RESOURCE SERIES 8

Proceedings of the Fifteenth Forum on Geology of Industrial Minerals

Theme: Industrial Minerals in Colorado
and the Rocky Mountain Region

Golden, Colorado / June 13 – 15, 1979

edited by Stephen D. Schwochow

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO / 1980

Resource Series 08

PROCEEDINGS OF THE FIFTEENTH FORUM ON GEOLOGY OF INDUSTRIAL MINERALS

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DOI: https://doi.org/10.58783/cgs.rs08.bzhu9800

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COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
STATE OF COLORADO
DENVER, COLORADO

1980

Foreword

This volume, the Proceedings of the Fifteenth Forum on Geology of Industrial Minerals, presents the papers of the three technical sessions of the Forum. Thus is recorded for posterity the serious words of numerous authors who spoke before 138 registrants (less one) on June 14 and 15, 1979, at the Holiday Inn Holidome in Golden, Colorado. The official hosts, the Colorado Geological Survey, the Colorado School of Mines Research Institute, and the Colorado Sand and Gravel Producers Association, and especially the 1979 Forum Program Committee formally thank each speaker in the three technical sessions: Construction Materials and Land Use; Clay, Limestone, and Silica Sand--Raw Materials and Products; and Potential Industrial Minerals in Colorado and the Rocky Mountain Region.

The opportunities to exchange ideas, to learn more about some of our less common industrial minerals, and to discuss operational problems with a wide variety of experts were further enhanced by loquacious liquidus sessions at poolside. All registrants were grateful to the Anaconda Company, Johns-Manville Corporation, Colorado Sand and Gravel Producers Association, and Alpha Portland Cement Company for their generous support of this phase of the Forum.

Special thanks go to the Society of Economic Geologists Foundation, Inc., for its $500.00 grant in continuing support of the Forum and printing of the Proceedings. We further acknowledge the assistance of Denver Brick and Pipe Company, Coors Porcelain Company, Johns-Manville Corporation, and Climax Molybdenum Company, who made the field trips so successful.

A. L. Hornbaker

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Chronology of the Forums on Geology of Industrial Minerals

Year, Place, Theme	Sponsor	Source of Proceedings
First, 1965, Columbus, OH "Industrial Limestone and Dolomite"	Ohio State University Dept. of Geology	Ohio Academy of Science 445 King Avenue Columbus, OH 43201 (Ohio Journal of Science, v. 66, no. 2, p. 97-191)
Second, 1966, Bloomington, IN "Cement Raw Materials"	Indiana Geological Survey and Indiana University	Indiana Geological Survey Dept. of Natural Resources Indiana University 611 North Walnut Grove Bloomington, IN 47401 (A Symposium on Geology of Cement Raw Materials) (out of print)
Third, 1967, Lawrence, KS "Industrial Mineral Exploration and Development"	State Geological Survey of Kansas and University of Kansas	State Geological Survey of Kansas University of Kansas Lawrence, KS 66044 (Spec. Distribution Pub. 34, 174 p.)
Fourth, 1968, Austin, TX "Geology of Chemical Raw Materials" and "Depositional Models in Economic Stratigraphy"	Texas Bureau of Economic Geology and University of Texas at Austin	Texas Bureau of Economic Geology Box X, University Station Austin, TX 78712 (Proceedings of the Fourth Forum on Geology of Industrial Minerals, 174 p.)
Fifth, 1969, Harrisburg, PA "Geology of Sand and Gravel Deposits" and "Can Industrial Mineral Production Survive Urbanization and Conservation"	Pennsylvania Bureau of Topographic and Geologic Survey	Pennsylvania Bureau of Topographic and Geologic Survey Bureau of Publications 10th and Market Streets Harrisburg, PA 17125 (Mineral Resources Rept. M 64, 278 p.)
Sixth, 1970, Ann Arbor, MI "Chemical and Industrial Rocks and Minerals" and "Building and Construction Stones and Minerals"	Michigan Geological Survey, University of Michigan, and University of Toledo	Information Services Center Michigan Dept. of Natural Resources Box 30028 Lansing, MI 48909 (Michigan Geol. Survey Miscellany 1, 155 p.)
Seventh, 1971, Tampa, FL "Geology of Phosphate, Dolomite, Limestone, and Clay Deposits"	Florida Bureau of Geology	Florida Bureau of Geology P. O. Box 631 Tallahassee, FL 32302 (Spec. Pub. 17, 228 p.)
Eighth, 1972, Iowa City, IA "Limestone, Gypsum, and Shale"	Iowa Geological Survey, University of Iowa, Iowa State University, and University of Northern Iowa	Iowa Geological Survey 16 West Jefferson St. Iowa City, IA 52240 (Public Inf. Circ. 5, 194 p.)
Ninth, 1973, Paducah, KY "Geology of Fluorspar"	Kentucky Geological Survey and Illinois State Geological Survey	Kentucky Geological Survey 307 Mineral Resources Building Lexington, KY 40506 (Series X, Spec. Pub. 22, 107 p.)
Tenth, 1974, Columbus, OH "Reclamation of Pits and Quarries" and "Carbonate Rocks in Environmental Control"	Ohio State University Dept. of Geology and Ohio Geological Survey	Ohio Geological Survey Dept. of Natural Resources Fountain Square Columbus, OH 43224 (Misc. Rept. 1, 100 p.)

Year, Place, Theme	Sponsor	Source of Proceedings
Eleventh, 1975, Kalispell, MT "Industrial Minerals of Montana and Contiguous States and Provinces"	Montana Bureau of Mines and Geology and Flathead Valley Community College	Montana Bureau of Mines and Geology Room 203-B, Main Hall Montana College of Mineral Science and Technology Butte, MT 59701 (Spec. Pub. 74, 186 p.)
Twelfth, 1976, Atlanta, GA "Industrial Minerals of Georgia and the Southeastern States"	Georgia Geologic Survey and Georgia State University	Georgia Geologic Survey Dept. of Natural Resources 19 Hunter Street, SW Atlanta, GA 30334 (Inf. Circ. 49, 78 p.)
Thirteenth, 1977, Norman, OK "Gypsum, Silica-Rich Sediments, Natural Brines, and Energy in the Industrial-Minerals Industry"	Oklahoma Geological Survey and University of Oklahoma	Oklahoma Geological Survey 830 Van Vleet Oval, Rm. 163 Norman, OK 73069 (Circular 79, 107 p.)
Fourteenth, 1978, Albany, NY "Geology of Industrial Minerals in the 1970's"	New York State Geological Survey, Empire State Concrete & Aggregate Producers Assoc., State Univ. of New York at Albany, New York Dept. of Transportation, New York Dept. of Environmental Conservation, Renssalaer Polytechnic Inst., and Dunn Geoscience Corp.	New York State Geological Survey State Education Building Albany, NY 12234
Fifteenth, 1979, Golden, CO "Industrial Minerals in Colorado and the Rocky Mountain Region"	Colorado Geological Survey, Colorado School of Mines Research Inst., and Colorado Sand & Gravel Producers Assoc.	Colorado Geological Survey 1313 Sherman St., Rm. 715 Denver, CO 80203 (Resource Series 8)
Sixteenth, 1980, St. Louis, MO		
Seventeenth, 1981, Albuquerque, NM		
Eighteenth, 1982, Bloomington, IN		
Nineteenth, 1983, Toronto, Ontario		
Twentieth, 1984, Maryland		
Twenty-First, 1985, Arizona		

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Keynote Address:
Development of Industrial Minerals on Federal Lands

by

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INTRODUCTION

Probably the most neglected resources on Federal lands are the industrial minerals. Only within the past few years have federal agencies such as the Bureau of Land Management (BLM) and the Forest Service (FS) begun to realize the vast potential and importance the industrial minerals present on the public domain. This awareness was brought about by crises such as the need for barites for drilling mud, shortages of Portland cement, the increased use of limestone for scrubbing stack emissions, and the legal complexities surrounding bentonite and zeolites. Very few (if any at all) resource inventories were conducted for industrial mineral materials in the same manner and degree as for the base and precious metals.

Of the total revenue produced by non-energy minerals in 1978, 65 percent was represented by nonmetallics. In addition the industrial minerals are the only mineral group not imported. In fact the U.S. exported $8.8 billion worth of raw and processed nonmetallics in 1977, including $1.3 billion of ore-grade nonmetallics.

Neglect of the industrial mineral wealth on the public land is due in large part to the "metallics mentality" and the lack of trained and interested people in the govermental agencies.

CURRENT STATUS OF INDUSTRIAL MINERAL DEVELOPMENT ON FEDERAL LANDS

If one were to survey the industrial mineral deposits in the western United States today, it is probable that 75 percent or more would occur on lands managed by BLM and the Forest Service.

Under current law some of the nonmetallics can be developed under any of the three mining laws:

Locatable	(1872 Mining Law)
Leasable	(1920 Leasing Act as amended)
Saleable	(1955 Minerals Materials Act as amended)

Some of the industrial minerals are clearly held to be locatable. Others, such as the borate minerals can be leasable or locatable depending upon such factors as chemical composition. Limestone is an example of a mineral product that can be either locatable or saleable. In one special case where minerals have been acquired by the United States, all minerals are either leasable or saleable.

The development of industrial mineral deposits on federal lands is occurring with continuously increasing restraints. The strongest controls now affecting development on public lands are state, county and other local land-use and reclamation laws. In other words, in the case of a locatable mineral company can explore, locate, and develop an industrial mineral deposit with very little interference from the BLM. On Forest Service lands location and development are regulated by the Forest Service mining and reclamation regulations.

Regulation and Industrial Minerals

Management of the industrial minerals on federal lands has been difficult only from the standpoint of classifying a deposit as locatable, saleable, or leasable. Some concern has been caused by lack of information on the distribution, quality, and quantity of the nonmetallics in the public estate. Regulations and legislation that have been proposed and are expected to be proposed will significantly affect the location and development of all minerals.

Current Regulations

Among the current regulations affecting location and development are state and county reclamation laws and the Federal Land Policy and Management Act of 1976 (BLM Organic Act or FLPMA).

Reclamation Laws in the Western States

Nevada and Arizona are the only two western states that do not have surface reclamation acts. The rest all have controls that affect reclamation and surface disturbance on all lands within the state, including federal lands. Much of this responsibility over public domain will vary from state to state. Generally speaking, California, Montana and Wyoming have the strongest reclamation laws and the most control over mineral exploration, extraction, and processing activities on federal lands.

These states require detailed reclamation plans and filing of plans of operation prior to

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development. Although originally passed for energy minerals (Wyoming, Montana), state and county reclamation laws now cover mining of all mineral commodities.

Federal Land Policy and Management Act of 1976

The Federal Land Policy and Management Act of 1976 contains three sections that affect the location and development of mineral materials.

Mining Claim Recordation(Sec314)-This section states that all unpatented lode and placer mining claims, mill and tunnel site claims on public lands shall be recorded with the "appropriate" BLM office for the state in which they occur. In addition th the recording of all mining claims, the Act also requires claimants to file (1) a copy of affidavit of assessment work performed, or (2) a copy of the detailed report of geological, geophysical, and geochemical surveys as required under 30 USC. 28-1 or (3) where a suspension or deferment of annual assessment work has been granted, a notice of intention to hold the mining claims. These are filed in lieu of a copy of affidavit of assessment work.

In the past much confusion has arisen over the dates of deadlines for filing. As a result some claimants have lost their properties by having the claim voided "ab initio" because of late claim recordation and assessment work filings.

In cases where the claimants have appealed their losses, every decision has upheld the BLM ruling (U.S. vs. Byram, 1979; U.S. vs Hesslegessner, 1979; U.S. vs Jensen, 1979).

The deadline is drawing near (October 22, 1979) for those persons who staked mining claims on or before October 21, 1976. Claims located after October 21, 1976, must be recorded with the BLM within 90 days after location. Proof of labor and notices of intention to hold claims must be

Table 1 - ASSESSMENT WORK FILING DEADLINES

MINING CLAIMS LOCATED ON OR BEFORE OCT. 21, 1976

IF MINING CLAIMS WERE RECORDED IN THE PROPER BLM OFFICE DURING ONE OF THE FOLLOWING CALENDAR YEARS...	...THEN THE FIRST FILING OF EVIDENCE OF ASSESSMENT WORK OR NOTICE OF INTENT TO HOLD MUST BE FILED ON OR BEFORE THESE DATES	...AND SUBSEQUENT FILING OF EITHER EVIDENCE OF ASSESSMENT WORK OR NOTICE TO HOLD MUST BE FILED ON OR BEFORE THESE DATES:
1976	Dec. 30, 1977	Dec. 30, 1978 and Dec. 30 each year thereafter
1977	Dec. 30, 1978	Dec. 30, 1979 and Dec. 30 each year thereafter
1978	Oct. 22, 1979	Dec. 30, 1980 and Dec. 30 each year thereafter
January 1 through October 22, 1979	Oct. 22, 1979	Dec. 30, 1980 and Dec. 30 each year thereafter

MINING CLAIMS LOCATED AFTER OCT. 21, 1976

IF MINING CLAIMS WERE LOCATED DURING ONE OF THE FOLLOWING CALENDAR YEARS...	...THEN THE FIRST FILING OF EVIDENCE OF ASSESSMENT WORK OR NOTICE OF INTENT TO HOLD MUST BE FILED ON OR BEFORE THESE DATES...	...AND SUBSEQUENT FILING OF EITHER EVIDENCE OF ASSESSMENT WORK OR NOTICE TO HOLD MUST BE FILED ON OR BEFORE THESE DATES:
1976	Dec. 30, 1977	Dec. 30, 1978 and Dec. 30 each year thereafter
1977	Dec. 30, 1978	Dec. 30, 1979 and Dec. 30 each year thereafter
1978	Dec. 30, 1979	Dec. 30, 1980 and Dec. 30 each year thereafter

filed on or before December 30 each year after the claims were located. Table 1 explains in greater detail the time frames for recording assessment work.

Unnecessary Degradation (Sections 302b, 603c)

The jurisdiction that the Secretary of Interior has in preventing undue impairment of public lands by mining is defined in Section 302b of FLMPA. This section states that the Secretary shall, "by regulation or otherwise, take any action necessary to prevent unnecessary or undue degradation of the lands." Protection of proposed wilderness areas from undue degradation caused by mining is laid out in Section 603c. In this subpart, the Secretary "shall continue to manage such lands according to his authority under this Act and other applicable law in a manner so as not to impair the suitability of such areas for preservation as wilderness, subject, however, to the continuation of existing mining and grazing used and mineral leasing in the manner and degree which the same was being conducted on the date of approval of this Act." The "manner and degree" in which existing operations were conducted on October 21, 1976 is open to interpretation.

Proposed Regulations

Three important new sets of regulations being proposed will have significant impacts on the development of industrial minerals on federal lands. The proposed Wilderness Exploration and Mining (43CFR3802) and the Mining Claim Surface Reclamation (43CFR3809) regulations have been published for comments in the Federal Register. The proposed regulations on minerals materials sales should be published in August or September. The BLM material sales proposals will be published in conjunction with similar ones by the Forest Service.

Mineral Materials Disposal (43 CFR 3600)

These proposed regulations will clarify and update the Material Sales Regulation listed in Part 3600 of Title 43 of the Code of Federal Regulations (43CFR Part 3600). Obsolete sections have been deleted and new sections added to provide additional authority and guidance for the disposal of mineral materials. The more important changes in these regulations are:

1. Subpart 3601 - a new section has been added to allow sampling and testing of mineral materials prior to issuance of a sale contract or permit.

2. Subpart 3604 - the acreage limitations on community pits have been abolished in order to allow flexibility in managing a greater variety of mineral materials deposits. Sizes may vary from 20 acres or less for a sand and gravel deposit to several hundred acres for scattered surficial deposits of decorative stone.

3. Subpart 3610 - determination of fair market value will be made by a qualified mineral appraiser. The number and type of sale contracts are being revised to reduce paperwork and to save time and issuance.

4. Subpart 3611 - limitations on the amounts of minerals and materials that may be sold noncompetitively have been increased and are now expressed as volumes (or weight equivalent) instead of dollar-value limits. The authorized officer will be able to sell noncompetitively sale mineral materials not to exceed 100,000 cubic yards or weight equivalent in any individual sale. The total noncompetitive sales that may be made in any state for the benefit of any individual or corporation in any calendar year shall not exceed 200,000 cubic yards. A new section has been added to allow noncompetitive sales of up to 200,000 cubic yards mineral materials for use in developing federal mineral leases. This should assist in the timely development of such leases.

5. Subpart 3612 - bidding and sales procedures on competitive sales have been simplified.

Mining Claim Surface Reclamation - Wilderness Exploration and Mining

These two proposed rulemakings were published in the Federal Register for comments in December 1976, and January 1979, respectively. They can be discussed essentially as one since the BLM has rewritten the Mining Claim Reclamation proposals to conform to the Wilderness proposals. Both were scheduled to be implemented at the same time. Because an environment impact statement (EIS) has already been written, BLM would like to see the Mining Claim Reclamation regulations implemented before July 30, 1979. This may not be realized if the EIS written on these regulations is not approved by this date. The Council for Environmental Quality has issued new guidelines intended to go into effect on August 1, 1979. This means that any proposed regulations not finalized by this date essentially must begin the process all over. Therefore, there is some question if these regulations will ever issue.

The current situation governing the development of locatable nonmetallics is that no notice of intent or plan of operations is required by the BLM. The only authority the BLM has at the present time is to monitor surface disturbance on mining claims as specified in FLMPA, Sections 302b and 603c.

LAND ACQUISITION

Title to Minerals can be acquired under one of the three basic mining laws of the United States. These three, the Mining Law of 1872, the Leasing Act of 1920, and the Materials Sales Act of 1955, cover the entire range of minerals.

1872 Mining Law - This law includes most metals and selected nonmetallics commonly referred to as "locatable" minerals. Three types of mining claims can be located--placer, lode, and mill site. Although nonmetallics are usually located as placer claims, a recent decision (U.S. vs Bowen, 1979) addressed the question of lode vs placer claims on nonmetallics. This case concerned perlite, and the finding was that perlite is properly located as a lode claim. The reasoning behind this decision is as follows:

> "...when placer mining claims have been located as placer for perlite which lies in a blanket or pancake in an almost horizontal plane and in its original state is encased between two different types of rock, where in places, the upper rock or layer has been eroded away leaving the perlite exposed at the surface in other places the upper layer is still present, and the mining of perlite is characterized as essentially a hard rock operation, and when it is just extracted from the ground and then processed or, in effect, milled to produce a marketable product, the perlite is properly classified as a lode deposit which will not sustain a placer location."

Another recent case (U.S. vs Lane, 1976) reemphasizes the fact that annual assessment work must be done and can result in contest of the claim.

1920 Leasing Act - Industrial minerals under this act are primarily the evaporite-type minerals. In recent years other minerals such as zeolites (U.S. vs Union Carbide, 1977) and bentonite have been considered for classification as leasable minerals. The Act, as it was written, includes phosphate, oil shale and the chlorides, sulfates, carbonates, borates, silicates or nitrates of potassium and sodium. The controversial part of this classification is the inclusion of silicates and what is meant by silicates of potassium and sodium. Both zeolites and bentonite have been considered for classification as silicates of sodium.

