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# Secondary Minerals in Rock as a Cause of Pavement and Base Failure.

LEWIS E. SCOTT, *Chief Geologist,*
*Oregon State Highway Department*

SECONDARY or alteration minerals were found in large percentages in the rock used in base and pavement of several highway sections which failed under use. The most common of these are kaolin clays, chlorite, serpentine, calcite, and limonite. Their presence causes rock in the ¾- to 0-inch size to disintegrate or dissolve when subjected to water and traffic loads. Rock in larger sizes does not seem to be affected, probably because of the sharp decrease in surface area. Microscopic study and field data indicate 0 to 20 percent of secondary minerals in a fine aggregate will have little effect; 20 to 35 percent will produce some failures and borderline results; and 35 percent and above will almost certainly cause failures.

● THE application of the principles of soil mechanics has made possible a more intelligent design of pavement foundations. There are, however, other features that must be considered. Failures have occurred in spite of the best design and most careful control. These failures commonly affect a whole section of a highway rather than an area of a few square yards. Such failures are not new, and therefore, have been subject to examination and study by many engineers for a considerable period of time. These, and and the writer's, studies showed that the failures usually occurred within, or affected the whole of a single construction unit. They were consistently confined to the base and paving courses; only rarely was the subbase or subgrade affected.

These characteristics all point to the surfacing rock as the probable cause of trouble. In Oregon, these failures were concentrated in the northwestern quarter of the state. As a basis for study, twelve sections which had failed or caused trouble were selected on the advice of the Construction Engineer. All sections were on western Oregon highways.

The investigation began with the location and examination of the quarry which had supplied the rock for each section. In each case the quarry which supplied the base or surfacing aggregate showed the rock to be badly weathered or composed of altered submarine rock. In all cases the rock used was the black basalt typical of western Oregon. Without exception all deposits studied were intrusive bodies, such as dikes, or submarine lava occurring as flows interbedded with sediments. In hand samples the rock appeared sound but of poor quality.

Table 1 shows the results of the routine laboratory tests run on these twelve sources over the last 20 years. In all cases the rock was passed as acceptable although the quality was borderline in several instances.

Geologic study of the quarries and of hand samples showed the rock to be extensively altered. Thin sections were cut and examined under a petrographic microscope which revealed large percentages of unstable secondary minerals as alteration products. A research project was set up within the Geology Section of the Oregon State Highway Department to

TABLE 1

| Quarry | Petrographic Test Decomposition Minerals | LAR | $Na_2SO_4$ | STRIP | PI | LL | Sp. G. |
|---|---|---|---|---|---|---|---|
| I. Rocks with more than 35% decomposition minerals passed by laboratory tests. All rock in this group has caused failure | | | | | | | |
| | % | | | | | | |
| 1. Widdow Creek | 78 | 20.9 | 22.8 | Failed | 8 | 32 | 2.56 |
| 2. Crozer | 65 | 19.0 | 18.7 | Failed | 5 | 36 | 2.67 |
| 3. Enegren Ferry | 48 | 29.0 | 35.8 | Failed | 8 | 30 | 2.61 |
| 4. Steinmetz | 43 | 20.9 | 1.9 | Poor | 0 | 26 | 2.69 |
| 5. Coffin | 42 | 19.0 | 16.0 | Poor | 0 | 29 | 2.75 |
| 6. McLeod | 40 | 27.2 | 14.9 | Failed | 14 | 36 | 2.67 |
| 7. Racetrack | 38 | 20.9 | 7.8 | Failed | 9 | 29 | 2.66 |
| II. Borderline rocks passed by petrographic and laboratory tests. Failures not universal from this group | | | | | | | |
| 8. Stuckle Mountain | 35 | 25.4 | 2.8 | Failed | 0 | 27 | 2.68 |
| 9. Valley Junction | 35 | 31.8 | 5.1 | Failed | 0 | 23 | 2.79 |
| 10. Lambert | 30 | 21.8 | | Poor | 5 | 28 | 2.74 |
| 11. Quartz Creek | 30 | 20.0 | 3.1 | Failed | 2 | 27 | 2.66 |
| 12. Vernonia | 25 | 19.0 | 17.9 | Failed | 0 | 24 | 2.71 |
| 13. Wren | 25 | 18.1 | | Poor | 0 | 24 | 2.80 |

*Note:* The location of the above quarries is given in Figure 1 by number.

determine if, and how, the presence of secondary minerals caused failure in base courses and pavements, and what percentage of them was necessary to produce failure. It was found that there is a direct relationship between the presence of secondary minerals and surface failures.

