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Addresses of Authors

Banino, George M., Dunn Geoscience Corporation, 5 Northway Lane North, Latham, N.Y. 12110
Dunn, James R., Dunn Geoscience Corporation, 5 Northway Lane North, Latham, N.Y. 12110
Galdiero, Vincent A., Seeley Stevenson Value and Knecht, Inc., 1 Dupont Street, Plainview, N.Y. 11803
Gandhi, Poduru M., General Engineering Department, University of Puerto Rico, Mayaguez, P.R. 00708
Giguere, Michael J., Boothe, Prichard and Dudley, 4103 Chain Bridge Road, Fairfax, Va. 22030
Graham, Edward K., Vulcan Materials Company, P.O. Box 4195, Winston-Salem, N.C. 27105
Hart, Michael J., Flatiron Sand and Gravel Company, P.O. Box 229, Boulder, Colo. 80306
Hellert, John R., Dunn Geoscience Corporation, 5 Northway Lane North, Latham, N.Y. 12110
Kayyali, Obada A., Department of Civil Engineering, University of Kuwait, P.O. Box 5969, Kuwait
Lappegaard, Ray, J. L. Shiely Company, 1101 North Snelling Avenue, St. Paul, Minn. 55108
Luck, Charles S., III, Luck Quarries, Inc., P.O. Box 29682, Richmond, Va. 23229
Lytton, Robert L., Texas Transportation Institute, Texas A&M University, College Station, Tex. 77840
Petrarca, Richard W., Agricultural and Tech College, State University of New York at Farmington, Melville Road, Farmington, N.Y. 11735
Reining, Don, Southern California Rock Products Association and Southern California Ready Mix Concrete Association, P.O. Box 40, Pasadena, Calif. 91030

Part 1
Symposium on Reducing Constraints on Mineral Aggregate Development

Preface

JAMES R. DUNN

During the past two decades producers and users of mineral aggregates have been increasingly concerned with difficulties of developing construction mineral resources. Considerable literature pertaining to the problem has developed in journals associated with the mineral industry, in state and federal government publications, and in special publications. Authorities are in agreement that development problems have two primary causes: zoning ordinances in combination with the application of "participatory democracy" to a highly technical field. This combination has effectively prevented the development of aggregate minerals in vast areas of the United States to the detriment of the general population.

The papers in Part 1 consist of information presented at the Symposium on Reducing Constraints on Mineral Aggregate Development at the January 16, 1984, Annual Meeting of the Transportation Research Board of the National Research Council. The first four papers presented at the symposium were by Edward K. Graham, Vulcan Materials Company, Winston Salem, North Carolina, and Michael J. Giguere, Boothe, Prichard and Dudley, Fairfax, Virginia; by Michael J. Hart, Flatiron Sand and Gravel Company of Boulder, Colorado; by Ray Lappegaard, J.L. Shiely Company, St. Paul, Minnesota; and by Charles S. Luck III, Luck Quarries, Inc., Richmond, Virginia. These papers, although different in detail, made similar points. They demonstrated that in much of the United States success in the mine permitting process required the mineral producer to have a similar orientation and to go through a similar data-gathering and presentation process. Because of these similarities and in an effort to reduce the number of pages of this document so that the experience of these authors can be shared with other producers, the salient points of these papers are condensed in a single paper.

The second component of this document is a short discussion of the nature of the public hearing process as it applies to permitting of mineral aggregate operations and some broader implications about mineral resource management. This is based in part on the paper by Michael J. Hart, amplified by James R. Dunn, symposium leader.

The final two papers are by George M. Banino and John R. Hellert, Dunn Geoscience Corporation, Latham, New York, and by Don Reining, Southern California Rock Products Association and the Southern California Ready Mix Concrete Association, Pasadena, California. In these papers alternative answers to problems of minerals management and the environment, as dealt with in New York State and California, are summarized.

It is clear from the papers in this symposium that no final answer to the problem of developing mineral resources in terms of public interest is forthcoming. It is hoped that this symposium will contribute in some small way to solving the problem of minerals and the environment.

[Because many of the concepts presented at TRB's Symposium on Reducing Constraints on Mineral Aggregate Development have potential value to the industry, to regulatory agencies, and to community permitting bodies, the papers have been condensed to create a publication brief enough for mailing to a broad audience. It should be noted that entire texts of each paper are available by writing to James R. Dunn, who edited the papers for Part 1.]

Toward Successful Permitting of Mineral Aggregate Operations

MICHAEL J. GIGUERE, EDWARD K. GRAHAM, MICHAEL J. HART, RAY LAPPEGAARD, and CHARLES S. LUCK III

ABSTRACT

Obtaining a permit to develop a new mineral reserve from which mineral aggregate can be manufactured is a long and complex process. The producer must coordinate data and efforts of many outside experts and of his own company personnel to assure that all required information is presented. First, however, a site that will have minimal environmental problems must be selected. Then all potential environmental problems associated with operating that site and the means of mitigating any such problems should be determined. Talking with permitting agencies early in the permitting process is important. Usually, talking with people who live nearby to describe who the operating people are, where else they operate, and what they hope to do is also important. In most cases public hearings will be required, and it is usually necessary for presentations of experts to be integrated and coordinated. This can often be done by an attorney, preferably one who is familiar to local people, who has a good reputation, and who understands the local ordinances and the permitting process. An extremely important component of a presentation is for the company to be able to demonstrate that at other locations at which they operate they have already put into practice the sorts of things that they plan at the new operation. Even if all steps are taken carefully and skillfully and with sensitivity to the local population's feelings, there is no assurance of success in obtaining a mining permit, because the results of public hearings are not predictable. But if the producing company touches all required bases, the chances of success increase enormously.

The purpose of this paper is to review and distill the permitting experiences and knowledge of four mineral aggregate producers and a lawyer who have been successful in obtaining permits to operate aggregate deposits. In most cases the permitting process involved requesting changes in zoning ordinances of town or county political bodies that act in a quasijudicial capacity.

Some aspects of quarry siting and the sort of information that may be required by producers seeking permits are discussed. Some techniques for presentation of producers' information are suggested, and the nature of the public hearing process is described. The authors presented papers at the January 16, 1984, Annual Meeting of the TRB Symposium on Reducing Constraints on Mineral Aggregate Development, and their papers have been integrated here.

SITE SELECTION

The first requisite for getting a permit to operate is the selection of a suitable site where permitting problems will be minimal. Location is dictated by geology, transportation, and market of a region, and often there may be several alternative sites within a region where those parameters are suitable. Other factors being equal, the best sites are likely to be remote from population centers and should have a population with low or moderate income because the economic benefits from an operation would be more important to them. A site that is not highly visible and has haul routes passing through a minimum number of densely populated areas is also ideal. Sites that fit all these requisites are becoming rare, particularly in the more populous states.

No site is so remote, however, that some people will not find problems with it. For example, Flatiron Sand and Gravel Company in the Denver area observed that in each case the major objection to permitting mining operations had been truck traffic. Flatiron totally eliminated the need for gravel trucks on public roads by choosing a site that was on the main line of a major railroad, thereby allowing the stone to be shipped by rail. In addition, the area around the site had one of the lowest population densities in the county. The site was not visible from the nearest developed area, which was more than 4 miles away on the opposite side of the mountain from the quarry. Although this site would seem ideal, Flatiron has not yet been successful in getting a permit after 2 years of trying.

Proper site selection is extremely important, but it does not by itself assure success in permitting.

PUBLIC EDUCATION

Most producers of mineral aggregate who have been successful in obtaining permits to mine have found that a program of public education was necessary. The general public has many apprehensions about mining operations in its vicinity. The people may be concerned about truck traffic, dust, noise, ground vibrations, or scenic changes, or they may wonder about the impact of an operation on wildlife, groundwater, property values, or their own quality of life. Some concerns are based on misconceptions, some problems may be real but can be mitigated, and some other problems exist and may be difficult to minimize. It is generally the producer who must educate his neighbors about the potential impacts of his operation--both positive and negative.

In the education process the main thing that the public should understand is that the producer is sensitive to public feelings and concerns. If this does not come across, chances of obtaining a mining permit are probably minimal.

It is mandatory also to communicate and cooperate with local officials who are involved with the permitting process. In addition, working closely with the local media is an important part of educating the public.

In some states the public education process may be taken care of, in theory, by the environmental impact statement (EIS). This will be discussed later in the papers by Banino and Hellert and by Reining. Where an EIS is not required, the public education process will require the equivalent of an EIS to answer all of the questions that may be asked.

Some points commonly addressed by a producer are as follows: days and hours of operation; blasting hours; blasting safety, including total pounds of explosives per shot and per delay, and security and location of explosive storage; locations of truck entrances and exits; seismic monitoring; dust control; stockpile and equipment height; and air quality monitoring.

The public should be informed about the nature of any (a) entrance beautification plans; (b) green belts (buffers between property lines and disturbed areas); (c) fencing (location and specifications); (d) lines of sight relative to plant and stockpiles; (e) quarry and plant location as related to both reserves and neighbors, including phasing of the pit size and periodic relocation of plant conveyors and crushing equipment; and (f) truck wash system for highway trucks.

In addition, for presentation purposes, some producers have found the following to be helpful: (a) a scaled model of the quarry facility and surrounding area; (b) slides and drawings showing typical operations and beautification plans of entrances; (c) colored drawings demonstrating operational concepts; and (d) tours of existing operations (if applicable) for zoning officials, neighbors, politicians, and interested citizens.

Information is transmitted by documents (i.e., EIS), company personnel, or outside experts at hearings to individuals or small groups or to local media. Many producers have found that presentations at hearings are best made by lawyers because they are likely to be experienced speakers and are likely to be knowledgeable about the problems. Luck Quarries, Inc., is careful to select a lawyer with a good reputation, good local credibility, and knowledge about local zoning boards. Vulcan Materials Company stresses the value of an attorney who specializes in land use, where such a person is available.

Usually written or oral presentations may also be made by a quarry superintendent or manager who can discuss operations and personnel; by a company officer who can describe financial implications for a community; by an environmental control manager or equivalent who can explain about such things as control of dust, noise, erosion, and drainage; by a blasting expert who can explain how blasting is done; by a seismologist who explains the effects of blasting; and by a hydrologist who can discuss the impact of the operation on surface and subsurface waters. A geologist, ecologist, landscape architect, engineer, planner, real estate appraiser, or other professional may be useful or necessary under some circumstances.

Often such professionals as lawyers, site engineers, planners, geologists, landscape architects, or public relations specialists coordinate the data-gathering and dissemination processes.

Company personnel have found it of value to talk to local people individually or in small groups well in advance of any significant activity at a site. In this case the personality of the individual is critical, because he must both understand and clearly project sympathy with local concerns. This individual could be a public relations specialist, sometimes a quarry superintendent or company officer, or perhaps a lawyer hired by the company.

TRACK RECORD

What a company is, where else it operates, and what else it does should all be explained to the local people. A record of reliability, stability, and concern has been found to be invaluable, because good public relations consist of good deeds followed by good words. In this case, it means that companies with other operations should be certain that those operations demonstrate their expressed intentions at the new operation. Most people will consider that a company's past record is the best indication of what it might do in the future.

Luck Quarries found that letters from local officials at other communities where they operate, stating satisfaction in its manner of operation, were valuable. In one case the company obtained a petition from homeowners in a subdivision near one of its operations showing local support and substantiating its claim to being a good neighbor. Luck Quarries also found that color photographs of its other operations showing, in particular, attractive, landscaped entrances, clean yards, and well-maintained buildings can be helpful. Vulcan Materials has found that an ongoing community relations program at its operations is valuable, and that contributions to various charitable or other community projects in the form of personnel, equipment, products, or money can demonstrate a good neighbor policy.

THE HEARING PROCESS

Before a permitting application for mineral aggregate mining is submitted, a company's energy has been devoted to gathering hard data about the potential effects of the proposed operation in order to meet the various requirements of the rezoning process. Once all of the data have been collected, analyzed, assembled, and submitted to the appropriate agency or agencies, the company's energy and efforts shift from the factual to the political.

A permitting request is usually made to a municipality or county, whichever has local jurisdiction in the permitting process. Ultimately, the decision regarding a new mining operation is political, as opposed to strictly legal. Thus the hearing process is quasi-judicial, and standard rules of evidence and judicial decorum may or may not exist.

In some cases companies have found that public hearings are fairly routine. The local public and their political representatives may be satisfied that the operation will be beneficial or have no significant negative impacts. Under such conditions the public hearing room may be a lonesome place, populated only by company representatives and hearing personnel. When this situation occurs, companies have usually followed the guidelines outlined in the previous pages. As was noted, however, following guidelines is not a guarantee for success. Most operations have found that there has to be an element of luck as well as skill.

More often public hearings devoted to obtaining a permit to mine mineral aggregate are difficult, even when a producing company has taken heroic measures far beyond those required for most businesses. By nature, producers of mineral aggregates are generally doers, builders, and action oriented. Debate and public presentations in the frequently emotional environment of public hearings are not their strengths. Often their virtues--virtues that are needed to build our world--become a handicap in the emotional world that Naisbitt (1) calls "participatory democracy." Unfortunately, participants in democratic hearings are often as limited in their capacity to deal with complex technical aspects of mineral extraction as are the technicians in dealing with emotion and politics.

SUMMARY

Obtaining a permit to operate a new mineral aggregate resource is a complex process requiring a good company record and reputation, along with a site that has a minimum number of potential environmental problems. A carefully integrated plan for obtaining and summarizing information and for presenting that information to the public is essential in order to reduce problems at public hearings. If the whole process is executed well, and if there is a little luck as to the nature of the local population, a public hearing may go smoothly and a permit to mine may be granted.

Is there any suggested course of action in the event luck is not with the applicant?

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Public Hearings and the Mine Permitting Process

JAMES R. DUNN and MICHAEL J. HART

ABSTRACT

Few situations are more difficult for the mineral aggregates producer than public hearings. By nature most mineral producers are men of action, and debating and politics are not normally their greatest strengths. Yet supplying mineral aggregates for construction, so critical to the welfare and economy of the people of the United States, must be carried out by mineral producers in an environment that is intensely political and often highly emotional. This environment tends to evolve toward a polarized atmosphere in which decisions in the true public interest may be virtually impossible. The cost to the United States of not managing or mismanaging mineral resources is enormous, and can be measured in billions of dollars per year.

The euphoria that mineral producers feel after a happily uneventful public hearing is not common, because uneventful public hearings for mining permits are not common. How the environment of public hearings commonly evolves is described in this paper. Some estimates of the cost of this environment in terms of the general public are summarized, and some possibilities for reducing the magnitude of such problems are proposed.

This paper also serves as an introduction to two papers that review the approaches to solve problems of mineral resource development and the environment that were taken in California and New York.

PUBLIC HEARING ENVIRONMENT

The public hearing is the essence of "participatory democracy" as defined by Naisbitt in his book "Megatrends" (1). Yet the effect of the public hearings process may not be truly democratic, in that the participants often represent an insignificant proportion of the populace. There is considerable doubt that the general public is well served by the process, with respect to mineral aggregate production. It is not clear that the local people potentially affected by an aggregate operation are well served or in agreement with decisions based on the hearing process, or that regional aspects of mineral planning have ever been considered. A short review of the hearing environment is instructive.

Those who participate in the hearing are most often the people who strongly oppose the permit that is the subject of the hearings. Moderates often do not attend, do not speak up if present, and do not follow the process through to its conclusion.

Michael J. Hart of Flatiron Materials Company has suggested that opposition to a permit or zoning change tends to have an evolutionary pattern. Initially people meet because of what they visualize as a potential threat to their quality of life. Many of the people simply wish to be informed about the facts. Gradually, those who conclude that they will not be affected drop out of the opposition group. As time goes by the group often tends to become radicalized or polarized; that is, those who could be described as opposed, yet willing to work toward a solution acceptable to all, ultimately drop from or are driven from the group by the hard-core opposition.

The radicalization or polarization process is far from being restricted to hearings involving mine permits, and motivations may be quite unselfish. To cite a parallel example, hearings involving evaluation of the risk from asbestos in public schools are attended by teachers, school board members, and parents. All of them want one thing: the best that they can afford for the welfare of the children. Yet the radicalization or polarization process may be very much in evidence. A few people have made up their minds, with or without evidence, as to the nature of the danger and what should be done about it. They have fixed opinions, generally obtained through brief and lurid media accounts, and those opinions can rarely be altered by facts or reason. Too often hysterical participants carry the day and schools spend large sums of money to remedy a problem that may in reality be minor.

Hart has further observed that as the aggregate permitting hearings continue, the crowds tend to dwindle, perhaps from several hundred at the first couple of hearings, down to a handful during the last few. Although the discussions involve air pollution, noise, blasting damage, effects on groundwater, reduced property values, and increased traffic, these are often not the real issues, but names by which people describe the larger issue at hand, which is the perceived threat to their quality of life.

Each of these issues is highly technical and does not lend itself to short seductive media reports. Yet the producer has usually spent substantial time and money in regulatory compliance in these areas. His information is apt to fall on deaf ears.

The processes so essential to democracy itself--mediation and compromise--are often virtually impossible in such an environment. In the eyes of the hard-core opposition, there is often no alternative to preventing the operation for whatever reasons that they may find.

Perhaps more important, politicians who must make decisions are aware that the formidable energies of the hard-core opposition may likely be redirected toward defeating them in the next election. Making sound decisions in the best interest of all of the people they represent is difficult for politicans. Decisions made in the best interest of the greater public, beyond the local people, are probably only accidental. Certainly, in the field of local mineral resource management, the implications to that greater public are rarely considered and, if considered, are not a major component in any deliberation.

A recent (1984) election in the town of Rotterdam, New York, a Schenectady suburb, is illuminating. A developer wanted to open a large shopping mall but was fought for years at public hearings. One of the candidates in the election ran on the plank that he had been strongly and actively against the mall. He was defeated in the election by more than a 2:1 ratio. Although the moderates voted their opinions, their voices were rarely heard at hearings, and the impression that most people had (and probably the defeated candidate had) was that most people in the local community were against the mall. The problem is that there is no such thing as a radical moderate; consequently moderates, almost by definition, do not usually get angry enough (or brave enough) to express their feelings at hearings. Impressions gained from hearings, or from media reports of the hearings, may be quite different than the reality.

PUBLIC SUBSIDIZATION OF LIFE-STYLES

Although it would appear to be an ideal democratic forum, the hearing process often may not be democratic in effect. This is especially true because preventing an aggregate operation may be perceived as a local gain by a limited public, whereas the general and much larger public may suffer staggering losses in terms of costs for materials, increased wear on public roads, increased material consumption, and a larger number of contact miles with trucks (because more truck miles expose more people to whatever problems occur with truck traffic).

In a sense the general public is subsidizing the life-style perceived by a small number of people to be desirable. Several authors have put a price on the amount of this subsidization. For example, in 1962 Hewitt (2) calculated that the increased cost to the people of Toronto would be $6,500,000 per year if producers of mineral aggregate were forced to move 10 miles farther away because of population pressures. According to Bronitsky and Wallace (3) of Rensselaer Polytechnic Institute, the cost for the New York City area was placed at $30,705,000 (1970 dollars) per year if better planning was not employed in obtaining aggregates closer to the point of use. In 1983 Dunn (4) found that the cost, as it actually turned out, is about $32 million annually as of 1982 (1970 dollars). The California Division of Mines and Geology placed the cost of bad resource planning to the people of California at $17 billion over the 30-year interval from 1970 to 2000 (5). The National Academy of Sciences report by the Committee on Surface Mining and Reclamation in 1980 pointed out that the annual cost in the United States of a single mile extra of average haul distance per ton of aggregate would be $140 million, or translated to energy, 400,000 barrels of fuel per year (6). In an economic sense, these costs can be called a wealth transfer from the general society to specific small segments of society.

ARE THERE PRACTICAL ALTERNATIVES?

Some sort of alternative to the permitting process as it usually is structured would appear to be warranted, because the long-term interest of the general public is not being addressed. However, the driving force to make major changes in mineral resource management policies is notably weak. John Baden of the Political Economy Research Center in Montana states the reason clearly: "Those who will never receive the products that are not developed are unaware of the causes of the increased scarcity while those not employed in producing goods are equally uninformed regarding their losses."

One alternative system exists and is in constant use: simply set down rules in an unemotional environment in advance of decision making. An action is then considered satisfactory if it conforms to these rules, and unsatisfactory if it does not. A typical example would be restrictions on housing, whereby if a lot and a house to be constructed are within a certain size range, approval of the local land use authorities is automatic. A similar arrangement has been proposed for mining permits in Carroll County, Maryland (7). A proposed zoning ordinance is integrated with a mineral resource overlay (MRO) map, on which is outlined the areas where potentially economic mineral resources are most likely to occur and where they can be developed with minimal negative sociologic, economic, and environmental impacts. Within these areas compliance with a set of environmental regulations pertaining to mining assures that permission to mine will be granted.

Another alternative is to be good enough--and perhaps to be lucky enough--to be able to keep all discussions on an unemotional level. As previously indicated, some mineral producers have, at times, been able to do this. However, the real question may be: Can we allow something as important as our mineral resources to be developed only by the few who are skillful enough or lucky enough to be able to handle the problems of public hearings?

The following two papers describe two alternatives at the state level currently being practiced in California and New York State.

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Impact of New York Reclamation Law on Aggregate Source Development

GEORGE M. BANINO and JOHN R. HELLERT

ABSTRACT

New York State's Mined Land Reclamation Law of 1975 committed the state to the balanced policy of assuring the orderly development of its mineral deposits while mitigating adverse environmental effects of the mining process. A new mining operation requires a permit from the New York State Department of Environmental Conservation (DEC), with the permit based on a mining plan and a reclamation plan. Because the state cannot contravene town land use laws, operating a new property usually requires action also by the town in which the mining is to occur. Thus situations arise in which the state issues a permit but the town does not. However, the state law has proved helpful in that the DEC has a professionally trained staff that understands the mineral industry, its environmental impacts, and their mitigation. The presence of the staff and the advice they give is that of a detached third party that can answer questions with professional objectivity. In the event that the town requests an environmental impact statement (EIS), the DEC helps by supplying a format for the EIS and evaluating it once completed. Although the state does not assure that needed deposits can be developed, the Mined Land Reclamation Law has made it possible that some deposits have been developed that otherwise may not have been. The DEC has ultimately approved more than 90 percent of the requests for mining permits. However, there are no statistics about the number of mining permits that ultimately have received local approval.

On April 1, 1975, New York State passed the Mined Land Reclamation Law (MLRL). The legislature thereby committed the state to a policy of balance: On the one hand the purpose was orderly economic development of the mining industry to meet the state's needs, while on the other hand the law also protected the environment by requiring the industry to carry out sound reclamation, designed to return the mined land to further usefulness.