If "leasable" minerals are comingled with "locatable" minerals, the courts have consistently held that leasing will predominate. This was recently reaffirmed in U.S. vs Foote Mineral Company (1978) and concerned a brine deposit from which lithium minerals were extracted at profit. The decision stated that sodium and potassium leases convey the exclusive rights to all minerals, including lithium, dissolved in the brine.

Materials Sales Act of 1955 - This act, originally passed in 1947 and amended in 1955, is intended to dispose of materials, specifically including but not limited to "common varieties" of sand, stone, gravel, pumice, pumicite, cinders, clay and petrified wood. Deposits of these nonmetallics having properties that give them special and distinct value can remain locatable under the 1872 Mining Law. This condition is responsible for the majority of contest proceedings held on industrial minerals. BLM has the sole authority for determining (interpreting) the unique or special values and properties of a mineral material. Numerous contests are still being initiated over this very question. Two recent and very typical ones are U.S. vs Bolinder and Turner (1976) and U.S. vs Verdugo and Miller (1978).

One of the reasons the Materials Sales regulations have been updated is to enable companies and individuals to acquire these materials more easily and economically under a Material Sales contract rather than the 1872 Mining Law.

TO PATENT OR NOT TO PATENT?

Once a claimant has located a mining claim, he can apply for a patent to the claim which, if granted, gives fee simple title to the land embraced in the claim. Unfortunately, many companies and individuals apply for patents before devloping the claims, often acting on advice from lawyers, company officials, and others. They are told that unless the claim is patented, the BLM will take it away. The fact is that mineral contests are only initiated when the following occurs:

1. The lands are needed for a federal program, i.e., Wilderness, Primitive areas, water developments, and so on.

2. The mining claim conflicts with a surface disposal application, i.e., parks and recreation sites, landfill sites, mineral sales applications.

3. The claim is being used for nonmining or mineral purposes (such as a summer cabin and so on).

4. The mining claimant has filed for patent.

The BLM has shown little interest in mining claims on public domain unless they do fall under one of the above four provisions.

If a claim is contested, the claimant must show (1) a discovery of "valuable mineral" under the mining law and (2) that he can mine and market this material at a profit if he so desires. On lands that have been withdrawn, and for which the claim predates the effective date of withdrawal, the situation is the same. He must show as of date of withdrawal that he had under the mining law a discovery that could be marketed at a profit.

In order for the BLM mineral investigators to properly evaluate a property and to speed up the entire process, a claimant should have available at the time of the mineral investigation the following information:

1. Discovery points, drill cores (if available) and maps all clearly marked.

2. Analytical data showing that the mineral material in question meets all specifications for the use which it is intended.

3. Market feasibility reports, data projections, plant capacity, mining costs, transportation costs, environmental costs.

4. Tonnage estimates--proven and inferred reserves, total resources.

The question of excess reserves will enter at this point. Of all the above, marketability and prudent man tests are most significant.

Mining claims located on speculation do not establish a market (U.S. vs Christiansen, 1977). Establishing the marketability of a mineral deposit requires more than showing that the mineral is theoretically marketable or intrinsically valuable. The claimant must demonstrate present continuing demand for his mineral (U.S. vs Slater, 1978). Nor is it sufficient to show that attempts are being made to explore for possible markets or to promote the use of the mineral. Past sporadic sales do not establish a market.

In another recent case (U.S. vs Tempest Mining Co., 1979) it was stated that a claimant must show more than just a prudent man would explore the claim further. It must be shown that a valuable mineral deposit has been physically exposed within the limits of the claim.

On the placer claims the "10-acre rule" comes into effect. The government contends that in those cases where a discovery has been made on portions of a claim, those portions that do not contain a valuable discovery should be eliminated. The part of the claim that contains no discovery is often termed "non mineral in character."

In U.S. vs Meyers (1974) it was stated that a discovery on one 10-acre portion of an association placer claim does not establish the mineral character of the entire claim. The 10-acre rule and the question of excess reserves was ruled on recently in Idaho (U.S. vs Oneida Perlite, 1979).

Patenting of mill-site claims presents an entirely different situation. Administrative and IBLA decisions have through the years provided firm guidelines on mill-site patents. For example, a mill site must be nonmineral in character. Often a claimant will have to show physical evidence such as drill cores, that it is nonmineral. Mill sites must be occupied and used for mining and milling purposes. In other words a working plant or mill of specific capacity or some step directly connected with the process of mining or milling a mineral material must be evident upon the mill-site claims at the time of the application for patent. As is true in the case of placer or lode claims, past or future use does not validate a mill site. Those claims with permanent structures will usually be patented. Mill-site claims used for stockpiling, tailings and settling ponds are also likely to be patented.

Reclamation is not a function associated with milling or mining of ore and, therefore, does not validate a mill site. Excellent discussions of mill-site patents can be found in two recent decisions (U.S. vs Silver Chief Mining Co., 1978; and U.S. vs Utah International, 1979).

WITHDRAWALS AND INDUSTRIAL MINERALS

Theoretically, before and during the time a particular area is proposed for withdrawal, a comprehensive mineral inventory is conducted (FLPMA, Section 201, 43USC 1711). The U.S. Geological Survey has always been charged with the mineral resource inventory on all public lands. For the most part the industrial minerals have been neglected in these inventories. The "metallics mentality" has predominated. It becomes apparent, therefore, that many designated and proposed wilderness areas have not been fully inventoried and evaluated for industrial minerals. As stated before, the reason for this is the general lack of understanding the significance of these materials and the disinterest in nonmetallics prevalent in the government agencies. The California Desert Conservation Area mineral inventory is a prime example of how industrial minerals have been neglected.

California Desert Conservation Area (CDCA) Story

Since 1974 the California Desert Planning Staff of the BLM has been inventorying mineral commodities. They have utilized such methods as heavy-metal geochemical analysis and various remote sensing techniques. Very little, if any interest was given to the occurrence of nonmetallics. Finally in January 1979, a crash program was begun to evaluate and document industrial minerals in the CDCA. Within the allotted time frame this work is nothing more than a high-powered literature survey. However, certain facts about the industrial mineral wealth in Southern California did surface.

In order to fully appreciate the potential importance of the nonmetallics in Southern California, one should consider some basic economic facts. According to the U.S. Bureau of Mines (1978) each person in the U.S. consumed an average of 750 lb of cement, 500 lb of clay, 430 lb of salt, 8,800 lb of stone, 8,600 lb of sand and gravel and 1,000 lb of miscellaneous nonmetallics. The Bureau of Mines (1979a, 1979b) projects that industrial minerals will average a 3.5-percent growth increase annually to the year 2000. This means that the annual per capita consumption of cements, clays, salt and miscellaneous nonmetallics will double and in some cases triple by the year 2000.

Projected upon the above facts is that (according to the Head Planner of the California Desert Planning staff) the population growth in CDCA will increase at a rate of 63 percent by the year 2000. Growth rates in the western U.S. "Sunbelt States" are projected at 80 percent by the year 2000. Industrial minerals in Southern California conceivably could be the source of raw materials for this growth expansion. Even today the industrial mineral production in the CDCA is significant, particularly in rare-earth chemicals, gypsum, talc, borates, sodium minerals, and limestone.

Table 2 lists 23 important industrial minerals known to occur in the CDCA and their estimated tonnage and increase in demand. The tonnage estimates are gathered from published information, private communications and field examinations. Based on 1978 commodity prices these mineral materials have a value of over $200 billion. This indicates that lands in the CDCA have an average mineral value of $15,000/acre. Note that stone, aggregates, sand and gravel were not included. The value would be even greater if these commodities are included.

Most of these known and undeveloped commodities occur in areas now proposed for withdrawal from mining as wilderness, primitive or roadless.

The deposits of nonmetallics that will be discovered in the future and that possess the tonnage and properties to be of commercial interest will probably occur on public domain lands in the western U.S. The demand for these commodities will be centered in the western U.S. and in the southern "Sunbelt Areas." The opportunities for the challenges to the development of these deposits are tremendous. The individuals and companies who will be most successful in this field must aim at improving and establishing good government liaison relations. They will need personnel and other resources to enable them to become knowledgeable of mining laws environmental impacts, and maintain a basic working relationship with federal and state agencies. Cooperation with these agencies is a primary key to success.

The industry needs to loosen its "cloak of secrecy" and reveal to the government agencies involved with land management and withdrawals any nonmetallic resources that are known to occur in designated areas. As mentioned previously,

Table 2 - Known Undeveloped Industrial Minerals in the California Desert Conservation Area

Industrial Mineral	Percent Increase in Demand by Year 2000	Estimated Tonnage (million short tons	Net Value (millions of dollars) Based on 1978 Costs
Barite	- 25	11	396
Limestone (>95% $CaCO_3$)	+180	1,100	11,000
Clays	+280	120	1,500
Diatomite	+100	--	--
Feldspar	+150	--	--
Garnet	+180	0.10	10
Gypsum	+120	1,000	800
Mica	+100	--	--
Perlite (expandable)	+190	1,100	1,000
Pumice	+150		
Pumicite	--		
Talc	+100	0.60	42
Dolomite	+120	11	110
Magnesite	+200	0.61	91
Silica (>90% SiO_2)	+300	0.70	28
Fluorite	+150	0.10	9
Zeolites	+500	5	500
Pyrophyllite	+200	0.10	7
Celestite	+100	0.50	50
CaCl	+100	1	50
Evaporites -			
Borates	+200	1,000	100,000
Sodium minerals	+200	280	5,000
Potash minerals	+100	2	200

government has neither the funds nor the people to cover in depth all of the resources in these areas.

The blame for the neglect of industrial minerals in the past is not only the government's. Industry must take the major share of this responsibility and promote its industrial image to both the government and the public.

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Problems in Developing Cement Raw Materials in Western States

by

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The title may be a little misleading as we will talk on the problems associated with Colorado. The quarry and plant construction began in 1968. The laws were not so severe at that time; however, shortly after this, things got into high gear with anything related to the environment. The laws have become very strict and have defined certain pollution items. During the first two years of construction and operations the Lyons Plant had more than 270 inspections by the State and local health department.

The Lyons Plant has five irrigation ditches along with three seepage claims that had to be watched daily during the quarry opening. Settling ponds had to be built to keep muddy water from entering the farms downstream. During periods of heavy rains or runoff, we could be blamed for muddy irrigations canals. The water could not be diverted; it had to go where it originally flowed. We sampled all irrigation water coming onto the property and compared it with water leaving the property. We sent water samples to a laboratory monthly for analysis. Local wells were monitored monthly for 3 to 4 years to check the fluctuations in the water table.

Quarry development has to be shut down before 9:00 p.m. as some of the neighbors went to bed early, and they complained of the noise from the equipment. We have had several noise surveys, but the noise was not bad at all; it was just a different kind of sound. Readings taken as close as possible to the homes showed that the noise from cars and crickets was louder than the quarry equipment.

Don't be surprised if you get telephone calls on a daily basis at 4:00 a.m. and no one is on the other end.

The quarry is vulnerable to high winds. In fact, we received a citation from Boulder County for fugitive dust during a 125-mph windstorm. We continually sod, seed, and plant trees in areas that have been disturbed. We keep a 10,000-gal water truck busy every day to keep roads and potentially dusty areas wetted down. The plant also uses waste oils and lignin sulfonate to control fugitive dust. We have also put down approximately 5,000 yds of concrete and have purchased sweepers to keep the areas clean. We have received telephone calls and visits from the State pointing out that trucks going down the road were leaving a trail of dust; therefore, we installed a truck wash so that every truck leaving could be free of any dust. Although these trucks can also come from other plants we might possibly get the blame.

The plant installed a weather station to record wind velocity, direction and temperature. We employed a meteorologist to help us determine the best time to blast in the quarry. If we blasted in the morning, the dust would travel to the east and onto neighboring property. It was found that after 11:00 a.m. (normally), the wind would be upslope and would carry the dust onto our property and away from neighbors. The seismograph monitors every blast in the quarry, and we have a blasting consultant on our payroll to check each shot. We have placed this seismograph on porches, patios and walkways of neighboring homes to record any vibration. We were in a lawsuit over blasting but, according to our records and consultant, we did not damage the neighbor's home, and the suit was dropped. We notify every house in the area when we are going to blast.

We feel sure that, as operators, you are aware of the changes in the new mining and reclamation law and that complete reclamation plans are required for the life of a quarry. Our plan goes to the year 2025, and our bond must be in effect five years after the quarry has shut down.

Our operations were proceeding fairly well until we purchased additional limestone reserves in Larimer County, Colorado. The land was zoned properly, and the division engineers (Health Department) recommended approval of our quarry plans. However, the Director of the Health Department would not grant the permit because of the citizens' petition and involvement.

The quarry opening was then referred to the Air Pollution Control Commission. The permit was delayed for 90 days so that existing air quality in the area could be studied and to see if fugitive dust emissions from the quarry would meet the standards defined by present regulations. After the 90 days expired, we had a full-blown public hearing. Anyone that cared to voice his opinion on the proposed quarry had the right to express himself.

After this meeting it was decided to delay the permit until we installed four high-volume samplers around the quarry area. They were kept in operation for 12 months. We had to prove that the new quarry would not degrade the air standards. During this period we met many times with local citizens, State Senators and Representatives, attorneys, town councils, and the Governor. The high-volume samplers were serviced regularly, and our meteorologist reported to the State. It was found that the median dust level was 96 $\mu g/m^3$. The fugitive dust was attributed to an unpaved county road.

After one year of meetings and fugitive-dust testing, Martin Marietta was granted a permit to open the quarry but with 14 stipulations. During this time the Company helped pay for the paving of two miles of county highway. We also have made modifications to five highway bridges and structures and have paid for new bridges installed over creeks and canals so that stone could be hauled over the county roads. We have met with the Superintendent of Schools to make sure school children would be safe along the county haul roads.

As the plant then moved in, overburden removal and topsoil stockpiling marked the original opening of the quarry.

After two full years the plant received its first load of stone from the Larimer Quarry. The monitoring continued for an additional 12 months, and these results were relayed to the State Health Department. It was shown that the median fugitive-dust level dropped from the original 96 to 43 $\mu g/m^3$. The toughest stipulation in opening the Larimer County Quarry was that the exposed portion of the quarry could not exceed 5 acres at any given time and that no more than 15 acres of the property shall have the soil exposed or disturbed at any time.

In 1977 the new reclamation law went into effect. Today many preliminary steps are necessary before a new mine can be opened up. Most of these are the red tape involved in the federal, state, and local governments. This is probably the most time consuming and most frustrating part of developing a new mine. The laws and regulations become much more restrictive the farther down one goes on the government ladder. In most cases it is relatively easy to abide by the federal and state regulations. Therefore, it is essential to research the county and municipal regulations for the area to be mined.

Some of the county problems to be recognized are: (1) Zoning. If mining is not included in zoning, can the zoning be changed? It is of utmost importance that all activities to be done at the mine are acceptable under the zoning that is desired. (2) Comprehensive Plan. Many counties have comprehensive plans to control growth and development. Does a mining operation fit into those plans? If not, can changes be made in the comprehensive plan or can the mining plan fit the comprehensive plan?

Once these requirements are researched, a reclamation plan must be drafted. This plan is very exhaustive and requires considerable time to prepare and obtain approval. The outline to follow on the reclamation plan includes the following:

(A) Legal Description - This is usually a metes-and-bounds description by section.

(B) Index Map - This map shows the mine site in relation to surrounding towns, roads, and other landmarks.

(C) Mining Plan Maps - These maps show the property plan, original vegetation plan, original contour, and pit plans.

(D) Mining Plan - This includes the schedule of operations, methods of mining, equipment to be used, timetables, and so on.

(E) Reclamation Plan - This includes the methods of reclamation, the overall changes or restoration of the mined land when mining has ceased. The land use is described also, i.e. pastureland, farmland, lakes, and so on.

(F) Reclamation Plan Map - This map shows what the land will look like when reclamation is completed.

(G) Water Information - This is a study of surface water and underground aquifers and the effect of mining will have on these, if any.

(H) Wildlife Information - This is a study of wildlife in the area, i.e. birds, animals, fish. What immediate and permanent impacts will the mining have on these species. Oftentimes, reclamation enhances wildlife growth.

(I) Soils Information - This is a study of soils, usually done by a chemical laboratory. Items checked include pH, moisture saturation, particle size, organic matter, phosphorous, potassium and sodium absorption.

(J) Vegetation - This study determines the species of vegetation growing naturally in the area.

(K) Climate - Climatological data for the area is included in this section.

(L) Reclamation Costs - This is an estimate used to determine the required bonding.

(M) Local Government Approval - This is approval by the County Commissioners to open up a mining operation. This is usually accomplished after many public hearings at which the pros and cons of the proposal are weighed. In most cases the neighbors do not want a mining operation next door; however, by working with them, their animosity tends to subside and cease after a couple of years of operation.

This reclamation and mining plan takes 6 to 12 months to prepare and obtain approval.

As I said before, the local government has the most restrictive regulations. In opening a new mine, no stone should be left unturned. It is extremely important to research the requirements of all governmental regulating agencies, local to federal, involved with mining and to fit the mining plan to comply with their needs. Another aspect is to initiate a good public relations program immediately and secure the support of the neighbors as well as the neighboring businesses.

The Past Decade—
Mineral Aggregate Resource Management in Ontario

by

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ABSTRACT

Unrest in the late 1960s between the aggregate industry and residents of high-production municipalities threatened the availability of aggregate resources. At the request of the aggregate industry, the Ontario Provincial Government examined the situation and in 1972 passed the Pits and Quarries Control Act. The intent of the Act was to regulate the operation of pits and quarries and provide for their rehabilitation.

Four years later, in 1975, the limitations of the Act prompted the formation of the Ontario Mineral Aggregate Working Party to examine the situation and suggest improvements. Despite considerable improvements brought about by the Act, difficulties such as resource protection still existed. The Working Party was a new concept to the Ministry of Natural Resources because it incorporated a public participation program into its policy recommendations.

New legislation, to be known as the Aggregates Act, has been drafted and is expected to be passed before the end of 1979. It will replace the present Pits and Quarries Control Act. As well, policy guidelines are being formulated to aid municipalities in the preparation of official plans and zoning bylaws in an effort to designate and protect mineral aggregate resources.

Rehabilitation of pits and quarries continues to be a high-priority item, as evidenced by the research being undertaken and funded by the Province. Efforts are also continuing in resource inventory and in public education in an effort to promote acceptance of the aggregate industry. The management of aggregate resources in Ontario has progressed substantially in the past ten years, but a sustained effort in management and control must continue.

INTRODUCTION

Ontario, with a population of 8.3 million, is Canada's most populated and industrialized province. This population figures represents 36 percent of the overall 1976 Canadian population of 23 million (Statistics Canada, 1978). For these reasons, Ontario, especially southern Ontario, represents probably the highest demand area for aggregate of any region in Canada. Aggregate is an essential raw material to the Province's construction industry and, therefore, is vital to Ontario's economy.

Ontario contains a large land mass of 1,067,000 sq km (412,000 sq mi), equivalent in area to the combined states of Colorado, Utah, Arizona, and New Mexico. Despite this large area, seven-eighths of the population concentrates itself in the southern one-eighth of the Province, in the vicinity of the Great Lakes. As shown on Figure 1, 19 of the 23 cities with a population greater than 50,000 are located in southern Ontario. Toronto, with a population of 2.1 million (Ontario, Province of, 1979), is the largest urban market area for sand, gravel, and crushed stone.

