APPLICATIONS OF GEOLOGY TO HIGHWAY ENGINEERING IN KENTUCKY

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Kentucky, too, is a state where geology abounds. Little credit for this, however, lies with the highway field, because such a prosaic subject is frequently overshadowed by such features as Mammoth Cave, Sky Bridge, Cumberland Falls, Pine Mountain, and extensive underground mineral deposits. Nevertheless, the influence of geology in the highway industry is growing, and it is obvious that some potential contributions have not yet been realized.

General applications of geology to highways have actually been in practice several years. Probably the most tangible of these pertains to the development of aggregates. Almost all evaluations of natural aggregates - sand, gravel, or stone - which are proposed for highway construction are made under the direction of a graduate geologist in the Highway Department's Division of Materials. These are not limited just to the usual application of acceptance tests, but involves classification of materials - sometimes on a petrologic or a chemical basis, and always with a view toward the intended use. For example, every producing quarry in the state is included in the Department's Annual Quarry Report (1);
which is, in effect, an inventory and rating of quarry materials, ledge by ledge. So far as the annual report itself is concerned, there are no specific geologic interpretations identifying the formations as time units. Such information would prove superfluous to quarry operators and to highway engineers in general. However, stratigraphic identification has been a part of the work, and these identifications are ultimately published by the Kentucky Geological Survey for the good of those who are in a position to use them (2) (3).

Prior to the time that the annual inventory was developed, many quarries were worked somewhat haphazardly with little or no geologic or mineralogic correlation between ledges. This, of course, led to expensive operations in some ledges before there was any evidence from physical test and chemical analyses to show whether all the stone was acceptable for use. Correlation of ledges greatly reduced the chances of producing large quantities of unsound aggregate, and put aggregate production on a more scientific basis.

In some cases, quarries had to be abandoned because there was not sufficient material of high quality to justify continued operation. At one location, a surface quarry was abandoned, and a shaft was opened to a 30-foot ledge of high-quality limestone laying 240 feet beneath the surface. It is interesting too that a similar operation, but in a drift mine running laterally from the face of an entrenched river valley, was already producing high-quality aggregate from precisely the same formation at a location 20 miles away. Geologic knowledge of the formations - their continuity and their uniformity - was a basis for
confidence in an expensive undertaking of this sort. Core-drill records, logging the desired ledge, naturally provided final confirmation.

Formative research in aggregate development has involved more specific uses of geologic and petrologic approaches. For example, there have been numerous instances, not only in Kentucky but in practically all states, where current test procedures indicated that an aggregate had dependable qualities, yet service experience has ultimately proven it unsound. In other words, the test-criteria failed to detect these faulty characteristics, and it took several years of service experience to reveal them. One instance of this is illustrated by Fig. 1. The concrete pavement shown there, was built with an aggregate which then showed no apparent signs of weakness. It was hard, resistant to abrasion, had low absorption values, held up well in soundness tests, and seemed well suited for the use intended. After a service period of about 1\frac{1}{4} years, the pavement suffered very extensive cracking. It was obvious that the aggregate had "grown", thus exerting a tremendous pressure within the concrete. Ultimately, pieces of coarse aggregate at the surface began to split or "pop" out in fractured sections.

At that time a comprehensive aggregate study (4) was in progress, and one of its objectives was to determine what possible component of stone - limestone in this case - might have caused the destructive expansion. Some indications of the ledge or ledges at fault were revealed in weathered quarry tailings, such as the disintegrated block in Fig. 2. During the course of the study, the face of the quarry was sampled foot by foot, and numerous tests were made. In addition to
Fig. 1. Failure of concrete pavement which began after 1½ years of service under moderate traffic.

Fig. 2. Weathered quarry tailings such as these offered a clue to the ledge causing the failure.
those normally used for engineering purposes, thin sections were prepared for observation of gross structure; and other tests such as porosity, insoluble residue, and clay mineral identification by x-ray diffraction were included. Concrete specimens were made in the laboratory, and tested by prolonged exposure to water and by alternating freeze-and-thaw temperatures. The freeze-and-thaw test, within the limits usually applied, did not have the severe effect anticipated. However, after an extended period of combined exposure in the durability test, deterioration such as that shown by the specimens in Fig. 3, closely resembled that observed on the concrete pavement.

Another application of geologic techniques - this again having to do with aggregates - was fundamental to the development of sandstone as a usable paving material. The sandstones and shales of Pennsylvanian origin, which are so prevalent in West Virginia, also blanket the entire eastern portion of Kentucky. As shown by Fig. 4, this region represents almost one-fifth the area of the State.