Although 4 years passed before the law was implemented in a meaningful way, it quickly produced benefits for both the general public and for members of the mining industry. The presence of a detailed mining law that objectively addressed mining and reclamation issues demonstrated that a balance of economic development and sound environmental practice was feasible. Experience has now proved that the requirements of MLRL actually assist in obtaining local mining permits, zoning changes, or special use permits.

In this paper the ways in which the aggregate industry has found the New York State MLRL to be advantageous are discussed.

AGGREGATE INDUSTRY IN NEW YORK STATE

New York ranked 14th in the nation among producers of sand and gravel and crushed stone on a dollar basis in 1982, with a total value of nonfuel mineral production in 1982 of $500 million. In tonnage of portland cement and nonfuel minerals produced, the state ranked seventh. Records of the New York State Department of Environmental Conservation's Division of Mineral Resources indicate that, of 1,220 presently permitted mines in the state, 88 percent produce sand and gravel and 9 percent produce crushed stone, leaving only 3 percent of the mines producing minerals other than construction aggregate.

Aggregate producers are distributed throughout the state, but they are concentrated for the most part in urban counties. For example, Region 8, with 11 counties in the Rochester area, has the largest number of permitted mines, followed closely by the 6-county Buffalo area (Region 9). However, the boroughs of New York City (Region 2) have no mines, and their suppliers of aggregates and cement include areas as far as 75 miles north near Kingston, New York, as well as New Jersey, Connecticut, Massachusetts, Pennsylvania, and Canada.

In many areas of the state aggregate resources are diminishing rapidly. Two primary causes for this trend are, first, that existing reserves are being depleted by mining, and second, that developmental pressures continue to nullify resources by adverse zoning or by building over them. Most urban areas are now importing aggregates from sources well outside their immediate boundaries.

NEW YORK RECLAMATION LAW

The purposes of the MLRL are to foster and encourage the sound development of the New York mining industry and to assure that the development is carried out in a sound environmental manner. Specifically, the law states that New York's policy is as follows:

> To foster and encourage the development of an economically sound and stable mining and minerals industry and the orderly development of domestic mineral resources and reserves necessary to assure satisfaction of economic needs compatible with sound environmental management practices. The legislature further declares it to be the policy of this state to provide for the wise and efficient use of the resources available for mining and to provide, in conjunction with such mining operations, for reclamation of affected lands; to encourage productive use including but not restricted to: the planting of forests, the planting of crops for harvest, the seeding of grass and legumes for grazing purposes, the protection and enhancement of wildlife and aquatic resources, the establishment of recreational, home, commercial and industrial sites; to provide for the conservation, development, utilization, management and appropriate use of all the natural resources of such areas for compatible multiple purposes; to prevent pollution; to protect and perpetuate the taxable value of the property; to protect the health, safety and general welfare of the people, as well as the natural beauty and aesthetic values in the affected areas of the state.

The law requires two plans: a mining plan and a reclamation plan. The mining plan deals with geologic, engineering, and environmental aspects of the site; and the reclamation plan deals with returning the mined land to an environmentally acceptable and useful condition. A reclamation bond is required, usually $1,500 per acre for land affected by mining.

The mining plan requires discussions of the method of excavation, the impacts on air and water resources, and methods of preventing adverse impacts on the environment. The reclamation plan requires a general statement of the proposed use of the property following mining, discussions of drainage, revegetation, removal of equipment, and a reclamation schedule.

The New York State Department of Environmental Conservation (DEC) administers the MLRL through mining specialists in each of DEC's nine regions throughout the state. The mining specialists work under the general direction of DEC's Division of Mineral Resources in Albany, and follow the rules and regulations developed by DEC to administer the MLRL. Regional administrators have at least a general knowledge of the mining industry and, through the exercise of their duties, learn the practical aspects of the industry. They are technically oriented people, ranging from ex-aggregate industry employees to geologists or forestry experts. For the most part they work cooperatively to help aggregate producers meet the requirements of the MLRL in a realistic manner.

LOCAL MINING REGULATIONS

Of New York's 932 towns, a few have developed land use ordinances with provisions for extractive industries. A much larger number, however, exert their principal control over mining through zoning ordinances, and New York's policy of "home rule" does not allow the state to contravene town land use laws. MLRL states specifically that nothing within the law shall prohibit municipalities from enacting ordinances with more stringent requirements than the state's law. MLRL does not replace local law, but rather it is an additional permit that is necessary before mining.

Thus many cases are known where the state issued a permit, but the town refused to enact the zoning change that would permit mining. Article 78 of the law makes provisions for legal action against the town by applicants if they believe the town acted in an arbitrary and carpicious manner in denying their request.

APPLICATION OF MINING LAWS

The local and the state mining laws tend to be applied in different ways. Local administrators of land use laws are usually volunteers from a wide variety of backgrounds that seldom include a knowledge of mining. The local permit process is often surrounded by emotionalism, lack of understanding, misinformation, and political interests, and the producer may find himself fighting a quagmire of innuendos and issues that have little bearing on the facts of the application. The state permit process, however, is far more predictable. Regional mining specialists understand mining and ways to mitigate environmental impacts. More important, they do not have to answer politically to special interest groups, although they must take such comments into account. Thus the permit application will be reviewed fairly and, if environmental problems can be resolved, the permit will be granted.

One of the most positive benefits of the MLRL is that it has set an example for rational decision making--a situation that exists unevenly at the local level. The following case studies show that both towns and mineral producers may seize on MLRL's objective framework as an evaluation tool, especially when a mining specialist or other technical expert enters the picture as a disinterested party to explain the technical aspects and mitigating features of contemporary mining law and practice.

EXAMPLES OF MLRL APPLICATION

MLRL Replaces Local Law

The Norlite Corporation, a lightweight aggregate producer near Albany, made its initial application for a mining permit in 1977, soon after MLRL was applied to the industry. As part of the application for the operation, Norlite notified the town of Colonie in accordance with DEC regulations. Complications arose when the town attempted to consider the application under its soil removal ordinance, a law that was not designed to meet conditions of a deep shale mining operation such as Norlite's. Further, the property was split by a town line. Once Norlite and its geologic consultant demonstrated that the town's interests were met by the extractive and environmental conditions of MLRL, the problems were resolved when the town waived the soil removal ordinance and accepted the terms of MLRL as the town's requirement. This not only removed the need to try to conform to an inappropriate ordinance, but also removed a level of inspection and regulation by local people with little knowledge of the mining industry.

Framework for Data Presentation and Review

The crushed limestone operation of Concrete Materials, Inc., in the town of Sweden, north of Rochester, was operating with the required state and local permits. The company desired to expand westward into reserve land that it owned, but the land was improperly zoned. Because of a small number of vocal opponents, the town wanted Concrete Materials to address broad and irrelevant environmental aspects of the proposed expansion in a potentially detailed and expensive study. Negotiations between the town and the MLRL regional mine specialist led to restricting the report to technical and environmental issues directly affected by mining; in other words, to topics that were required to be addressed by the MLRL. This greatly limited the scope of study. It also became the framework for review by comparing proposed actions and impacts with regulatory guidelines.

Award of Permit in Face of Opposition

Although MLRL requires proof of notification of the town by obtaining a signature from the principal administrator, the state recognizes that some town officials may refuse to sign for political reasons, even though such a signature is in no manner an approval by the town. Thus after an appropriate length of time, proof of attempt to notify (registered mail receipt) and perhaps conversation with town officials by DEC personnel, the regional mine specialist will proceed with the review. This has led to a number of occasions when the state permit was received during deliberation by the town.

Red Wing Properties, Inc., in Green Haven, east of Poughkeepsie, applied for a permit for a new sand and gravel operation to both the town and the state. In spite of the town's refusal to sign the application, the state eventually proceeded with the review and awarded the permit. This gave Green Haven's Town Board and Planning Board members, who were generally in favor of the proposal but were confronted by vocal opposition, ammunition to respond to local complaints. They ultimately awarded the permit. It was a dramatic moment during the public hearings when the applicant announced that he had received his state permit that day.

Basis for Operational Changes

MLRL lays out guidelines and specifications for mining and reclamation and thereby creates a measure of the degree of positive action undertaken by the applicant.

Valente Gravel, Inc., in North Greenbush, east of Troy, had an ongoing operation and wanted to expand across a town line into their reserve property. Only part of the area was properly zoned for mining. In general, town officials were favorably inclined toward the expansion but, again, had to meet concerns of local opposition to the zoning changes. Valente runs a large sand and gravel operation. Its operation predates MLRL and, therefore, parts of the former mining areas are not subject to reclamation requirements. The producer, however, began an aggressive reclamation program following guidelines of the present law, developing an ongoing reclamation plan to continue throughout the life of the operation. The agreement to carry out reclamation that was not legally required gave them credibility, and the MLRL provided the ability to measure progress against specifications. Further, it provided town officials the kind of data needed to respond to local complaints and award the zoning change.

MINING ADVOCACY

The MLRL is leading gradually to another benefit: actions by the state as a supporter of the mining industry. In New York there are no public interest groups other than industry associations that have as their mission the promotion and support of mineral development to meet the state's needs. In the past this had led to the difficult situation of a producer facing opposition from local government and interest groups, and opposition as well from state agencies such as the Department of Agriculture and Markets, which represents farmers.

MLRL clearly lays responsibility for fostering and encouraging mining on the DEC. Some say that this role conflicts with the more broadly based requirement of DEC to act as regulator and protector of environmental interests. Industry leaders, however, expect DEC to also serve the purpose of the MLRL by becoming more of an advocate for the industry. They hope that DEC will undertake activities such as public education on the needs and benefits of mining, support through dissemination of data to be used to applicants' benefit before localities, and even perhaps to appear at local hearings to discuss needs and benefits of mining and positive experiences of other mining operations.

Meanwhile, a DEC spokesman estimates that more than 90 percent of the applicants are granted permits to mine. Occasionally problems arise when applications are not as good as they should be, and occasionally environmental protection requires restrictive clauses; but by far the majority of applications are granted.

There is at least one example in which a producers' application for a zoning variance for quarry expansion produced 2 years of bitter fighting and alleged illegal actions by townspeople. Eventually, DEC interceded, proper legal action was taken, and permits were issued.

DEC's simultaneous support for mining and for environmental protection is a goal that is not yet achieved on a statewide basis, but movement in that direction is under way. In practice, the MLRL is already providing some advocacy for New York's mining industry. DEC regional mining specialists understand industry needs and impacts and constantly must look beyond the emotionalism of local opposition. They often meet with town officials, discuss various technical and procedural aspects with those officials, and will occasionally attend public hearings to discuss the application of the mining law.

SUMMARY

The MLRL has benefited both the state's mining and environmental interests in a number of ways. It provides a statewide, rational framework for regulating mining to supply minerals needed for New York State's development while it also protects the state's environment. Most producers have received even-handed and intelligent assistance from the professionals who administer the law in the state's nine regions and who understand the special conditions in their region.

Still, the law is not yet problem free. Some people still call the MLRL a poor law, citing problems with uneven administration, especially during the early years of its administration. Uncooperative or even antagonistic state officials have been encountered. In fact one producer took DEC to court on a point of interpretation and finally won the right to mine, after the case went through two lower courts. Further, some sophisticated special interest groups have used MLRL rules and regulations to their advantage to forestall applications.

Although it may not be the final answer, everyone agrees that the MLRL is a good place to start. Towns generally rely on the state's knowledge of mining and reclamation procedures and producers appear to be in accord on the benefits of reclamation--benefits that accrue to both the community and to themselves.

Generally, implementation of New York State's MLRL has placed order into an otherwise chaotic condition. With increasing experience and with greater understanding between industry leaders and environmentalists, the ability to meet community needs for basic construction materials in an atmosphere of government and public cooperation is coming closer to reality.

Positive Impact of Urbanization on the Aggregate Industry

DON REINING

ABSTRACT

The planning and environmental control process, as it relates to mining in California, was triggered essentially by a 1967 amendment to California's General Code, which added "natural resources" to those things that must be considered in land use planning. Then in 1973 the California Division of Mines and Geology published a report that showed (a) the need for mineral resources, (b) how mineral resources were being needlessly lost to the people of the state, and (c) what the cost to the citizens of California was likely to be by the year 2000. The state has officially acknowledged that management of mineral resources is a critical part of the planning process. California currently has laws in which quantification of mineral resources is under the California Division of Mines and Geology, land reclamation is administered under the Surface Mining and Reclamation Act, and opening new deposits requires environmental impact reports that are administered under the California Environmental Quality Act. Development of laws relating to environmental and economic impacts of the mineral industry in California was accomplished in close cooperation with the state's mineral aggregate producing associations and with the approval of the Sierra Club. Some specific efforts of the Southern California Rock Products Association are also noted in this paper. This body of laws has proved beneficial to some mineral producers. However, the process of evaluating requests for approval to mine has been slow, often with a 10-year period between the first submittal of a proposal and actual mining. This prolonged process is costly and tends to eliminate the small mineral producers that dominated the aggregate industry in the past.

During the past two decades the Southern California Rock Products Association has been involved with legislation that vitally affects the mineral industry and the people of the state of California. The long and complex interplay between California's legislature, some of its bureaucracies, conservation groups, and the mineral industry has resulted in many compromises. There is a better understanding now among the contributing groups of each other's importance, perspectives, and requirements. Legislation resulting from the interplay of forces is innovative and in many ways the first of its kind. A few highlights of the history of these laws and some of the practical results of the legislation are summarized herein.

LEGISLATIVE HISTORY

In 1967 California's General Code was amended to include the words "natural resources" among considerations in land use planning. Cities and counties were required by law, for the first time, to recognize natural resources in their general plan or statement of development policies and were also required to include a diagram(s) and text setting forth objectives, principles, standards, and plan proposals with respect to natural resources. Before this, cities and counties had been planning for housing, business, industry, agriculture, and so forth, but not for their natural resources. The cart had been before the horse.

LOSS OF MINERAL RESOURCES

In 1973 the California Division of Mines and Geology (CDMG) republished a landmark document that gave credence to mineral resources as a vital link in the state's future development (1). According to the authors, the loss of mineral resources in California due to urbanization between 1970 and 2000 was estimated to total $17 billion if practices at that time were continued. Mineral resources under greatest urbanization pressure were found to be construction materials, especially sand, gravel, and crushed stone. In the CDMG report the estimated losses were based largely on the added costs: the cost to the public of increased transportation, the cost of relocating mining operations farther from markets, and the cost involved in use of lower grade deposits that require more processing. Some mineral deposits being threatened by urbanization were shown to be unique and not replaceable. However, the report did not include in the $17 billion figure the environmental costs of using mineral deposits farther from markets, such as more vehicles required, more energy used, resultant increased air pollution, and increased road maintenance.

It was concluded by Alfors et al. (1) that

> Mining operations required to supply urban needs should be located as close to markets as suitable deposits permit, and appropriate land use designations should be provided. Unique mineral deposits, especially, should be protected from urbanization.

Deposits of all minerals on earth that are of economic size and quality constitute only a small fraction of 1 percent of the earth's crust, making them one of the rarest, and most valuable, parts of the environment. In their report, the CDMG urged local governments to protect critical mineral resources, access thereto, and the mining thereof within their jurisdictions by special zoning, with buffer zones around them as necessary. In turn, the division urged that mine operators be required to conduct operations as compatibly as practicable with their surroundings and be required to rehabilitate depleted mined lands for subsequent beneficial use such as parks, open space, or other forms of urban development.

THE SURFACE MINING AND RECLAMATION ACT AND RELATED LAWS

In 1975, to solve the problem of dwindling mineral resources and in part to head off federally imposed regulations, the Surface Mining and Reclamation Act (SMARA) was passed by the California State Legislature and signed by the Governor. The bill (S 756) had the approval of the mineral aggregate trade associations and the Sierra Club. SMARA requires the state geologist to classify, according to mineral content, urban and urbanizing areas in the state. The Act further requires reclaiming mined land to a usable condition in accordance with adopted state policy and local ordinances. The California Environmental Quality Act (CEQA), along with SMARA, has imposed additional environmental regulations on the aggregate industry.

The legislation opened new horizons for surface mining operations and reclamation of mined lands in California. The Southern California Rock Products Association supported the passage of Senate Bill 756 because it made sense environmentally, and it was good for business and for society in general.

SMARA provides for mineral resource classification in the state's urbanized areas. The state geologist is instructed to categorize mineral resource availability without regard for current land use activities. As a result, construction aggregate maps are prepared to date for six "production-consumption regions" in the Los Angeles metropolitan region and environs, and the four regions in the San Francisco Bay Area. The maps show the distribution of usable materials based on current technical specifications of physical and chemical characteristics.

It is important to note that the majority of the information on which these classifications are based is currently available, and CDMG staff has garnered this information, interpreted it, and put it into the classification format. This makes the process cost effective and distinguishes it from mineral exploration by the industries, which is of a more intensive and expensive nature appropriate to the private sector.

Where construction aggregate resources exist, unencumbered by incompatible land uses, the state geologist establishes mineral resource sectors and estimates the volume of that aggregate material. The state geologist estimates the volume of construction aggregate materials that will be used in each production-consumption area by decade during the next 50 years. These newly assembled maps provide local governments land use information with new insights regarding both the occurrence of usable construction aggregate resources and the extent of geographic locations within their jurisdiction that may satisfy the required needs during the next 50 years. Such insights allow enlightened and prudent management of land uses and mineral resources. The provision of the classification information by the California State Geological Survey establishes the information with objectivity, because this scientific group has no regulatory responsibilities or any vested interests of any type.

Eighty-six local governments in California now have surface mining and reclamation ordinances. In most cases these agencies have recognized that extraction of minerals is essential to the economic well-being of their areas. They note that minerals are important to many industries, including construction, transportation, and chemical processing. The use of many mineral deposits is enhanced by their close proximity to urban areas. The nonrenewable characteristic of mineral deposits necessitates the careful and efficient development of mineral resources to prevent the unnecessary loss of these deposits due to uncontrolled urbanization.

Whereas the industry was previously at odds with planners, planners are now more likely to see mining as a transitional land use that is critical to the needs of the general public and that requires their sympathetic attention. To ensure implementation of a mining and reclamation plan, there is a coordinated effort between the concerned government agencies and the industrial association.

Designation of mineral resource deposits, including construction aggregates, constitutes a policy development process accorded to the state Mining and Geology Board by SMARA. The board is authorized to designate deposits exceeding a specific threshold value as "deposits of regional significance." Further, the statute requires that the "lead agency" (land use regulatory jurisdiction of local government) inform the Mining and Geology Board on how they are using that designation information in their land use planning decisions. Every community shall, in accordance with state policy, establish mineral resource management policies to be incorporated into its general plan. The Mining and Geology Board also has the opportunity to comment on any planning or regulatory decisions made by local government. As the Mining and Geology Board has carried out the designation process, they have held public hearings on each set of impending designation decisions for specific production-consumption areas and an environmental impact report (EIR) has been prepared. The designation process provides an opportunity for dialogue between the state Mining and Geology Board and local government regarding deposits designated to be of regional significance.

The major reason why the sand and gravel industry supported passage of SMARA was because of the classification and designation of mineral lands. Pursuant to the requirements of the Act, the state Mining and Geology Board adopted the "Guidelines for Classification and Designation of Mineral Lands" following a June 1978 public hearing.

In accordance with their responsibility under SMARA, the CDMG provides technical advice on reclamation planning to both local government land use regulators and to the mining industry. For example, CDMG offers technical commentary on plans submitted for staff review, it develops general information publications, and it conducts workshops on reclamation. CDMG is now preparing a major publication on reclamation in California and is organizing a promising series of workshops. CDMG's influence in the area of constructive advice for producers and users of aggregates should continue to grow.

UNIQUE NATURE OF SMARA'S RECLAMATION AND MINERAL RESOURCE CONSERVATION PROGRAM

SMARA provides information on mineral resource availability and reclamation at the state level without exerting a true state regulatory role. In most states that have a reclamation act, however, the state administers the reclamation process as a regulatory body. The state Mining and Geology Board establishes policy on reclamation regulations that is then implemented by the local governments, a desirable arrangement that allows the small reclamation staff at the state level to provide information rather than administering regulations. The key to its success, however, is the assurance that appropriate local governments are enforcing the regulatory responsibilities in a acceptable manner. This is generally the case throughout California.

Thus the classification-designation process provides a significant opportunity for improved land use decisions based on knowledge by local governments regarding the mineral resource potential within their jurisdictions, and the significance of that mineral potential in satisfying the foreseeable future needs within local production-consumption areas. The reclamation element of SMARA also provides an opportunity for information transfer without obligating the state to administer the reclamation regulatory process.

POTENTIAL IMPACT OF CLASSIFICATION AND DESIGNATION IN CALIFORNIA

As the SMARA programs continue to function, local governments will be able to make more sophisticated and rational decisions regarding land use permits because data will be available on future needs for construction aggregate materials, as well as on the broader implications of their decisions. This in turn should lead to more sustained availability of important aggregate resources in areas where intense land use competition is expected during the coming decades.

Considering reclamation, shorter lag times between the development of new and desirable technologies and their applications in California should result from CDMG's information activities under the policy guidance of the state Mining and Geology Board.

CASE HISTORIES

Case History 1

In January 1981, when the 900-acre residential "Horse Thief Canyon Plan" was being processed before the Riverside County Planning Commission, the California Department of Conservation requested that the developer prove in his EIR that the development would not threaten the potential extraction of sand and gravel in that immediate adjacent area. By law the developer is now required to discuss how his development will relate to the community's mineral resource management policies if the minerals are in the adjacent area. Sand and gravel will be produced from the area once economic conditions justify it.

Case History 2: Reclamation with Inert Materials

A new mobile home park with 150 units on 16 acres of reclaimed land now exists in Orange, California, immediately adjacent to the Conrock Company, a large sand and gravel producer. The development is compatible with the production plant because, during the developer's permitting process, the aggregate company protected itself from future complaints under provisions of the CEQA.

At the public hearings held by the city of Orange Planning Commission to approve the developer's EIR, Conrock challenged the developer's EIR contention that their plant would have no adverse impact on the proposed trailer park. The commission agreed with Conrock, because the closest units would be within 450 ft of the plant, and prospective residents could be adversely affected by the noise from the plant.

According to the commission's orders, the developer modified the EIR with noise-mitigation measures. The developer subsequently spent more than $85,000 to install noise-abatement panels on Conrock Company's plant, which lowered the noise to an acceptable level inside the park's boundaries.

The city's approval was also conditioned on the developer placing a thick cap of compacted fill over the entire site, because the property had been excavated for sand and gravel and subsequently refilled with silt from the production process by ponding.

The most convenient access to the site for the trucks hauling in the required cap material was to cross property owned by Conrock Company. In exchange for allowing the developer to cross Conrock property, the developer agreed that each resident who moved into the park would agree in writing that they were aware of the existence of the sand and gravel production plant; that they accepted the fact that there may be noise associated with the operation of the plant during the legal operating hours; and that they waived their right to file any complaints regarding plant noise.