The Province of Ontario, through its Ministry of Natural Resources, has been involved with the management of the Province's aggregate resources for the past decade. This paper will review the experiences, both successes and failures, of the Province of Ontario over that period related to mineral aggregates. Discussions will centre on the basic provincial management tools--legislation and policy--as well as ancillary measures taken by the province as inventory, research and public education.

A discussion has also been included on rehabilitation, since this is where the past and future management efforts of the Province have and will be concentrated.

CHARACTERISTICS OF THE INDUSTRY

Aggregate production in Ontario is estimated to be over 135 million tonnes* for 1977 (Ministry of Natural Resources, 1979). Preliminary 1977 statistics list structural materials (clay products, cement, lime, stone and gravel) as the largest mineral commodity by tonnage produced in Ontario and the third largest in dollar value behind nickel and copper (Ontario, Province of, 1977, p. 11).

Mineral aggregate is largely used within the construction industry with approximately half going to the construction, repair and maintenance of roads. The remainder is used as backfill and foundation material, and in accessory uses such as for fluxes in metal smelting, for glassmaking, filtration and insulation.

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*1 tonne = 1.1023 tons(short)

In Ontario there are two main sources of mineral aggregate. One is sand and gravel deposits of glaciofluvial and glaciolacustrine origin unevenly distributed throughout Ontario. These deposits comprise outwash plains, outwash channels, kames, eskers, and glacial lake deposits, which were formed in the late Wisconsin phase of the Pleistocene epoch, between 7,000 and 16,000 years ago. The other major source of aggregate is the Paleozoic sedimentary bedrock underlying most of southern Ontario. The Niagara Escarpment, a southwesterly dipping cuesta capped by a resistant Silurian dolostone, forms the most important bedrock source (see Figure 1).

Mineral aggregate production by country or region is shown on Figure 2. As can be seen from the map, the highest production areas correspond to the most populated areas of the Province. Because mineral aggregates are a low cost/high bulk commodity, transportation costs usually form the largest portion of the final delivery price. This necessitates extraction to be as near the market as possible.

Therefore, pits and quarries tend to concentrate near urban areas where demand is the greatest. Metropolitan Toronto alone uses between 11 and 13 million tonnes/yr (Ministry of Natural Resources, 1978). The three immediately adjoining regions of Peel, York and Durham produce nearly 21 million tonnes/yr (Ministry of Natural Resources, 1978). As a result of this distance restriction on transportation, localized shortages are becoming imminent in the Ottawa-Carleton, Niagara, Sarnia and London areas.

The proximity of this resource to its market is a major economic asset, but this proximity has also created social and physical complications of its own. The outward expansion of urban centres has resulted in the superimposition of cities over aggregate resources, effectively sterilizing these deposits. Less obvious but no less important

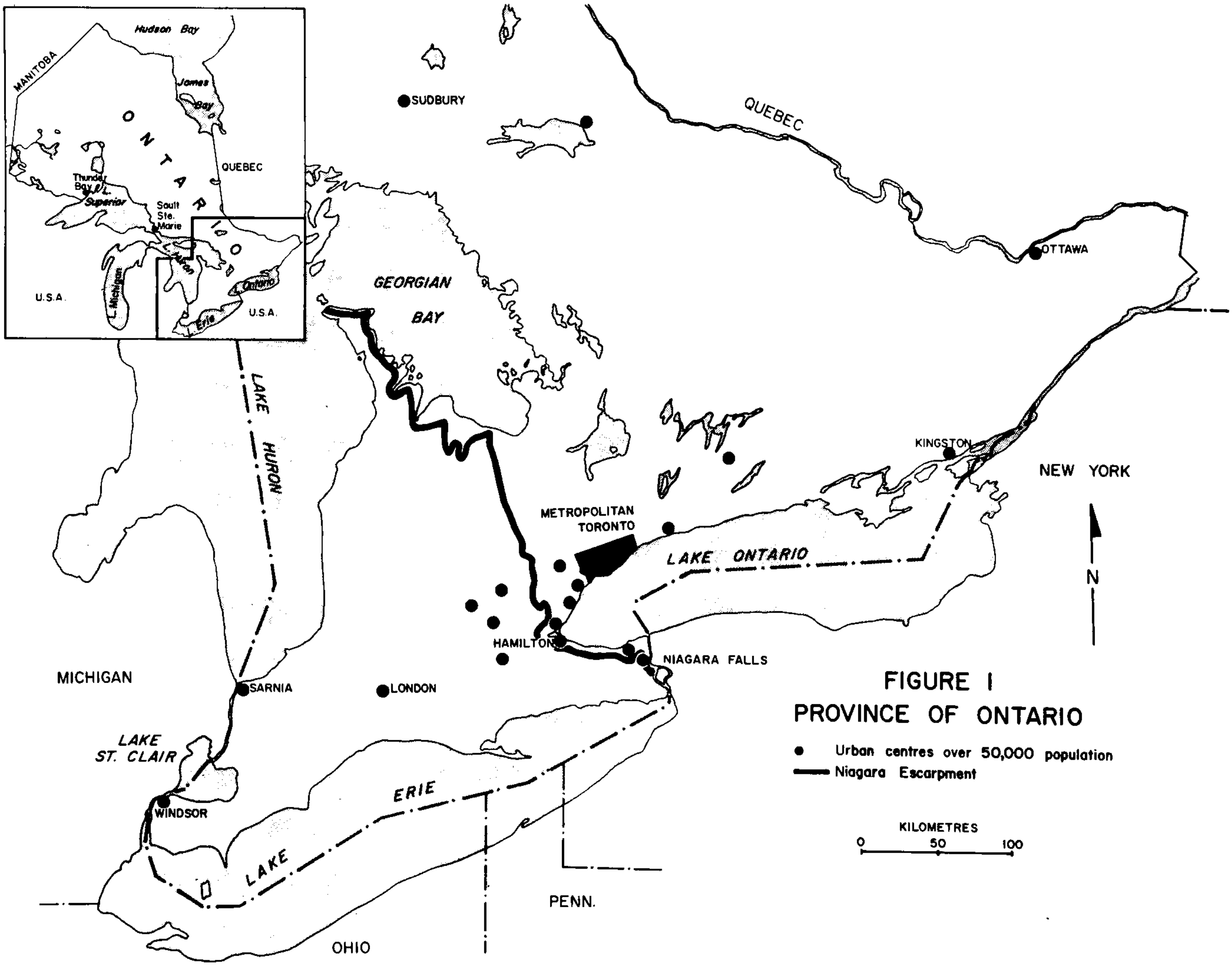

FIGURE I
PROVINCE OF ONTARIO

- ● Urban centres over 50,000 population
- ▬ Niagara Escarpment

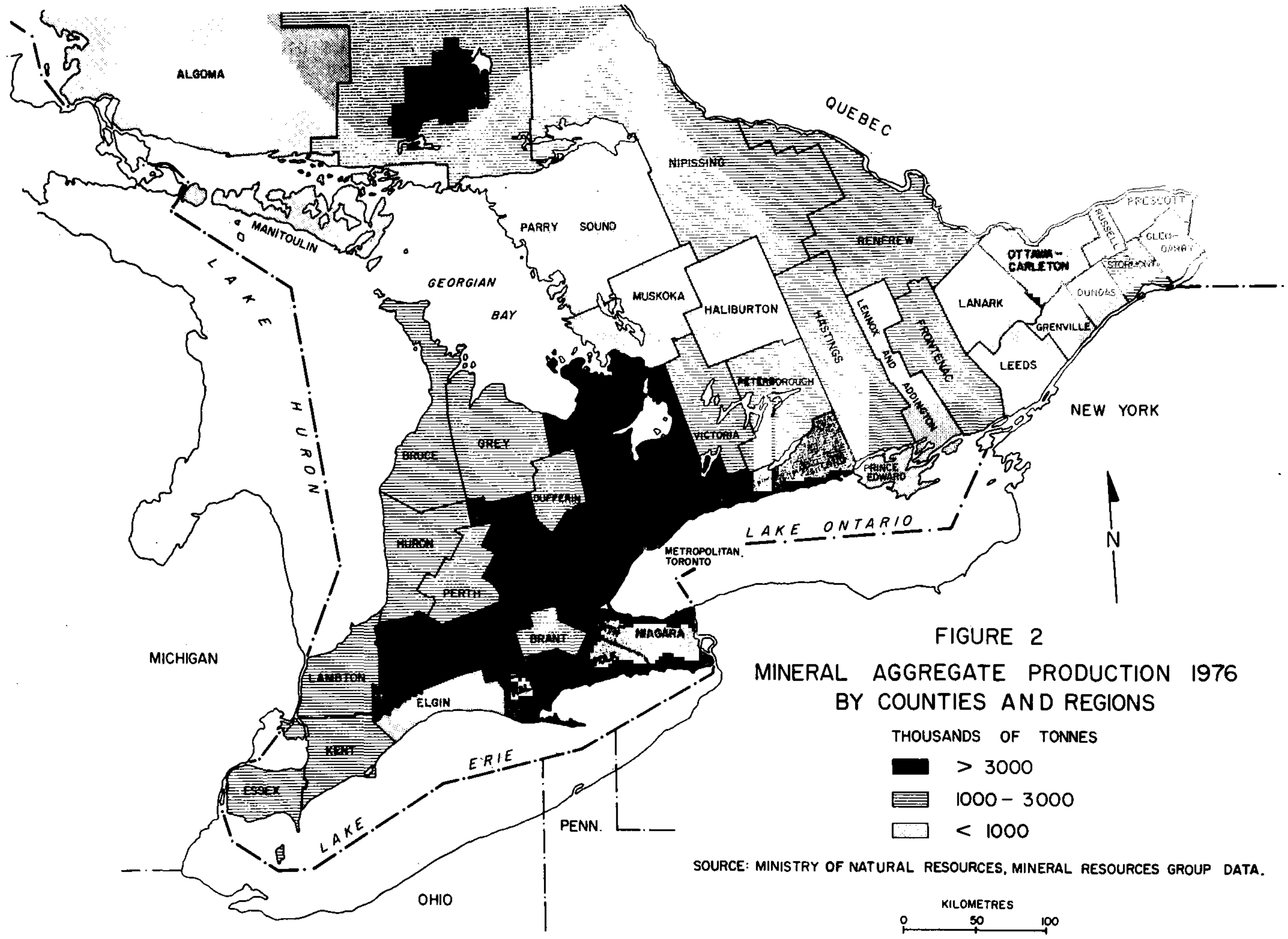

FIGURE 2

MINERAL AGGREGATE PRODUCTION 1976 BY COUNTIES AND REGIONS

THOUSANDS OF TONNES

■ > 3000

▤ 1000 - 3000

☐ < 1000

SOURCE: MINISTRY OF NATURAL RESOURCES, MINERAL RESOURCES GROUP DATA.

influences also threaten production outside of the immediate urban area. With an increasing mobility of the urban population caused by, among other things, improved transportation technology and economic well-being of the population, the desire for urbanites to live and spend leisure time in the rural-urban fringe has brought these exurbanites into direct conflict with the aggregate industry. As a result, the aggregate industry finds itself in competition for land with other activities such as industry, recreation, housing, commercial establishments and agriculture. A third complication is that 90 percent (Proctor and Redfern Limited, 1974, p. 8-2) of the mineral aggregate is moved by truck over Ontario's highway system, unlike other mineral commodities that are largely moved by rail. The excellent road system in southern Ontario makes truck haulage very versatile and economical. At the same time, however, truck haulage brings the aggregate industry into the eye of the general public.

In addition to this high visibility of the industry, several other common characteristics have given the industry a less than acceptable image. In the early 1960s, some aggregate producers ran their operations in disregard for the rights and comforts

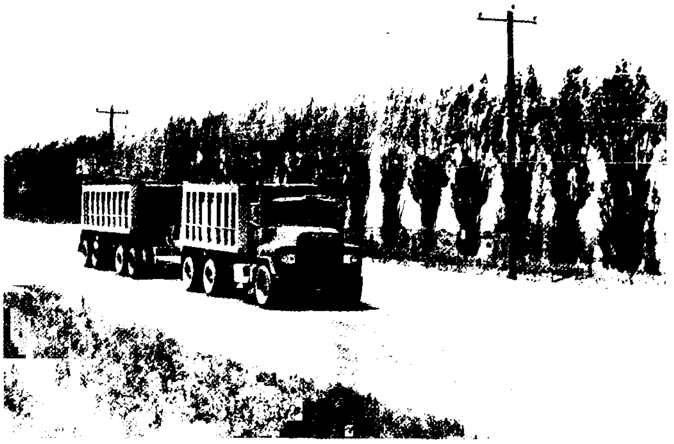

PHOTO 1. 90 percent of mineral aggregate in Ontario is transported by truck.

of adjacent landowners. This has produced a generally unfavourable public image of the industry in spite of the fact that industry in general presently shows extreme sensitivity to the rights and concerns of neighbouring groups. Unless operations are conducted with extreme care, incompatibilities with adjacent land uses and the natural environment may occur. These could include excessive truck traffic, dust, noise, ecological upsets, vibration from blasting, landscape disturbances, stream siltation, social disruptions and visual pollution. The issue has been intensified by the existence of old, unrehabilitated pits and quarries (abandoned) that can have a negative visual effect on the Ontario landscape. Quite often, preconceived notions of the aggregate industry are the reason for public objection rather than the actual conduct of the operator on a particular site.

HISTORY OF AGGREGATE EXTRACTION IN ONTARIO

Like many other industries in Ontario, the aggregate industry had meager beginnings. At the end of the last century, the industry consisted mainly of small borrow pits scattered over the countryside. Relatively large pits spring up near some of the large urban centres such as Toronto, Ottawa, London and Hamilton, but even these were diminutive in comparision to some of today's operations.

Pits and quarries were usually small family-run enterprises that supplied the modest needs of neighbours and the nearest village, town or city. Complaints concerning pits or quarries were few since the extraction activity was not usually operated on a continuous basis. There were also a general recognition on the part of all concerned that these operations fulfilled a necessary community need.

This situation more or less continued unchanged up to the middle of this century. However, by the 1950s, Ontario along with the rest of the western world experienced an unprecedented surge in economic growth-- a growth rate that was to be accompanied by vigorous construction activity.

Along with this growth, demand for aggregates increased. Existing pits and quarries were called on to increase their output and numerous new operations began opening up. To achieve economies of scale and cope with sophisticated marketing techniques, large corporations and even multinational corporations joined the ranks.

Larger production meant intensification of problems. In some rural municipalities large quantities of aggregate were being shipped beyond their boundaries to supply adjacent urbanizing municipalities. The local populace could no longer justify the presence of the industry on the basis of fulfilling their own needs. Increasing environmental concern in the mid-1960s saw focusing of attention on the effect of these operations on the natural environment. No meaningful provincial regulations were in place at this time to effectively control these operations. As a consequence some members of the industry ran their operations in disregard for the environment, the rights of neighbouring landowners, or their obligations as good corporate citizens.

Since the 1950s, this problem was compounded by an increasing rural nonfarm population. As the number of these exurbanites increased, so did their effectiveness as an irritant to the aggregate industry.

Responding to pressure from exurbanites, many local municipalities enacted bylaws effectively prohibiting expansion of existing operations and the starting of new operations. By the late 1960s, industry recognized the possibility of a shortage crisis and requested the government to take remedial action, preferably in the form of legislation.

GOVERNMENT RESPONSE

In response to industry's persistent requests to examine the problem, a small Investigating Committee in November, 1968, comprising representatives of directly concerned provincial government ministries, reviewed briefs submitted by the Aggregate Producer's Association of Ontario and the Quarry Operator's Section of the Ontario Mining Association. In the briefs the aggregate industry requested government to protect existing sites and potential future sites and to introduce reasonable legislation that would regulate and have regard to rehabilitation.

Mineral Resources Committee

The Investigating Committee recommended the formation of a formalized committee comprised of industry and provincial representatives to examine the problems of the mineral aggregate industry. The Provincial Government responded by forming a joint committe of government and industry responsible for investigating and making recommendations for new legislation to govern the siting, operation, development and rehabilitation of pits and quarries. Appointed as the Mineral Resource Committee by the Minister of Mines in January 1969, their report was published and distributed in September 1969. This Committee ultimately recommended increased provincial control over the industry together with rudimentary suggestions on how to improve resource mapping and rehabilitation practices.

The fact that the municipal level was not represented on the Committee was a significant and major omission, and from the beginning the Committee report proved unacceptable to many municipalities. A supplementary committee report produced in 1970 addressed many of the municipal concerns, but the lack of direct municipal input was still an irritant to the municipalities.

As a result, a series of conferences were held in eight Ontario cities in May 1970. These conferences confirmed the need for provincial legislation but suggested that there was a need for more municipal involvement in the process, for more data, and for greater protection for sensitive areas.

Three more steps were taken in June of 1970. First was the commissioning of a study on the economic feasibility of transporting aggregates by rail to the Toronto area from more remote parts of the Province. This study was not particularly encouraging mostly because of the lack of deposits near rail lines, coupled with high freight rates. A second step was to speed up the mineral resource mapping of southern Ontario in accordance with a recommendation made by the Committee. The third step was the passing of Bill 79, an "Act to provide for the Preservation of the Niagara Escarpment and its Vicinity." This was introduced as interim legislation to protect the Niagara Escarpment area pending passage of Province-wide pit and quarry legislation (Ontario Mineral Aggregate Working Party, 1977, p. 4).

The Pits and Quarries Control Act

A direct result of the Mineral Resource Committee's efforts was the passing of the Pits and Quarries Control Act. Proclaimed on November 3, 1971, the intent of the Act was to provide rules and regulations that would accelerate rehabilitation and minimize the environmental impact of pit and quarry operations while still providing for the requirements of the Province to be met within the Province.

