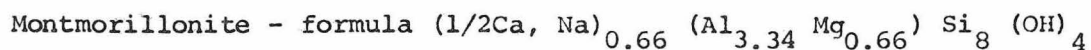
A mineral group which is a solid solution series, formula  $(Na, Ca) Al (Al, Si) Si_2 O_8$ , with end members  $Na Al Si_3 O_8$  (Albite, Ab) and  $Ca Al_2 Si_2 O_8$  (anorthite, An). The mole-fraction of anorthite in a given crystal is

designated as An<sub>x</sub> where x is a percentage. The An content of rocks sampled in this study ranged from An<sub>47</sub> to An<sub>69</sub>. Plagioclase within this range of composition is called labradorite (actually An<sub>50</sub> - An<sub>70</sub>). Labradorite is relatively susceptible to either deuteric alteration or weathering to clay (in cases of this study, montmorillonite and/or nontronite). However, labradorite is often quite fresh in these rocks. Chlorite may also form within plagioclase crystals by deuteric alteration. Labradorite, together with augite and/or pigeonite, forms the most abundant proportion of minerals in these rocks.

#### Smectite

This term is used to designate a group of clay minerals which includes montmorillonite, the aluminous member of the group. These minerals are extremely fine-grained, possess marked swelling properties, and high cation exchange capacities. According to current usage (Deer et al., 1962, Vol. 3, p. 226; Grim, 1968, p. 77), the name smectite is now applied to what has been previously called the Montmorillonite Group of clay minerals. Actually, both terms are in current usage, although an effort is generally made to restrict the name montmorillonite to one member of the group.

The members of the smectite group which may occur as alteration products in the basalts of the present study include the following:



$\text{nH}_2\text{O}$  vermiform, lamellar or scaly - yellow or brown color.

Nontronite - formula  $(1/2 \text{ Ca, Na})_{0.66} (\text{Fe}^{+3})_4 (\text{Si}_{7.34} \text{ Al}_{0.66}) \text{O}_{20} \cdot (\text{OH})_4 \cdot \text{nH}_2\text{O}$  green, brown-green, yellow green vermiform, spherulitic or radial aggregates. Pleochroic in green and yellow.

Saponite - formula  $(1/2 \text{ Ca, Na})_{0.66} \text{Mg}_6 (\text{Si}_{7.34} \text{ Al}_{0.66}) \text{O}_{20} \cdot (\text{OH})_4 \cdot \text{nH}_2\text{O}$  golden, amber, fibrous radial aggregates or scaly masses. Saponite is undoubtedly present in the alteration minerals of these rocks, but it could not be positively identified by X-ray diffraction.

A number of substances which may occur as alteration products of primary igneous rock-forming minerals of basalts are now known to consist of a smectite mineral or smectite plus other minerals. These alteration products are probably fundamentally deuteric in origin, being later further developed by weathering processes. (Deer et al., Vol. 1, pp. 18-20).

The following list defines these substances:

Bowlingite - According to Henin and Caillere, 1951, bowlingite is fibrous saponite. Deer et al., (1962, Vol. 1, p. 19) point out that X-ray studies by Wilshire show bowlingite to be composed of mixed-layer smectite-chlorite, together with serpentine and minor amounts of talc, quartz, mica and possibly sepiolite. Bowlingite is typically fibrous and green. It occurs in some of the olivine-bearing rocks of this study such as those from the State quarry.

Iddingsite - This alteration product of olivine may give the appearance of being a discreet mineral species because of optical homogeneity. However, X-ray studies by Wilshire, cited in Deer et al., (1962, Vol. 1, p. 19), show that iddingsite is composed predominantly of smectite and chlorite, together with goethite (red coloration); also with quartz and calcite and more rarely with mica and talc. Iddingsite is typically deep red-brown and may be lamellar or fibrous. It occurs with olivine and replacing olivine in a few of the rocks studied, such as those of the Bible Creek Quarry.

The X-ray identification of smectites and other alteration products which include smectites is complicated by the variability of hydration (inter-layer water), exchangeable cations, including the up-take of many different sorts of organic molecules, and the possibility of interstratification with other layer silicates such as chlorite. In general, the basal spacings of smectites lie between 12 and 15 angstroms.

The identification of individual smectites in this present study depended upon comparison of X-ray diffractograms and optical determination with the polarizing microscope. Nontronite is more easily identified as the most common and ubiquitous of the smectites present owing to its prominent green pleochroic color in rocks of this study. Yellow and brown smectites, seen under the microscope, are probably montmorillonite and/or

saponite. However, since the X-ray diffraction peaks for the smectite minerals in these rocks are commonly quite broad, due to the complications cited above, it was not possible in this initial investigation to identify specific smectites in the same sample.

### Zeolite

This name is given to a group of hydrated aluminum-calcium-sodium minerals, many of which are analogous to various feldspars. The general formula of the group is  $(\text{Na}_2, \text{K}_2, \text{Ca}, \text{Ba}) [(\text{Al Si}) \text{O}_2]_n \cdot \text{XH}_2\text{O}$  (Deer et al., 1963, Vol. 4, p. 351). There are 22 mineral species included in the group. Many of the zeolites are fibrous. They are all colorless, and have a very low birefringence. Specific zeolites must be determined by X-ray diffraction, owing to the very fine grain size of the crystals. Many of the zeolites are common in hydrothermally altered basalts. In rocks of this study, fibrous zeolite was sometimes found filling fractures. Quantitatively, this fibrous zeolite appears to be unimportant since it was not evident in X-ray diffractograms.