In essence, the sand and gravel plant has protection to continue operation because its product is needed on a regional basis. Assurance that the plant will continue in operation was brought about by an alert industry representative who worked with the developer and the planning commission.

The property is now productive piece of ground on which 150 families make their home. Probably few residents even know that the land on which their trailers are located was once a sand and gravel pit that had been excavated to a depth of 90 ft.

In prior years the owners of the mobile homes would probably have stormed city hall shortly after they moved into the development. Land limit restrictions, air pollution, noise level complaints, and other problems would have forced the sand and gravel company to move to a fringe area where they would no longer get complaints from their neighbors, and where added transportation would add significant amounts of money to aggregate costs.

Case History 3: Government Helps Sand and Gravel Industry

California's Coastal Commission Act requires the Coastal Commission to approve the general plans of cities and counties within its jurisdiction. A large sand and gravel producer applied to the city of San Diego for a conditional use permit to mine its sand and gravel property in the city's Border Highlands. The city denied the permit, partly because their general plan showed a proposed expansion by the state of an adjacent small park.

However, before the Coastal Commission's public hearing, held to certify the city's general plan, company officials found that a changing financial situation prohibited the state from acquiring the property for park expansion. The company obtained a letter to that effect from the State Park Commission, which it submitted to the commission at the hearing. On receipt of the letter, the Coastal Commission agreed to certify all of the city's general plan, except the area covering the Border Highlands. The city was directed to restudy the area and to submit a revised plan for the Border Highlands showing a designation on the property that would allow for excavation of the sand and gravel deposit. The commission even contributed $17,000 to the study it ordered (2). The study was subsequently completed and the city revised its general plan for the Border Highlands area, acknowledging the existence of the deposit and indicating the future use of the property for sand and gravel extraction. The revised plan was then submitted to the Coastal Commission, which certified the revision.

Currently Fenton Material Company is mining, and Conrock Company should be able to mine their reserves in the future when needed.

Case History 4: Same Plot of Land Used Four Different Ways

The hypothetical situation that follows illustrates the potential value of sequential land use.

In the Los Angeles area in 1978 you could purchase 40 acres of land suitable for sand and gravel mining for $400,000. If the market was good you could expect the sand and gravel company to whom you leased the property to dig the 40 acres in 9 years.

Nine years later, when 9,375,000 tons of aggregates would have been sold, your $0.15 per ton royalty would have provided an income of $1,406,000. In 1987 your 40 acres would then be depleted. You could then lease your land to a reclamation company. In 8 years the empty hole will be filled with class II material that permits inert and decomposable waste, such as household refuse. At $0.25 per cubic yard, your royalty rate would provide an income of $1,526,500. Now your 40 acres have been reclaimed and Mother Nature could start working for you.

For the next 15 years you could then be collecting methane gas after your wells have been established and a compressor plant has been built. You may find a company that would dig the well, install the scrubber equipment, and sell the gas at no cost to you. They would pay an estimated income to you in the amount of $7,000,000 over the next 15 years. Not bad for an original investment of $400,000.

Thus the income derived from sand and gravel mining, sanitary land fill, and methane gas extraction is as follows:

Year	Land Use	Income ($)
9	Mining	1,400,000
8	Landfill	1,500,000
15	Gas recovery	7,000,000
32	Reclaimed land	9,900,000

Don't forget, you would still own the 40 acres. Why not build a golf course on your property or a drive-in theater?

Every step of the way we pay money and we complain, but we ultimately comply with the CEQA and other environmental regulations. We prepare EIRs. We have a dozen different agencies that must approve our environmental report.

Ten years ago no producers had gone through this sequential use exercise; but today reclamation operations are beginning to reap the benefits of sound business practices that sometimes are imposed on the sand and gravel industry by government agencies and the general public. In the long run the industry has survived. It has made a profit for its stockholders and paid its taxes, although California producers often count on a 7- to 10-year battle with government agencies to get permits.

SUMMARY

California's SMARA is the first legislation in the United States that establishes a statewide mineral resource policy governing mining activities that recognizes regional resource needs and retains local autonomies.

The Southern California Rock Products Association supported the proposed legislation, and through its efforts the SMARA was passed.

Local planning and zoning processes, which are so critical to the industry, have been significantly improved with implementation of SMARA. Recognition of the importance of the mining industry is now being fostered by the state Mining and Geology Board and the CDMG. Authority is being established by documented reports prepared for the designation process. Credibility of the industry is further strengthened with the partnership between local and state governments.

SMARA directs the state Mining and Geology Board, in cooperation with CDMG, to classify areas previously identified by the Office of Planning and Research as lying in the path of urbanization with respect to the nature of mineral deposits in such areas. Such areas of information shall be included in the general plan of the community within 12 months, in accordance with state policy. Communities are required to establish mineral resource management policies to be incorporated into their general plans.

Before permitting a use that would threaten the potential to extract minerals in an area classified or designated, the community permitting agency must show cause for an evaluation of the area to be prepared in order to ascertain the significance of the mineral deposits located therein.

In accordance with a time schedule, and based on guidelines adopted by the board, the state geologist shall classify, on the basis solely of geologic factors and without regard to existing land use and land ownership, the areas identified by the Office of Planning and Research and any area for which classification has been requested by a petition that has been accepted by the board.

Within 12 months of receiving the mineral information after the land has been designated as an area of statewide or regional significance within its jurisdiction, each local land use agency, in accordance with state policy, shall establish mineral resource management policies to be incorporated into its general plan.

California has made considerable progress since Senate Bill 1401 was signed by the Governor on September 2, 1967. This Act requires that the land use element of a city or county general plan designate, among other things, the proposed general distribution and general location and extent of the uses of the land for natural resources. The bill further provides that the general plan for city or county development may include as a part of a conservation element the location, quantity, and quality of the rock, sand, and gravel resources.

In California obstacles to development of aggregate deposits have been reduced substantially during the past 20 years, thanks to the legislature and the administrative assistance of California's state government. Most aggregate producers believe that the law has been beneficial, and planners appear to better understand the need for aggregate production in terms of its economic impact on the people of California.

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Part 2
Research in Pavement Aggregates

Summary of Testing of Recycled Crushed Concrete

RICHARD W. PETRARCA and VINCENT A. GALDIERO

ABSTRACT

To investigate the performance of recycled concrete aggregates (RCA), physical test data from 1977 through 1982 are summarized in order to present typical characteristics of the RCA material. In situ deflection test results on various projects since 1974 are summarized. Deflection testing was performed on pavements constructed with crushed stone, asphaltic concrete, and recycled crushed concrete base courses. Analysis of the data indicates that the pavements constructed with recycled crushed concrete bases have strengths equal to or higher than stone or asphalt base pavements. The results of both laboratory work and test pavement experiments on the use of RCA in asphaltic concrete mixtures are also presented. In both cases it was found that the RCA-asphalt mixtures have 1.5 to 2.0 times the stability and are 15 percent lighter than a standard crushed stone-natural sand mix. In addition, the RCA mixture requires 0.5 to 1.0 percent more asphalt cement to have equal air voids and filled criteria. Finally, data from the Texas State Department of Highways and Public Transportation's long-term experience with the use of RCA-asphalt mixes are presented.

In 1977 a recycling corporation located in Hicksville, New York, began producing recycled concrete aggregates (RCA). Since the inception of the company more than 1.0 million cubic yards of material have been produced and sold for use as a granular dense-graded base course on various residential roads and parking fields throughout Nassau and Suffolk counties.

The original plant equipment consisted of a 22 x 50-in. Telsmith jaw crusher, a 48-in.-diameter Telsmith cone crusher, a 5 x 16-ft double-deck vibrating screen, and miscellaneous chutes and conveyors. This equipment was used to crush and screen the recycled materials.

In 1982 additional equipment was added to the plant, which consisted of a 45-in.-diameter fine cone crusher and a 5 x 16-ft triple-deck vibrating screen.

All concrete used for recycling was obtained from various locations throughout Nassau and Suffolk counties and consisted of concrete from sidewalks, driveways, curbs, and a limited amount of pavement.

The purpose of this paper is to summarize the results of quality assurance testing performed by consulting engineering firms, private laboratories, and county and town engineering departments. The testing was performed on material supplied to road reconstruction projects throughout Nassau County. In addition, experience relating to the use of RCA in asphaltic concrete mixes is summarized.

TESTS AND EVALUATION OF RECYCLED CRUSHED CONCRETE

During the 1977-1982 construction seasons a substantial amount of testing was performed because of the large volume of material used. The results of this testing are summarized in order to present typical physical characteristics of the RCA material.

Specifications required that samples be obtained from the supplier's stockpile and from the field after the material was placed, graded, and rolled. The field sampling was supervised by representatives of Nassau County and the consulting engineer on the particular project. The frequency of the testing was as follows:

1. Stockpile samples were taken each day of production and a washed gradation analysis (ASTM D422) was performed.
2. Every 2 weeks a stockpile sample was obtained and the following tests were performed: Los Angeles abrasion test (ASTM C131), magnesium soundness test (ASTM C88), plasticity index (ASTM D424), California bearing ratio (CBR) test (ASTM D1883), and moisture density test (ASTM D1557).
3. Field samples were obtained each week from Nassau County and town of Hempstead betterment projects, and the following tests were performed: washed gradation analysis (ASTM D422), Los Angeles abrasion test (ASTM C131), magnesium soundness test (ASTM C88), plasticity index (ASTM D424), CBR test (ASTM D1883), and moisture density test (ASTM D1557).

Testing Results from 1977 Through 1982

A summary and comparison of the test results for the years 1977 through 1982 are given in Figures 1 and 2. A study of Figure 1 indicates that the average gradation curve falls within a relatively narrow limit. Figure 2 shows a comparison of physical properties of RCA from 1977 through 1982. The values of Los Angeles abrasion, magnesium soundness, and maximum dry density are all extremely consistent from year to year. The CBR test results are relatively uniform from 1978 through 1981. There was a dramatic increase in CBR values in 1982. This increase is consistent with the addition of a third crusher to the plant operation; the increase in the quantity of crushed particles would explain the increase in stability.

A statistical analysis of the data indicates that from 1977 through 1982 the Los Angeles abrasion mean value was 36.5 percent and the standard deviation was 3.6 percent. The magnesium soundness results showed a similar consistency, with a mean value of 3.75 percent and a standard deviation of 1.3 percent. This was based on 112 Los Angeles abrasion tests and 107 soundness tests.

The CBR and maximum dry density test results were analyzed during two periods: from 1977 through 1981 and for 1982. The plant crushing operation was changed in 1982 and the additional crushing would effect the CBR and density results more than the abrasion and soundness values. The analysis indicated that before 1982 the CBR mean and standard deviation results, based on 133 tests, were 143.8 and 28.7 percent, respectively. In 1982 the values, based on 24 tests, were 168.7 and 27.2 percent. The maximum density results before 1982 had a mean value, based on 119 tests, of 128.5 pounds per cubic foot (pcf) with a standard deviation of 2.6 pcf. In 1982, 24 tests were reported and the results showed

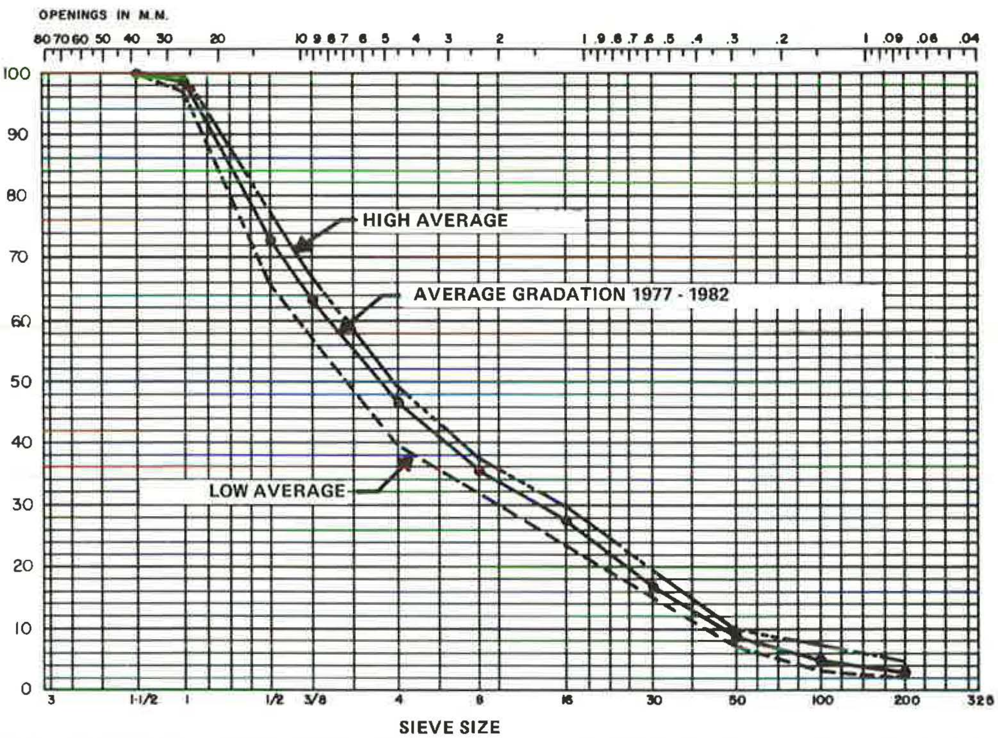


FIGURE 1 Yearly comparison of gradation testing.

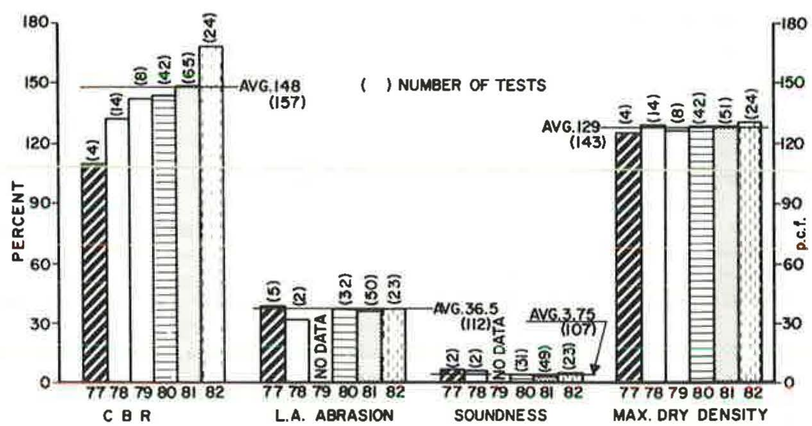


FIGURE 2 Yearly comparison of physical tests (1977-1982).

an increase in mean maximum dry density to 130.0 pcf with a standard deviation of 1.6 pcf. The crushing and screening operation at a recycling plant apparently can have a considerable effect on the stability of RCA granular base material.

One other physical test was performed consistently since 1977--the plasticity index. A total of 106 tests were performed and the plasticity index was zero (nonplastic) for all tests.

Evaluation of Recycled Concrete Dense-Graded Aggregate Base

An enormous quantity of testing indicates that recycled crushed concrete consistently complies with all the parameters required for excellent long-term performance. The material is well graded, it is nonfrost susceptible, the fines are nonplastic, and the material is crushed and has cubical shaped, rough textured particles.

The RCA material exhibits high strength and stability (average CBR of 148). The magnesium soundness and Los Angeles abrasions are consistent with mean values of 3.75 and 36.5 percent, respectively. All test results are well above the minimum specification requirements for dense-graded aggregate bases and subbases.

Additional Studies

An independent study of RCA was performed by the Port Authority of New York and New Jersey (1). The initial scope of work was limited to the testing of RCA for use as an alternative material for a dense-graded aggregate base course, which is the highest quality unbound aggregate currently used by the Port Authority.

The RCA materials were evaluated for the following characteristics: resistance to wear, resistance to breakdown, resistance to weather, absorption of water and specific gravity, gradation, compaction, bearing capacity, chloride content, and composition of material. The materials tested by the Port Authority were sampled from five recycling plants located within New York City and Westchester County.

A comparison of the physical test properties for the material from the five plants in the Port Authority report and the Hicksville plant is given in Table 1.

TABLE 1 Comparison of Physical Properties from Various Recycling Plants

Test	Port Authority Report	Hicksville Plant Report
Los Angeles abrasion (%)	37.1	36.5
Magnesium soundness (%)	3.3	3.5
CBR[a] (%)	148.0	148.0
Maximum dry density (pcf)	128.0	128.8

[a]CBR corrected for reverse curvature.

The Port Authority testing was performed in 1982; the results given in Table 1 are the average of five tests, one for each of the producers. The Hicksville data are an average of all data since 1977 and represent approximately 150 tests. The physical properties show an amazing consistency. The Port Authority report studied the potential effect of compaction on the RCA in order to approximate the amount of breakdown (degradation) that would occur under field conditions. The test method used was developed by the New Jersey Inter-Agency Engineering Committee and uses the modified Proctor compaction test. The test was performed on RCA obtained from each of the five producers, as well as on dense-graded aggregate base material samples made from trap rock, gneiss, and dolomitic limestone. The RCA samples ranged from 4.4 to 14.5 percent loss with an average of 9.8 percent. The loss for trap rock, gneiss, and dolomitic limestone was 13, 14, and 24 percent, respectively.

The Port Authority also presented nondestructive testing data that were performed on a field installation of one supplier's RCA, which indicated that the in-place bearing of the specific supplier's RCA was equal to or greater than that of a control installation of typical quarry-processed dense-graded aggregate base course (DGABC) material.

The final report, issued in June 1983, made the following conclusions and recommendations.

1. The results of laboratory testing indicate that RCA has the potential to be used as an alternative for DGABC. However, because of the divergent sources of raw material and the resultant variability of RCA, a formal quality assurance system, in which the contractor is responsible for his quality control and the owner exercises a comprehensive acceptance testing plan, is required.
2. Current soil aggregate specifications for fill, filter material, and pipe bedding should be reviewed to include the use of RCA.
3. Any initial field installation of RCA should be monitored to evaluate its materials handling characteristics and the compactive effort required to obtain satisfactory density.
4. RCA is readily available in the New York area, as evidenced by the existence of eight producers of this material at this time. This should result in competitive pricing of this material and lower materials costs to the Port Authority.
5. If RCA is deemed an acceptable substitute for DGABC, the potential benefits include lower construction costs, reduced energy use, and effective use of a waste material.

IN SITU TESTING OF PAVEMENTS

During the past few years attempts have been made to measure the in situ strength of pavements constructed with recycled crushed concrete aggregate bases.

The method used in this determination was to measure pavement rebound deflections caused by a standard truck with an axle load of 18,000 lb. The equipment used for measuring the deflections was a Benkelman beam. Deflections have been used in evaluating pavements since the early 1950s. This experience has shown that long-term pavement serviceability with minimum maintenance will occur if the initial characteristic spring-time deflection of the pavement is less than or equal to 0.050 in. for secondary roads (2). (Note that characteristic deflection is the mean value plus 2 standard deviations.)

All deflection testing was performed by Sidney B. Bowne and Son, Consulting Engineers, Mineola, New York. All the work was in conjunction with road reconstruction projects within the town of Oyster Bay, New York. The procedure used by the consultant was to perform a deflection survey on the original pavement before reconstruction, and then a second survey on the finished reconstructed pavement. The town allows three pavement alternatives: a 3-in.-thick asphalt base, a 6-in. dense-graded crushed stone base, and a 6-in. dense-graded RCA base.

Each of the equivalent pavements were topped with a 1.5-in. binder course followed by a 1-in. wearing surface. A summary of all the deflection data since 1974 is given in Table 2.

TABLE 2 Summary of Pavement Strengths

	Stone Base	Asphalt Base	Crushed Concrete Base
Weighted average, final characteristic deflection (in.)	0.050	0.034	0.023
Weight reduction in deflection (%)	33.13	44.90	60.88
No. of projects	3	12	5
Total square yards of pavement tested	39,000	339,853	309,420

The data in Table 2 indicate that all the pavements are performing well. However, the pavements constructed with RCA bases are stiffer and stronger than the crushed stone and the full-depth asphalt base pavements.

RCA IN ASPHALTIC CONCRETE MIXES

Locally, within the past 3 years, there has been an effort to use RCA in asphaltic concrete mixes. This effort included a pavement test strip at Abbey Lane in the town of Hempstead in 1981, plus some additional unmonitored binder work in the town in 1982. During this time some laboratory mix designs were made to compare RCA-asphalt mixtures to asphaltic concrete made with standard virgin aggregates. In 1982 a second, more extensive, test strip was constructed in Hempstead at Blacksmith Lane in Levittown.

Laboratory Studies of RCA-Asphalt Mixes

Abbey Lane

On July 22 and July 23, 1981, a laboratory study was performed and a comparison of the Marshall test properties was made between a New York State (NYS) type 3 binder made with 100 percent RCA and an identical mix using 50 percent crushed stone and 50 percent natural sand. The aggregate gradations are given in Table 3.

TABLE 3 Abbey Lane Type 3 Binder Mix

Sieve Size	Job Mix (% passing)	Specification (% passing)
1.5 in.	100	100
1 in.	100	95-100
0.5 in.	74.4	70-90
0.25 in.	65.3	48-74
0.125 in.	55.1	32-62
No. 20	30.7	15-39
No. 40	18.3	8-27
No. 80	6.9	4-16
No. 200	2.5	2-8

Note: For asphalt concrete, the job mix had various percentages passing and the specifications called for 4.5 to 6.5 percent passing.

Three Marshall specimens (50 blows per side) were made at each asphalt cement content for each mix. The standard stone-natural sand mix was molded at 4.5, 5.0, and 5.5 percent asphalt contents. The RCA mix used 5.0, 5.5, and 6.0 percent. All mixes were compacted at a temperature of 255°F and the gradations of all specimens were identical. The test procedure conformed to ASTM C1559, and nine molds were made for each mix.

The optimum asphalt contents, based on stability alone, would be 5.00 percent (Marshall stability = 1,539 lb) for the standard stone-natural sand mix and 5.50 percent (Marshall stability = 2,550 lb) for the RCA mix (see Table 4).

TABLE 4 Summary of Marshall Test Results, Abbey Lane

Mix	Asphalt Content (%)	Stability (lb)	Flow	Density (pcf)
Standard stone-natural sand mix	4.50	1,428	10	146.5
	5.00	1,539	11	148.4
	5.50	1,418	13	149.6
RCA mix	5.00	2,285	10	123.8
	5.50	2,550	11	123.7
	6.00	2,383	14	125.4

A comparison of the tests results revealed some surprising facts. The RCA-asphalt mix had stability values approximately 60 percent higher than the crushed stone-natural sand mixes at all asphalt contents studied. The comparison also indicated that the RCA mix was approximately 16 percent lighter than the stone mix.

Based on the laboratory study, the RCA mixes had considerably higher stability and offered a potentially enormous economy because it would require approximately 16 percent fewer tons of mix to pave equivalent areas of equal thickness. With this information in hand, it was then decided to construct the Abbey Lane test strip.