Deep in the heart of this eastern region, where the distance to sources of service-tested aggregate are great, the shipping cost of importing these materials sometimes reaches almost twice the cost of the material itself. Under this stimulus, highway engineers have long been interested in possibilities for utilizing local sandstone. In 1949, a program of development was started in earnest, with the Division of Maintenance prepared to staff and implement quarry and plant operations as well as hot-mix bituminous plant and paving operations for a 3½-mile test.
Fig. 3. Concrete specimens after prolonged freeze-and-thaw weathering.
Fig. 4. Map showing Pennsylvanian Sandstone regions and location of test road.
road project. In its formative stage the program was, to a large extent, dependent upon the success of the Research Division in establishing fundamental engineering design data applicable to sandstones and to locate the most promising quarry sites. Geologic considerations came to the forefront, not only in the field surveys and in sampling the outcrops, but also in the laboratory tests for intrinsic properties.

From the beginning, evaluations were based on the premise that the utility of sandstone would be determined largely by the degree of strength imparted to the stone by the cementing media. This general principle was augmented by physical tests for properties such as permeability, porosity, and voids; chemical tests for soluble silicates and basic salts; and optical determinations for roundness of grains, size and frequency of grain distribution, degree of grain-interlocking, type of cementing material, percentage of cement, and mineralogical composition (5). As expected, composition was extremely variable with major minerals consisting principally of quartz. Minor companion minerals were plagioclase feldspar, muscovite, calcite, biotite, sericite, and chlorite. Predominant constituents of the interstitial or cementing materials were sericite, quartz, chlorite, calcite and various iron oxides. Fig. 5 shows a typical specimen as viewed through crossed nicols on the petrographic microscope at about 80 x magnification. Quartz, of course, predominates. The interstitial material in this case is largely sericite and quartz, but iron oxides, chlorite, and calcite contribute prominently to the cementing action.
The final laboratory evaluation, preparatory to tests with small-scale bituminous mixes, consisted of strength determinations under combined compressive stresses. This provided a basis for correlation between the properties previously mentioned and the strength factors measured by the triaxial compression test. A sample under test is shown in Fig. 6. Confining pressures ranged from 0 to 5000 lb. per sq. inch; and intrinsic cementing strengths, normally termed cohesion, varied from 600 to 3300 lb. per sq. inch. Grain-to-grain friction, of course, constituted a second strength factor.

Some correlation between the measured intrinsic strength and the degree of cementation as established by optical determinations was apparent - the cementing value of this sense representing the combined influences of percentage cement and degree of grain-interlocking. Discrepancies were observed which may possibly be attributed to variations in the type of cementing material, but the analyses were not sufficient to substantiate this assumption from the standpoint of mineralogical composition alone.

Combined work in the laboratory and on the test road carried over a period of three years; and this project, along with three contract surfacing projects using sandstone, were completed in 1952. Stone for these pavements came from two large quarries, one of which is shown in operation in Fig. 7. Four general grades of material, ranging from very weakly-cemented to firmly-cemented stone, were used successfully. Three of the grades were represented at different levels (Fig. 8) in this one
Fig. 5. Photomicrograph of sandstone thin-section, crossed Nicols, 80X magnification

Fig. 6. Triaxial pressure cell used for testing inherent strength of sandstones.
Fig. 7. Sandstone Quarry at Quicksand.

Fig. 8. Generalized Section of the Quicksand Quarry.
quarry. The entire research project definitely established the fact that even though sandstones are extremely variable, a wide variance in composition and physical characteristics are tolerable when the material is used as a plant-mix bituminous paving aggregate (6).

Contrary to the impression conveyed thus far, applications of geology to highway engineering in Kentucky have not been limited entirely to aggregate investigations. The role of geology in classifying soils according to origin is, of course, well established and requires no particular mention here. In Kentucky there has been no deliberate effort in the highway field to catalogue and map soils according to the pedologic or geologic approaches, yet all the soil samples taken — at least for research purposes — are classified by these systems, where possible. This information now serves as a guide for correlation among samples, and it may ultimately provide a basis for a comprehensive project relating origin and engineering properties of soils throughout the state.