The Pits and Quarries Control Act and its regulations control the operation and rehabilitation of pits and quarries in municipalities of Ontario that have been designated by the Lieutenant Governor in Council by regulation. This Act applies to those areas as shown on Figure 3. This effectively covers a large part of the Southern Ontario and the Sudbury and Sault Ste. Marie areas of northern Ontario. The designations correspond to the higher production and more urbanized areas of Ontario. The licensing procedure applies to large and small operations, whether they be commercial or farm-related. Temporary operations known as wayside pits and quarries required for specific road and highway projects are established by permit--a system that shortens the approval process considerably. The

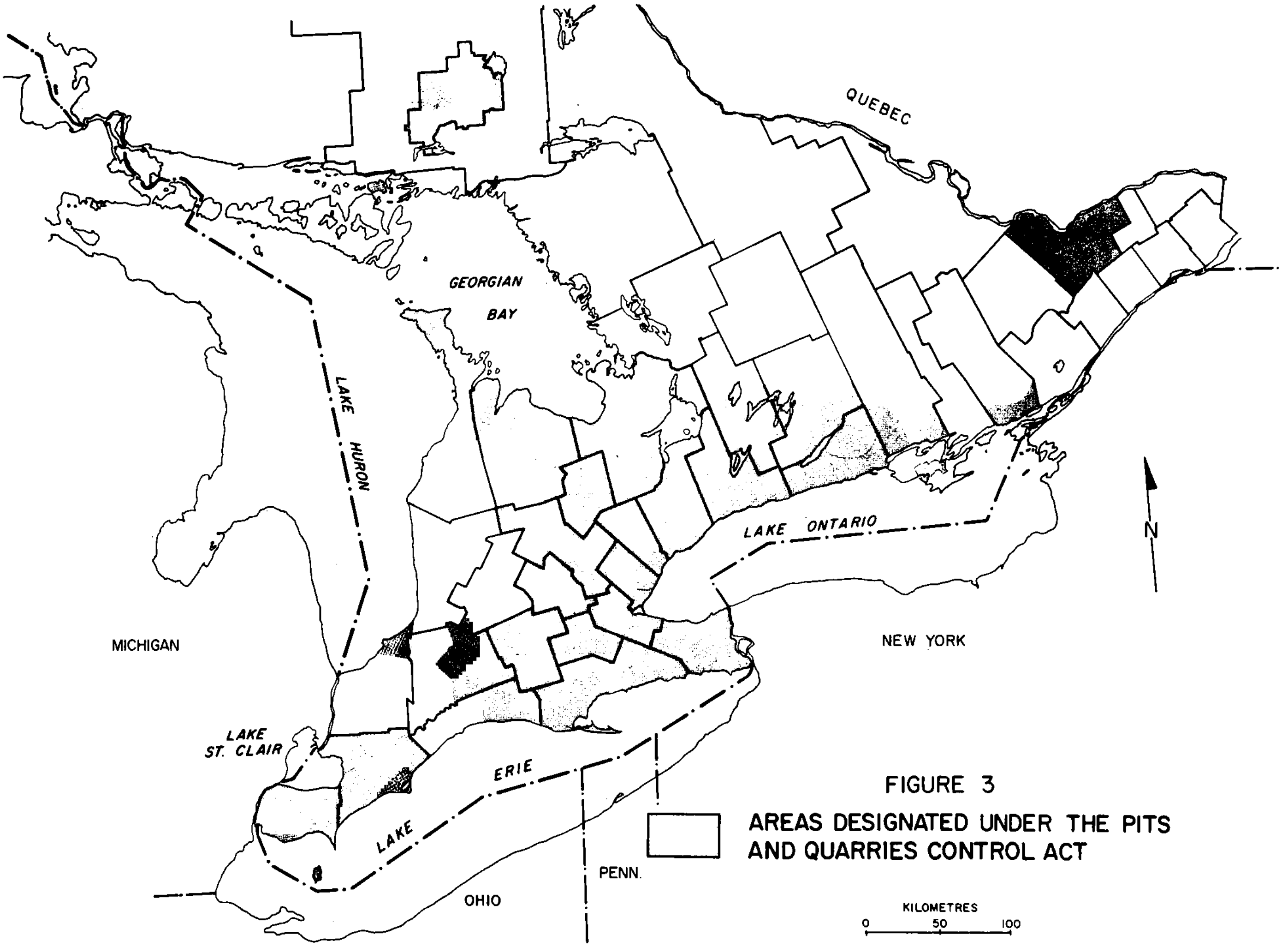

FIGURE 3

☐ AREAS DESIGNATED UNDER THE PITS AND QUARRIES CONTROL ACT

Pits and Quarries Control Act is enforced by the Minister of Natural Resources. Under the terms of the Act a license application must be accompanied by a site plan that must include:

"(a) the location, true shape, topography, contours, dimensions, acreage and description of the lands set aside for the purposes of the pit or quarry;

(b) the use of all land and the location and use of all buildings and structures lying within a distance of 500 feet of any of the boundaries of the lands set aside for the purposes of the pit and quarry;

(c) the location, height, dimensions and use of all buildings or structures existing or proposed to be erected on the lands set aside;

(d) existing and anticipated final grades of excavation, contours where necessary and excavation set backs;

(e) drainage provisions;

(f) all entrances and exists;

(g) as far as possible, ultimate pit development progressive and ultimate road plan, any water diversion or storgage, location of stockpiles for stripping and products, tree screening and berming, progressive and ultimate rehabilitation and, where possible, intended use and ownership of the land after the extraction operations have ceased;

(h) cross-sections where necessary to show geology, progressive pit development and ultimate rehabilitation; and

(i) such other information as the Minister may require or as is prescribed by the regulations" (The Pits and Quarries Control Act, 1971, sec. 4(2))."

Somewhat less information is required for an operation producing less than 15,000 tonnes of material annually. The reason for this is to protect the small businessman and to maintain the competitive nature of the industry. From 1975 figures it has been determined that 54 percent of licensed operations extracted less than 20,000 tons annually (Ontario Mineral Aggregate Working Party, 1977, p. 79). This indicates the importance of not placing an unfair burden on the small operator.

Once the applicant has filed an application with the Minister, the applicant must, prior to the Minister's approval, give public notice of the application by placing an advertisement in two successive issues of at least one daily or weekly newspaper having general circulation in the area.

Written objections may be filed with the Minister by the Municipal Council or any other authority having an interest or by an person affected by issuance of a license. The Minister will set a closing date for receiving objections. An objection requires the Minister to refer the matter of issuance of a license to the Ontario Municipal Board, a quasi-judicial tribunal. The Minister may refer the matter to the Board on his own if he feel a hearing is warranted.

After weighing the evidence given at the hearing, the Ontario Municipal Board recommends to the Minister whether or not the license should be issued. On the basis of the Board's recommendation and report, the Minister has 30 days to make the final decision on whether to issue the license.

In making this decision the Minister must consider the following criteria:

"(a) the preservation of the character of the environment;

(b) The availability of natural environment for the enjoyment of the public;

(c) the need, if any, for restricting excessively large total pit or quarry output in the locality;

(d) the traffic density on local roads;

(e) any possible effect on the water table or surface drainage pattern;

(f) the nature and location of other land uses that could be affected by pit or quarry operations;

(g) the character, location and size of nearby communities" (The Pits and Quarries Control Act, 1971, sec. 6(1))."

The Minister cannot issue a license that is in contravention of a municipal official plan or zoning bylaw. Terms and conditions may be attached to the issuance of the license. Regulations to The Pits and Quarries Control Act must also be followed. The regulations deal with such matters as screening, setbacks, maximum slope, stockpiling of topsoil, screening, berming, fencing, location of entrances and exits, and blasting.

In respect to rehabilitation, the regulations require a security deposit of 2 cents/ton up to 100,000 tons or $500/acre, whichever is greater. This money is returned upon satisfactory rehabilitation.

In early 1979 the total number of licensed pits and quarries in the designated municipalities covered by the legislation was estimated to be 1,590 (Ministry of Natural Resources, 1979). A drawback to the licensing process is the length of time necessary for approvals. Two to five years and considerable sums of money are required to take an application before the the Ontario Municipal Board. Because legislation is not passed to put existing operations out of business, a pit or quarry operating at the time of passage of the Pits and Quarries Control Act was issued a license.

PREPARING FOR THE FUTURE

Legislation and Policy

The Pits and Quarries Control Act has been in existence for more than seven years now. It has brought about considerable improvement, but the Ministry of Natural Resources fully realizes its limitations, and the time has come for revisions. Efforts are currently underway to finalize new legislation, to be known as The Aggregates Act. It is expected to become law by the end of 1979.

This new legislation represents more than three years of research, begun in December 1975, with the appointment by the Minister of Natural Resources of the Ontario Mineral Aggregate Working Party. The Working party was a new concept for the Ministry in formulating policy because all concerned parties were involved throughout the entire process. The fourteen Working Party members were selected to represent those groups most concerned with problems associated with pits and quarries--regional and municipal councillors and staff, concerned ministries, industry and special interest groups such as the Niagara Escarpment Commission and the Conservation Council of Ontario.

In just over one year, in January 1977, the Ontario Mineral Aggregate Working Party submitted its report, "A Policy for Mineral Aggregate Resource Management in Ontario." This was a remarkable fact considering the complex nature of the aggregate industry and the fact that a public participation program was conducted. In its report the Working Party presented 64 recommendations.

The Minister presented the report to Cabinet and released it to the public the same month. Cabinet asked that the report be reviewed and brought back with an indication of public reaction.

Over the next six months, the report was extensively reviewed by a wide variety of interested groups and individuals. After considering the comments, the Ministry of Natural Resources adopted 12 major policy guidelines, in general support of the Working Party's recommendations. These major policy guidelines are summarized below:

(1) Municipalities naturally endowed with aggregate resources should share responsibility for meeting future Provincial aggregate demands.

(2) Regional or county government is the most appropriate level of local government to establish land-use policies and to deal with licensing and enforcement matters related to aggregates.

(3) There should be provincial/municipal shared control in planning and approval procedures. The Province should retain licensing- and enforcement-related responsibilities at this time, but individual counties or regions should be permitted and encouraged to assume these delegated responsibilities once appropriate policies for mineral aggregate management are included in county/regional Official Plans and aggregate areas are protected through zoning by local municipalities.

(4) The designation and protection of resource areas should occur through the regional/county and local municipal Official Plan process.

(5) Normal zoning powers related to pits and quarries should continue until such time as areas of high potential are identified and appropriate policies for mineral aggregates are incorporated into regional/county Official Plans.

(6) Aggregates must be available at reasonable cost to the consumer including environmental, transportation and energy costs.

(7) The Ministry of Natural Resources should have ultimate authority to ensure adequate supplies of aggregate are kept available for future use. Official Plans should ensure the availability of the municipalities' fair share of future aggregate supplies.

(8) Annual license fees should be available to compensate government at all levels for the costs incurred.

(9) Pits and quarries on Crown land in designated areas should be subject to the same conditions as those on private lands. Additional areas should be designated only as the need arises.

(10) Because of time and cost constraints, wayside pits and quarries require special approval procedures. The Ministry of Transportation and Communications has implemented special procedures for all MTC road contracts. A system of performance bonds for all municipal wayside pits and quarries on an experimental basis is also suggested.

(11) The Ontario Municipal Board should continue to be the appeal board but should be provided with additional technical staff.

(12) All other legislation affecting aggregates should be amended to achieve conformity with the new Aggregates Act.

These guidelines were adopted by Cabinet as government policy. They formed the framework for the writing of the new legislation agreed to by Cabinet.

The Aggregates Act

The new Aggregates Act is about to receive first reading in the Ontario Legislature. This Act will replace The Pits and Quarries Control Act of 1971. In the new legislation a number of sections and definitions in The Pits and Quarries Control Act have been reworded, and new sections and definitions have been added to provide for better administration and enforcement. New provisions in the Aggregates Act provide for better rehabilitation, more municipal liaison, municipal remunerations, and power to suspend a license. Pits and quarries on Crown land in designated areas now come under this new legislation.

Until the Aggregates Act is released, only general comments may be mentioned at this time. The Aggregates Act is expected to provide for:

(1) Municipal Liaison:

The Pits and Quarries Control Act does not require the Ministry to liaise with municipalities with regard to applications for a license to operate a pit or quarry. The Aggregates Act will generally require consultation with municipalities and a review of site plan every five years.

(2) Suspension of Licenses and Detailed Site Plans:

Under the present Act the Minister may suspend a license where the operation of the pit or quarry constitutes an immediate threat to the interests of the public. This does not provide for a method by which to deal with day-to-day violations of the Act or regulations. Although charges can be laid, this is a lengthy and costly procedure. It is proposed that the Aggregates Act will allow the Minister to suspend a license immediately for any period of time, not exceeding three months, until the licensee has complied with the notice served upon him.

(3) Remuneration to Municipalities:

Over the years local municipalities have maintained that they should be compensated for costs resulting from aggregate operations. The Working Party reviewed the problem and recommended that municipalities be compensated. This provision will be in the new Act.

(4) Definitions:

The definitions in the present Act are inadequate in that some words requiring definition are missing while others are poorly worded. The definition section of the new Act has been expanded, and present wording has been clarified.

(5) Rehabilitation Security:

At the present time the amount of the rehabilitation security is 2 cents/ton of material removed from the pit or quarry property. The Working Party examined the security fee and concluded that it was too low in view of current costs. In the Aggregates Act the amount of the security deposit is 8 cents/tonne of material excavated from a pit or quarry property. Since the money on deposit is increased fourfold, the operators should perform more and better rehabilitation in order to get their money back.

(6) Rehabilitation of Abandoned Pits and Quarries:

The present Act has no provisions to deal with the rehabilitation of abandoned pits and quarries. The Aggregates Act will require that 10 percent of the annual license fees be set aside in a fund and disbursed for the purpose of conducting surveys or studies of respecting the rehabilitation of abandoned pits and quarries and for the rehabilitation of abandoned pits and quarries.

Mineral Aggregate Resource Guidelines

The Province has also realized that management of a resource does not stop with the adoption and enforcement of appropiate legislation. In addition to the new Aggregates Act, the Ministry of Natural Resources has also adopted a multifaceted approach to resource management which includes public education, research, and the provision of technical expertise and guidance to local government and the aggregate industry.

One of the more important ancillary functions will be the preparation and adoption of guidelines to regional/county and local municipal government on how to prepare mineral aggregate management policies. Local municipalities have major land-use planning and management powers in the private lands of Ontario. This role is basically delegated to local government by means of The Planning Act and The Municipal Act. The fundamental tools used to implement mineral aggregate policy at the local level are the official plan and zoning bylaw. It is crucial that the Province initiate basic policy direction to ensure that provincial interests are protected and that basic resource management principles and practices are adhered to. This includes the requirement that municipalities share the responsibility for meeeting provincial aggregate demand.

Resource Inventory

Another major focus of activity of the Ministry of Natural Resources is the improvement of its data base. In the past, aggregate deposits were identified from general geological mapping compiled by the Ontario Geological Survey and the Geological Survey of Canada such as would be found on general Quaternary or bedrock maps. Information derived from such sources was highly interpretive since the mapping in general was not specifically designed for aggregate resource identification. In 1976, however, the Ministry of Natural Resources formed the Aggregate Resources Inventory Program. This program entails mapping on a local municipality basis of sand and gravel deposits of quality and quantity suitable for commercial production and of bedrock areas suitable for the production of crushed stone on a local municipality basis. This inventory is being undertaken by the Ontario Geological Survey to to provide planners in Ontario with the geological information required to identify and protect potential aggregate resources in their planning strategies. The ultimate intent is that such areas may be protected for aggregate production before being built on or otherwise eliminated from potential use as a resource.

Research

Since 1962 the Ministry of Natural Resources and its predecessor, the Department of Mines, have pursued a research program geared to the problems of the aggregate resource industry. The earlier publications generally identified and discussed the emerging mineral aggregate problem in respect to diminishing supply. In 1970, with publication of Industrial Mineral Report 33, the Ministry entered a new phase. This report, "A Guide to Site Development and Rehabilitation of Pits and Quarries" (Bauer, 1970), marked the first time that research had really gone beyond the descriptive stage. Earlier reports primarily dealt with the quantity, quality and location of mineral aggregates. This report introduced aggregate producers in Ontario to the advantages and techniques of rehabilitation.

Since that time the Ministry of Natural Resources has continued its inquiries into the complexities of the aggregate industry. In 1975 a report on the use of trees, shrubs, grasses and legumes in pit and quarry rehabilitation, entitled "Vegetation for the Rehabilitation of Pits and Quarries", was released (Ministry of Natural Resources, Division of Forests, 1975). Just recently two reports prompted by the findings of the Working Party were published. One deals with the rehabilitation of abandoned pits and quarries in southern Ontario (McLellan, Yundt and Dorfman, 1979), and the other reviews the quality and amount of rehabilitation that has taken place since the passing of The Pits and Quarries Control Act of 1971 (Coates and Scott, 1979).

Since 1974 a series of five studies covering selected areas in Ontario has been undertaken. The first three studies effectively examine southern Ontario: Central (Proctor and Redfern, 1974), Eastern (Proctor and Redfern and Gartner Lee, 1975), and Southwestern (Proctor and Redfern ande Gartner Lee, 1976). The final two studies cover the Sudbury (Proctor and Redfern, 1978) and Thunder Bay (James F. MacLaren, 1978) areas of northern Ontario. Specific objectives of the studies involved geological inventories to determine the extent of aggregrate resources and to assess such constraints on supply as existing land use, local planning policies, and accessibility problems. Further objectives were to project demand from existing consumption patterns, to study supply-demand relationships, to discuss alternative sources or substitutes for mineral aggregates, and to analyze distribution and transportation problems.

At present the Ministry of Natural Resources is involved in two ongoing aggregate research programs. One is a bulk transportation study that will examine the possibility of moving aggregate from more distant areas (by boat, rail, truck and pipeline). The other is a comprehensive study of the use of trees and shrubs in the rehabilitation of pits and quarries. Depending on the subject matter, research is either contracted to private consultants or universities, or conducted internally. This approach permits the broadest range of viewpoints to be incorporated into the research program, including practical and academic.

Public Education

Another important program directive is in the area of public education. The Ministry of Natural Resources' aggregate resource staff is encouraged to actively give talks and lectures whenever and wherever the opportunity arises. The Ministry of Natural Resources also provides a public information service that includes the preparation and distribution of informative and educational brochures.

A small brochure has been prepared by the Ministry of Natural Resources staff and entitled "Ontario Mineral Aggregates: A Vital Resource." This pamphlet briefly outlines the characteristics and problems of aggregate production. Work is also underway on brochure regarding rehabilitation, in an effort to portray to all concerned parties the basic principles and merits behind rehabilitation. As well, a report entitled "From Pits to Playgrounds" (Yundt and Augaitis, 1979) has recently been released to the public. This publication is intended to develop an awareness with the public as to just how many former sand and gravel pits, in Toronto alone, have been rehabilitated. The report is presented in the form of a tour guide to enable citizens to observe firsthand what can be accomplished through rehabilitation.

Since the success of any mineral aggregate management program depends to a great extent on the actions and attitudes of the aggregate industry, municipalities, municipal associations and other groups, the Ministry of Natural Resources continually works to establish a close liaison with these groups. This includes meeting with the industry's collective voice, the Aggregate Producers' Association of Ontario, to promote contact with the public in an effort to improve their public image. As well, municipalities are made aware of, primarily through municipal associations, the problems and characteristics of the aggregate producers in order that they might better understand the importance of the industry and thereby be more supportive of it.

Rehabilitation

Although rehabilitation forms only a segment of the aggregate industry's total operation, the achievement of an efficient rehabilitation program is seen as the cornerstone to gaining public acceptance of the industry. Rehabilitation satisfies two important objectives. First, it returns extractive sites to an afteruse compatible with the surrounding landscape. Obviously the more rehabilitation that can be achieved within any given year, the more compatible the industry will be to its surroundings and the more it will demonstrate industry's willingness to fit within the community framework.

Secondly, rehabilitation makes more land available for other high-priority land-use requirements. As stated previously, pits and quarries are generally located on the fringes of the more urbanized areas of the Province where competition and demand for land is the greatest. In these areas land is at a premium, and rehabilitated land often can be quickly incorporated into the overall land-use pattern.

PHOTO 2. Willowdale Park "Christie Pits" is located in a densely urban part of Toronto. This rehabilitated site is used for recreation in summer and winter.

The aggregate industry has already completed many excellent rehabilitation projects. As many as 44 percent of the licensed operations in a selected study area have been rehabilitated since the enactment of The Pits and Quarries Control Act in 1971 (Coates and Scott, 1979, p. 6). The 2-cents/ton security deposit undoubtedly had some effect in promoting this rehabilitation, but most large producers state that an improved public image was their motivation. Greater amounts of rehabilitation are anticipated with the new Aggregates Act's proposed 8-cents/ton rehabilitation security deposit. Hopes for the near future include reaching a level of efficiency and cooperation where rehabilitation will equal or exceed the acreage going into production.