Blacksmith Lane

The asphalt base mixes used on Blacksmith Lane were the same as those for Abbey Lane. The job mix formula from Abbey Lane was used for the type 3 RCA mix and the type 3 crushed stone mix. An additional job mix formula was developed by using HVEEM criteria for the emulsion base. The emulsion base was formulated to conform to the NYS type 3 binder specification. The emulsion mix design was performed by McConnaughay Asphalt Lab in Lafayette, Indiana.

A comparison of the RCA type 3 and the standard crushed stone-natural sand job mix formula showed results similar to the Abbey Lane project. At their optimum asphalt contents of 5.7 percent for the RCA mix and 5.0 percent for the standard mix, the Marshall stability and density of the RCA mix was 70 percent higher and 11.5 percent lower, respectively. It should be noted that the air voids at these optimum asphalt contents were 3.20 percent for the RCA mix and 4.23 percent for the standard mix. The 5.0 percent asphalt content should probably be increased by approximately 0.2 percent to equalize the voids. This would increase the density, and the difference in densities would be closer to the 16 percent difference noted on Abbey Lane. The mix design for the RCA type 3 mix is given in the following table:

Compactive Effort	Value
Blows per side	50
Optimum asphalt content (%)	5.7
Marshall stability (lb)	2,700
Flow	13.2
Air voids (%)	3.2
Voids filled (%)	77.0
Unit weight	135.0

Comparisons of Mix Designs

In 1981 and 1982 the Materials Testing Lab of Flushing, New York, made Marshall mix designs for two New York State Department of Transportation (NYSDOT) mixes consisting of a type 3 binder and a type 6 top. These mixes were tested with RCA and with crushed stone and natural sand. Comparisons of the mixes are shown in Figures 3 and 4.

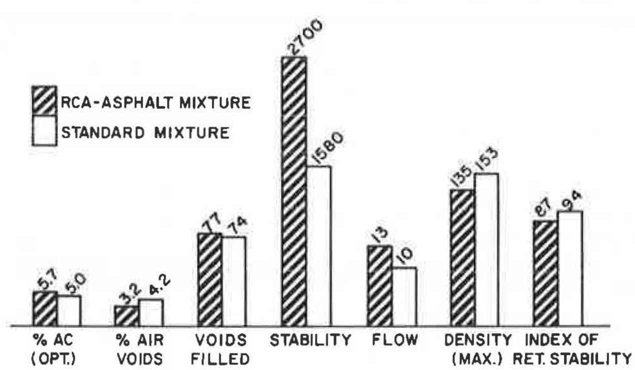


FIGURE 3 Comparison of Marshall properties (NYS type 3 binder).

The mix design comparison shows the following consistent characteristics:

1. At a given percent asphalt content (%AC) the RCA mixes have from 1.5 to 2.0 times the stability of the crushed stone-natural sand mixes.
2. At a given %AC the density of the RCA mixes is approximately 15 percent lighter than the stan-

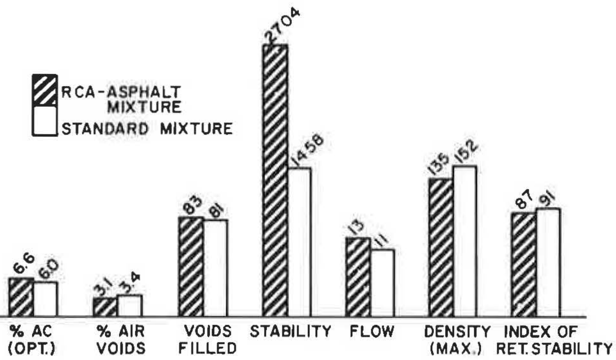


FIGURE 4 Comparison of Marshall properties (NYS type 6 top).

dard mix. The RCA mix will cover 15 percent more volume for the same tonnage as the crushed stone-natural sand mix.

3. The RCA mix requires approximately 0.5 to 1.0 percent more AC to have equal air voids and void filled criteria.

Test Pavement Experiments

Abbey Lane

In June 1981, Lizza Industries and Twin County Recycling Corp. combined their efforts to sponsor a test strip where a RCA-asphalt cement pavement could be constructed and tested. A testing program was developed in order that the quality of the mix could be monitored and compared with other standard paving materials.

The town of Hempstead, the largest township in the United States, volunteered to participate in the experimental road section.

The town had a project under construction in Levittown, New York, and a section of roadway 780 ft long and one lane wide was chosen as the location of the controlled test strip. Lizza Industries was the general contractor of the existing construction project. The consulting engineering firm of Sidney B. Bowne and Son was retained by the town to do the quality control and write an evaluation report for the project. The experimental mix chosen for this investigation was a NYS type 3 binder.

In order to control the construction and strive for uniformity, it was decided to test the subgrade to locate any weak soil conditions. On August 14, 1981, representatives of Sidney B. Bowne and Son performed a Benkelman beam deflection survey on the subgrade area to be used in the test strip. The testing was witnessed by representatives of Nassau County Department of Public Works, Town of Hempstead Department of Public Works, and Twin County Recycling Corp.

Test points were chosen in two paths parallel to the curb line. The first path was 4 ft 3 in. east of the edge of the west-side concrete gutter. The second path was 6 ft east of the first path. Deflection readings were taken at 20-ft intervals along these paths, and 80 readings were obtained from station 4+50 to station 12+50. The proposed test section was 14.50 ft wide (one-half the pavement width) and was bounded by the edge of the west-side gutter and the centerline of Abbey Lane.

An analysis of the deflection reading indicated that the subgrade condition for all three sections of the test strip were approximately equal in strength and unformity. This ensured that one of the most important variables of the experiment (i.e., the subgrade strength) was constant for each of the three bases to be evaluated.

On August 18 the controlled test strip was constructed. The purpose of the test strip was to evaluate the structural performance of three base course materials:

1. NYS type 3 binder: 2.5 in. thick made with crushed stone and natural sand with 5.00 percent asphalt cement,
2. NYS type 3 binder: 2.5 in. thick made with 100 percent RCA and mixed with 5.00 percent asphalt cement, and
3. Item 398: DGABC comprised of recycled crushed concrete 5 in. thick.

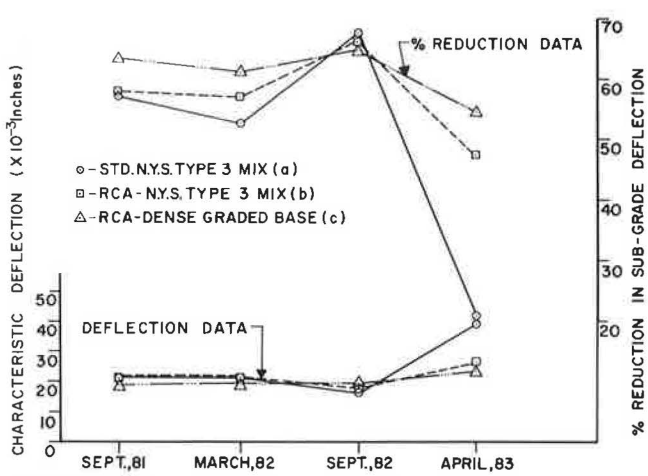
The gradation specifications are given in Table 5.

TABLE 5 Gradation Specifications for DGABC

Sieve Size	Percent Passing	Sieve Size	Percent Passing
1.5 in.	100	No. 16	22-36
1 in.	90-100	No. 30	11-27
0.5 in.	65-85	No. 50	6-20
0.375 in.	55-75	No. 100	3-15
No. 4	40-55	No. 200	1-10
No. 8	30-45		

A 2-in.-thick layer (NYS type 6 mix) was placed on the experimental base strips as a wearing course. All of the asphalt mixes were produced by Midhampton Asphalt Company in Hicksville, New York. (Midhampton Asphalt Company is a subsidiary of Lizza Industries.)

On August 27 a second deflection survey was performed on top of the finished base, and on September 30 a third deflection survey was performed on top of the 2-in. asphaltic concrete wearing course. The deflection surveys on the wearing course were repeated on March 18, 1982, on September 9, 1982, and on April 26, 1983. A summary of the Abbey Lane Test data is shown in Figure 5.



(a) Average core density from 8 tests = 145.26 pcf, average Marshall density from 3 tests = 148.28 pcf, average Marshall stability from 3 tests = 1,544 lb, and average % AC from 6 cores = 5.33 percent.
(b) Average core density from 13 tests = 128.63 pcf, average Marshall density from 3 tests = 129.56 pcf, average Marshall stability from 3 tests = 2,266 lb, average Marshall flow from 3 tests = 11.0, and average % AC from 9 cores = 5.60 percent.
(c) CBR from 1 test = 191 percent.

FIGURE 5 Abbey Lane deflection data.

The final report by Sidney B. Bowne and Son, issued on July 11, 1983, concluded the following (3):

1. "The deflection testing has shown the RCA type 3 to be performing better than the NYSDOT type 3."

2. "The results of the second spring deflection test performed April 26, 1983, as well as a plot of percent change from subgrade versus time, indicate that section III (RCC base) is the most consistent in performance followed by section II (RCA type 3 base) and section I (NYSDOT type 3 Base), in that order."

Blacksmith Lane

In early 1982 a committee of engineers was formed in order to design a second, more extensive test strip on Blacksmith Lane in the town of Hempstead. This experiment would duplicate the work of Abbey Lane with some additional quality control. In addition, a stone base and an emulsion base pavement were tested. A total of seven 300-ft-long, 29-ft-wide test sections were constructed. Two of the seven sections were topped with a NYS type 6 wearing surface mix using RCA. The remaining five sections used a standard crushed stone-natural sand type 6 mix.

In addition to plant extractions and plant Marshall specimens being made, a careful elevation survey was made at the top of each of the pavement layers so that an accurate thickness determination could be made for the base and the wearing course. Deflection surveys were also made on the top of each pavement layer.

The firm of Sidney B. Bowne and Son was retained to do the quality control and write the evaluation report.

A deflection survey and an elevation survey were performed on top of the subgrade on August 5 and 6, 1982, just before placement of the base course. This process was repeated on top of the finished bases on August 5, 6, 10, and 12. The deflection and elevation surveys on the finished pavement were completed on September 9 and 13.

A summary of the deflection data to date from Blacksmith Lane is given in Table 6.

The preliminary report by Sidney B. Bowne and Son, issued in September 1982, stated the following (4):

> Examination of the data will show that all sections are performing approximately the same with the exception of the RCA/EMULSION (insufficient curing time may be the reason). All the S.B. and RCC sections are approximately equal, while the RCA TY 3 is performing better than either the NYSDOT TY 3 or RCA/EMULSION TY 3.

LONG-TERM PERFORMANCE OF RCA-ASPHALT MIXES

The state of Texas and the city of Minneapolis, Minnesota, both have had successful experiences with RCA-asphalt mixes for long periods of time. Texas, in particular, has RCA-asphalt pavements that date back to 1969. Some of the projects in Texas that use RCA-asphalt mixes are given in Table 7.

Two papers that were presented at the annual Association of Asphalt Paving Technologists (AAPT) meetings of 1976 and 1980 outline the details of this work (5,6). The papers present information on mix designs, design gradations, and properties of the in-place mixes.

In July 1983 the authors of this paper made visual inspections of US-54 and State Highway 36.

Construction History of US-54

In 1972 US-54 was reconstructed from Farm Road (FM) 694 (approximately 6 miles southwest of the intersection of US-87 and US-54) for a distance of 15.4 miles southwest to Middle Water, Texas. The original pavement consisted of an 8-in.-thick calieche crushed stone base with a 2-in. asphalt concrete wearing course.

The pavement was widened to include shoulders, and the entire area was overlaid with a 3-in. asphalt concrete base, topped with a 2-in. RCA asphalt concrete wearing surface. The wearing surface was made in a standard batch plant, and the aggregates were 100 percent recycled crushed concrete with a 6.1 percent type AC-10 asphalt cement. The recycled concrete was obtained from an abandoned airport

TABLE 6 Blacksmith Lane Deflection Test Results

Base Pavement Material	RCA Type 3	Standard Type 3	RCA-Emulsion Type 3	Crushed Stone[a]	Crushed Stone[a]	RCA Base	RCA Base
Property thickness (in.)	2.5	2.5	2.5	5	5	5	5
Subgrade characteristic deflection[b] (in.)	0.070	0.068	0.043	0.086	0.067	0.072	0.076
Base characteristic deflection[c] (in.)	0.064	0.048	0.046	0.030	0.052	0.032	0.044
Wearing course characteristic deflection[d] (in.)	0.017	0.027	0.024	0.023	0.020	0.023	0.023
Change in subgrade deflection (%)	76	60	44	73	71	67	70

[a] Wearing course 2-in. thick with RCA-asphalt type 6 mix.
[b] Survey performed August 5 and 6, 1982.
[c] Survey performed August 5, 6, 10, and 12, 1982.
[d] Survey performed September 9 and 13, 1982.

TABLE 7 Texas Projects Using RCA-Asphalt Mixes

Highway	Pavement Type	Location	Date Constructed
US-54	Wearing course	From FM 694 to Middlewater in Hartley County (15.4 miles)	1972
US-60	Wearing course	From Lipsomb County line to Glazier in Hemphill County (5.5 miles)	1974
US-60	Wearing course	From Glazier to US-83 (8.4 miles) in Hemphill County	1979
I-40	Wearing course	1 mile west of McLean to 1 mile west of Alan Reed in Gray County in westbound lane[a]	Under construction
State Highway 36	Base and binder course	From Lyons north to Caldwell (12.12 miles) in Burleson County	1969

[a] Eastbound lane is a 10-in. continuous reinforced-concrete pavement with RCA as coarse aggregate; it is currently under construction.

pavement. The coarse aggregate in the concrete was a local river gravel.

Traffic

Moderate traffic was noted during the study. Representatives of the Texas State Department of Highways and Public Transportation (TSDHPT) stated that approximately 3,000 vehicles per day used the two-lane highway. Approximately 30 percent of the traffic was heavy trucks. Representatives from TSDHPT noted that there were no weigh stations on US-54 and that there is a serious problem with overloaded trucks with excessively high tire pressure.

Climate

The climate conditions are extremely severe. The yearly high-low temperature range is from 100°F to -15°F.

Present Pavement Conditions

The pavement showed no signs of alligator cracking (fatigue cracking) and there was no evidence of rutting in the cross section. There was a continuous longitudinal crack at the centerline of the road located at the paving construction joint. In addition to the longitudinal crack, there were transverse temperature cracks approximately 25 to 50 ft on center throughout the entire 15-mile length. The cracks appear to be nonload associated and appear to be caused by the severe temperature conditions.

Construction History of State Highway 36

In July 1969 reconstruction of 12.12 miles of State Highway 36 in Burleson County, Texas, was completed. The cross section of State Highway 36 consisted of a prepared embankment of lime-stabilized subgraded material 8 in. thick, overlaid with 10 in. of lime-stabilized crushed clayey sandstone. This was topped with 5 in. of asphalt-stabilized base, 2.5 in. of type B surface mix, and 1 in. of type E modified surface mix.

Before construction the existing pavement was a lightly reinforced-concrete slab with a bituminous concrete overlay that was no longer suitable for traffic. The old concrete and asphalt pavement were recycled together and the material was used for the aggregate in the new asphalt-stabilized base as well as the type B surface mix.

Tests performed on the recycled blend of aggregates indicated that the material had a free asphalt cement content ranging from 0.1 to 0.9 percent and a Los Angeles abrasion value of 32 percent.

Two basic mixture designs were used on the project. The initial design consisted of a blend of the recycled aggregate and a locally available field sand in an 85 to 15 percent proportion at the cold feed.

Job control extraction tests yielded asphalt cement contents of 5.3 to 7.1 percent. Excess asphalt cement present in the recycled aggregate was caused by the old asphalt concrete overlays and was the reason for the relatively high asphalt cement contents obtained from the field samples.

The asphalt-stabilized base was surfaced with 2.5 in. of type B surface mixture in one lift. Two basic mixture designs were used for this layer. The initial design consisted of a blend of 65 percent coarse recycled aggregates, 15 percent fine RCA, and 20 percent field sand combined with 4.8 percent asphalt cement. The second design consisted of a blend of 35 percent coarse recycled aggregates, 25 percent of fine recycled aggregates, 12.5 percent of coarse and 12.5 percent of fine washed river gravel, and 15 percent of field sand combined with 4.6 percent asphalt cement.

The new pavement was surfaced with a 1-in.-thick crushed stone-slag hot-mix surface course. The aggregates used were 30 percent crushed limestone, 45 percent Alcoa slag, and 25 percent field sand. The aggregate blend was combined with 6.5 percent type AC-10 asphalt cement to form a mixture with an average Hveem stability of 40. Construction of the two-lane highway was completed in 1969.

Traffic

Representatives from TSDHPT reported that approximately 7,000 vehicles per day, of which approximately 40 percent are heavy trucks, used this two-lane road. Because of the extreme activity in oil field construction in this area, TSDHPT has issued special overload permits for gross weight to 110,000 lb. However, trucks weighing in excess of 200,000 lb have been recorded on State Highway 36.

Climate

The climate is moderate with no extreme temperature ranges. There was no evidence of non-load-associated transverse cracking in local pavements.

Existing Pavement Condition

There was no sign of pavement rutting or shoving in the cross section. Cracking was minimal, and only three small patched areas were noted in the entire 12-plus miles of pavement.

SUMMARY AND CONCLUSIONS

Test data for RCA from 1977 to the present have been compiled and summarized herein. During this period an enormous amount of data has been obtained. All physical test results have been uniform and have shown high strength, stability, and durability qualities.

An independent study of RCA by the Port Authority of New York and New Jersey shows close agreement with the Hicksville plant data with respect to test results on strength, stability, and durability of RCA. This close agreement of test values indicates a consistency of physical properties. Finally, both reports indicate that any degradation caused by handling and compaction is equal to or less than that which would occur with standard quality granular base materials.

An attempt has also been made at measuring and comparing the in situ strengths of various pavement types by using pavement deflection test results from 1974 to the present. Five projects, totaling approximately 310,000 square yards, have demonstrated that roads constructed with recycled crushed concrete bases can provide strong, stable, and economical pavements that exhibit strengths equal to or greater than other standard quality granular base materials.

Laboratory studies to determine the feasibility of using RCA in asphaltic concrete indicated that the RCA mixes had 1.5 to 2.0 times the stability of crushed stone-natural sand mixes. The RCA mixes are approximately 15 percent lighter than standard mixes, and therefore will cover 15 percent more volume for the same tonnage. The RCA mixes will require approximately 0.5 to 1.0 percent more AC to have equal air voids and voids filled criteria.

Based on the laboratory findings, two controlled test strip pavements were constructed. A testing program was developed so that the quality of the mix could be monitored and compared with other standard paving materials. Test results from the two controlled strips indicate that the RCA mixes are performing better than the standard paving mixes, and that if properly designed and constructed, RCA-asphalt mixes are capable of providing a strong, economical, stable pavement that will yield low deflections.

Pavements constructed in Texas as long as 14 years ago confirm that the RCA-asphalt mixes can yield excellent long-term performance. TSDHPT has enough confidence in RCA-asphalt mixes to have let a contract to pave an Interstate highway with an RCA-asphalt mix.

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Study of Aggregates Used for Concrete in Kuwait

OBADA A. KAYYALI

ABSTRACT

The research reported in this paper was necessitated by (a) the great volume of local and international building contracts in the Middle East and (b) the search for the reasons behind the phenomenon of extensive concrete deterioration. Petrological classification, and chemical and x-ray analyses were performed on the aggregates used for concrete production in Kuwait. The results indicated that the coarse aggregates contain no deleterious materials and have no potentially adverse reactions. Thus the aggregates are suitable for good concrete production. Fine aggregates in their unwashed condition are contaminated with clay and contain too much fines, which necessitates careful washing before being used. High-quality concrete made with these aggregates should be expected if efficient washing of the sand is made and if proper mix design and workmanship are provided.

Concrete in the Middle East has been the subject of several recent publications (1-4). The Middle East, however, is a large area that is vaguely defined. Most of the papers that have the words Middle East in their titles tend to generalize certain conditions that may be true only in a limited part of the area. Evans (5) summarized some important information related to the geology and soil conditions of the countries in the Arabian penninsula: Iran, Iraq, and Egypt. His report implied the distinct differences in concrete products in each of these various countries because of several different factors related to materials, geology, climate, and other variations. Thus, in spite of the temptation for arriving at general rules, it should be borne in mind that local conditions in each state can be of major significance. It is believed that determination of the properties of the constituents of concrete in each region is essential for understanding the factors that influence its behavior in the fresh and hardened conditions.

In this paper identification and properties of the aggregates used in the concrete industry in Kuwait are reported. The reported results are part of continuing research aimed at obtaining a basic understanding of the causes of concrete deterioration in this part of the Middle East.

GENERAL DESCRIPTION

The state of Kuwait is situated in the northeast corner of the Arabian peninsula. It is bordered by Iraq to the north and west, by Saudi Arabia to the south, and by the Gulf of Arabia to the east (Figure 1). Kuwait covers about 15,900 km² and has a popu-

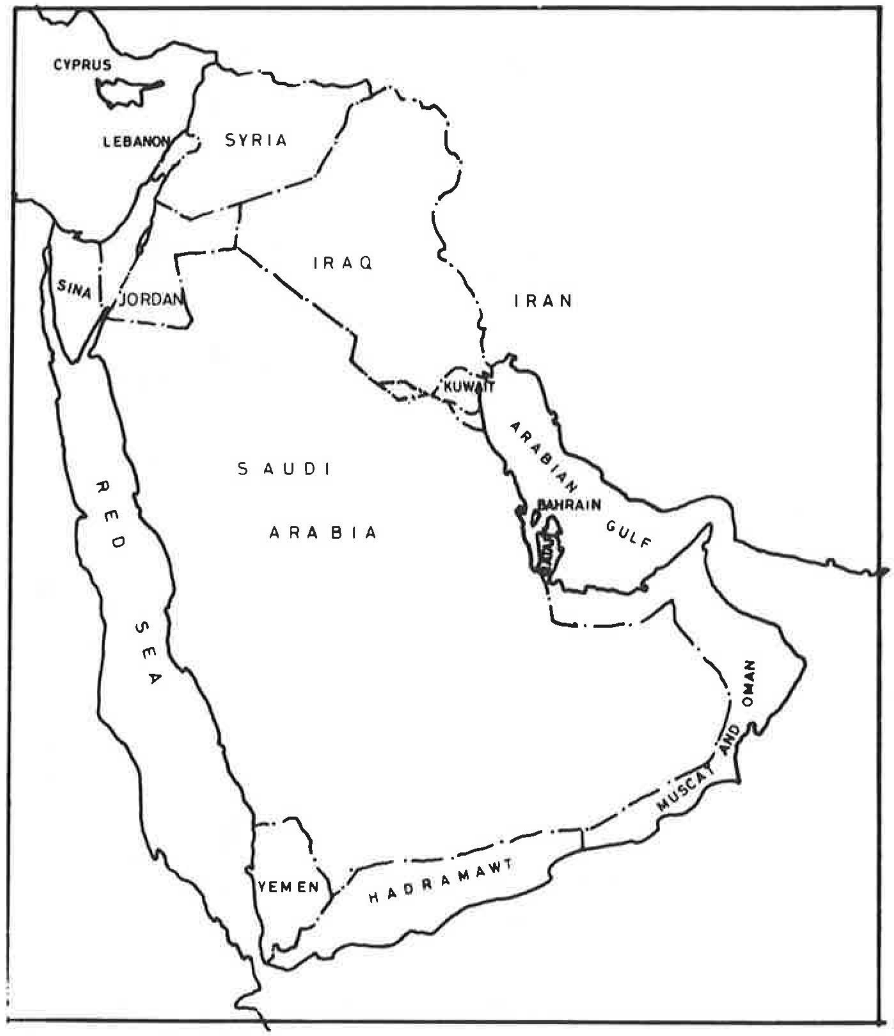

FIGURE 1 Geographic position of Kuwait.

lation of 1.5 million people. The main source of national income is petroleum production, which puts it in the forefront of countries as far as per capita income and standard of living. It is a country of extremely hot weather, where the temperature in the shade during the summer months can exceed 50°C, and the mean maximum in-shade temperature from June to October is about 42°C (6). The surface of Kuwait is formed by sedimentary rocks belonging to the Cenozoic era, ranging from Middle Ecocene to Recent (7,8).