As a result of this study begun two years ago, all quarries questionable in the opinion of a geologist have been examined, and all new sources are checked for the presence of secondary minerals. Several quarries have already been rejected as sources of surfacing rock on the bases of petrographic examination. The inclusion of a petrographic examination, in addition to the standard ASTM rock tests in the general contract specifications, is now under consideration.

### SECONDARY MINERALS DEFINED

Secondary minerals may be defined as minerals resulting from alteration of primary minerals. They are formed as the result of deep chemical weathering of igneous rocks by ground water, air, hot gasses, or dissolved organic acids, or by extrusion into water as in the case of submarine basalt. These agents attack the surface of a rock body, penetrate into the larger cracks, the microfractures, and finally into the individual mineral crystals themselves. The deterioration varies from partial alteration on the surface or margins of a crystal to the complete replacement of a primary mineral by a less stable mineral which retains the shape of the original crystal. Any holes or voids in the rock fabric are filled with secondary minerals which retain the shape of the opening. Formation of a secondary mineral is often speeded by recrystalization expansion which shatters the surrounding rock.

The composition of a fine-grained igneous rock is limited to a few families of minerals. The feldspars, which form up to 60 percent of basalts, are altered to kaolin type clays and calcite. The clays are unstable and usually extremely hydrophilic. The calcite (calcium carbonate) is water soluble and breaks down readily. The iron bearing minerals, which may form up to 50 percent of any one basalt sample, and which give it its dark color, are altered to limonite, chlorite and serpentine. Chlorite and serpentine are highly unstable minerals which break down rapidly into clays. Both have little structural strength and shear easily. Limonite, while more stable, is much weaker structurally than the mineral it replaces.

Igneous rocks are hard because of the strong, tough minerals which form them. They are strong because of the interlocking nature of the multitude of these small, angular crystals. Even a moderate amount of decomposition affecting only the margins of the crystals, can seriously weaken a rock if it is disseminated throughout the structure. In this case the crystals retain most of their initial strength but the interlocking bond between them has been destroyed. Extensive and progressive deterioration of this type produces a rock which essentially retains its original appearance and structure, but is so weak that it tends to crush under wheel loads.

### EFFECT OF SECONDARY MINERALS

The presence of secondary minerals in base or oiling aggregates has caused two principal types of failure. The most prevalent is the disintegration or dissolution of fines by water. This process is often aided or accelerated by wheel load pressures. Less commonly, badly altered rock is subject to crushing by wheel load pressures. Base and topping courses on failed sections have been carefully studied and both types of failure noted in a given section, although one or the other is usually dominant. Petrographic study of the surfacing rock used showed high secondary mineral percentages and bore out the theory that unsound rock was the basic cause of failure. Subsequent field studies have shown that any concentration of fines containing secondary minerals will produce a clay pocket within a short time.

It was found on some sections that the quarter minus (¼ to 0-inch) material in the topping had been largely reduced to clay. Field evidence suggest that the clay had been derived from the quarter minus material itself by a progressive disintegration. Moisture already in the aggregate or that derived from rainfall probably caused the initial dissolution of the finest material. The clayey product being hydrophilic attracted more moisture setting up a chaim reaction effect. The flexing of the increasingly unsupported pavement would produce a kneading or crushing action, which would speed the disintegration.

In an oil mat or pavement, the reaction seems to be similar. Any moisture within, or on, a piece of aggregate tends to cause deterioration on or near the surface. The formation of even a minute film of clay between the surface of the rock and the asphalt binder would effectively destroy the cohesion between the two at that place. A progressive formation of such a film would soon produce enough separation to allow a passing wheel to whip the aggregate piece from the pavement.

Such a situation apparently occurred west of Eugene on the Territorial Highway in the vicinity of Lorane. Observers reported a progressively rapid disintegration of the pavement itself until it was almost entirely gone at the end of a year. The reaction time has been found to vary from this extreme to a period of several years.

Microscopic and field data both show that the fine material below quarter inch size is very susceptible to disintegration. The susceptibility decreases as the size of the material is increased because of reduction of surface area and the greater structural strength of larger sized pieces. The degree of susceptibility is also dependent upon the percentage of secondary minerals contained in the rock.

While no sharp lines can be drawn, certain limits have been established during the two-year study of the problem. Study of 13 highway failures caused by unsuitable rock shows that the rock used in the worst of complete failures contained over 35 percent secondary minerals. Rock containing 20 to 35 percent secondary minerals produced borderline results. Highways constructed of rock containing up to 20 percent secondary minerals showed little adverse effect.

Field studies indicate that for aggregate containing 35 percent secondary minerals or over, the ¾-inch-minus size is critical. The fines of such a material will almost certainly disintegrate. The ¾-inch limit is somewhat arbitrary, but very little deterioration has been observed on larger sized pieces. It is convenient, however, because the top course of the base, or leveling course, is entirely composed of this sized material in Oregon.