Two specific types of rehabilitation concepts are being promoted by the Government of Ontario. These are progressive rehabilitation and sequential land use. Progressive rehabilitation can be described as a process by which the rehabilitation of a pit or quarry is taken in a step-by-step fashion so that part of the site is gradually changed to another use or condition that is compatible with the use of the adjacent land, while extraction is going on in another part of the site. In this way visual conflict with the surrounding landscape and the time required to ultimately rehabilitate the site are minimized. In comparison to rehabilitation of fully extracted sites, the cost for progressive rehabilitation can be substantially less because of the ready availability of heavy equipment and because overburden and topsoil need not be moved as far or as often.

Sequential land use refers to the practice whereby mineral aggregate resources are removed immediately prior to the area being built over by the expansion of adjacent urban centres. Sequential land use is a three-step land conversion process. In respect to mineral aggregate extraction, this means that an area is initially used for a compatible use such as agriculture; is then converted to a pit or quarry; and upon removal of the aggregate is ultimately converted to a use such as housing that would have otherwise sterilized the aggregate resource. The basic approach is to consider mineral aggregate extraction as an interim land use rather than a final land use. This approach represents optimum land resource management.

The rehabilitation of abandoned pits and quarries stands as a high-priority objective with the Province of Ontario. Largely because The Pits and Quarries Control Act was not made retroactive to already extracted sites, many acres of disturbed land sit unused in southern Ontario.

It has been indicated in a study commissioned by the Ministry of Natural Resources that the vast majority of these derelict sites could be rehabilitated within a decade if a rehabilitation fund, as envisioned in the new Aggregates Act, is implemented.

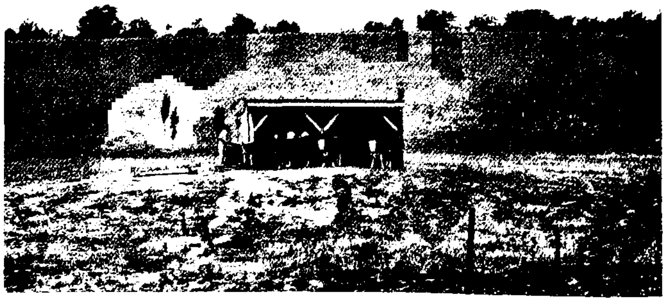

PHOTO 3. Nelson Crushed Stone is progressively rehabilitating this quarry near Hamilton. The quarry faces are backfilled, topsoiled, and seeded. Beef cattle then graze the slopes all summer.

Some of the larger aggregate producers in Ontario conduct their own experimentation in the art of rehabilitation. Their efforts will hopefully provide innovative and refined rehabilitation techniques, particularly in rehabilitation to agriculture. Crops of corn, wheat, barley, alfalfa and soybeans and even a commercial cherry orchard are examples of rehabilitation to agriculture in depleted pits and quarries. Some operators are now grazing sheep and cattle on rehabilitated and revegetated pit and quarry faces while extractive operations continue. These efforts testify that pits and quarries can be successfully returned to productive and viable farm uses. Production levels in the initial post-rehabilitation years cannot be expected to be at their maximum potential. The reestablishment of a well-developed soil structure and profile takes time even when preextraction stripping carefully separates topsoil from the overburden.

A problem faced in rehabilitating back to an agricultural use is familiarizing aggregate producers with agricultural techniques. Aggregate producers are not farmers and are not well versed in the principles of crop science or animal husbandry. Smaller aggregate producers may not be able to afford the services of an agricultural advisor, thereby precluding them from the more innovative programs. A simple example of poor crop selection is corn. This is a nitrogen depleting crop as well as a row crop that is highly susceptible to erosion. A nitrogen-fixing and root-binding crop such as alfalfa or clover is advisable in the first year of cultivation combined with a cereal crop. This type of crop not only fertilizes but aerates the soil as well.

CONCLUSIONS

The Province of Ontario, through its Ministry of Natural Resources, has been seriously working on the management of mineral aggregates for a decade. A great deal has been accomplished, but it is fully realized that there is a long way to go to achieve the ambitious goals of resource management, protection and conservation. In this ten years there have been successes and failures. Much has been learned from these experiences, and it is hoped that by passing them on, others may benefit.

To capsulize, the Province of Ontario's efforts have been concentrated on controlling or regulating the aggregate industry by means of legislation over the past decade. As this area is being tidied up, efforts are now being concentrated on protection of this nonrenewable resource by means of a policy intended to guide local governments in their land-use planning functions. In addition a vigorous research, educational, and public relations program will be implemented to promote greater public acceptance and awareness of the aggregate industry.

The lessons to be learned are perhaps best summarized under the following points:

(1) Any management program for aggregate resources must be based on a complete data inventory.

(2) In developing resource management policies that affect industry, the municipalities, and the public, involvement of all parties from the outset of the program is crucial.

(3) Legislation aimed at regulating the aggregate industry must provide remedies for problems created in the past as well as preventing problems that may occur in the future. This, of course, refers to the problem of abandoned pits and quarries.

(4) Rehabilitation policies must ensure full rehabilitation on all sites. This would mean imposing controls to ensure results but not so severe as to stifle competitiveness or drastically inflate consumer prices.

(5) To ensure that the spirit and intentions of legislation or policy are adequately enforced, government must provide adequate staffing and training.

(6) Government must maintain a vigorous research program to address existing problems, to keep abreast of the latest management techniques and innovations, and to maintain an adequate data base. Research programs should actively encourage input from outside sources such as private consultants and universities to complement internal research, thus ensuring the broadest possible viewpoint.

(7) Legislation should be regularly evaluated and reviewed to make certain than intended objectives are being met and that the legislation remains consistent with current social goals.

At a time when government bureaucracy in North America is coming under fire for excessive spending and regulation, the importance of mineral aggregate resource management and long-term planning must be made clear. In Ontario it was the aggregate industry that pushed for government involvement, not environmental groups or the public. Now the government has taken over research, management and control of mineral aggregates, and environmental groups and municipalities are constantly seeking improvements. To ensure the future economic well-being of the Province of Ontario or, for that matter, any state or province, mineral aggregate resources must be made available now and in the future in an environmentally and socially acceptable manner. It is the responsibility of government at whatever level to ensure that the problems are overcome and that these essential resources are available.

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Geological Mapping and the Aggregate Resources Inventory in Ontario

by

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ABSTRACT

The Province of Ontario covers 1.07 million sq km and was completely glaciated during the Pleistocene. The glacial deposits cover the whole province and although thin and discontinuous in the north are up to 300 m thick in the south. The glacial drift supplies most of the 135 million metric tonnes (t) of sand, gravel and stone consumed each year in the province. Paleozoic limestones and dolostones are the source of large quantities of crushed stone.

The mapping of the surficial deposits of southern Ontario was accelerated over the past 10 years, and coverage at scales of 1:50,000 to 1:125,000 is now almost complete. Considerable map coverage at 1:50,000 of the Paleozoic deposits is also available.

In northern Ontario, map coverage is much less extensive, but a new 4-year programme of engineering terrain analysis covering 400,000 sq km at a scale of 1:100,000 will provide a base for more detailed mapping in selected areas.

With the available map coverage of surficial and Paleozoic deposits and concerned with the need to keep potentially valuable aggregate resources available for extraction, the Province has initiated a programme to present the results of the geological mapping in a format that nongeologists, such as planners, can use in the preparation of official plans for municipalities.

INTRODUCTION

Professional geologists have always had the responsibility to undertake their work with full respect for scientific principles and integrity. This must always remain the case. In recent years, and perhaps in some circumstances more than others, a new responsibility has fallen on the professional--a responsibility to inform and advise those members of the public who are not geologists and to pass on to them the significance and effects of geological studies in terms that are relevant to the everyday concerns and particular interests of the community, be they politicians, planners or members of the public at large.

In public service this added responsibility is perhaps greater than in some other areas of endeavour, and today I propose to report on the progress of geologic research and public communication in the field of aggregate resources in the Province of Ontario.

The Province of Ontario covers 1.07 million sq km and is populated by 8.3 million people most of whom live in some 133,000 sq km in southern Ontario.

The whole of Ontario was glaciated during the Pleistocene, and even today in the northernmost parts of the Province some areas are affected by a permafrost condition.

The cover of glacial drift is variable, and although generally thin and discontinuous in the north, it is, for the larger part much thicker in the south, commonly to 50 m and up to 300 m in buried valleys. The glacial drift is the source of the greater part of the over 135 million metric tonnes (t) of gravel, sand and stone that are extracted and consumed in Ontario each year.

In southern Ontario, the Paleozoic bedrock supplies much of the material quarried for the production of crushed stone and clay products, and, in a few localities, Precambrian rock is quarried for the production of special rock products.

MAPPING ONTARIO

Both the Geological Survey of Canada (GSC) and the Ontario Geological Survey (OGS) (and its predecessors) have contributed to the mapping of Ontario's surficial deposits, but the efforts were largely sporadic prior to 1940. After World War II, the GSC started mapping to the east and north of Toronto, and a few years later the (then) Ontario Department of Mines started mapping to the west of Toronto.

Federal geological mapping was at a scale of 1 inch to 2 miles, and Provincial mapping at 1 inch to 1 mile and later at 1:50,000. With almost all of southern Ontario mapped at one of these scales, the mapping has formed the base for the inventory of our aggregate supplies.

Over the past 10 years the accelerated Quaternary mapping programme of the Ontario Survey has produced a series of maps and reports of high calibre (Figure 1). The geologists responsible for the work have made major contributions to our understanding of the glacial history of the Province

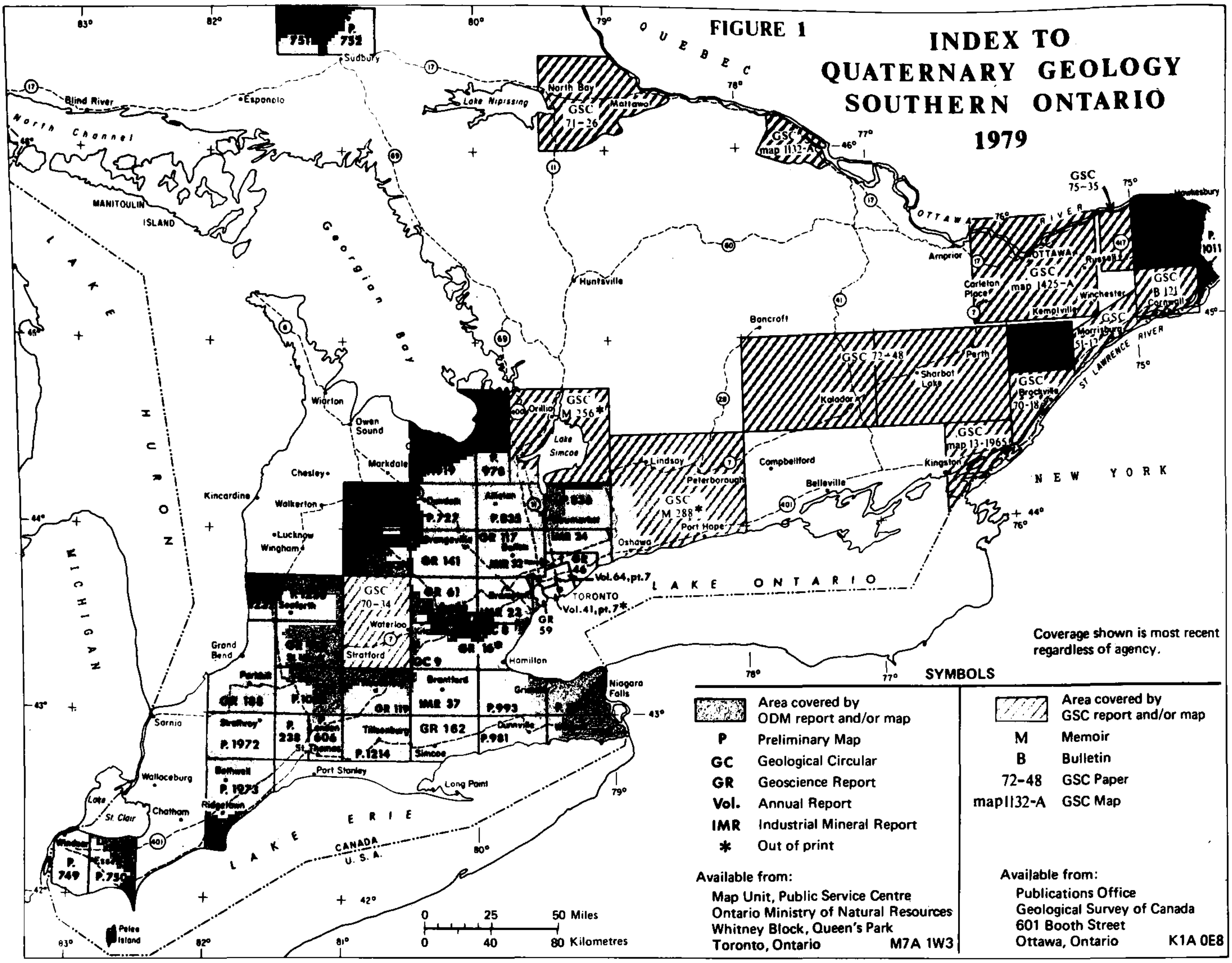

FIGURE 1

INDEX TO QUATERNARY GEOLOGY SOUTHERN ONTARIO 1979

as well as to the glacial history of the whole of the mid-west of the continent.

The maps and reports are prepared following a season or more of field studies, supplemented by airphoto interpretation and the examination of geotechnical and water well records maintained by other government ministries, engineering consultants and others. In recent years the study of the surface exposures has been supplemented by stratigraphic drill holes. Field studies themselves involve the examination of road cuts, excavations, and test pits, the examination of cliffs and bluffs by lakes and streams, and of pits and quarries as well as soil probing at least 1 m deep. Both public and private properties are traversed. Field parties usually totalling four or five persons, most of whom are university undergraduates, are headed by a party chief who is either a staff member or a graduate student employed on contract. Each party will map 500 to 1,000 sq km per season. The 1:50,000-scale preliminary map (uncoloured) is issued within six months of completion of the field work, and the final report is usually published up to 3 years later.

The maps essentially show the materials and landforms at the surface, but with the aid of the legend a Quaternary geologist can interpret the nature of the subsurface material. The reports contain a full discussion of the geology as well as discussions of applied aspects such as sand and gravel deposits and engineering geology.

The maps and reports are scientific documents written for geologists and other knowledgeable professionals. They are not popular treatises, nor are they documents that planners or politicians can handle unless they have some background in the subject. To deliver the information to a wider client group or to a lay audience, the style of presentation must change, a topic that I shall discuss later.

The mapping of the Paleozoic bedrock of southern Ontario has also been a function of both the GSC and the OGS. Most of the mapping prior to 1970 was undertaken by the GSC, but in the past few years the OGS has been mapping or remapping the bedrock at a scale of 1:50,000 (Figure 2).

Initially concentrated along the Niagara Escarpment (the source of much of the crushed stone) the Paleozoic mapping has subsequently been extended east and west. At the moment a 5-year programme involving considerable drilling activity is underway on Manitoulin Island in order to define more closely zones of significant physical and chemical properties of the limestone and dolostone in that area.

In northern Ontario the availability of geological information is in a much more rudimentary state. With a small number of widely separated communities, a much smaller population and despite the consumption by the mining industry, the demands for sand and gravel supplies have not been very great except in the two largest cities, Sudbury and Thunder Bay.

In recent years, spurred by government involvement in the production of official plans for every community and a general realization that gravel sources will not last forever, a veritable forest of demands for information on aggregate supplies has suddenly developed.

To partially satiate this demand for information and to supply a basic level of information across the Province in a minimum amount of time, a programme has been initiated in which a number of consultants in engineering geology and terrain evaluation have produced and are producing a series of reports and maps at a scale of 1:100,000 over a total area of 400,000 sq km (the Northern Ontario Engineering Geology Terrain Study (NOEGTS)). This is essentially an exercise in airphoto interpretation with limited ground investigations. The terrain is evaluated in terms of landform, materials, topography and drainage, with particular

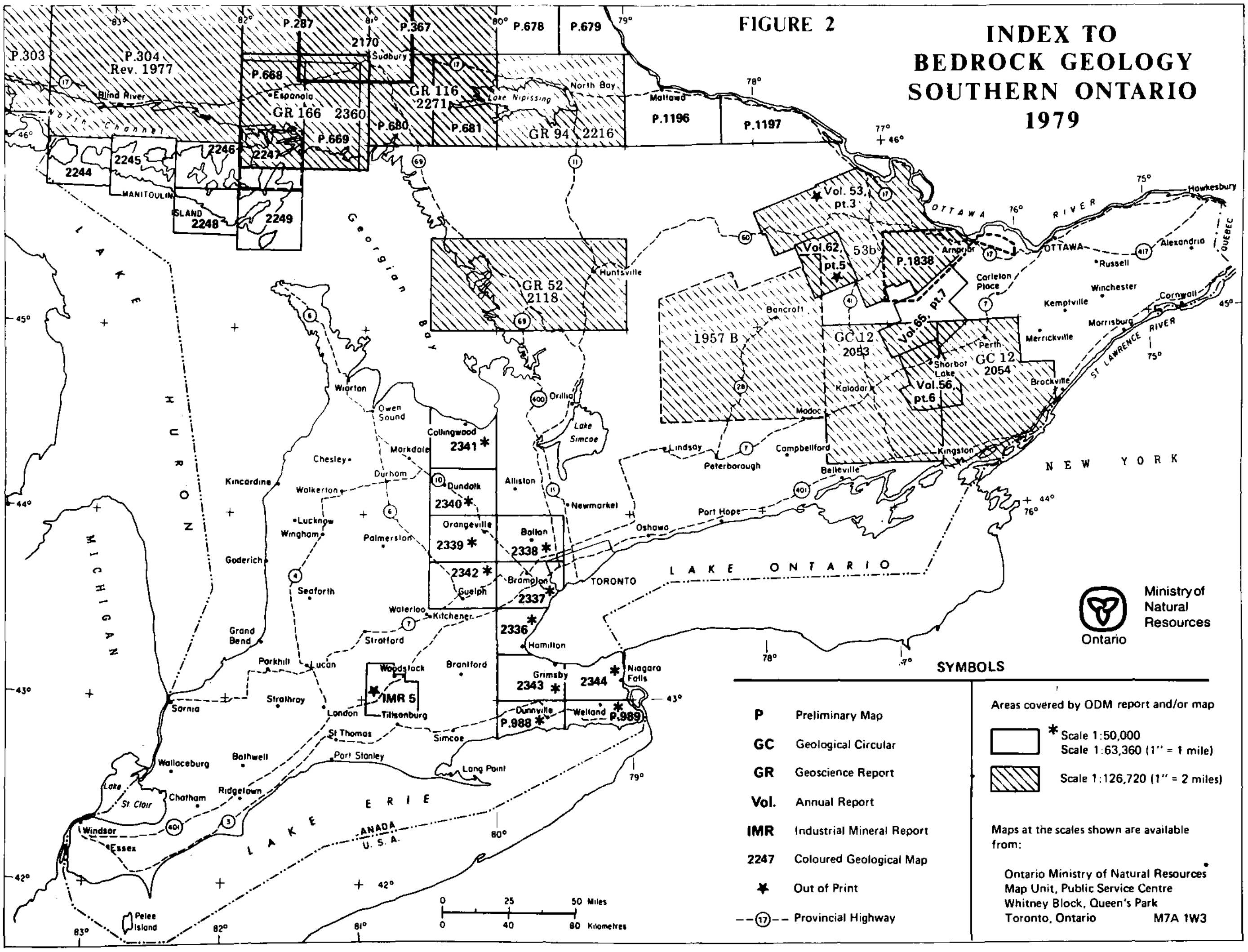

FIGURE 2

INDEX TO BEDROCK GEOLOGY SOUTHERN ONTARIO 1979

Ministry of Natural Resources
Ontario

SYMBOLS

P	Preliminary Map
GC	Geological Circular
GR	Geoscience Report
Vol.	Annual Report
IMR	Industrial Mineral Report
2247	Coloured Geological Map
✱	Out of Print
--⑰--	Provincial Highway

Areas covered by ODM report and/or map

☐ *	Scale 1:50,000 Scale 1:63,360 (1" = 1 mile)
▨	Scale 1:126,720 (1" = 2 miles)

Maps at the scales shown are available from:

Ontario Ministry of Natural Resources
Map Unit, Public Service Centre
Whitney Block, Queen's Park
Toronto, Ontario M7A 1W3

emphasis on potential sources of aggregate and general engineering performance. The whole programme will be completed within four years, and the results will be made available through the publication of over 100 maps and reports (White and Gartner, 1978). A user's manual and a number of special derived maps to show how the basic engineering geology data can be interpreted for particular special interests will also be published.