Studies in clay mineralogy and on the influence of different types of clay on soil properties have utilized a number of techniques familiar to the geologist (7). These have, in general, been methods for mineralogical analysis which, in their most practical sense, are simply the means by which the desired information is obtained; that is, information that will in some way enhance the understanding of these otherwise obscure soil constituents. One of the most interesting aspects of these studies is illustrated by Fig. 9. Certainly a knowledge of mineralogical composition is essential to any rational approach to soil chemistry and soil physics. Ultimately, and quite logically, mineralogical composition may be interpreted in terms of geologic origin — not on the basis of
Fig. 9. Electronmircograph of a "shadowed" Illite-Kaolinite clay mixture extracted from soil. Particle size: -1 μ, Magnification: 22,700 times.
quartz sands and silts which occur almost universally but rather on the basis of clays and other complex silicate minerals. At least, there is a suggestion of this possibility from the present data (6)(9).

Physiographic features and subsurface conditions in different regions of the state have an important bearing on a drainage research project which is progress at the time of this writing. The objective in this program is to correlate rainfall and runoff on small drainage areas, and to develop hydrologic criteria for designing the hydraulic capacity of drainage pipe or culverts. The system now used is obviously obsolete, but it is treated in such a way that the design is always on the safe side—sometimes toward opening that are 3 to 4 times the size required for a so-called 25-year storm.

The work principally involves the analysis of long-time rainfall records to determine storm intensities and storm frequencies and measurements of rainfall and runoff relationships on specific areas strategically located throughout the state. One such area, equipped with stream flow recorder and automatic rain gauges, is outlined on the aerial photograph listed as Fig. 10. Several areas under study, either with these elaborate recorders or with more limited facilities such as staff gauges or peak stage indicators, are included in the project.

The important point, at the moment, is the fact that geologic divisions seem to provide a reasonable basis for zoning the state according to runoff characteristics. This does not mean necessarily that the Mississippian regions are set apart from the Silurian regions, for example, nor that zoning according to similarities in rock type or structure is
Fig. 10. Airphoto layout of a drainage test area.
a foregone conclusion. It does mean, however, that runoff on the Carbonaceous Devonian Shales in the Knob Region (bordering the Blue Grass) is distinctive; and that, for similar sizes and shapes of drainage areas, runoff under a given storm intensity can be predicted with reasonable accuracy. For other regions the relationships may not be so definite, but it seems logical that such a grouping can be made within the general limits mentioned.

A rather serious manifestation of another type of drainage problem is illustrated by the severe corrosive action of highly acid mineral waters on concrete bridge piers. An example of this is shown in Fig. 11. Here, the relationship to geology in this problem is better defined. Damage of this type, even on small drainage structures and culverts has resulted in intolerable maintenance costs. Because of this, a survey was made throughout the state, not only to determine the extent of damage already sustained, but also to determine where conditions producing such damage were most prevalent.

In the field survey, certain tell-tale features such as the presence of iron stains or the absence of vegetation were easily recognized. Water samples were analyzed and rated conductometrically as an indication of their corrosivity. From the earliest inception of the project, a general knowledge of geology, physiographic features, and mineralogical composition of underlying strata offered a general criteria from which to judge the corrosivity of waters in the principal areas of the state. To a large extent, the results of the field survey simply provided factual confirmation of these guiding generalities. This
Fig. 11. Bridge pier damaged by exposure to highly acid mine drainage.
relationship to geology may be more fully realized from the generalized
cross-section of the state, included here as Fig. 12. Sulfur-bearing
coals and shales interbedded with the sandstones characterizing the
eastern and western parts of the state provided the principal sources
of corrosive solutes; but, of course, the limestone areas of the Blue
Grass and Pennyroyal were particularly free from these acid-producing
minerals. These structural and mineralogical aspects are naturally
correlative with the principal physiographic regions of the state (Fig. 13); and the areas where high acidity prevails are shown by the boundaries
of the Eastern and Western Coal Fields. Several mineral springs and
wells originating in sulfur-bearing shales within the Knob Region have
had some historical significance but have now fallen into obscurity.
Field data from this area indicated a much milder degree of acidity
than was generally found for the coal fields. This type of information,
combined with about 17,000 inspections on in-service drainage structures
(10), provided a reliable basis for the selection of corrosion-resistant
materials for use within these critical areas.

These applications described are, of course, typically selected
cases and possibly represent instances of personal association; but even
this seems particularly appropriate since neither of the authors is a
trained geologist - at least, in the academic sense.
Fig. 13. Approximate Boundaries of Physiographic Regions of Kentucky.
REFERENCES