For testing and examination purposes the Oregon State Highway Department had until recently designated the allowable limits of secondary minerals to be 30 percent in penetration macadam and 35 percent in asphaltic concrete. The difference in percentages is recognition that asphaltic concrete forms a better seal against entrance of moisture and the fact that the aggregate is heat dried prior to mixing. A recent order has reduced the allowable limit of secondary minerals to 20 percent.

### PREVENTION OF FAILURE

Base and pavement failures caused by secondary mineral disintegration can be prevented of the following precautions are observed. All material sources should be inspected for indications of deep chemical weathering. Usual evidences are heavy overburden, stained or discolored rock, vein fillings in shear and fracture zones, and cloudy appearance and lack of sharp edges on freshly broken surfaces. If the rock shows any of these characteristics it should be submitted for petrographic study to determine the degree of alteration.

Use of a material source found to contain borderline or excessive amounts of secondary minerals requires special care. All the material used should be scalped on a 1-inch screen after the primary crusher to remove vein fillings, scale, and soft rock. This will ensure that only the best of the material will remain to be processed.

This scalped, selected rock has been found suitable for base rock and for sizes larger than ¾-inch. All of this rock in the ¾-minus size range should be rejected as unfit for highway construction, even as shoulder rock or backfill material. On the basis of petrographic evaluation the quarries shown on Table I as containing over 35 percent secondary minerals have been listed as unsuitable for rock less than ¾-inch in size. Last year the contractor supplying rock for the resurfacing of the failed section of the Territorial Highway, referred to earlier, was allowed to use the nearby Race Track quarry for his base rock source, but was required to manufacture the ¾-inch minus material from a better quarry at the other end of the job.

Deep chemical weathering also affects older gravel deposits. Extensive weathering will alter the surface of the individual pieces to such an extent that only gravels large enough to be crushed are suitable for use, even though the centers are sound. Laboratory tests recently run on small, badly weathered gravels showed that movement of one rounded piece upon another ground off the weathered material which had an average P.I. and L.L. of 4 and 38, respectively. The weathered zone, being a part of the rock, could not be washed or shaken off. Since the gravel was too small to crush, the deposit, which ironically, was on line at the center of the job, had to be rejected.

### RECOGNITION OF SECONDARY MINERALS

The presence of secondary minerals in a rock can be determined by petrographic study of representative thin sections or is sometimes indicated by analysis of laboratory test results. The petrographic method is superior because the secondary minerals can actually be seen and their presence positively determined. In addition, an accurate determination of the amount or percentage can be obtained by actually counting the minerals seen. Petrographic study also provides information as to the type of weathering that has occurred, the extent of secondary minerals present, and the degree of alteration that has taken place.

The petrographic test used by the Oregon State Highway Department has been developed as experience and knowledge of the subject has expanded. The standard test at present consists of microscopic examination of three thin sections, one each taken from the the top, middle and bottom of a rock face, or in the direction of weathering. Determination of the percentages of the various secondary minerals is accomplished by systematic grid counting or by use of a mechanical counter, which is so conducted that it may be duplicated by a privately employed petrographer if the contractor should so desire.

The presence of secondary minerals in a rock is sometimes indicated by analysis of laboratory reports. The laboratory report form gives the results of tests for abrasion (Los Angeles Rattler), specific gravity, and plasticity index, which are standard ASTM tests, and an asphalt stripping test which is indicative only. Until a year ago sodium sulphate ($Na_2SO_4$) tests were run only when requested. By this system, i.e., abrasion, specific gravity, plasticity index, and stripping, all the rock listed in Table 1 was passed as suitable for use and was used on one or more jobs. The addition of the sodium sulphate test passes two, lists three as borderline, and rejects two out of the seven proven bad sources.

As the result of, and in conjunction with, this investigation of substandard rock the highway department laboratory has been experimenting with a degradation test involving a rock on rock type of abrasion. Plastic index (P.I.) and liquid limit (L.L.) values are run on the natural fines produced by this test to measure the clay content. High values on these and on the sodium sulphate test indicate unsoundness in a rock, the limits set by experience being 25 to 30 percent L.L., 6 to 9 percent P.I., and 12 to 15 percent $Na_2SO_4$. These values do not indicate the origin of the unsound nature nor whether it is due to chemical or mechanical breakdown. However, a general correlation between them and the petrographic test is possible.

The presence of secondary minerals can

sometimes be detected in the field by careful study of hand samples. Basalts containing 30 to 40 percent secondary minerals often show small pits up to a millimeter in diameter, which are filled with a soft, soot-like powder. These pits represent the original location of an easily affected crystal, such as augite, which has been completely altered to a black, serpentine-type clay. Fresh fractures do not produce sharp, jagged edges and the rock appears dull and somewhat crumbly in texture.