The geological staff of the Survey will follow up the terrain evaluation with more detailed ground studies in areas requiring attention. These areas are mostly those in which detailed information is sought around towns and cities to assist in the preparation of official plans. The Ministry is concerned to ensure that aggregate in the vicinity of a settlement is not lost to future use by the construction thereon of housing or airfields, or the establishment of other restrictive features when such facilities could be appropriately sited elsewhere. Although the mapping areas are selected with the aggregate and planning requirements strongly in mind, the projects are designed to contribute to our primary data based on the geological history of the Province.

Even farther north, the rest of the Province is also under investigation by the Ontario Centre for Remote Sensing (OCRS). Following a three-year field programme to supplement the airphoto analysis, this project is expected to produce about 50 maps at a scale of 1:250,000 showing the major geomorphic forms over an area of 500,000 sq km. Although not directly concerned with the question of aggregate supplies, these maps should give an indication as to the occurrence of aggregate-bearing deposits in this vast area (Figure 3).

Thus we have and are developing a geological data base across the whole province--methods, scale and product varying according to circumstances, but nevertheless, a scientific product from which ourselves, other geologists or trained personnel can readily prepare an aggregate inventory.

But the data base is not in a format that many persons who "need to know" can use. If the Province wants the planning authorities to incorporate into their official plans information on mineral aggregate resources in order to protect those sources, the information must be made available in a palatable form. So, the Aggregate Resources Inventory Project was established to cover the area where the demand is the greatest, i.e. in southern Ontario.

The Aggregate Resources Inventory Project is designed to provide municipal planners with adequate information on aggregate resources that will permit them to recognise such areas as a nonrenewable resource. Hopefully these areas will be protected from development until the resource is extracted and the extracted area rehabilitated.

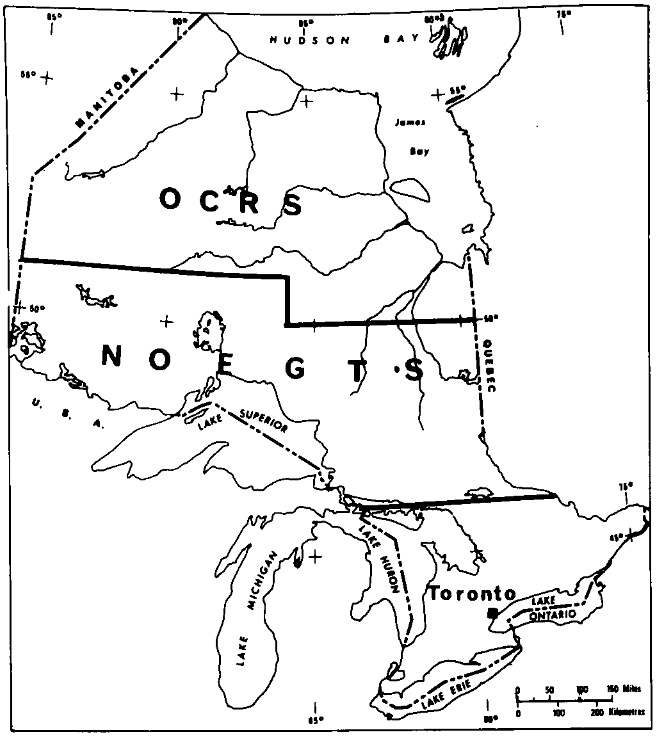

Figure 3. Areas covered by the Northern Ontario Engineering Geology Terrain Studies (NOEGTS) and by The Ontario Centre for Remote Sensing (OCRS).

Experience has shown that appropriate technical and statistical data extracted from geological and statistical reports are not adequate for the majority of planners. Faced, in some cases, with large areas of potential resources or with areas with little information, many planning staffs are either unable or unwilling to choose among the several areas to be "protected" from development and thus tend to ignore the available information.

The Ministry, determined to have this information considered, undertook to supply adequate data in a useable format for all the municipalities (i.e. "townships") that had been designated under the Pits and Quarries Control Act (1971). One hundred and seventy-five municipalities have been so designated, and these cover an area of over 50,000 sq km, mostly in southern Ontario.

Two permanent staff are assigned to the project and are assisted by seven long-term contract personnel, all with degrees in geology, geological engineering, or physical geography. This group is further assisted in their data gathering by appropriate staff in the District Offices of the Ministry and by staff in the Ministry of Transportation and Communications (MTC), the Ministry of the Environment (MOE), and by staff in other units of our own Ministry of Natural Resources (MNR).

Three stages are involved in getting the information into the hands of the user--compilation, evaluation and publication.

Compilation

All known sources are used to put together whatever may be known of the aggregate supplies in a particular township. Geological maps are the prime source, but airphotos may be interpreted if no maps are available. Field studies and inspections are undertaken where necessary. Additional and often extensive consultations are held with the staff of District offices of the MNR, other ministries, universities, municipal and industrial organisations.

Evaluation

At this stage determinations are made of each deposit in terms of thickness, overburden depth and probable workable depth. Potential tonnages are then calculated. Deletions are determined for previously extracted material and for material for which extraction may be constrained generally because of cultural features (i.e. roads, buildings, and so on). Gravel content, known quality limitations (i.e. lithologic and physical) and geological origins are noted for each identifiable area. A similar procedure is followed to determine appropriate areas for bedrock resources where bedrock is of significance in a particular municipality.

With all this information at hand, the most appropriate deposits will be identified as Selected Resource Areas. The selection is based on factors such as size of deposit, aggregate quality, location and setting, but the process also takes into consideration potential sources in surrounding areas. Thus in one township, only the largest deposits or those of highest quality will be identified as "Selected Resource Areas", but in other townships where aggregate supplies are minimal, virtually all known deposits will be "selected" for the planner's consideration. Selected Resource Areas are identified as being of primary, secondary or tertiary significance, and the group designated as being of primary significance is given an internal ranking or priority. A similar selection process is applied to bedrock resources wherever appropriate.

Publication

For each municipality (i.e. township) a separate report will be published and accompanied by three maps. Each report has three parts; parts I and II are common to all reports. Part I explains the methodology involved, and Part II discusses the presentation of the data in the tables and maps. Part III is unique to each report and includes a brief description of the geology of the municipality. Part III also provides a written description and rationale for each resource area that has been selected for consideration by the municipal planners. The tables list the present pit and quarry licenses and summarize the quantities available in the Selected Resource Areas.

The three maps at a scale of 1:50,000 are really the core of the presentation:

Map 1 is essentially a simplified geologic map showing all the known deposits of sand and gravel. Each aggregate deposit is identified directly on the map by a "deposit symbol" that indicates the percent gravel content, the average thickness, the geologic origin (type of deposit) and any known quality limitation.

Map 2 shows the areas that have been selected as sand and gravel resource areas of primary, secondary and tertiary significance. Additionally, the primary areas are ranked within that group.

Map 3 relates only to the bedrock resources of the area but delineates (in three categories) all bedrock within 50 ft (15 m) of the surface and shows the selected bedrock resource areas with a priority rating for resource protection. The first report in this project--for Mono Township, Dufferin County--has been printed and is scheduled for public release on June 22, 1979 (Ontario Geological Survey, 1979).

As a geological survey, this we believe, is as far as we can go. We have acquired the basic geologic data and have presented the aggregate resource information of greatest significance to the planners in a format that we believe they can readily use. Undoubtedly in most cases, more information is desirable, but we are of the opinion that for municipal planning purposes, additional information should be obtained by the municipality.

It has been a pleasure to have this opportunity to present this account of the aggregate resources programme of the Ontario Geological Survey from the scientific survey to acquire the data base to the presentation of the information in a format that we trust will lead to the protection and judicious use of a most valuable mineral resource in the Province of Ontario.

This paper is published with the permission of the Director, Ontario Geological Survey, Ministry of Natural Resources, Toronto, Ontario.

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The Effects of Mineral Conservation Legislation on Colorado's Aggregate Industry

by

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ABSTRACT

The gravel and stone industries have recently set record production levels to satisfy the country's demand for raw construction materials. In many metropolitan areas conflicts arising from urban-suburban expansion over mineral resource areas have caused severe aggregate shortages. To prevent such a shortage in the populous areas of Colorado, the State legislature passed House Bill 1529 in 1973 to identify the aggregate resources and to provide for a rational plan of management, extraction, and reclamation. City and county planning commissions were directed to prepare resource conservation plans following completion of the Colorado Geological Survey's 10-month aggregate mapping study. Only two of the nine designated counties met the legislated July 1, 1975, deadline.

Nonregulation, urbanization, and intensive mining through the 1960s and early 1970s have reduced the high-quality gravel reserves along the South Platte River and Clear Creek to ony a few small areas. The last large available reserve is a lower grade deposit in Adams County along the South Platte River north of Denver. The County's master plan will play a crucial role in managing this deposit because, as one alternative to the shortage problem, producers have recently opened several large pits there and are proposing many more. Other alternatives include 1) the operation of gravel unit trains, 2) the manufacture of lightweight expanded aggregate, and 3) the development of crushed-rock quarries in the Front Range crystalline complex and in small, high-quality igneous deposits along the mountain front in Jefferson and Boulder Counties.

Quarries have operated for many years in the Golden-Morrison area, but new quarry applications have caused serious social, environmental, and logistical concerns in Jefferson County. To alleviate the problems, the producers have gone to great lengths in preparing comprehensive, workable, and acceptable mining and reclamation plans.

The intensification of the lower South Platte and quarry alternatives suggests that HB 1529 failed to preserve what was left of the high-quality gravels due to local governments' noncompliance and delays in adopting the required master plans. However, aggregate production should increase to meet the current demands, but a larger portion of the supply likely to come from crushed-rock quarries.

In the Grand Junction area on Colorado's western slope, either HB 1529 or the later HB 1041 land-use law should be effective in maintaining an adequate supply of aggregate to meet the anticipated growth.

INTRODUCTION

In recent years the gravel and stone industries have set record production levels to meet the demands of the current construction boom. Many metropolitan area producers at the same time have met heated resistance to opening new deposits in attempting to satisfy the heavy urban-suburban demand for raw materials. Such conflicts can readily be seen along the Colorado Front Range, particularly in the Denver metropolitan area where most of the state's aggregates are produced and consumed. An impending shortage of mineral construction materials here was forecast nearly 25 years ago. The Colorado Sand and Gravel Producers Association (1957), the Inter-County Regional Planning Commission (1961) (forerunner of the Denver Regional Council of Governments), the U.S. Bureau of Mines (Sheridan, 1968), and again the local producers (Cooley, 1971) all recognized and stressed the need for local regulations or mineral conservation legislation that would insure that valuable aggregate deposits would be excavated ahead of the rapidly expanding development. In spite of the warnings, suburban development and intensified mining in available areas during the 1960s and early 1970s reduced the remaining high-quality reserves to a critically low level. Only with substantial prodding from the gravel industry did the Colorado legislature finally attack the problem in 1973 by passing House Bill 1529. In this landmark act the governing body declared that

> (1) "the state's commercial mineral deposits are essential to the state's economy,
>
> (2) the populous counties of the state face a critical shortage of such deposits,
>
> (3) such deposits should be extracted according to a rational plan, calculated to avoid waste...and cause the least practical disruption to the ecology and quality of life of the citizens..."

In the following sections I will examine the components of this bill, review the status of compliance, and look at the history of and alternatives to problems that have arisen either directly or indirectly from this law.

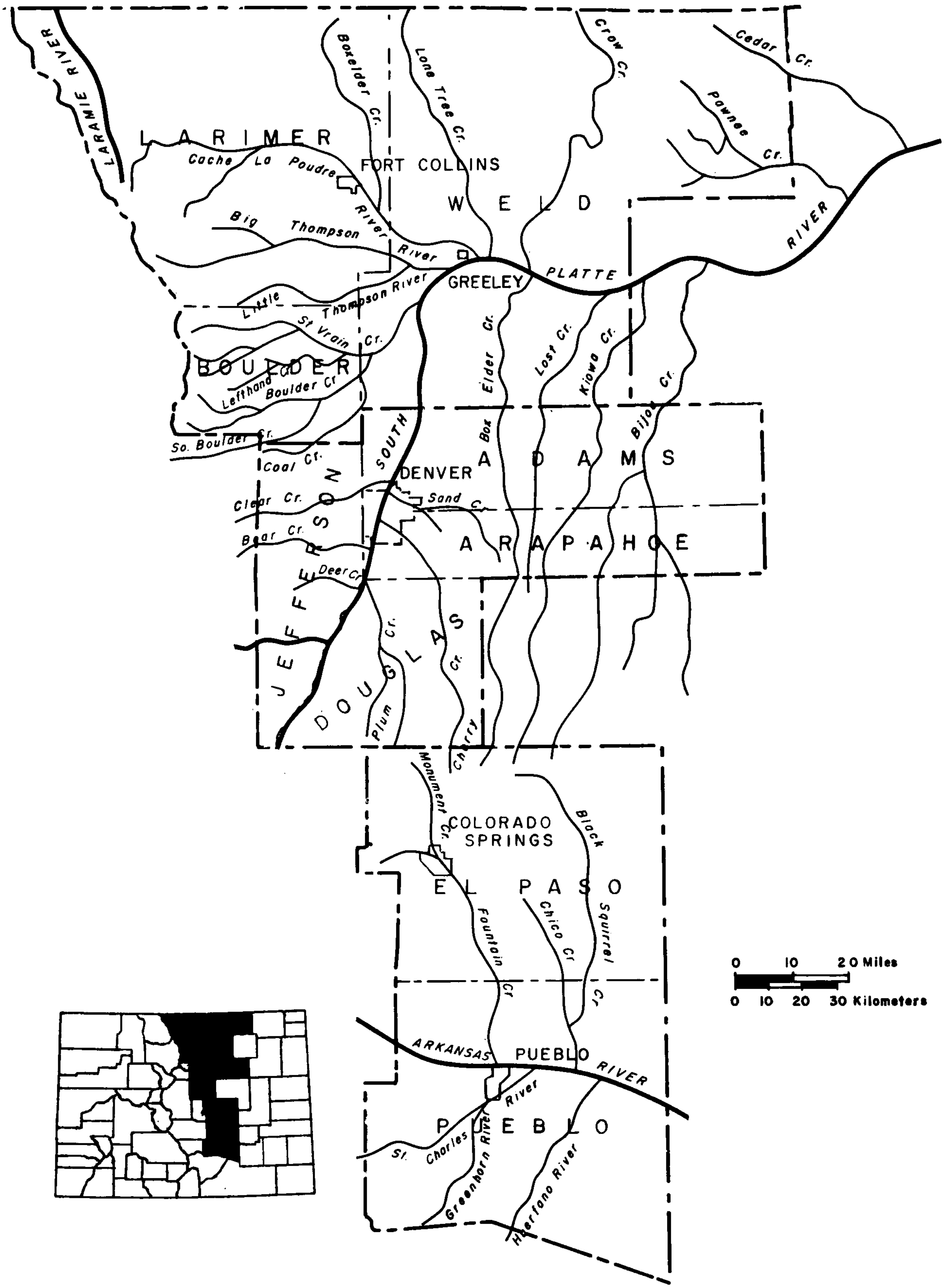


Figure 1. The Colorado Front Range counties, with principal rivers and tributaries.

COMPONENTS OF HB 1529

Actually HB 1529 consisted of two separate acts, subtitled "Colorado Open Mining Land Reclamation Act of 1973" and "Preservation of Commercial Mineral Deposits." In the first part, the State established procedures for obtaining mining permits, posting reclamation performance bonds, and general guidelines for the reclamation of surface-mined land. However, these regulations applied only to coal, sand, gravel, quarry aggregate, and limestone for construction use. A 5-member board was created to review mining applications, issue permits, and formulate reclamation standards. The reclamation statutes were extensively revised by HB 1065 in 1976 to include all mineral resources and most kinds of exploration activities.

The second part of the bill defined a "commercial" mineral deposit" as

> "...a natural mineral deposit of limestone used for construction purposes, coal, sand, gravel, and quarry aggregate, for which extraction...is or will be commercially feasible and regarding which it can be demonstrated by geologic, mineralogic, or other scientific data that such deposit has significant economic or strategic value to the area, state, or nation."

A populous county was defined as one with a population of at least 65,000, thereby limiting the jurisdiction to nine counties along the eastern slope. The Colorado Geological Survey was charged to contract for a mapping study of the deposits in these counties. Using the maps from this study, the city and county planning commissions within the study area were directed to devise and adopt "master plans for extraction" that would consider a number of factors:

1) "potential for multiple-sequential land use,
2) use of land to enhance attractive surroundings,
3) quality of life of the residents in and around the resource areas,
4) other city and county master plans,
5) maximizing the extraction of commercial mineral deposits, and
6) ability to reclaim the mined areas."

A third important feature was a special clause pertaining to zoning:

> "After July 1, 1973 [date of enactment] no board of county commissioners, governing body of any city and county, city...or other governmental authority which has control over zoning shall, by zoning, rezoning, granting a variance, or other official action or inaction, permit the use of any area known to contain a commercial mineral deposit in a manner which would interfere with the present or future extraction of such deposit..."

Local governments effectively could permit neither permanent structures on known mineral deposits nor any other use that would preclude extraction (except agriculture). Although the bill exempted lands that were unfavorably zoned prior to July 1, 1973, no official legal opinion has been given regarding the applicability of the law to those same lands should they be proposed for rezoning.