Materials suitable for different construction purposes can be exploited from different parts of the country. Limestone is occasionally found at shallow depths in central and southern Kuwait (9). Exploitable limestone is found to the south of Ahmadi and is currently being used for marine structures and for the manufacture of mineral filler for asphaltic concrete (8). Potentially exploitable sandstone, which could be used for building blocks and low strength concrete, is also found in central areas (8). However, in this paper attention is focused on materials that can be used to produce good quality concrete. These materials are found in exploitable quantities in the northwestern and central regions. Among the formations shown in Figure 2, the materials considered suitable for good concrete production are the gravel-capped ridges and their surroundings and the medium to coarse grey sand. These formations belong to the Pleistocene epoch (9). Materials of lower quality are found in the Dibdibba Formation, which contains medium to coarse, occasionally cemented gravel and sand with calcareous and gypsiferous structure. Fuchs et al. (7) reported that large reserves of loose gravels suitable for concrete use are present in vast areas in northern, central, and western Kuwait. Excavations indicate that loose gravels in sandy matrix occur only on or near the surface.

A comprehensive survey (8) was prepared in 1974 for the purpose of controlling and organizing the natural resources, and it was conducted for most areas of potential and operational gravel pits. It could be concluded from that survey that there existed more than 10 million cubic meters of exploitable gravel that is suitable for good concrete work. The amount of good quality sand suitable for this purpose is estimated around 13 million cubic meters. Based on the previously mentioned studies, the Ministry of Commerce and Industry gave permission for quarries to operate in some parts of the areas of dense gravel and sand (Figure 3).

CLASSIFICATION OF GRAVEL SAMPLES

For the purpose of this investigation, nine samples of about 200 kg of gravel were taken from different active quarries in an area 20 km long by 10 km wide. Five samples of sand of similar quantity were taken from the sand pits of the Al-Jahra area.

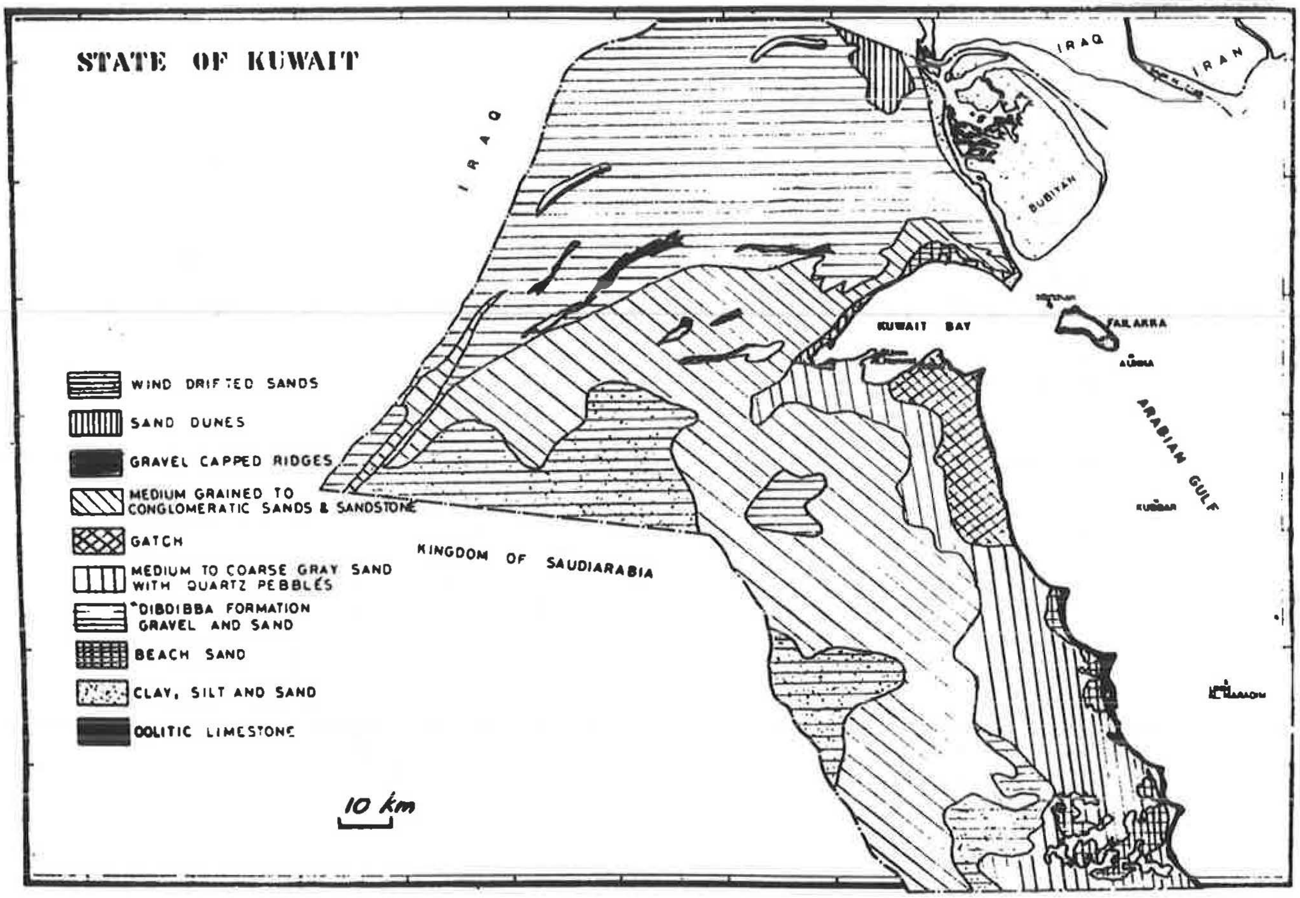

FIGURE 2 Gravel and sand formations of the Kuwait surface.

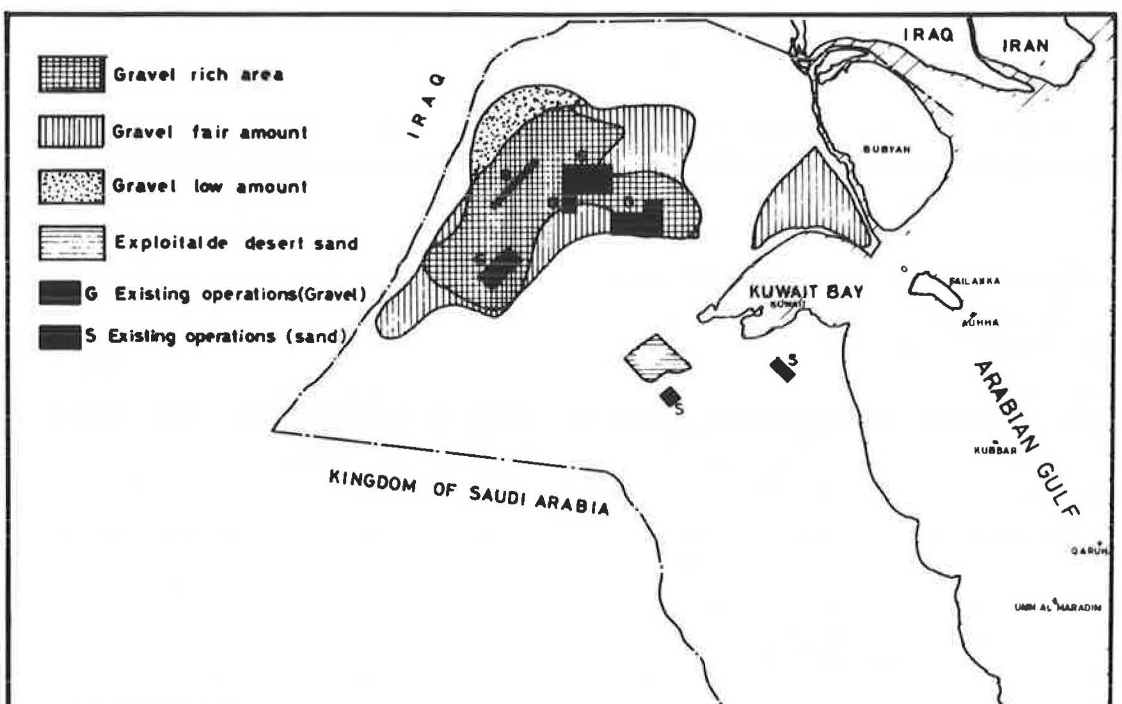

FIGURE 3 Exploitable gravel and sand areas.

Petrological classification of the samples facilitated their separation into eight distinct types, as shown in Figures 4-11. The approximate percentages of total aggregate comprised by each of these eight aggregate types are given in the following table:

Type	Approximate Proportion of Aggregate (%)
Quartz	31
Andesite	22
Felsite	14
Silicified serpentine	8
Cemented sand and gravel	8
Granite	8
Rhyolite	6
Basalt	3

TESTS ON GRAVEL

Two sets of laboratory tests were performed. The first set (A) consisted of tests performed on samples taken from each quarry. The second set (B) of tests was performed on the aggregates after grouping them into eight types according to the petrological classification.

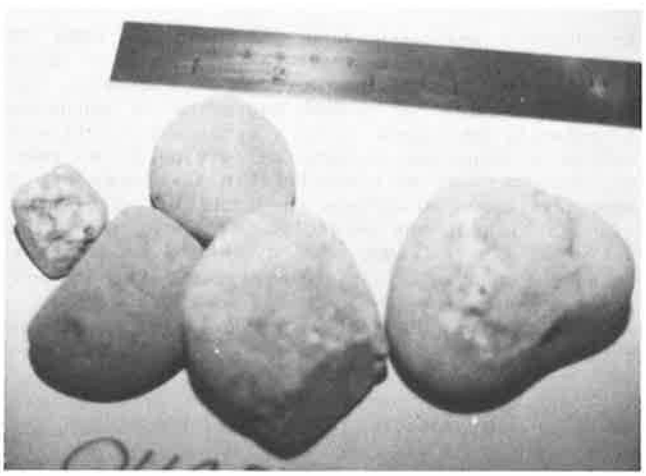

FIGURE 4 Quartz.

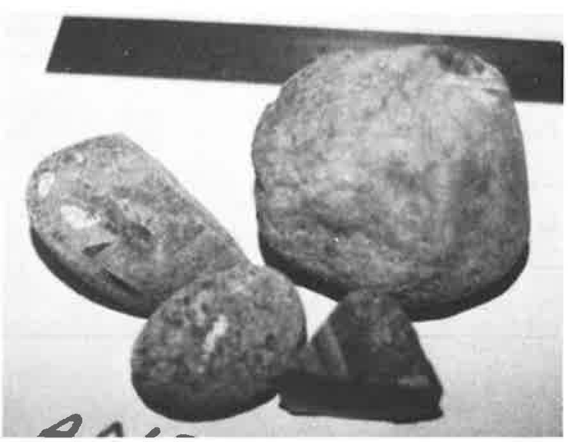

FIGURE 5 Andesite.

Set A

Tests for Chlorides and Sulfates

Soluble chlorides were determined volumetrically by Mohr's method (the silver nitrate-potassium chromate method). The acid soluble sulfates were determined gravimetrically by precipitation as barium sulfates (10). Results from eight randomly selected quarries in the area are given in Table 1.

From the data in Table 1 it can be seen that the highest chloride content was 0.0175 percent by weight of the coarse aggregate, which is within the

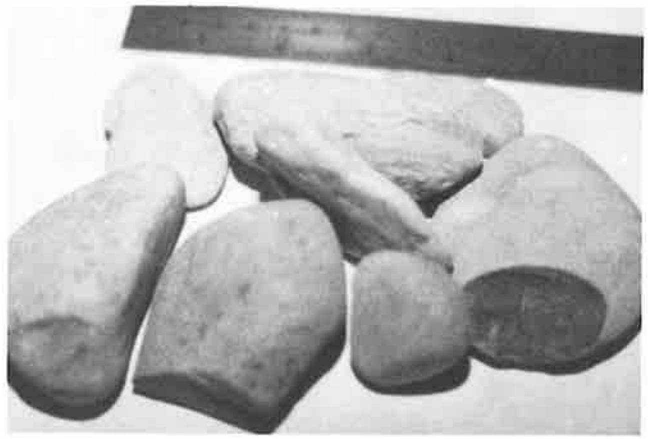

FIGURE 6 Felsite.

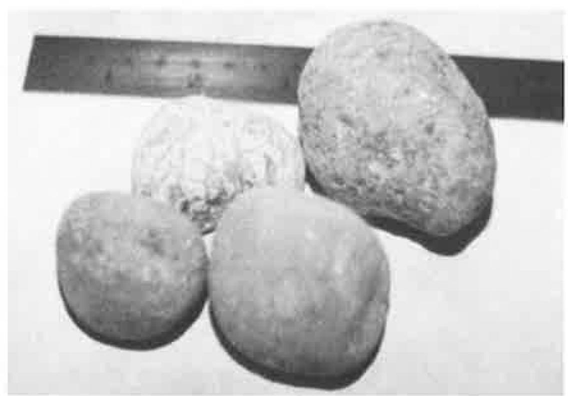

FIGURE 7 Silicified serpentine.

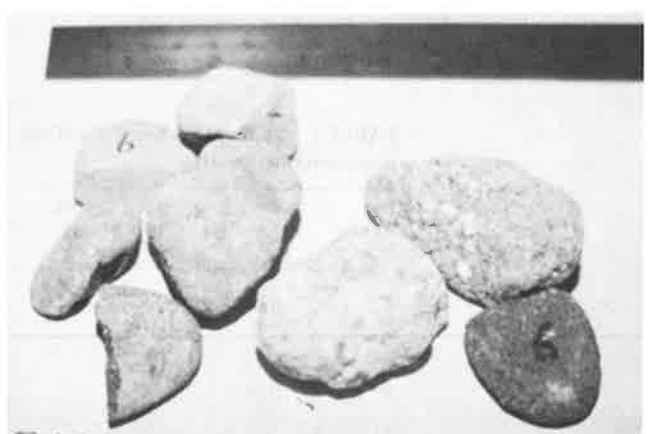

FIGURE 8 Cemented sand and gravel.

strictest limitation of 0.02 percent of Greater London Council (GLC) (11). It is also well within the much less severe limitation of the Building Research Establishment (12), which restricts the chloride content for a low risk of reinforcement corrosion to less than 0.4 percent of the weight of cement. This is equivalent to about 0.1 percent of the weight of coarse aggregate for a typical concrete mix (11).

The highest sulfate content recorded in this series was 0.35 percent by weight of the coarse aggregates. The average sulfate content for the eight pits was 0.14 percent. Both these values fall below the limit of 0.37 percent proposed by the Cement and Concrete Association for the case when even as high as 0.5 percent SO_3 is expected to be present in the fines (11).

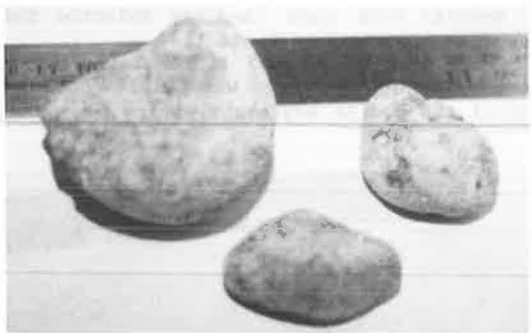

FIGURE 9 Granite.

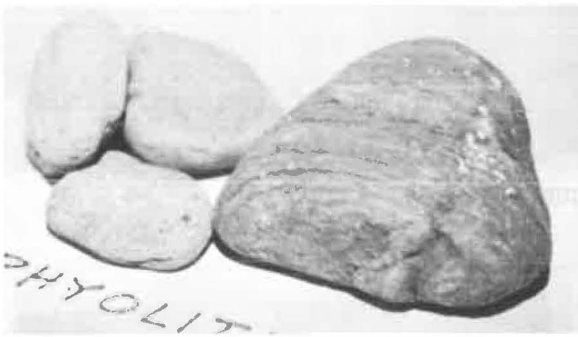

FIGURE 10 Rhyolite.

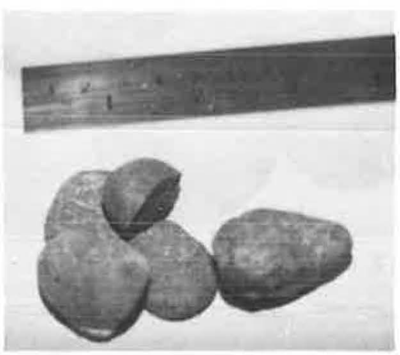

FIGURE 11 Basalt.

Tests for Organic Matter Content

These tests were performed according to ASTM C40 (ASTM Standard C40-66, Test for Organic Impurities in Sand for Concrete). The method is colorimetric. The acids in the sample are neutralized by a 3 percent solution of NaOH, prescribed quantities of aggregates, and the solution being placed in a bottle. The mixture is vigorously shaken to allow the intimate contact necessary for chemical action, and it is then left to stand for 24 hr, when the organic content can be judged by the color of the solution. The greater the organic content, the darker is the color.

The results indicated that the samples do not contain organic impurities.

Tests for Soundness of Aggregates

Soundness tests were done according to ASTM C88 (ASTM Standard C88-71a, Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate). A sample of graded aggregate is subjected alternately to immersion in a saturated solution of sodium or magnesium sulfate and drying in an oven. The formation of salt crystals in the pores of the aggregate tends to disrupt the particles. The reduction in size of the particles, as shown by a sieve analysis, after a number of cycles of exposure denotes the degree of unsoundness. The loss on sieves for unsound coarse aggregates is about 6 percent.

The results indicated the soundness of the aggregates (Table 1).

Tests for Determination of Potential Reactivity

Reactivity tests were performed according to ASTM C289 (ASTM Standard C289-71, Test for Potential Reactivity of Aggregates, Chemical Method). The method measures the reduction in the alkalinity of a normal solution of NaOH when placed in contact with pulverized aggregate at 80°C. The amount of dissolved silica is also determined by using a photometer and a series of solutions of known silica con-

TABLE 1 Summary of Results of Tests Performed on Aggregates Taken from Representative Quarries

Quarry No.	Soluble Chlorides (ppm)	Acid Soluble Sulfates SO_3 (ppm)	Soundness [total loss on sieves (%)]	Dissolved Silica (millimoles/L)	Reduction in Alkalinity (millimoles/L)
1	105	750	2.59	17.0	75
2	100	500	2.85	13.0	90
3	105	1,000	2.93	10.0	120
4	110	1,000	3.02	14.0	135
5	140	1,000	2.68	16.0	140
6	140	2,500	3.87	9.0	130
7	175	3,500	2.89	11.0	150
8	105	1,000	2.65	11.0	160

Note: ppm = parts per million.

centration varying from 0.0 to 0.5 millimoles/L. The result is plotted on a graph representing reduction in alkalinity versus silica dissolved. A potentially deleterious reaction is indicated if the plotted test result falls to the right of a specified boundary line.

The results, which are given in Table 1, indicate that the aggregates are considered innocuous and have no deleterious effects on concrete.

Set B

This set of tests was made on the aggregates after being grouped according to petrological classification. X-ray diffraction analysis and classical wet chemical analysis were done for each group. Figure 12 shows the results of x-ray diffraction, which indicate that the aggregates are composed mainly of quartz and feldspar with the presence of calcite and gypsum. The presence of mica is also indicated, although its quantity is believed to be small. This qualitative analysis was supplemented by analysis using classical methods of analytical chemistry, which revealed the composition given in Table 2.

It may be concluded from these results and from the estimation of the proportions of each type of gravel that the main oxide percentages present in the total coarse aggregates that have been surveyed are as follows:

Oxide	Percent
Silicon dioxide (SiO_2)	76.21
Iron oxide (Fe_2O_3)	3.67
Aluminum oxide (Al_2O_3)	6.63
Calcium oxide (CaO)	4.44
Magnesium oxide (MgO)	1.07
Sodium oxide (Na_2O)	2.26
Potassium oxide (K_2O)	2.50
Sulfur trioxide (SO_3)	0.115
Loss on ignition	2

Thus the sulfates content was 0.115 percent of the weight of the coarse aggregates. This value is well within the generally adopted safe limit value of 0.4 percent (13).

ANALYSIS OF SAND

Although sand is abundant in almost all regions of Kuwait, it is usually contaminated with sulfates, chlorides, calcite, silt, and clay. As shown in Figure 2, an extremely unsuitable sand called gatch is found in areas in and surrounding the capital. Gatch is a marine-deposited sandy soil. The word gatch is Iranian meaning gypsum. However, the sand that could be used for construction purposes can be divided into the following groups (14): (a) dredged seashore sand, (b) Jahra sand, (c) desert sand, and (d) sand from windblown sand dunes.

Group a, although the best as far as grading is concerned, is more difficult to obtain and is much less abundant and needs more extensive processing. Group c contains too much fines, and group d is a single-grained sand. Group b, however, can be classified as type 2 or type 3 according to British Standard 882 (15), and thus it is suitable for concrete work. Jahra sand is the sand that is more widely used in Kuwait because it is the most suitable sand for construction, and because the area is the only area left for sand exploitation and is still not restricted by different government schemes or environmental considerations.

The sand of Jahra belongs to the Miocene-Pliocene age. Its thickness is between 6 and 14 m and consists mainly of brown to greyish quartz grains (9). The pit area is about 20 km inland, and the exploitable layers lie under an overburden that is less than 2 m thick. All excavation activities occur in sections well above the brackish water level; thus there is no contamination from salt deposition. The amount of fines passing the No. 200 sieve is between 2 to 24 percent and is mostly silt and clay. Thus efficient mill washing will ensure separation of fines and produce sand that is suitable for good quality concrete.