During crushing operations a rock containing a high percentage of secondary minerals will usually produce an excessive amount of crusher dust. Often such rock will change color from blue to brown in the stockpile over a period of a week or two as the moisture in the air begins to react with the freshly exposed surfaces. In one instance, an aggregate having a large percentage of secondary minerals and sulphides become partly cemented and formed enough heat to be felt by the hand due to chemical recrystalization after being stockpiled.

### LOCATION AND GEOLOGIC AGE OF ALTERED BASALTS

The most common type of rock in Oregon, both in quantity and distribution, is basalt. For this reason nearly all of the aggregate used on the state highway system is basaltic and all rock described in this paper has been basalt. However, any igneous rock subjected to deep chemical weathering or alteration will react similarly.

The altered basalts examined, sampled, or inspected in the course of this study fall into definite location and geologic patterns in western Oregon. These basalts occur either as small intrusives, such as plugs or dikes, or as submarine flows interbedded with marine sediments. All of the submarine basalts and most of the intrusives are Eocene in age: from 40 to 50 million years old. The other intrusives occur as dikes in younger sediments which lie upon the Eocene formations.

The distribution of the sites studied is shown on Figure 1. The lined areas indicate

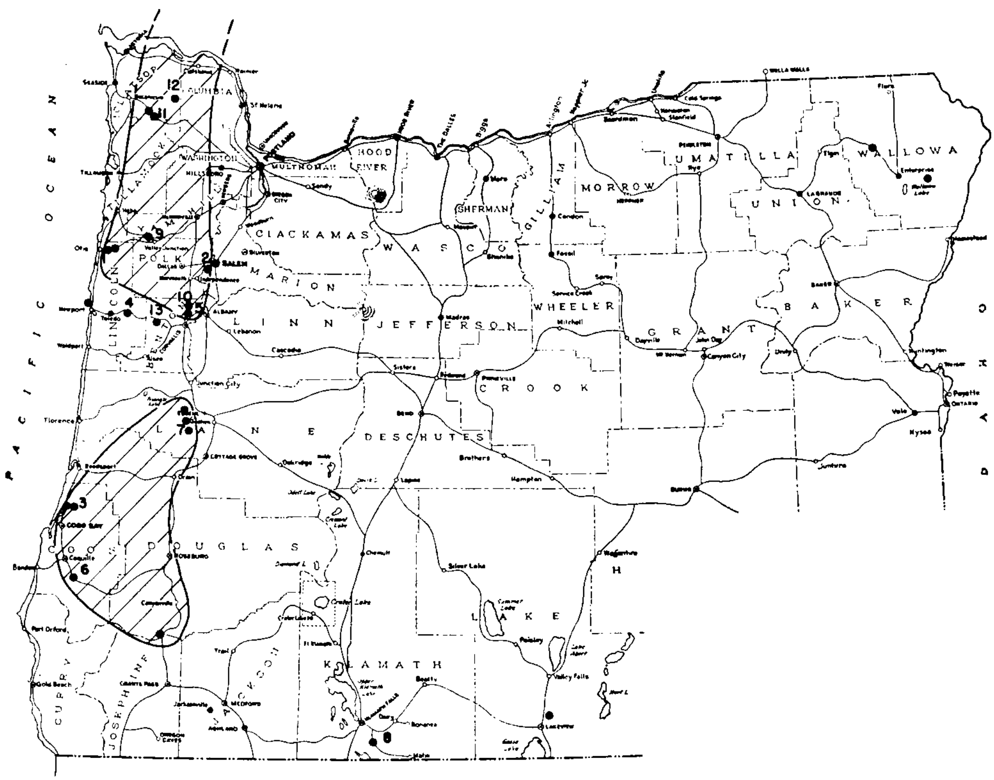


**Figure 1. Location of quarries known to contain secondary minerals as of September, 1954.**

exposures of Eocene basalts in western Oregon; the area between them, covered by younger sediments, has only exposures of a later age. It will be noted that the Eocene exposures form a belt 50 to 60 miles wide, extending to the northern boundary of the state. The writer has personal knowledge of altered basalts of similar type and occurrence from western Washington as far north as Seattle. The deep, uniform weathering of the submarine Eocene basalts is due to an initial alteration of the feldspars by water during the cooling period. These weakened basalts have been protected by a thick cover of later sediments. Where erosion has exposed them, further weathering has been speeded by a warm, humid climate and low, rolling topography.

The later Miocene lavas are generally sound, except in locally laterized areas. The altered rock occurrences found in eastern Oregon were few and scattered. The cause of deep weathering of these rocks apparently is the result of local causes and no correlation as to age, origin or climatic conditions could be drawn.

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