Aggregate Mapping Study

To contrast the comprehensive inventorying that has been done in Ontario, I would like to outline the study that was performed under contract to the Colorado Geological Survey in 1973-74, as mandated by the bill. The CGS was given one year and a fund of $65,000 to complete the work. Amazingly the three geologists and one draftsmen who were hired in September 1973, finished all the work before the July 1, 1974, deadline. The index map in Figure 1 shows the geographic setting of the state's nine populous counties--all along the Front Range. Although Douglas County did not meet the 65,000 population requirement, we mapped the resources in it to complete the picture of the South Platte River basin and to bridge the gap between it and the Arkansas River basin. Part of a third river basin, the Laramie River, is included in northwestern Larimer County.

The 10-county area encompasses 16,000 sq mi (41,400 sq km) and overlaps the Front Range section of the Southern Rocky Mountain physiographic province, the Colorado Piedmont, and part of the High Plains province. The Front Range uplift is composed of complexly folded and faulted metamorphic rocks of Precambrian age intruded by several granitic batholiths of Precambrian and Tertiary age. The Late Cretaceous-Early Tertiary Laramide orogeny uplifted the Front Range, upturned and exposed the Pennsylvanian to Late Cretaceous sedimentary section. For the aggregate survey, the most important deposits are the variety of Quaternary alluvial deposits and several Tertiary intrusive and extrusive rocks along the mountain front.

In developing the basic mapping units and criteria, we wanted a simple mapping scheme based primarily on geology and phyisography. We selected seven simple aggregate-bearing landforms somewhat characteristic of the piedmont area:

F	flood plain (physiographic)
T	terrace
V	valley fill (narrow valleys or where F and T are not distinguishable)
U	upland deposits
A	alluvial fan

E wind-deposited sand (usually dunes)

G glacial

Glacial deposits (G) were included in the original classification, but none of any importance were mapped in this survey. A special category, man-made deposits (M), was applied solely to the slag pile at the CF&I steel plant in Pueblo.

The variety of high-quality aggregate resources listed in Table 1 spanned nearly the entire geologic column. We recognized the vast Precambrian crystalline complex of the Front Range as a quarry aggregate resource because of the operating quarries there but did not designate it as such on the maps for practical reasons.

The next step was to assign general quality ratings to the landforms based on grain-size distribution, amount of fines, weak and incompetent rock, and calcium carbonate development (Table 2).

Table 2. General rating system for aggregate-bearing landforms.

┌—Landform unit
F1
└—Resource classification

Coarse Aggregate
(at least 30% retained on #4 screen, visual estimation)

1 Gravel: relatively clean and sound

2 Gravel: significant fines, decomposed rock, calcium carbonate

Fine Aggregate
(greater than 70% passing #4 screen, 60% retained on #200 screen, visual estimation)

3 Sand

Unevaluated Resource

4 Probable aggregate resource

These criteria and cutoff values were based on interviews that we conducted initially with many aggregate producers in the region. Supplementary map information included 1) pit and quarry locations, 2) published well logs citing thickness of overburden and resource, and 3) field-station observations in a symbolic fraction format.

Considering our legislated objectives, intended map users, and the inherent difficulties in the bill's definitions, we selected this overall mapping system with several ideas in mind. First, keep the number and scope of map units to a minimum for planning purposes. Second, a mapping system based on geology has the advantage of providing stability through time, thereby eliminating the bias of some systems based on politics, zoning, "point occurrences", or other abstract entities. Third, maximize the utility of the maps by showing supplemental data useful to industry. The Survey's file maps can easily be kept current by adding new logs, pit locations, and permit application boundaries. Fourth, we could account for deposits that "are or will be commercial" initially by mapping practically everything. In following up the study, the Survey would work individually with each county and select which of the mapped deposits were most critical to that county. At that point the county could use zoning overlays and other means to legitimately reduce the total mapped resource area to the actual "reserve" or what could be defined as the "commercial" deposit. The master plan then would apply to those designated areas. During the 10-month study period we simply could not afford to gather the economic and other information that would have allowed us to designate those reserves.

Table 1. Quarry aggregate resources in the Colorado Front Range.

Geologic Age	Rock Type	Area
Oligocene	rhyolite	Castle Rock, Douglas Co.
Paleocene	latite monzonite rhyodacite	Table Mtns., Jefferson Co. Ralston Res., Jefferson Co. Lyons, Boulder Co.
Mississippian	limestone	Colorado Spgs., El Paso Co.
Precambrian	granite gneiss metaquartzite	Front Range Eldorado Spgs., Boulder and Jefferson Cos.

All of the mapping was done from airphoto examination directly onto USGS 7.5-minute topographic maps (scale 1:24,000). In four areas, northeastern Weld County, eastern El Paso, Adams and Arapahoe Counties, where this scale of mapping had not yet been completed, we used 1:125,000-scale base maps from the Division of Highways. Wherever possible we checked our interpretation with published and open-file geologic maps. Field work involved a rather rapid reconnaissance to confirm landform boundaries and pit locations and to visually determine some of the deposits' physical properties.

We produced a set of 213 aggregate resource maps (equivalent to 234 quadrangles) for the 10 Front Range counties. All these maps were reduced to a scale of 1:75,000 for publication in a convenient book-sized atlas. Accompanying the summary text was a 1:250,000-scale regional compilation. Our average rate of "production," including photogeology, field work, and drafting, was one quadrangle per day. The report and all maps were distributed to the respective cities and counties about two weeks before the July 1, 1974, deadline. Thus, the statutory charges to the Survey had been satisfied.

Master Plans

The city and county planning commissions were given one year (until July 1, 1975) to complete their master plans using the maps that the Survey had prepared. Only two counties, El Paso and Weld, successfully met that deadline. Presently, Boulder, Adams, and Jefferson Counties and several cities (Longmont, Broomfield, Wheat Ridge, and Aurora) have adopted such plans. I determined several reasons for the delays and noncompliance. First, no state funding was provided for this phase of the program. Second, the bill contained no penalty for missing the deadline or for not complying at all. Third, a number of local governments claimed that they had no personnel to work on the plans or that their staffs were working on higher priority issues. The fourth reason stems from what one might call "personality conflicts." Some agencies felt that the state was overstepping its authority in passing the zoning restriction, thereby excercising control over land within local jurisdiction. For a while some even questioned the constitutionality of the law, but it has never been challenged in court. In at least two cases, misinterpretation of the law's intent has brought about a general antimining philosophy, which is quite contrary to the bill's purpose. In spite of these drawbacks, the counties who have successfully worked out their master plans have taken some logical, innovative, and quantitative approaches to the problem.

COLORADO AGGREGATE PRODUCTION

Let us look briefly at the magnitude of Colorado's aggregate industry. The production data for the curves in Figure 2 were compiled from U.S. Bureau of Mines statistics and are probably conservative. The state's 1973 peak production of 33,767,000 tons reflects the nationwide peak,

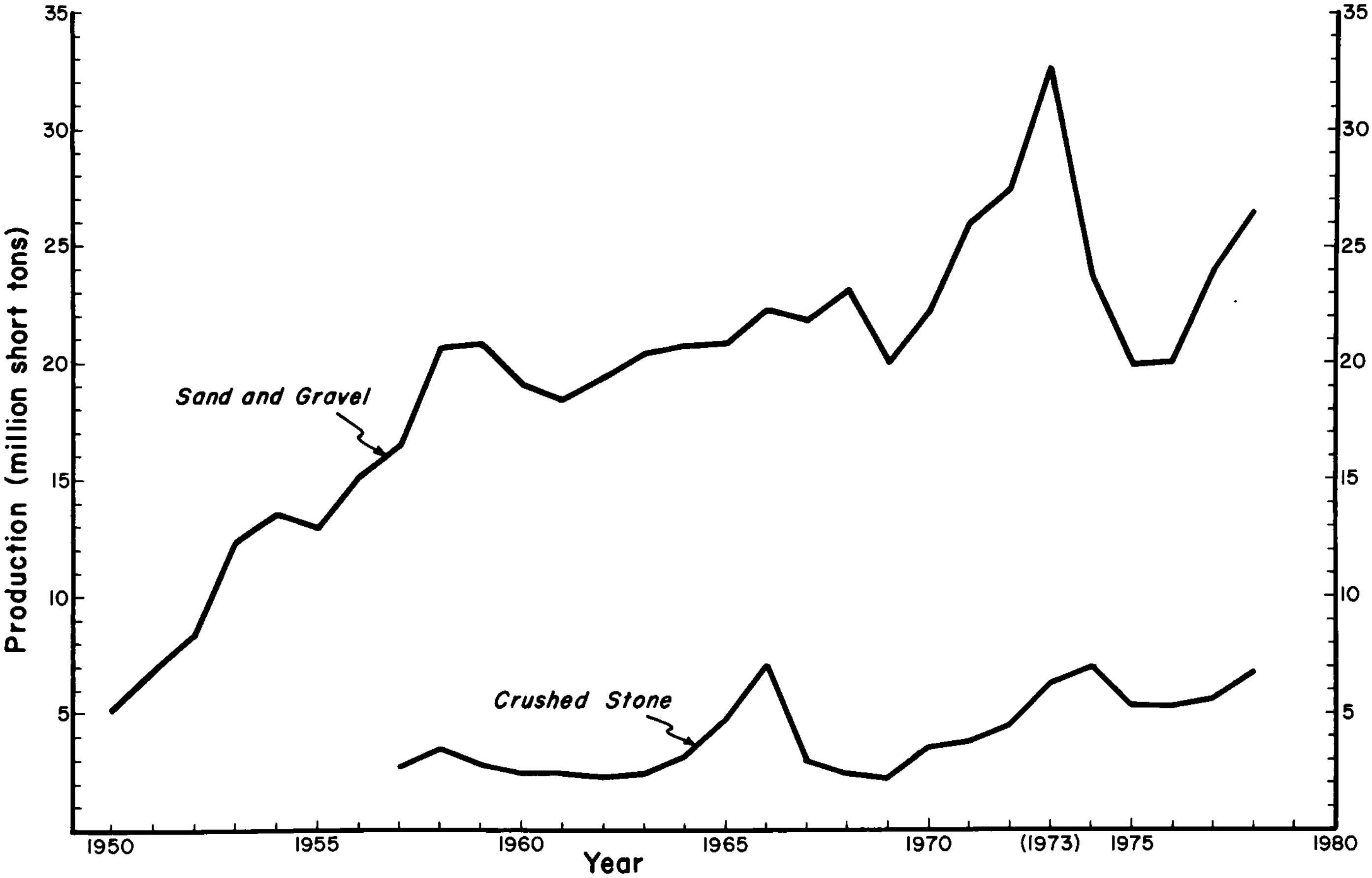


Figure 2. Colorado aggregate production (from U.S. Bureau of Mines Minerals Yearbooks and Annual Advance Summaries).

followed by a sharp 2-yr decline of 41 percent of the peak. However, the last two years' records show nearly a 20-percent increase over the 1975 low. The number of reported active gravel operations dropped from a high of 395 in 1967 to 176 in 1977. In contrast, the total value of sand and gravel has steadily increased to a high of $50,527,000 in 1977, giving an average value of $2.00/ton. For 1977 the Colorado Division of Mines ranked sand and gravel fourth in value of mineral production behind molybdenum, oil and gas, and coal.

Figures for crushed stone production since 1957 show a sharp peak of 7,018,000 tons in 1965-66, which reflected contracts for riprap. A second increase since 1969 in part reflects the riprap requirements for Chatfield Dam. The second peak of 6,562,000 tons was reached in 1973-74 followed by a 19-percent drop. The importance of this curve relative to that for sand and gravel will become apparent later. In 1974 crushed stone was valued at $14,780,000, giving an average value of $2.25/ton. Although the total value of 1977 production was lower ($14,169,000), the average value increased markedly to $2.53/ton.

For sand and gravel the Denver metro area has contributed 30 to 32 percent of the state total since the late 1960s but had increased its share to 41 percent by 1975. For crushed stone the metro area has contributed only about 1 to 5 percent of the state total. This comparatively lower figure is due essentially to high-tonnage limestone quarries operating in El Paso, Larimer, Fremont, Boulder, and Chaffee Counties.

GRAVEL MINING IN THE DENVER AREA

Denver gravel producers have for many years recognized the high-quality reserves along the South Platte River and one of its principal tributaries, Clear Creek. A large percentage of original reserves along the river were lost to Denver itself. In this decade we have seen the virtual exhaustion of high-quality gravels in the remaining deposits that have now become surrounded by metro development.

Figure 3 shows the metro area's gravel resources and the areas where gravel mining has concentrated. Along the upper South Platte River between the Denver city limits and Chatfield Lake State Recreation Area, a number of older worked-out pits have been converted to sanitary landfill and recreational use. The few active operations left in this stretch of the valley will have little or no chance of expansion because of the encroaching residential subdivisions and the unfavorable political environment in Littleton and Denver. Upstream from the dam the waters of Chatfield Lake and its associated development will effectively preclude the use of an enormous reserve along the river and between the river and Plum Creek. Although a fair amount was extracted before and during the dam construction, most of the resource will be lost.

On the north side of Denver the South Platte gravels contain more sand and less coarse material, and very little of the flood plain and terraces has been mined, except at and just downstream of the confluence with Clear Creek, which has locally upgraded the deposits. On the east side several operations along Sand Creek and Cherry Creek supply concrete sand for the crushed-rock quarries, and masonry and other specialty sands.

A well documented and especially disheartening loss of high-quality flood-plain gravels has taken place along Clear Creek (Figure 4). Although the lower half of the valley (about 6.5 miles) has been essentially depleted and partly reclaimed, well over one-third of the valley's resources has been lost to development in two of Denver's western suburbs, Arvada and Wheat Ridge. From Harlan Street west to Tabor Street (about 4 miles) a vast gravel resource remains in the ground. About 50 percent of the reserves in the remaining 2.5-mile upper stretch has been excavated. Only a small fraction of the terrace deposits at each end of the valley has been worked.

GRAVEL RESERVES AND THE ALTERNATIVES

Nonregulation and intensive mining of available deposits in the last quarter century has led to a critical situation in terms of future reserves. Along Clear Creek a golf course near Golden represents the last untapped available tract of flood-plain gravels. A few small sites are available yet on some of the terrace deposits. Along the upper South Platte River, the gravels adjacent to the operating pits are questionable as reserves. A large and relatively untapped gravel resource lies within the Rocky Flats alluvial fan northwest of Denver, but experimental processing there in the last few years has revealed trouble with excessive fines in spite of the high content of hard, durable quartzite. However, some producers remain interested in the deposit.

I consider the last large gravel reserve in the Denver area to lie in Adams County along the South Platte from the Clear Creek confluence north to about 144th Avenue, a distance of about 11 miles. Not too long ago, producers showed no interest in the northernmost of these deposits because of the increased sand content and outlying location. Since about 1972, local operators have opened several large pits in that area, and many other sites are being applied for (see Figure 3).

The Adams County master plan will become very crucial in terms of properly managing this reserve. Although several versions of the County's plan have been proposed since 1974, none was finalized until last fall. Based on my recommendations in 1974, the County selected the flood-plain and lower terrace deposits along the river and lower Clear Creek as its most importance resources (see Figure 3). The plan divided this reserve block along 104th Avenue and designated the 5-mile stretch north of it as the "principal mineral conservation area." That to the south is called the probable or conditional mineral conservation area in which the County will weigh commercial and industrial development very heavily against mineral conservation. In the last few years

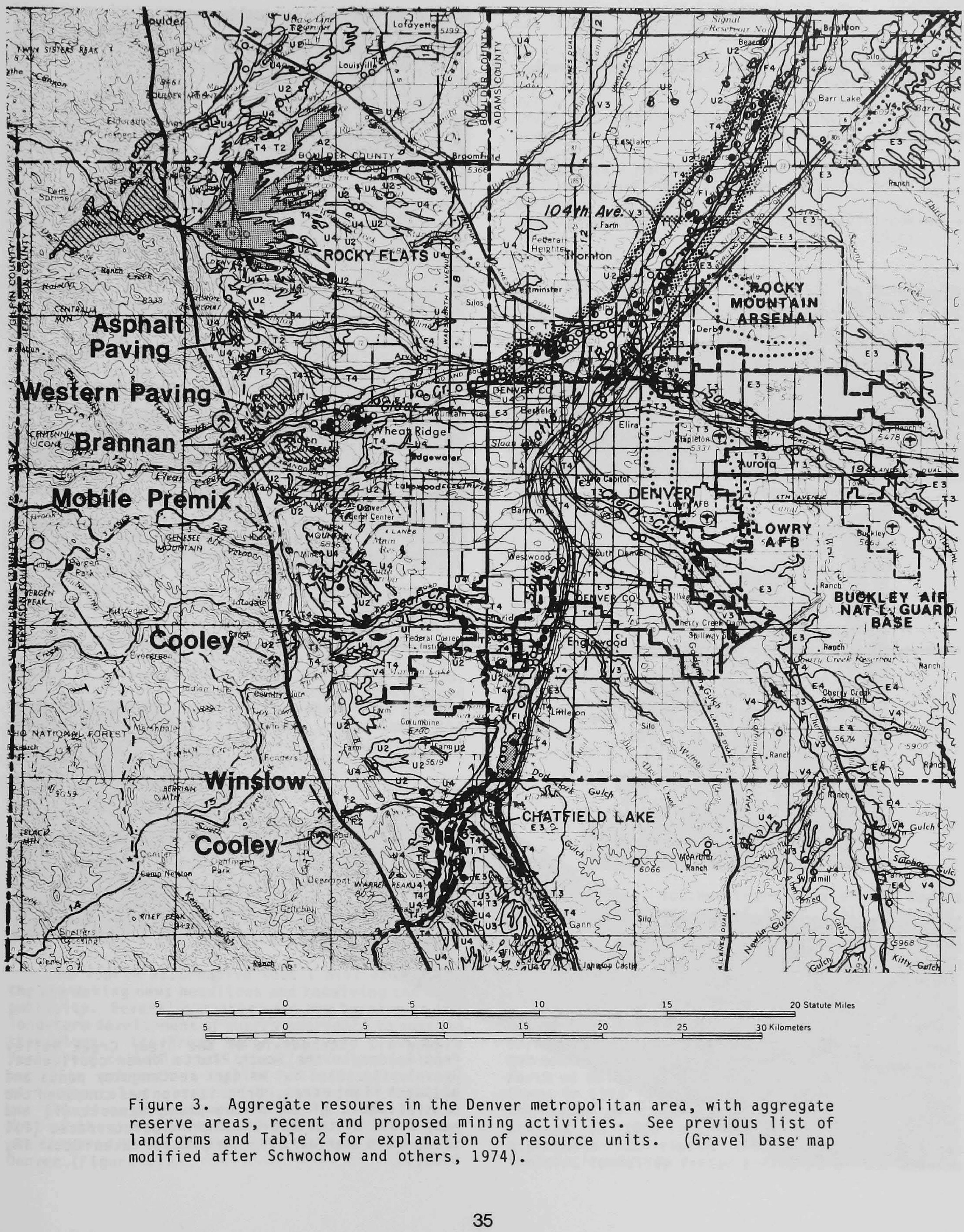


Figure 3. Aggregate resoures in the Denver metropolitan area, with aggregate reserve areas, recent and proposed mining activities. See previous list of landforms and Table 2 for explanation of resource units. (Gravel base map modified after Schwochow and others, 1974).

Figure 3. EXPLANATION

▨ quarry aggregate resources exclusive of Front Range crystalline rocks

▒ major gravel resources outside Adams County Mineral Conservation Area

░ Adams County Mineral Conservation Area (MCA). Principal MCA is north of 104th Avenue.