Analysis on five samples taken from different parts of the area was performed. The results obtained from chemical analysis and potential reactivity are given in Table 3. Samples 1 and 2 were from untreated sand, whereas samples 3, 4, and 5 were taken from washed sand ready for use. It may be concluded from the results that washing the sand had only a small effect on the main chemical structure. This is expected because this sand is not a seashore sand where water-soluble salts like the chlorides of sodium and potassium, or the sulfates of magnesium, sodium, and potassium, are expected to be present.

The salts that are present in this inland sand, which is high above the brackish water level, are mainly gypsum and calcite (sulfates and carbonates of calcium) that are not water soluble. Gypsum and calcite constitute the predominant part of the fines content (passing the No. 200 sieve), the quantity of which varies from 2 to 24 percent of the weight of sand (8). Thus the beneficial effects of washing are the removal of fines and of adhering particles of gypsum by the shear mechanical factor involved in the washing process. These effects are demonstrated in the results of the tests, where the average content of sulfates in the washed samples was lower than it was in the unwashed samples.

However, it should not be assumed that prolonging or repeating the washing process could get rid of the sulfates. Contractors in Kuwait often make the mistake of repeating the washing process of a rejected supply of sand, thus losing time, effort, and money. What they should do is change the site or the depth where their excavation was made. This reasoning applies as well to the chlorides, and it is clear that they are found in minor amounts in this type of sand.

Potential reactivity tests made according to ASTM C289 indicated that the sand is considered innocuous and has no deleterious effect on concrete.

CONCLUSIONS

This study demonstrated that the basic indigenous materials used for concrete production in Kuwait are of good quality and are suitable for producing good quality concrete. Thus it would be of importance to contractors and consultants who operate in that part of the Middle East to direct their efforts toward the strict control of concrete mix design and concreting practices that appear to be the factors more responsible for the extensive deterioration that is observed in this area. Washing of the aggregates is important for getting rid of fines and clay contamination, but it should not be thought of as the major remedy for the problems of concrete in Kuwait.

ACKNOWLEDGMENT

The study reported in this paper is part of a continuing research on the causes of concrete deterioration in Kuwait. The research is sponsored by the Science Research Council of Kuwait University.

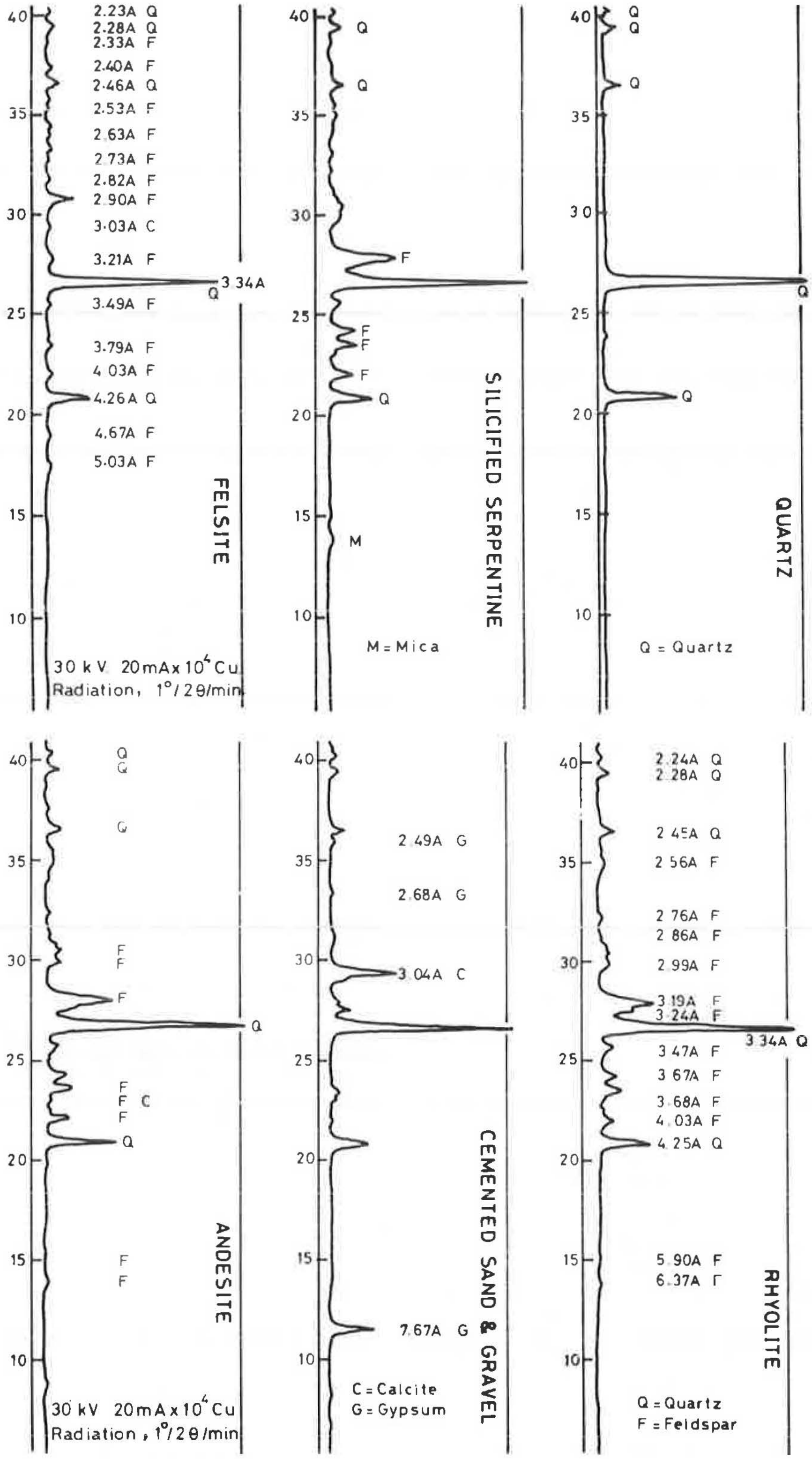

FIGURE 12 X-ray analysis of main types of coarse aggregates.

TABLE 2 Results of the Quantitative Chemical Analysis of Coarse Aggregate

Classification	Silica SiO_2 (%)	Ferric Oxide Fe_2O_3 (%)	Aluminium Oxide Al_2O_3 (%)	Magnesium Oxide MgO (%)	Calcium Oxide CaO (%)	Sodium Oxide Na_2O (%)	Potassium Oxide K_2O (%)	Sulfur Trioxide SO_3 (%)	Loss on Ignition (%)
Quartz	97.00	0.08	0.28	0.72	1.50	0.00	0.00	0.00	0.00
Andesite	72.26	4.49	9.94	1.50	2.79	4.87	1.89	0.00	0.30
Felsite	61.48	5.22	12.22	1.62	4.76	4.00	9.65	0.00	0.65
Silicified serpentine	70.99	3.59	11.67	0.11	2.17	6.06	5.00	0.00	0.95
Cemented sand and gravel	43.38	0.40	0.28	0.96	27.00	-	-	1.44	21.15
Granite	67.97	7.36	12.87	1.77	3.51	1.73	3.59	0.00	0.26
Rhyolite	82.86	5.80	9.35	1.00	0.00	0.00	0.00	0.00	0.75
Basalt	69.38	22.19	3.14	0.21	2.66	0.23	1.52	0.00	0.19

TABLE 3 Results of Quantitative Chemical Analysis of Sand

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Oxides (%)					
SiO_2	88.30	79.30	85.00	86.35	87.19
Fe_2O_3	0.45	1.28	1.46	1.18	1.25
Al_2O_3	4.78	2.89	5.67	4.96	4.85
CaO	3.86	8.65	3.69	3.82	3.55
MgO	0.38	0.55	0.85	0.75	0.59
SO_3	0.35	0.38	0.025	0.27	0.025
Cl^-	0.025	0.015	0.001	0.02	0.001
Loss on ignition	1.68	6.25	1.83	1.79	1.64
Potential reactivity (millmoles/L)					
Soluble silica	41.0	40.0	45.0	52.0	51.0
Reduction in alkalinity	285	305	315	330	310

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Utility Decision Analysis to Select Aggregates for Asphalt Pavements

PODURU M. GANDHI and ROBERT L. LYTTON

ABSTRACT

Several recent studies have indicated that significant aggregate shortages can occur in about one-third of the states. One important factor contributing to this shortage is that the current aggregate specifications in some states generally tend to disqualify some marginal aggregates that could otherwise give satisfactory service under certain conditions. The research reported in this paper was undertaken to assist in alleviating the aggregate shortage and broaden the base of\aggregate supply by selecting suitable aggregate evaluation methods. The research was conducted in two phases, each of which studied a different aspect of the problem. Phase I was concerned with the overall aggregate evaluation procedures that are used in various states. Phase II dealt with the evaluation of the laboratory tests and petrographic examinations that are used to determine whether aggregates meet specifications. A literature review and a survey of current state practices resulted in the identification of four alternative schemes that are used in the states for evaluating the quality and performance of aggregates. The schemes mainly differ in the relative emphasis put on the aggregate tests, asphalt mix tests, service experience, and the prequalification of aggregate sources based on certain aspects. The relative usefulness of the four schemes was evaluated by means of the utility decision analysis. It is also noted that there is a need to consider other factors such as aggregate reserves, production costs, haul distances, environmental factors, and energy use in addition to the evaluation of quality of an aggregate.

It is generally understood in the highway profession that significant shortages of quality aggregates are imminent in many states (1). One important factor contributing to this shortage is that current aggregate specifications in some states generally tend to disqualify many marginal aggregates that could otherwise give satisfactory service under certain conditions. This research was undertaken under the sponsorship of the National Cooperative Highway Research Program (NCHRP) mainly to address this problem. The main objective was to develop procedures for selecting aggregates for bituminous paving mixtures that may permit the use of marginal aggregates when warranted. The study was conducted in two phases. Phase I dealt with the identification and the development of a systematic procedure to aid in the selection process. Because the estimation of several of these factors involves some uncertainties, a methodology based on utility decision analysis was used. Phase II concentrated on the evaluation of various aggregate and asphalt mix test procedures that can be related to actual performance in the field. In this paper the work done during Phase I is summarized. Results of the Phase II study are reported elsewhere (2).

The current state of the art of methods for evaluating and selecting bituminous paving mix aggregates was assessed on the basis of the published literature and a national survey of state practices. A complete analysis of the national survey can be found in the interim report submitted to NCHRP (3). A summary of the prequalification requirements for aggregate selection in various states is given in Table 1. In addition, during visits to state highway materials offices, information was collected on their aggregate evaluation procedures. An analysis of current state practices and other factors resulted in the formulation of four possible alternative schemes for the evaluation of the quality and performance of bituminous mix aggregates. The schemes differ essentially in the relative emphasis placed on the laboratory testing of aggregates, testing of bituminous mixes, prequalification of sources of aggregates, and evaluation of in-service performance of aggregates. The four schemes are as follows:

TABLE 1 Summary of State Prequalification Requirements for Bituminous Mix Aggregate Sources

Requirement	No. of States Listing Requirement
No prequalification requirement	14
Qualification by laboratory and field tests	3
Qualification by general petrologic examination	2
Carbonate aggregates specifically limited or excluded	12
Other limitations[a]	6

[a] Limatations such as exclusion of all sedimentary rocks, serpentine, degraded basalt, weathered granite, scoria, coral, and shale.

Scheme I: Evaluation of aggregate performance based primarily on physical and chemical tests on representative aggregate samples, and a few tests on bituminous mixes.

Scheme II: Prequalification of aggregate sources based on relatively complex laboratory and field evaluation of bituminous mixes made with the aggregate.

Scheme III: Prequalification of aggregate sources based primarily on petrographic examination of samples coupled with field performance data on bituminous paving mixes.

Scheme IV: Same approach as Scheme I, but supplemented by prequalification evaluation for specific characteristics such as polish, stripping resistance, and durability.

Typical aggregate evaluation and test procedures making up each of these schemes are summarized in Table 2. How these evaluation schemes fit the practices in the states visited is described in Table 3.

TABLE 2 Procedures Considered for Alternative Bituminous Mix Aggregate Quality and Performance Evaluation Schemes

Procedure Category	Scheme I	Scheme II	Scheme III	Scheme IV
Aggregate tests	Gradation, soundness, abrasion, friable particles, sand equivalent value, polish resistance	Gradation, abrasion	Gradation	Gradation, soundness, abrasion, friable particles, sand equivalent value, polish resistance
Tests on aggregate-asphalt systems	Moisture damage (Lottman's test), mechanical behavior (Marshall and Hveem), mix workability	Moisture damage (Lottman's test), mechanical behavior (Marshall and Hveem), fatigue resistance, polish resistance	Mechanical behavior (Marshall and Hveem)	Moisture damage (Lottman's test), mechanical behavior, mix workability
Service and tests on pavement experience	Data collection on performance of aggregates for future improvements in the scheme	Formal data collection to correlate aggregate quality to performance	More detailed and formal data collection to correlate pavement performance to petrology (heavy emphasis)	Performance data related to skid resistance and stripping and performance of marginal materials
Petrographical examinations	None	Deleterious materials, chemical tests, lithology, petrographic examination in special cases (low emphasis)	Deleterious materials, chemical tests, lithology, detailed petrographic examinations (heavy emphasis)	Examinations mainly to identify carbonate rocks and those susceptible to stripping (low emphasis)

TABLE 3 Outline of Typical Aggregate Evaluation Schemes and Source Control in States Visited

	Rating of Relative Importance of Procedures in Aggregate Evaluation Scheme[a]						
State	Tests on Aggregate Samples	Tests on Bitominous Mixes	Petrology	Pavement Test Section Results	Service Experience	Estimate of Alternate Scheme[b]	Control of Aggregate Sources
Colorado	3-4	5	1	0	3	IV	Designated source; state controlled
Florida	–	–	–	–	–	IV	Privately owned pits or quarries
Georgia	2	4	1	0	2	I	Privately owned pits or quarries
Idaho	4	2-3	0-1	0	1	IV	Designated source; state controlled
New York	0	0	5	0	5	III	Privately owned pits or quarries
North Carolina	–	–	–	–	–	IV	Privately owned pits or quarries
Ohio	2	1	3	1	4	III	Privately owned pits or quarries; some by paving contractors
Pennsylvania	3	4	2-3	1	2	II	Privately owned pits or quarries
Texas	4	2	0-1	0	1	IV	Privately owned pits or quarries
Utah	1-2	4	1-2	0	3	II	Designated source; state controlled
Virginia	4	2	1	2	1	IV	Privately owned pits or quarries
Washington	4	1	1	0	1	IV	Designated source; state controlled

[a]Numbers indicate relative importance of procedure category in evaluation scheme: 0 = no importance and 5 = major factor in evaluation.
[b]Refers to alternate scheme designation defined in the text.

ANALYSIS OF AGGREGATE EVALUATION SCHEMES

The four aggregate evaluation schemes previously outlined were compared by means of utility decision analysis. Utility as used in this context is a measure of relative usefulness of the schemes and has a range from 0 to 1. A computer program developed at the Texas Transportation Institute was modified and used in this project for computing the utilities of various schemes. In this analysis the relative power (utility) of each scheme to meet four objectives (attributes)--namely, practicality, significance of evaluation procedures, cost, and implementation--were evaluated. Each attribute was further subdivided into several decision criteria that contribute to satisfying the objective. The details of utility decision analysis and the procedures used for quantifying and evaluating the decision criteria are explained in detail in the following sections.

Utility Decision Analysis

Utility decision analysis is a systematic procedure for considering all of the pertinent factors that influence a decision-making process. It is based on utility theory, a subject about which several textbooks (4-7) have been written. It has been used successfully in the analysis of several engineering applications, especially in the field of transportation (8). The advantage of the utility analysis lies in the fact that it allows the use of different types of information, subjective or objective, to make useful comparisons.

In utility decision analysis all of the factors that affect a decision-making process are carefully outlined and evaluated on a rational basis. A final choice is made based on the utility (power) of an alternative to meet certain objectives, usually called attributes. Each attribute is further subdivided into several decision criteria that contribute to satisfying the objective. Hence the first step in the analysis is to carefully define the attributes of the decision-making process and the criteria that comprise each attribute. The attributes and decision criteria for evaluating aggregate selection schemes are given in Table 4. Decision criteria 7, 8, and 9 also have some subdecision criteria, as shown in the table. The detailed definitions of decision criteria are presented in a later section of this paper.

The next step in this analysis involves establishing utility curves for each of the decision criteria. Utility is a measure of preference and it ranges between 0 and 1, depending on the value of a decision criterion. The shape of the curve generally depends on personal preferences of the decision maker and how much risk he is willing to take with respect to the value of that particular decision criterion. However, typical curves can be drawn by carefully considering opinions of experts in the field. A typical utility curve developed in this study is shown in Figure 1. There is always some uncertainty in estimating the decision criterion

TABLE 4 Attributes, Decision, and Subdecision Criteria for Aggregate Evaluation Schemes

Attribute	Decision Criteria	Subdecision Criteria
Practicality	1. Simplicity of evaluation scheme	
	2. Level of effort to evaluate an already developed source	
	3. Level of effort to evaluate a new or recently developed source	
	4. Personnel requirements	
	5. Level of technical training	
	6. Evaluation time	
Significance of procedures	7. Probability of rejecting an unsuitable aggregate	(i) Strength (ii) Durability (iii) Fatigue resistance (iv) Stripping (v) Skid resistance
	8. Potential for identifying marginal aggregates	Same subdecision criteria as above
	9. Repeatability of results	(i) Aggregate tests (ii) Tests on aggregate-asphalt systems (iv) Petrographic evaluations
Cost	10. Equipment	
	11. Field pavement evaluation	
	12. Laboratory evaluation	
	13. Field geological evaluation	
Implementation	14. Status of development	
	15. Degree of standardization	
	16. Required change from current practice	
	17. Additional training of personnel required	

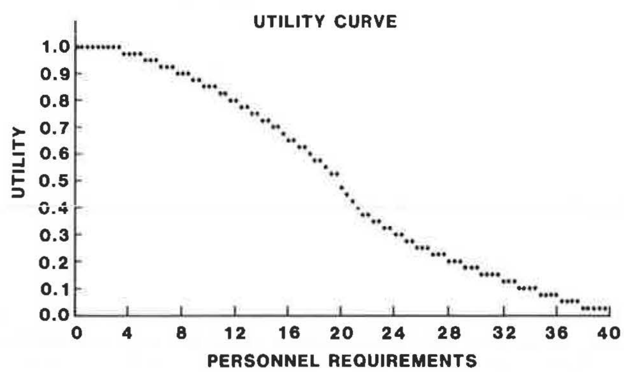

FIGURE 1 Typical utility curve fitted by the program.

input values. To estimate utility under conditions of uncertainty, each decision variable was assumed to have a probability density, f(x). For this study, a beta probability density function was chosen (Figure 2). The beta distribution for each decision criterion can be determined by simply assigning three values [optimistic (O), most probable (M), and pessimistic (P)]. To estimate these three values (O, M, and P) on a rational basis, detailed work sheets must be prepared for each decision criterion.

The expected value of the utility of a decision criterion is obtained by integrating the product of the probability density function and utility function over the range of decision criterion values:

$$E(u) = \int_{x_{min}}^{x_{max}} u(x)\, f(x) dx = u_i \quad (1)$$

where u_i is the mean utility of the decision criterion i. The variance of utility is given by

$$Var(u) = \int_{x_{min}}^{x_{max}} f(x)\, u^2(x)\, dx - u_i^2 \quad (2)$$

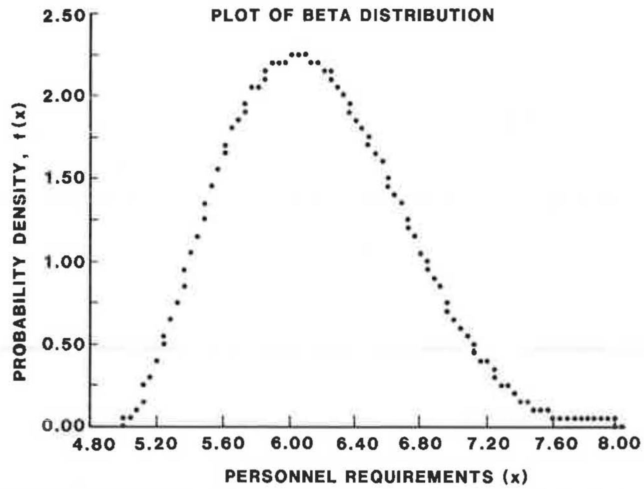

FIGURE 2 Typical beta-distribution curve fitted by the program.

The utility of a scheme is obtained by combining the individual utilities of decision criteria and attributes using a hierarchial additive weighting method, as follows:

$$\text{Utility of attribute } j = u_j = \sum_{i=1}^{n} = w_i u_i \quad (3)$$

where n, w_i and u_i refer to the number of decision criteria within an attribute, normalized weight, and utility of the decision criterion, respectively. The mean overall utility of the scheme (K) is given by

$$U_K = \sum_{j=1}^{n_1} w_j u_j \quad (4)$$

where n_1 and w_j refer to the number of attributes and normalized weight of the attribute, respectively. The utilities of the K schemes can be compared to aid in the final decision of choosing a particular scheme.

Variances multiplied by the square of their normalized weights, all added together, give the overall variance. For example, the overall variance is given by

$$Var(U_K) = \sum_{j=1}^{n_1} w_j^2\ Var(u_j) \quad (5)$$

From the mean overall utility U_K and the variance of U_K for any given scheme, confidence limits on the mean (mean ± 2 σ) can be established, which will indicate the variability expected in the estimation of the mean.

A computer program (UDAREM) developed recently at the Texas Transportation Institute on another project (9) was modified extensively and used to carry out various computations involved in Equations 1-5. From the input data, this program fits a utility curve to the sample points, fits a beta distribution to the three estimates (O, M, P), multiplies the two curves together, carries out the integration numerically using Simpson's rule, and finally arrives at the grand total utility and variance for the entire scheme.

Definitions of Attributes and Decision Criteria

Four attributes and 17 decision criteria, as listed in Table 4, were considered essential for judging the utility of aggregate evaluation schemes. The definitions of all of the attributes and decision criteria are outlined in the following sections. These definitions formed the basis for obtaining optimistic, most probable, and pessimistic estimates of the decision criteria on a quantitative basis. (Note that supporting data sheets were prepared to quantify the estimates of all decision criteria described in the following sections.)

Practicality Attribute

Practicality is an important attribute in judging any aggregate evaluation scheme. Schemes that involve complex equipment and testing procedures requiring highly skilled personnel will be considered impractical. Practicality may also depend on cost. However, because cost is a major factor to consider in evaluating any scheme, it is kept as a separate attribute. The following decision criteria were considered under practicality.

Simplicity of Evaluation Scheme

In order to determine whether a given scheme is simple or complex, the examination procedures in each scheme and their complexities have to be considered individually. A given evaluation scheme may involve laboratory tests, lithological and petrographic examinations, field performance evaluation procedures, and so forth. Depending on the nature of equipment needed, complexity of testing procedures, and the time involved in the evaluation, a complexity factor (F_1) may be assigned to each procedure in the scheme. Summation of these factors (F_1) for each scheme is a good measure of the relative complexity of the entire scheme.

Level of Evaluation Effort

The effort involved in any evaluation scheme depends on the number of sources and the degree of detail used in the evaluation of each source. A scheme that provides for different degrees of detail, depending on the number of aggregate sources, will be more practicable than a scheme that provides for a uniform degree of detail. Degree of detail may be defined as total complexity of the scheme. Optimistic, most probable, and pessimistic estimates of the number of aggregate sources can also be obtained for any given state. The product of the number of sources (s) and the degree of detail (d) can be considered as a measure of the evaluation effort.

Personnel Requirements

This criterion was used to evaluate the total number of personnel needed for the complete evaluation of a source using a given aggregate evaluation scheme.

Level of Technical Training

This is the average academic qualification and job experience of personnel needed for various phases of evaluation that are included in the scheme. A scale of 1 to 10 was used for rating the qualification and experience of personnel.

Evaluation Time

This criterion represents the total time required (in weeks) to completely evaluate an aggregate source with a given scheme.

Significance of Procedures Attribute

It is important that the procedures used in an evaluation scheme ultimately reflect the quality and performance of pavements. The evaluation procedures may include laboratory tests on aggregate samples, performance-oriented tests on aggregate-asphalt systems, judgment on the basis of service experience, results from pavement test sections, and interpretation of petrographic information. Finally, an evaluation scheme must be able to distinguish clearly between good, marginal, and poor aggregates. The quality of information obtained during the evaluation should have the potential for identifying problems associated with marginal aggregates and suggest suitable methods of upgrading them. Variability in test results should be low when the test is repeated on the same material. The following decision criteria were used to estimate the utility of this attribute.

Probability of Rejecting an Unsuitable Aggregate

An aggregate may be rejected on the basis of evaluations that are related to performance factors such as strength, durability, stripping, polish resistance, fatigue resistance, and skid resistance, which form subdecision criteria. The procedures provided in a scheme must be able to reject an unsuitable aggregate with high probability.

Potential to Identify Marginal Aggregates

In addition to rejecting a poor aggregate, an evaluation scheme will be still more useful if it can discriminate between poor aggregates and marginally acceptable aggregates. The ability to discriminate depends on the quality of the information provided by the laboratory and the field data gathered on a given aggregate. Depending on local conditions, suitable weight can be placed on this ability of an evaluation scheme to discriminate between acceptable, unacceptable, and marginal aggregates (i.e., aggregates that can be treated, improved, or used in other ways).

Repeatibility of Results

The testing procedures used in a scheme will have more validity and thus more significance if the variation is low when the test is repeated on the same material. This requires that the methods used are proven in practice for several years, and that records are available. A good measure of variability in test results is the coefficient of variation (CV).

Cost Attribute

Cost is an important factor in any evaluation scheme. Other factors being equal, a less expensive scheme will be more acceptable. The decision criteria included in this attribute cover all costs of transportation, personnel, equipment, and materials for various phases of laboratory and field investigations required to evaluate one source of aggregate. The exception to this is the cost of equipment, which is treated separately.

Cost of Equipment

Cost of all field and laboratory equipment and transportation vehicles are included in this criterion. This represents a one-time expense and is not prorated as cost per source because the decision may rest on the total initial expense involved in the purchase of equipment that is required for a particular aggregate selection scheme.

Field Pavement Evaluation Cost

This criterion includes personnel costs, transportation costs (excluding cost of vehicles), and materials costs for conducting various types of field evaluations related to in-service experience of existing pavements or performance of test pavement using a particular source. The evaluations may include visual rating of pavements, roughness measurements, skid resistance measurements, and taking field cores for laboratory tests.

Laboratory Evaluation Cost

This criterion includes costs related to various types of tests on aggregates, asphaltic mix tests, tests on field pavement cores, and laboratory petrographic analysis to evaluate one source. The costs include personnel and materials costs for all the procedures involved in a given scheme.

Field Geological Evaluation Cost

Personnel costs, transportation costs, and materials costs related to field geological investigation to evaluate one source are included in this criterion. Depending on the source, geological investigations may include making test pits and drilling cores for collection of samples and simple field tests for identifications of rocks.

Implementation Attribute

Successful implementation of a given aggregate evaluation scheme mainly depends on its acceptance by a state highway department. A scheme that has been proven effective uses standard tests that are well-known or easily taught, has a large amount of data and experience behind it, and can be implemented quickly. The scheme will have a better chance of acceptance if it represents only a small change from current practice in the state. The following decision criteria were used to evaluate this attribute.

Status of Development

This criterion is a rating of how completely developed a particular scheme is in a given state. A completely developed scheme should have a manual that defines the selection procedures in detail, a set of well-established acceptance criteria (specifications) for aggregates, good correlation with in-service experience for the evaluation procedures employed in the scheme, and all the equipment required for testing is available on the market. Subjective ratings were given on a scale of 0 to 10 for each scheme based on how the scheme satisfies these four elements in a given state.

Degree of Standardization

This criterion is a rating of the degree of standardization of the testing procedures used in the evaluation scheme. The implementation of any testing method is made much easier if it has been proven in practice, accepted as a standard by one of the standards associations (e.g., ASTM, AASHTO), and described in detail in the publications of one of these associations. The rating of the degree of standardization was done subjectively based on how the tests included in a scheme meet the criteria.

Required Change from Current Practice

If a suggested evaluation scheme deviates sharply from the current practice in a state, it may find little acceptance. Each item in the evaluation scheme is assigned a value between 0 and 1 (0 for no change and 1 for complete revision from the existing practice). The degree of change was obtained by summing up the score for various items and dividing it by the maximum applicable points.

Additional Training of Personnel

This criterion is a rating to determine the additional training of personnel that would be necessary to implement the scheme. New and complex procedures may require training of personnel to familiarize them with the procedures. The evaluation of the degree of additional training was obtained subjectively, similar to the criterion previously cited.

Utility Curves

As stated earlier, the shape of a utility curve depends mostly on the personal preferences of the decision maker and how much risk he is willing to take with respect to a particular value of the decision criterion. If the utility curve is a straight line, the decision maker has an expected value attitude (neutral) toward risk; if the utility curve is concave, the decision maker has a risk-averse attitude; and if the utility curve is convex, he has a risk-prone attitude (8). However, S-shaped curves appear to be most suitable for engineering-type decisions; the point of inflection associated with S-curves indicates the change of attitude of a person from risk prone to risk aversiveness. For example, an increase in cost might be tolerated up to a certain level, but beyond that level the decision maker may become aversive to taking risk. The computer program fits the utility curve for a given odd number of data points. About five data points are generally sufficient to plot the curves.

Data points were assumed for the 17 decision criteria, based on subjective judgment on each. However, for a different set of situations, these points can be changed. The computer program is written flexibly to permit such changes in the utilities and weights of decision criteria.

Weighting Factors

In this analysis three levels of weighting factors were assigned separately for attributes, decision criteria, and subdecision criteria in a descending hirerarchical order. The weights selected should reflect the actual preference of the decision makers. Presumably the weights can change, depending on the attitudes of the decision makers and the conditions in a state. For example, a state with a modest highway budget may place a heavy weight on cost. To take this factor into consideration, states were classified into different groups. The basis of classification is given in the next section.

The easiest way to determine weights is to put a 1.0 weight on the attribute or criterion considered to be most important and establish the remaining weights relative to this one. In the computer program the weights are normalized so that their sum is 1.0. Typical weights, initially assumed for the attributes and later modified by the consensus of a committee, are given in Table 5. Similarly, weights were also assigned for different decision criteria.

TABLE 5 Weights for Attributes

		Consensus Weights[a]	
Attribute	Original Weights	States A and B	States C and D
Practicality	0.9	0.7	0.9
Significance of procedures	0.7	1.0	1.0
Cost	1.0	0.5	0.8
Implementation	0.8	0.5	0.7

[a]While taking the consensus poll it was agreed by all those who attended that the cost of evaluation is a minor factor compared with the failure of a highway, and that the significance of procedures is the most important factor. Consensus weights are the averages of weights given by five staff members who attended the meeting. State classifications are as per Table 6.

State Classifications

Results of the national survey and discussions with several state highway materials agencies clearly indicated differences among the states with respect to their approach to aggregate evaluation; therefore aggregate availability should be taken into account when making a utility decision analysis. For this purpose, the states were classified into four different groups, depending on the estimated level of support for highway materials evaluation (assumed to be proportional to the annual highway budget for each state) and the potential number of aggregate sources to be evaluated, as indicated in Table 6.

The main effect of this classification was a variation in the weights assigned to the different attributes. The weights for decision and subdecision criteria were not changed in this analysis because they belong to a lower hierarchical order. However, these weights could be also changed if considered necessary. It was also assumed that in states with larger budgets, the status of development can be high and it will be easier to implement an aggregate evaluation scheme. Thus the input values for the decision criteria related to implementation were different for the two budget classifications. The classification based on number of sources mainly affected the input values for the level of evaluation effort, the effort being higher where the number of sources is large.

Comparison of Utilities of Different Schemes

The utility of each scheme was evaluated as the weighted sum of the utilities of its attributes, as explained earlier. The expected or mean utilities of the four schemes in different state classifications are given in Table 7. The relative rankings of the four schemes are also shown at the right of the table. It can be seen that the same rankings are maintained in all four state classifications.

It is apparent that aggregate evaluation Scheme I is preferred in all states to any of the other alternatives. After Scheme I, Schemes IV, III, and II are preferred in that order. This immediately raises the question: Are there any circumstances under which any other scheme would be preferred to Scheme I? To investigate the answer to this question, the following sensitivity studies were made:

1. A study of confidence limits to see if the same order of preference was maintained at 2 standard deviations above or below the mean;
2. A study of the sensitivity of the means to the relative weights of attributes;
3. A study of the sensitivity of the means to a biased estimate of the decision criteria, and
4. A study of the effect of implementing an entirely new evaluation scheme in a given state as opposed to implementing a variation of an evaluation scheme that is already in operation in the state.

Comparison of Ranges of Utilities

The confidence limits (mean $\pm$ 2 σ) for the mean values of these utilities are shown in Figure 3. If the utility values are normally distributed, these limits represent approximately 95 percent probability that the mean values lie in that range. In state classifications A and B, the confidence limits of Schemes I, III, and IV overlap, which indicates that these schemes are close to each other. Schemes I and IV are also similarly close to each other in state classifications C and D. Scheme II had the lowest range of utilities in all states. It may be concluded from this that the utilities of evaluation Schemes I and IV are not much different, but that Schemes III and II definitely rank lower than Schemes I and IV.

Sensitivity to Weights of Attributes

An analysis of the effects of changes in attribute weights on the utilities and relative rankings of

TABLE 6 State Classifications

Class	Support for Highway Materials Evaluation	No. of Sources	Typical States
A	High (total highway budget more than $500 million[a])	Large[b] (600-1,000)	California, Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, New York, Ohio, Pennsylvania, Tennessee, Virginia, Washington, Wisconsin
B	High	Average to small[b] (300-500)	Florida, Georgia, Louisiana, Maryland, Massachusetts, Missouri, New Jersey, North Carolina, Texas, West Virginia
C	Medium-low (total highway budget less than $500 million[a])	Large	Colorado, Kansas, Nebraska, New Mexico, Oklahoma
D	Medium-low	Average-small	Alabama, Alaska, Arizona, Arkansas, Connecticut, Delaware, Hawaii, Idaho, Maine, Mississippi, Montana, Nevada, New Hampshire, North Dakota, Oregon, Rhode Island, South Carolina, South Dakota, Utah, Vermont, Wyoming

[a]From 1975 FHWA highway statistics.
[b]Assumed very roughly on the basis of Figures 3 and 5 by Witczak et al. (*1*).

TABLE 7 Utilities and Relative Rankings of Schemes in Different State Classifications

State Class	Utilities of Schemes I	II	III	IV	Relative Rankings of Schemes in State Class
A	0.78	0.70	0.75	0.75	I, IV, III, II
B	0.81	0.76	0.79	0.81	I, IV, III, II
C	0.77	0.65	0.72	0.73	I, IV, III, II
D	0.81	0.71	0.76	0.71	I, IV, III, II

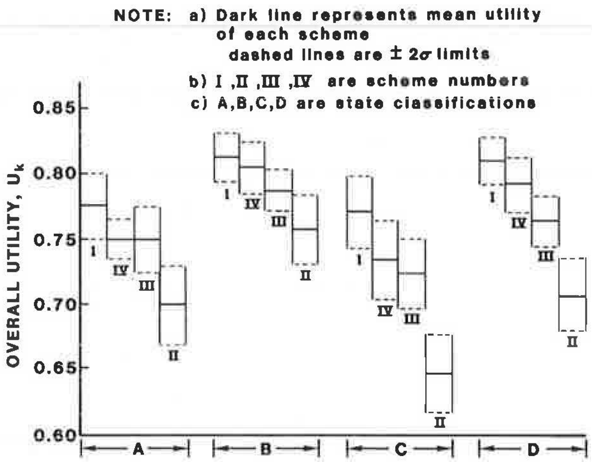

FIGURE 3 Utilities of different schemes in various state classifications.

different schemes was made for state classification B. Four different sets of weights for attributes were used, but the weights of decision and subdecision criteria were not changed in this analysis because they belong to a lower order of hierarchy. The first group of weights (original) placed a high emphasis on significance of procedures; in the second group all attributes were weighted nearly equally, with a little higher emphasis on cost, which is typical of a low budget state; the third group put equal emphasis to all attributes; and the fourth group kept least emphasis on cost and highest emphasis on implementation, which may be typical of a high budget state. A comparison of utilities with these weights indicated only minor differences in utilities, but no changes occurred in relative rankings of the schemes. It is thus concluded that changing of attribute weights will not significantly effect the rankings of the aggregate evaluation schemes.

Sensitivity to Change in Estimates of Decision Criteria

There is always a possibility of personal bias, especially when the estimates are subjective. A person may be more optimistic or pessimistic about a scheme, which will have an influence on the subjective ratings. With this in mind, Scheme III for state classification B was chosen to study the effect of a change of input decision criteria values by 10 percent on the optimistic side, while leaving all other schemes as they were before. With this input, the utility of Scheme III increased considerably, and it ranked first followed by Schemes I, II, and IV. This indicates the necessity of exercising care in estimating decision criterion values.

Effect of Status of Development of a Particular Scheme in the State

The utility values given in Table 7 are based on the assumption that the state does not have a scheme similar to the one being considered, and that the scheme must be implemented from the beginning. However, in some states, especially those that have large highway budgets, and aggregate evaluation scheme close to one of these four schemes under consideration may already be in operation. In such a case it will be easier to implement that scheme in the state with little additional personnel and equipment, and the input values for the decision criteria under the implementation attribute will be considerably higher. Making this adjustment in the input, utilities were again computed. It was found that in states where the current practice is similar to proposed Schemes III or IV, these schemes move up to the top rank, whereas Scheme II moves up only to second rank. Thus it appears that current practice in a state may have considerable effect on the utilities of the schemes.

Summary

The main purpose of having an aggregate evaluation scheme is to determine the quality and performance of an aggregate from a given source. However, in the selection of aggregate sources for highway construction, other factors such as aggregate reserves, production costs, hauling distances, environmental factors, and energy use also need consideration in addition to quality and performance. These factors are outlined in Figure 4.

A utility decision analysis program similar to the one used to rank aggregate evaluation schemes may also be applied for selecting an aggregate source while taking all of the factors in Figure 4 into account. It can be seen that the evaluation of quality and performance, using a given scheme, forms only one element of the decision-making process. It is quite possible that even a marginal quality aggregate or suitably modified aggregate may have a higher utility than normal aggregates when all the pertinent factors are taken into consideration. Such a source selection program represents a rational approach in making the decision whether or not to use marginal quality aggregates in a given situation, and thus can become an important tool in extending the aggregate supply in the United States for construction of flexible pavements.

Thus aggregate selection is a two-stage process. The first stage involves selection of a rational aggregate evaluation scheme most suitable for conditions in the state, and the second stage involves the evaluation of an aggregate source using this scheme and considering other factors previously mentioned. The computer program developed in this research can handle this two-stage aggregate selection process. Another important question is which aggregate, and which asphaltic mix tests and petrographic evaluations, are best predictors of aggregate performance. This aspect was also studied in the second phase of this research; the results are reported in another paper (10).

SUMMARY AND CONCLUSIONS

A survey of state practices resulted in the identification of four aggregate evaluation schemes. Utility decision analysis showed highest utility for Scheme I, which emphasizes aggregate tests but also

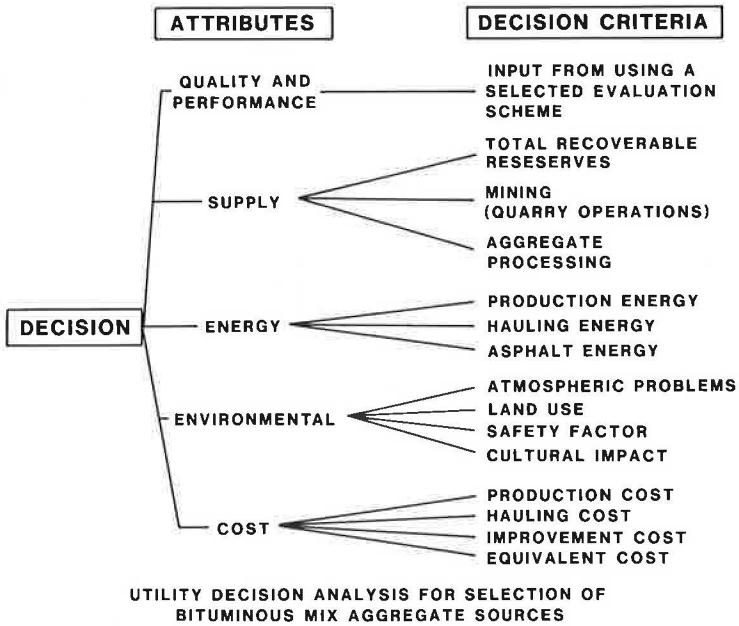

FIGURE 4 Utility decision analysis for selection of bituminous mix aggregate sources.

includes asphalt mixture tests for mechanical stability and moisture damage. Scheme IV, which includes prequalification evaluations for durability, polish resistance, and moisture stability, came in a close second. Thus either of these schemes, or a judicious combination of procedures included in these schemes, would probably be most suitable for aggregate evaluation in many states.

It is suggested that aggregate selection is a two-stage decision-making process. The first stage involves selection of an aggregate evaluation scheme to determine the quality of an aggregate, and the second stage involves selection of an aggregate source considering other factors such as aggregate reserves, production costs, haul distances, environmental impact, and energy use in addition to quality of an aggregate. The utility decision analysis program developed in this study can be helpful in the aggregate selection process.

An aggregate may be considered marginal if it is a borderline material with respect to some aggregate qualification tests such as abrasion value or soundness. However, if it has a satisfactory service record or receives a satisfactory petrographic evaluation or it can be improved with a combination of other coarse or fine aggregates, it may be accepted. Such a flexible approach would certainly enhance the use of marginal aggregates and help in the aggregate supply situation.

Although the evaluation of individual testing procedures formed the subject of another paper, some of the conclusions reached are given here for completeness of this paper.

The following tests were related to performance as determined from regression models: among aggregate tests--sulfate soundness, water absorption, crushed particles, Los Angeles abrasion, and and equivalent values; among asphalt mixture tests--Marshall stability, tensile strength, and tensile strength ratios (Lottman test); and among petrographic evaluations--general quality of rock, powder and film coatings, and chemical character of rock. Attempts were made to establish acceptance limits for these tests, but the results were inconclusive because of the limited number of aggregate samples tested in the study.

ACKNOWLEDGMENTS

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Deterioration of Bituminous Pavement Surfaces by Growth of Alum Crystals

JAMES R. DUNN

ABSTRACT

Some 1.5-in. bituminous pavements in Stafford County, Virginia, have developed numerous small domes from 2 to 4 in. in diameter and about 1 in. high. Each dome has a core of white, astringent-tasting crystals that are under the bituminous pavement and at the top of the subbase. The crystals appear to be closest in composition to pickeringite, a magnesium alum, which commonly results from the weathering of pyritic schists. The domes were observed primarily between vehicle wheel tracks and in areas of poorest drainage. The aggregate in the bituminous pavement is quartz sand and gravel and does not appear to be casually involved in the deterioration. The subbase aggregate is largely crushed biotite schist and granite and is from a quarry near Culpeper. Analyses of water in the quarry and of salts leached from stone piles indicate that the quarry is the probable source of the alum, and that the salts are in the subbase stone. It appears that salts concentrate under the bituminous pavement because water without the contained salts moves through the bituminous pavement, which appears to act as a semipermeable membrane. A particle count of subbase aggregate under the bituminous pavement indicates that the darker particles of biotite schist have produced local zones of capillarity in the subbase. This allows for water to be transmitted upward at certain spots, thus causing the salts to concentrate in mushroom-like masses under the bituminous pavement.

Work for the project described in this paper was done during August, September, and October 1982, and was financed by the General Crushed Stone Company. The objectives of this research were to (a) determine the cause of small mounds occurring in bituminous pavements in the area of River Ridge Estates, which is at the end of State Route 655 in Stafford County, Virginia, and (b) suggest remedies for minimizing the deterioration problem. The discussion in this paper concentrates on the causes.

The deterioration was first observed in 1981 and was brought to the attention of General Crushed Stone, which furnished the subbase aggregate. The Virginia Highway and Transportation Research Council (VHTRC) reported on the chemical composition of the substance associated with the deterioration in a memorandum dated October 1, 1981. Froehling and Robertson, Inc. (engineers and chemists), in a report dated December 31, 1981 (1), described the problem and made chemical analyses of salts that concentrated under the pavements. The Virginia Department of Highways and Transportation (VDHT) looked into the problem and took samples for investigation. In the fall of 1982 General Crushed Stone had samples of waters from the area analyzed by Environmental Systems Service, Ltd. of Culpeper, Virginia.

ROAD AND MATERIAL SPECIFICATIONS

The roads in which the deterioration occurs were constructed according to the following specifications.

1. Subbase, 6 in., type I, size no. 21A: "Type I aggregate base material shall consist of crushed stone, crushed slag, or crushed gravel; with or

without soil mortar or other admixtures. Crushed gravel shall consist of particles of which a minimum of 90 percent by weight of the material retained on the No. 10 sieve shall have at least one fractured face by artificial crushing" (2,p.99).

2. Size No. 21A consists of 100 percent passing a 2-in. sieve, 94 to 100 percent passing a 1-in. sieve, 63 to 72 percent passing a 0.375-in. sieve, 32 to 41 percent passing a No. 10 sieve, 16 to 24 percent passing a No. 40 sieve, and 8 to 12 percent passing a No. 200 sieve, according to VDHT specifications. Reports dated 1976 and 1977 of gradations of the subbase material used show gradations within the No. 21A ranges.

3. The soundness specifications for type I aggregate allow a maximum loss for 20 cycles of the freeze-thaw test (AASHTO T103) of 12 percent; for 5 cycles in the magnesium sulfate soundness test (AASHTO T104) the maximum allowable loss is 30 percent.

4. Seal or tack coat: An asphalt emulsion is "done after the surface is thoroughly compacted, cleaned of all dust, mud and foreign matter and the section to be sealed has been approved" (2,p.289).

5. Wear surface: It is a bituminous concrete plant mix, items S-5, ±1.5.

6. The subbase in General Crushed Stone's No. 26 crusher run and appears to be similar to No. 21A. A VDHT test form dated July 12, 1982, indicated that the stone had a magnesium sulfate soundness test loss of 17.2 percent, absorption of 0.8 percent, and Los Angeles abrasion test (AASHTO T96) loss at 500 rev. of 35.5 percent.

7. The aggregate in the bituminous pavement is a tan-colored gravel and natural sand; it is largely quartz.

OBSERVATIONS

Nature of Deterioration

The deterioration consists of roughly circular domes in bituminous pavements. The domes are from 2 to 4 in. in diameter and are up to about 1 in. high. Usually some tension cracking has occurred at the top of the domes, apparently because of stretching of the pavement when it is domed upward. The domes tend to occur in groups, with the individual domes from a few inches to about a foot apart (Figure 1). (Note the tendency of the domes to occur in between the areas of the maximum number of wheel passes. Tension cracks occur at the top of the domes.) In places, the domes coalesce and the deterioration becomes general. The domes tend to occur toward the middle of pavement areas and where vehicle wheels do not make many passes.

FIGURE 1 Distribution of deterioration domes in pavement.

At the center of each mound (mostly beneath the pavement, but in some cases working up into irregularities in the pavement) is a mass of fine-grained, white, crystalline salt with an astringent taste (Figure 2). (Note that the white salt is in the center of the dome, and none gets into the pavement.) Where the mounds coalesce, the crystalline material is more or less continuous (Figure 3). Where there were no salt domes, no white crystals were observed under the pavement.

FIGURE 2 Typical dome pried out of the pavement.

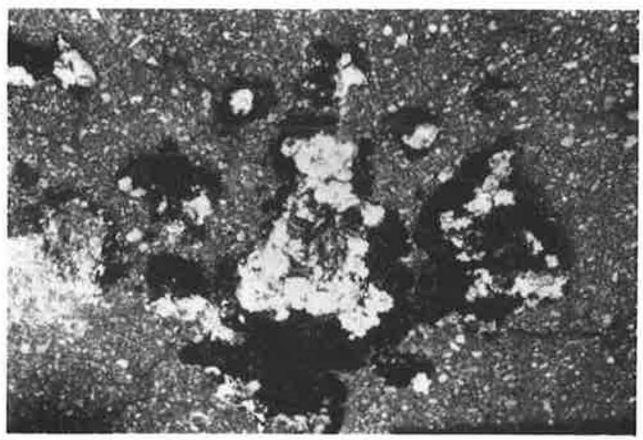

FIGURE 3 Zone of coalescing domes showing coalescing salt masses.

At two locations breached domes were observed (Figure 4). (Note that more typical unbreached domes occur around the breached dome.) Saline solution apparently had leaked through the dome, perhaps because of hydrostatic pressure from below. In each case a whitish concentration of salt was visible immediately around the dome and a damp-looking area about 6 to 8 in. in diameter ringed the dome.

The domes are what might be called "pavement salt domes" and, like salt domes that are found naturally in such places as the Mississippi delta, are caused by salt pushing upward from below. The doming in nature is caused by the upward movement of less dense salt from layers at depth penetrating the

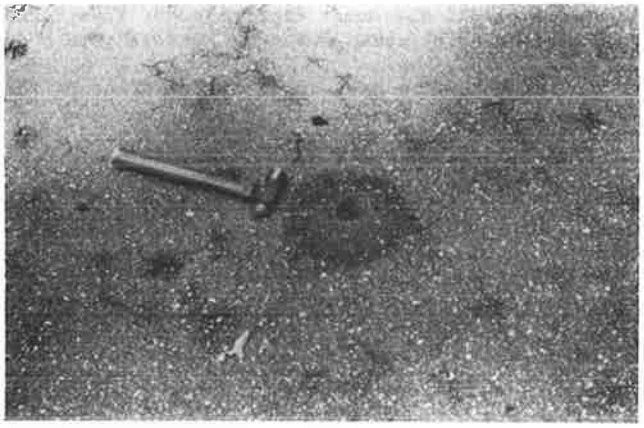

FIGURE 4 Breached dome from which salts apparently erupted to form a damp-appearing halo.

overlying sediments along vertical zones of weakness. In the present case, the salts are apparently forcing the pavement upward because of the growth of crystals.

Samples of bituminous pavement, the white salt, and base material were taken from 12 locations at two cul-de-sacs off River Ridge Lane, one called Ridge View Circle and the other Valley Lane. The samples were investigated under a zoom binocular microscope. The rock particles within the subbase under the mounds tend to be quite fine and sandy, and appear to be much finer than the original gradation. The larger particles tend to be about 1 in. across and consist of hard pieces of biotitic and muscovitic granitic gneiss and granite and deteriorated fragments of mica-schists with black, white, and tan micas. Some of the deteriorated schist contains metallic sulfides, probably iron pyrite (FeS_2), but the iron sulfide appears to be fresh. Some of the schistose particles observed were so weathered and disaggregated that they retained the form of particles only because they were held together by asphaltic material. They were, effectively, patches of sand. White crystals, about 0.125 in. long, apparently of the type associated with the deterioration, were observed within some of these disaggregated particles. In several cases the white crystalline material was found on top of the deteriorated schistose particles. The crystalline growths were not found directly on top of any fragments of granitic material.

One hundred and twenty-three particles of subbase aggregate from under the blacktop mounds were taken from the material collected on September 16, 1982. All particles were from -1 to +0.125 in. in size. The particles were counted under a binocular microscope; 118 (96 percent) were fresh micaceous granite gneiss and granite, some with hornblende. Two particles in the -0.5 to +0.375 in. range were friable and consisted of a piece of rusty, weathered granite and a piece of biotite schist; the remaining three friable particles were from -0.375 to +0.125 in. and were biotitic schist. The fines were mainly quartz, muscovite and biotite mica, and feldspar.

As a check on the relative soundness of the biotite schist and granite from the quarry, two 10-cycle magnesium sulfate soundness tests (AASHTO T104) were run in the Dunn Geoscience Corporation laboratory, one on dark aggregate particles and one on light particles. The dark biotitic particles had a 32.4 percent loss; the light granitic particles a 15.4 percent loss. Most of the granitic particles that deteriorated were somewhat weathered.

Observations at Spotsylvania Quarry

Spotsylvania quarry is of medium size and has a stripped area of red-brown saprolitic material that is about 30 ft thick. Below the saprolite is weathered metamorphic rock that is porous, locally oxidized to a reddish brown, which was derived from a mixture of granite, micaceous granite gneiss, mica schist, and graphitic schist. Iron sulfides occur in some of the rock, particularly in the graphitic and micaceous schists. The top lift of the quarry is largely in weathered rock and is about 60 ft high. The next lift is 50 ft high and is largely in the extension of the more granitic zone, which is in the first lift but is fresher-looking. The finer grained schists and graphitic rocks are less common in lower lifts. The lowest lift is 50 ft and is mostly in blocky granite and has a sump and pumping station at its lowest point.

The fresh granites, granite gneisses, and schists tend to vary from light to dark gray--the color influenced largely by the amount of hornblende or black mica (biotite). Some of the graphitic rocks are locally almost black.

Seepages of water along fractures in the rock were observed in several areas, and salts that varied from white to brownish were precipitated around the seeps (Figure 5). The seeps were most obvious at the upper two lifts, but some seepage was noted at the lowest lift. The sump pump operates intermittently at the rate of about 600 gal/min, averaging about 50,000 gal/day. The water is pumped to a surface pond that empties into a local stream. The quarry is closed during winter months, during which time the water rises to a depth of 15 to 20 ft.

FIGURE 5 Salt efflorescence around water course, upper lift, Spotsylvania quarry.

Several piles of broken stone products were observed. One pile of stone near the weigh station was reportedly gray when much of it was laid down about 4 years ago, but it is now a tannish to rusty brown. Minor parts of the pile have been in place for about 6 months and are gray. Salt precipitates were minor and difficult to see in runoff areas below the piles.

Another pile of crushed stone was observed south of the maintenance shop. The pile, which had been in place for about 2 years, showed little tannish or brownish stain and was primarily a medium to dark gray. Biotite schist was abundant, comprising about 75 percent of the pile in local areas. Abundant salts were observed around ponded areas, and the salts cemented much of the interior of the pile, particularly at the lower one-third (Figures 6 and 7). The salt crusts had an astringent taste. Some particles of biotite schist at the base of the pile were partially disintegrated.

FIGURE 6 Alum salt-covered Virginia size No. 19 aggregate particles, base of relatively fresh appearing aggregate pile, laid down 2 years, south of maintenance shop.

FIGURE 7 Salt-covered particles from pile shown in Figure 6.

CHEMISTRY OF SALTS AND WATERS

In a letter dated October 1, 1981, Gerry G. Clemena, research scientist for VHTRC, reported partial compositions for the white crystals associated with the deterioration of the pavements. Using X-ray fluorescence, he reported aluminum, manganese, nickel, sulfur, magnesium, iron, and calcium. He noted that the sulfur was in the form of sulfate and that the salt solution was quite acidic (5 percent H+ equivalent). Dissolution in water released gas, which he suspected was carbon monoxide. Based on X-ray diffraction, Clemena concluded that the substance is very likely a mixture of aluminum and other metallic sulfates. He concluded that the white substance is largely $Al_2(SO_4)_3 \cdot 18H_2O$ (alum plus some psuedo-alum). Clemena apparently concluded that the Mn, Ni, and perhaps the other metals are but minor components in a substance that is essentially alum.

From their analytical work, Froehling and Robertson, Inc. (1) concluded that the white material under the pavement (sample A) and the dissolved salt associated with the base material (sample B) had the compositions given in Table 1. A pH of 3.85 was observed, apparently in water in the base material. Mn and Ni were not observed, and Na was noted but not determined quantitatively.

TABLE 1 Analyses of Salts

Chemical Measured	Weight Percent Sample A	Weight Percent Sample B
SiO_2	29.75	18.40
Fe_2O_3	1.54	0.87
Al_2O_3	9.75	8.45
CaO	5.03	3.67
MgO	11.24	12.15
SO_4	33.01	ND
S	11.02	13.53
LOI	31.08	ND

Note: Wet analytical work by Froeling and Robertson, Inc. (*1*). Sample A salt is from under a blacktop pavement, and sample B salt is dissolved from aggregate.

The chemistry, according to Froehling and Robertson, Inc. (1), appears to be somewhat more complex than that suggested by VHTRC. Their analyses are most consistent with alum family salts. However, the SiO_2 content is somewhat puzzling, is not a normal constituent of alums, and may have come from some sort of contamination.

Samples of water from several locations taken by General Crushed Stone personnel in the fall of 1982 were analyzed by Environmental Systems Service, Ltd. The report, dated September 8, 1982, is summarized in Table 2. Only the water from the sump in the quarry could potentially precipitate alum on evaporation.

TABLE 2 Analyses of Waters

Constituent	Weight Concentration (mg/L) Quarry Sump	Plant Well	Pond Discharge	Black Top Plant Well	Water Dripping
Total alkalinity as $CaCO_3$	80	26	5.6	68	16
pH (S.U.)	6.75[a]	5.95[b]	5.55[b]	6.51[b]	7.13[b]
SO_4	457	452	380	3	8
Cl	3.5	6.6	1.2	135	0.2
Al	117	0.02	0.18	0.05	0.12
Ca	92.6	73.6	69	1.09	1.13
K	21.2	10	13.2	1	0.7
Mg	40	50	31	2	0.9
Na	40	25	40	6.4	13

Note: Water analyses were made by Environmental Systems Service, Ltd. Locations are all at the Spotsylvania plant of General Crushed Stone.

[a]At 26°C.

[b]At 25°C.

Samples of the white salts taken by the author on September 16, 1982, were analyzed by the New York State Department of Health (NYSDH), which has made hundreds of analyses of saline waters in recent years in connection with another Dunn Geoscience project. The results are given in Table 3.

DISCUSSION OF CHEMISTRY

The waters that were analyzed have different histories and are from different locations and hence vary considerably (of course, they are also reported

TABLE 3 Analyses of Salts

Compound or Element	Weight (mg/L) Salt on Stone[a]	GCS-C-4[b]	GCS-D-1[c]
Al	7,800	30,800	44,600
Cl	200	300	307
SO_4	120,000	354,000	415,000
SiO_2	24	63	48
Ca	50	70	70
Fe	280	1,010	1,480
Mg	13,900	46,800	52,300
MN	1,900	7,540	4,920
K	780	46	46
Na	1,400	108	340
Total	–	440,737	519,111

Note: Analyses were done by NYSDH.
[a]This sample is from the size 19 pile near the maintenance shop.
[b]This sample is from the cul-de-sac at the end of Ridge View Circle.
[c]This sample is from the cul-de-sac at the end of Valley Lane.

differently). The most critical water analyses are of the quarry sump, the water dripping, and the salts. Although the concentrations are considerably different, the ratios of sulfates and the metals are similar (i.e., evaporating the dripping water would produce a composition that is similar to the sump water, and evaporation of the sump water could produce salts of the type observed). These waters are characterized by high sulfate and high Al, Mg, and Ca relative to sulfate. Evaporating water of this composition could produce a salt similar to that observed under the bituminous pavement roads.

The compositions of the pond discharge water and the water from the well at the plant are similar to that of the sump water, except for the much lower Al content. There is no explanation for this difference, although Al concentration is sensitive to pH and oxidation potential causing precipitation of aluminum hydroxides.

The white salt under the road, according to VHTRC and NYSDH, is primarily an aluminum magnesium sulfate as is the salt taken from the bottom of the stone pile south of the maintenance shop at the quarry. The salt appears to be closest to the magnesium alum, pickeringite [$MgSO_4.Al_2(SO_4)_3.22H_2O$]. Dana and Ford (3,p.764) state that pickeringite is "formed by the weathering of pyrite-bearing schists." Variations in the composition of alum salts are quite common, and there appears to be considerable room in the lattice for such miscellaneous ions as Mg, Ca, K, and Na.

The compositions of the water in the sump and in the drip are probably highly diluted versions of the water in the rock. Rainwater and water that moves through the red-brown saprolitic overburden are probably fairly pure and more like the water of the well at the blacktop plant (Table 2). Such water seeping through fractures, and rainwater falling directly into the quarry, must considerably dilute the salt-rich water in the rock.

The changes that occur in the rock below the saprolitic overburden may be of the following type. Pyrite (FeS_2) reacts with water and oxygen to form ferrous sulfate and sulfuric acid:

$$FeS_2 + 7O + H_2O \longrightarrow FeSO_4 + H_2SO_4$$

The sulfuric acid along with additional acids from normal air (carbonic, sulfuric, and nitric mostly) attack the feldspar, biotite, and other silicates to remove Al, Mg, and Mn along with minor alkali. With decrease in acidity as the acids are used up, the ferrous iron (Fe^{+2}) oxidizes and precipitates as $Fe(OH)_3$, thus staining the rock brown. In humid, warm climates the Al^{+3} is usually slightly more mobile than Fe^{+3}, as indicated by the tendency for iron oxides to concentrate above aluminum oxides in weathering zones.

The chemical process of forming the weathered saprolite from silicate rock is slow, and the currently observed conditions have required millions of years of weathering. However, surface oxidation of iron sulfides usually occurs more rapidly than silicate weathering and may occur in relatively few years, geologically speaking. Even this process usually requires prolonged periods (many thousands of years) for completion. Apparently little oxidation of iron sulfide occurs under the pavement because unoxidized, fresh, yellow iron pyrite was observed in some of the sandy material in the subbase. Apparently any alum in the subbase was brought in with the aggregate.

The acidity of the waters varies because of dilution, chemical reactions, and the acidity of rainwaters. Keeping Al^{+3} in solution requires an acidic environment because acidity decreases Al^{+3}, hydrolizes, and goes to $Al(OH)_3$, which may precipitate or remain in suspension as a colloid.

GENERAL DISCUSSION AND CONCLUSIONS

The domes in the bituminous pavements are clearly associated with the growth of magnesium alum sulfate crystals. The alum masses grow at the interface between the subbase and the asphaltic pavement, preferring, possibly, to grow above particles of deteriorated rock in the base course. Sorptive effects enhanced by salts and the growth of the alum crystals within the schistose particles probably combine to cause their deterioration, thus breaking the particles down to a sand in many cases. (No sound pieces of biotite schist were observed in the base course aggregate.)

Precipitation of salts is often the result of a salt solution becoming supersaturated because of evaporation of the solvent. Quite probably evaporation can only occur off the top of the pavement. It is clear that the salt-rich water does not usually reach the surface of the pavement because salts are not visible at the surface (except where a mound has been breached), nor are salts observed within the pavement. In fact, the pavement does not appear to lose any integrity, which it probably would do if salts were growing within it.

Because water gets through the blacktop but salt does not, the pavement is apparently acting as a semipermeable or relatively impermeable membrane that transmits water but not its contained salts. When water moves to the surface of the pavement to evaporate, the salt apparently cannot get through, is left behind, and concentrates. Very probably the particles of mica schist start deteriorating before the salts saturate, and these particles are reduced to sand-size debris. The virtual absence of mica schist particles below the salt crystals is an indication of the probable efficiency of the deterioration process. The zones where such particles existed then become zones where capillary water is pulled to the top of the subbase after the water level has lowered around these sandy debris zones. Kovacs (4) calls such a zone the open capillary zone. Figures 8 and 9 show how the process of deterioration may operate.

[In Figure 8 note the nature of water in the soil-moisture zone (4). The critical area during salt concentrations in subbase road conditions appears to be Kovacs' open capillary zone, where concentrations of finer materials cause water to move upward more readily. Figure 9 shows that when the

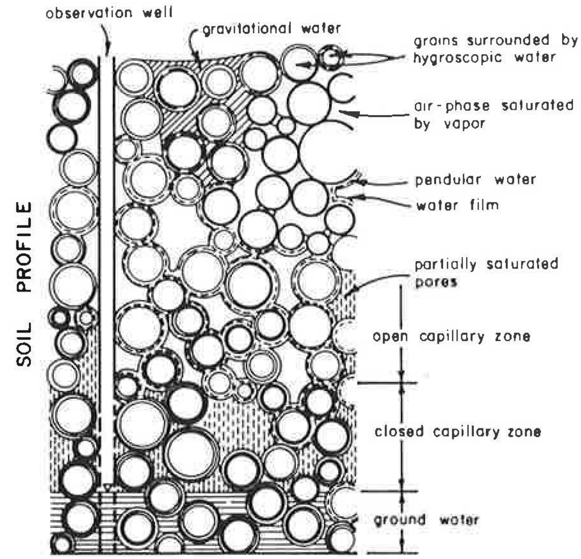

FIGURE 8 Types of water in soils.

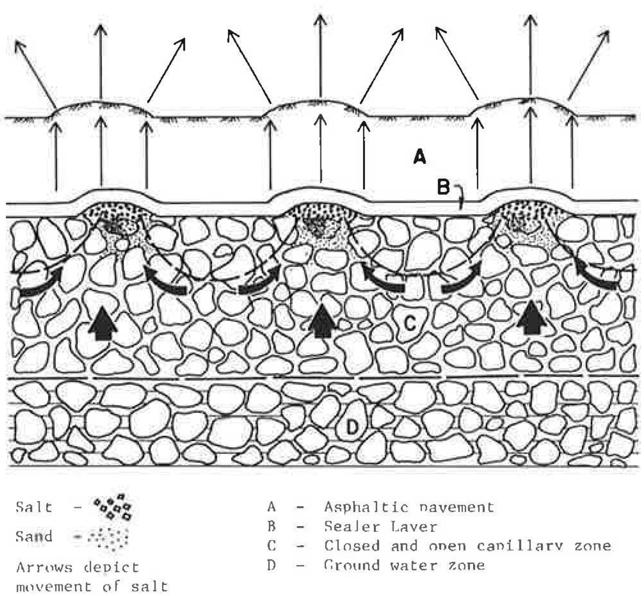

FIGURE 9 Mechanism of salt doming.

unsound particles under the pavement have disintegrated, they become, effectively, zones of fine sand within the subbase. During dry seasons when the level of groundwater drops to zone D, these sand patches become open capillary zones (see Figure 8) at the top of the closed capillary part of zone C. Evaporation off the surface of the pavement is apparently concentrated above these zones. Salt begins to precipitate directly under the seal as water without salt is pulled through the pavement to evaporate from the surface. The growing salt crystals dome the pavement upward.]

The saline solution above these capillary zones becomes supersaturated and the contained alum salts precipitate. Cooling at night may possibly be a factor that starts the initial crystallization. The original points or zones of supersaturation appear to be above what were micaceous particles. Thus crystallization appears to begin at the top of the particles where they are in contact with the pavement where the salts, in effect, are filtered from the water. Once crystals begin to grow, they grow upward as water evaporates from the top of the pavement. This process presumably continues until all available salt in the base material is used up.

The particles of micaceous (and/or graphitic?) rocks disintegrate as the micaceous particles warm and cool in the presence of saline waters. This sort of accelerated deterioration is common and is the probable cause of much of the deterioration of rock in the New York State freeze-thaw test in 10 percent NaCl solution. It has been shown that the saline solution in many of the least sound rocks in New York State never freezes because no heat of freezing is detected in differential thermal analysis. The deterioration process is related to increased expansion and contraction on cooling and warming in the presence of saline solution (5,6).

Crystals of salt growing within the deteriorating particles may accelerate the process similarly to the deterioration of rocks in sulfate soundness tests (although the subbase material may never dry completely as in the tests). The particles of mica-rich rocks are so disintegrated by this process that much of the micaceous sand under the pavement may well result from the breakdown of such rocks. The deterioration process is so effective that the only mica schist particles that were seen were friable and readily disintegrated when handled.

Although salt domes of this type have apparently been observed elsewhere in Virginia, their full extent is not known. Whether such a process might operate in D-cracking of portland cement concrete pavements, as has been suggested (7), is also not known.

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