┬─┬ mountain front edge of Precambrian crystalline rocks

- ○ inactive, abandoned, reclaimed gravel pit
- ● gravel pit active since 1973
- ◉ proposed new gravel pit
- ⚒ abandoned crushed-rock quarry
- ⚒ operating crushed-rock quarry
- ⓧ proposed new crushed-rock quarry
- ⚒ proposed reopening of inactive crushed-rock quarry

▲ expanded-shale aggregate pit

this area has been gradually consumed by very small development tracts that will effectively preclude mineral conservation unless a producer should obtain sufficient acreage for a mining proposal.

So far we have seen area operators turn to four alternatives to the resource shortage problem. The first alternative is the operation of a unit train to bring gravel in from more accessible deposits outside the metro area. Only one company, Western Paving Construction Company, has excercised this operation in Denver. The company's unit train hauls gravel from a pit and loading site at Lyons (Figure 5a) 45 miles southeast to its asphalt mixing plant on Clear Creek at Pecos Street (Figure 5b). The train began full-time operation in 1975, and its 32 Ortner rapid-discharge cars have a total capacity of 3,200 tons. However, this very unusual economic and logistical situation may not be feasible for more than one or two companies in the long term. The second alternative is the manufacture of lightweight expanded aggregate. Two companies in Colorado have been engaged in this branch of the industry. The Idealite Company operated a clay pit (Pierre Shale) and expansion plant at the north end of Rocky Flats until 1976. Fountain Sand and Gravel continues to process slag from the CF&I Steel Corp. in Pueblo.

Like the unit train, though, the possibility of future large-scale production of expanded aggregates in the Denver area is questionable and must await further evaluation. The third alternative has gained considerable momentum and importance in the last 6 or 7 years. Producers are now operating and planning large operations along the South Platte River on the north side of Denver. These deposits

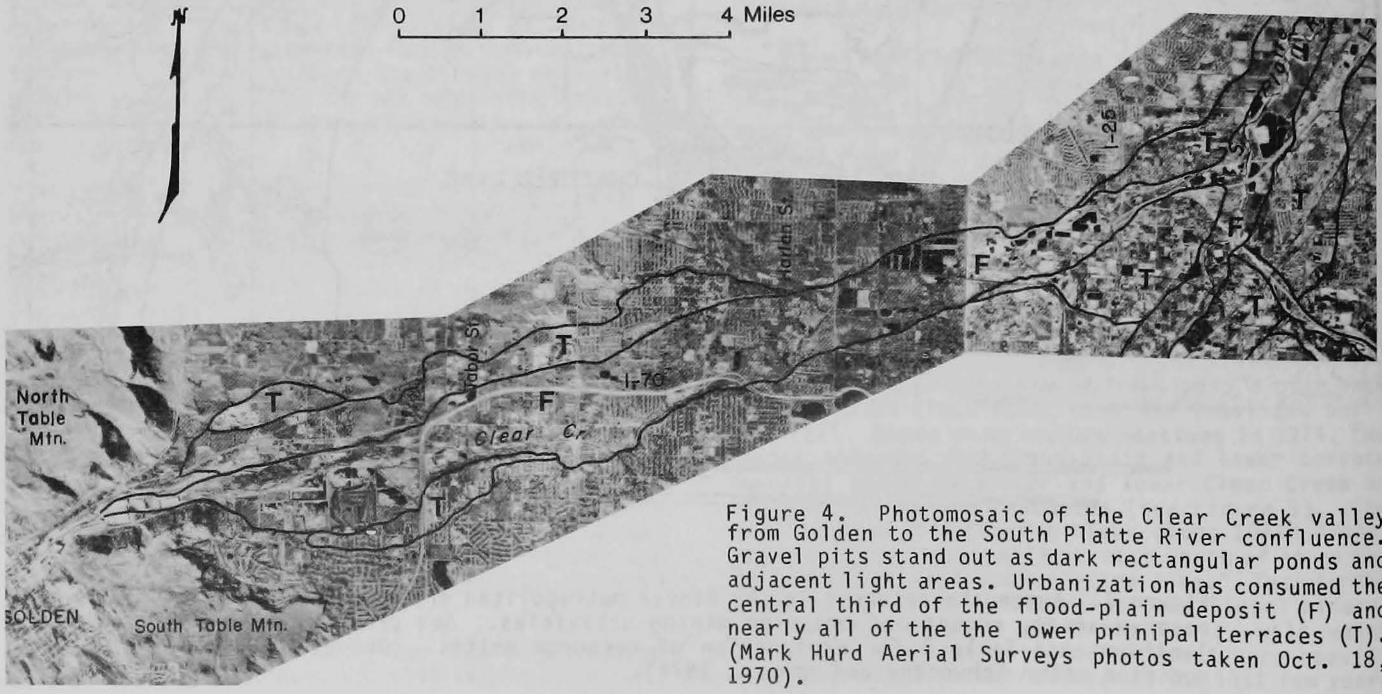


Figure 4. Photomosaic of the Clear Creek valley from Golden to the South Platte River confluence. Gravel pits stand out as dark rectangular ponds and adjacent light areas. Urbanization has consumed the central third of the flood-plain deposit (F) and nearly all of the the lower prinipal terraces (T). (Mark Hurd Aerial Surveys photos taken Oct. 18, 1970).

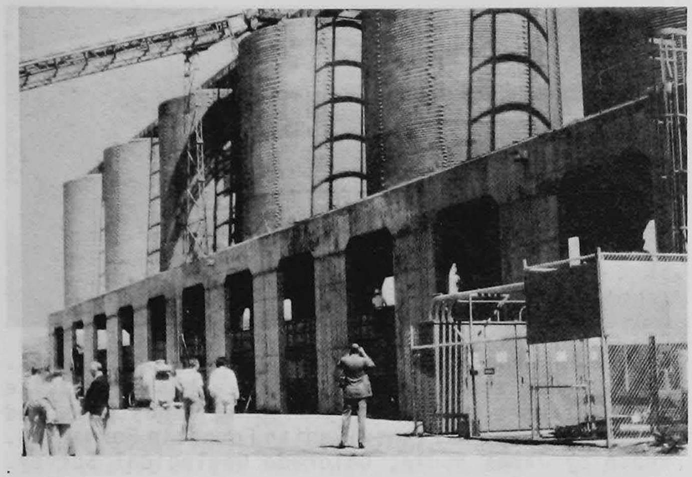


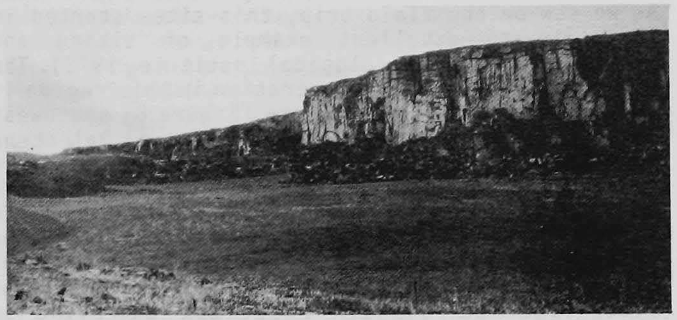
Figure 5. a) Top, Western Paving Construction Company's gravel loading facility on St. Vrain Creek at Lyons. Gravel is conveyed to a height of 65 ft and selectively dumped into the six 530-ton-capacity concrete-stave silos. Underneath, the rail cars are loaded at a rate of 200 ton/min/silo. b) Bottom, the 32 Ortner 100-ton-capacity cars are positioned on the 270-ft-long trestle to discharge the pit run into six 1500-ton-capacity bays. From there the material can be either surged to a stockpile or fed directly to the crushing and screening plant.

are known to contain more sand and less coarse material than upper South Platte and Clear Creek deposits, but they are the last large reserve closest to the Denver markets, and at least part of them is now protected by mineral conservation in Adams County. Figure 3 shows the locations of recently active pits in that area and the surprising number of new sites that have been applied for.

The fourth alternative that I will examine is the one making news headlines and receiving the most publicity. Several companies are now turning to the long-term development of quarry aggregate to sustain themselves. The Front Range not only provides a variety of suitable rock types (described earlier) but also presents a myriad of siting, mining, environmental, transportation, and social problems not always associated with gravel pit operations. Most of the past, present, and proposed activities are centered in the Golden-Morrison area due west of Denver (Figure 3).

The Quarry Alternative

To set the present scene let us briefly look at the history of quarrying in this area. Few people realize that the South Table Mountain latite in Golden was quarried as early as 1905. Four quarries there have yielded road materials, concrete and asphaltic aggregate, and riprap intermittently through the late 1950s. One quarry has been converted to a firing range, and another is used to test rock-drilling equipment. The one latite quarry unobtrusively located on North Table Mountain (Figure 6) began in 1925, was enlarged in 1949, and worked intermittently since then. Many years ago, two monzonite quarries operated at Ralston Reservoir north of Golden, and a new excavation was approved there in 1975 (Figure 7). The Bertrand quarry at the mouth of Clear Creek Canyon in Golden was started in 1926 and since then has provided aggregates and riprap intermittently until an imminent landslide forced a closure of the site in



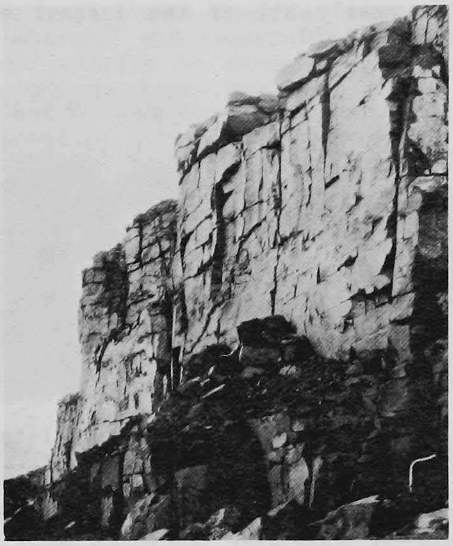


Figure 6. Top, southwestward view of the Rogers quarry on the west rim of North Table Mountain. Bottom, on the old quarry wall, notice how columnar jointing in the latite flow stabilizes the cut on the vertical face. Western Paving Construction Company plans to expand the old quarry eastward.

1975. The Holloway quarry on Jackson Gulch south of Golden started in 1965 and produced much of the riprap for Chatfield Dam. Mining was stopped last winter because of alleged dust-emission violations and since then has changed ownership. Only stockpiled rock is being removed now. The Deer Creek Canyon quarry, operated by Winslow Construction Co., started in 1970 and provides riprap mostly, but igneous rock now being encountered deeper in the excavation will provide a source of concrete aggregate (Gordon Hays, 1979, pers. comm.) This quarry's somewhat hidden and remote location in a side canyon has minimized its "impacts" on the area. Cooley Gravel Company operates the Strain Gulch quarry south of Morrison. As we saw on the field trip, this site, started in 1971, is an excellent example of siting and preplanning (Thorne Ecological Institute, 1972). The other notable commercial operation in this region is the Andesite Rock Company site (Figure 8) southwest of Lyons, a quarry developed in a Paleocene rhyodacite sill in the Fountain Formation. Rhyolite of Oligocene age caps a number of buttes in eastern and southeastern Douglas County. These deposits yielded a fine building stone in past years, but the only active quarry now is operated for crushed stone. One other deposit is now being evaluated for reopening. As one can see, rock quarrying is neither a new nor unusual land use in the Golden area, but nearly all of the largest operations started after 1970.

Figure 7. Working face at the new Ralston quarry, operated by Asphalt Paving Company. The company currently produces dark-gray monzonite from the oval-shaped intrusive at a rate of 3000 ton/day for use as road base and concrete and asphaltic aggregates.

What I find especially interesting is the industry's recent interest in applying for new quarry sites in this restricted geographical area. All of the applications either include one of the above-mentioned quarry sites or lie adjacent to the older or active operations. Hearings for the rezoning of 180 acres on the north side of South Table Mountain have continued for over 4 years but are scheduled to end on June 14. I attribute the delays in this case to faulty procedure on the part of Jefferson County and the fact that its master plan was not completed until the spring of 1977, two years late. Recent questionable involvement of the Solar Energy Research Institute has not helped in the case. If the rezoning and subsequent mining proposal are approved, the site will be operated by Mobile Premix Sand and Gravel, which also assumed ownership of the Holloway quarry.

Figure 8. Andesite Rock Company quarry on South St. Vrain Creek southeast of Lyons. This rhyodacite sill intrudes east (left)-dipping sandstones and dark shales of the Pennsylvanian Fountain Formation. Photo by James Soule, Colorado Geological Survey.

One of the most attractive and comprehensive application documents ever prepared in Colorado was presented by the Brannan Sand and Gravel Company (1979) for two sites near Golden--94 acres surrounding the old Bertrand quarry and a 233-acre site just to the north in Golden Gate Canyon. The first part of the proposal involves a 7-year effort to remove the Bertrand quarry's landslide hazard (which earlier had closed the site) and reclaim the entire excavation. The second phase is a 30-year quarry operation on the south side of Golden Gate Canyon. In an attempt to relieve transportation difficulties in the area, the company has changed its original plan to allow the quarried rock to be conveyed back over the hill to the Bertrand quarry site to a storage and load-out facility. For its application the company hired more than 20 consultants to prepare sections on geology, mining and reclamation, noise control, air and water quality, climatology, archaeology and history, materials analysis, slope stability, blasting and seismic monitoring, geophysics, safety, soils, vegetation and wildlife, and transportation. Brannan's hearings with the county and the public began in March of this year and are scheduled to end in June.

Directly across the highway from Golden Gate Canyon is North Table Mountain, on which Western Paving Construction Company (1979) proposes to reopen and expand the old quarry over a 375-acre site. WPCC's property has two advantages--1) rock will be conveyed down the west side to a processing plant at the base of the hill, thereby eliminating truck traffic on the steep access road; and 2) because of the high position near the west rim and primary crusher location on the quarry floor, the benched excavation will not be visible from Golden, Lakewood, or Denver. WPCC's hearings began in April of this year.

The Cooley Gravel Company has applied for mineral conservation zoning for a new quarry in Deer Creek Canyon very near the Winslow quarry. In Boulder County the C & M Gravel Company is now investigating intrusive rocks at the Geer Canyon site north of Boulder as a long-term source of crushed rock.

So in Jefferson County, three commercial quarries are now operating (Asphalt Paving Co., Cooley Gravel Co., and Winslow Construction Co.), four more are proposed (Cooley Gravel Co., Brannan Sand and Gravel, Western Paving, and Mobile Premix), and two are presently inactive (Bertrand, Holloway). Jefferson County's main legitimate concern is the cumulative effects of several quarries all operating in a small area--something that was not anticipated or addressed in its master plan. Just this spring, as a result of the hearings, the County organized a consortium of gravel industry and highway department officials to discuss traffic problems, proposed road improvements, and how the increased traffic might best be accommodated. It is unlikely that any current cases will be decided before that group has found a reasonable solution to the problem.

(All the above quarry proposals, including The Geer Canyon site and two new sites in Douglas County, are still pending as of December 1979. Brannan and Western Paving have made major design changes in their operating plans in direct response to concerns expressed during the public hearings--Ed.)

Why has this activity been centered around Golden and Morrison? First and most obviously, this area represents the shortest haul routes to the west and south Denver markets from the highest quality quarry-rock deposits. Perhaps more importantly, the intense interest in quarry development suggests a failure in HB 1529 to "preserve" what was left of the important gravels. In this respect very probably the quarry alternative and lower South Platte alternative were anticipated or inevitable before the law was passed. The bill may have prolonged the shift for a while, but the Colorado Sand and Gravel Producers Association prediction in 1957 seems uncannily accurate. The Association stated that without proper controls, all the high-quality gravel reserves within a 10-mile radius of downtown Denver would be depleted by 1977. I think a more direct factor was the delay and noncompliance of local governments in adopting the required master plans. As stated before, only Weld and El Paso Counties met the legislated deadline, but their situations were not as critical as Denver's.

WHAT HAS HB 1529 DONE?

My work with this law since its passage and my reviews of master plans, mining and development proposals point out some ideas that can be directly and indirectly correlated with HB 1529.

1) The original law set forth some excellent guidelines and procedures for mined-land reclamation. The overhaul of this initial legislation three years later expanded the concepts to all mineral resources in the state but added a large volume of paper work and "red tape" both to mining activities and to most kinds of exploration. However, the recent increase in energy resource development probably was the precipitating factor. The regulations have been particularly burdensome to the small operator in spite of the small-operator exemptions.

2) Delays and refusals to draw up the required master plans have contributed to the loss of more gravel reserves. In areas along the South Platte River and Clear Creek, development in the form of small-acreage tracts (generally less than 5 acres but sometimes more) has consumed some reserves in a "piecemeal" manner. "Noncommercial" tracts scattered across otherwise undeveloped resource land do not in themselves consume much acreage but subtly prevent the consolidation of commercial acreage among the tracts. Once the precedent for this type of development is set, I have found it most difficult to justify mineral conservation due to low low-density spread over the resource and the drastic reduction of mineable acreage by required property-line and right-of-way setbacks.

3) The Adams County master plan has successfully designated at least a portion of the last large South Platte River reserve in the metro area. Commercial and industrial development has been given priority on deposits south of 104th Avenue, but I have reviewed three recent applications for new pits there, and at least one is now operating. Although the deposits contain more sand and require more upgrading, producers have shown serious interest in securing them. With increased pressure to develop the lower South Platte River reserves, producers are being required to carefully evaluate and account for the water that will be evaporated during the reclamation phases of their proposed operations.

4) Not all the local governments have taken advantage of the flood-plain regulations subtly inherent in HB 1529. Managing flood-plain gravels for mineral conservation is an effective method of diverting development from the hazardous zones.

5) Even though the bill has been law for 6 years, I find a general ignorance yet as to its existence, what it does and what it does not do, and the exact role of local government. However, I have found that once people do find out, they talk to the local agencies and to the Survey before engaging in certain land sales, development plans, and rezoning procedures. In recent pit and quarry applications the aggregate companies have cited our mapping and report as evidence for commerciality of the deposits and the need for extracting them. So the industry is well aware of our efforts. Opponents to these proposals generally understand neither the mechanics of the bill nor the physical and economic constraints under which the industry must work in selecting, evaluating, and securing new mine sites.

6) Probably the biggest questions that come to my mind now are whether or not Jefferson County can

implement its master plan and whether or not it can effectively deal with the current interest in quarry aggregate. Obviously the new quarry proposals are too much for the county to handle at one time. The resolution of these problems is imperative because the quarry alternative will likely be the more economically popular of the two very long-term alternatives to the aggregate shortage in the metro area.

7) Another stumbling block is that no clear precedent has yet been set regarding quarry blasting and especially quarry reclamation in Colorado. Results of monitoring the currently active quarries should strongly influence the operation of the proposed sites. Because of the long-term nature of these operations, reclamation plans and economics may be subject to future modification, especially if the State chooses to overhaul the statutes again. Future revisions could conceivably force mine closures and other legal ramifications.

8) Metro area aggregate production will increase to satisfy the current construction and development boom, and an increasingly larger portion of that supply must come from crushed-rock quarries but from relatively few actual sites. Price figures suggest that although production has fluctuated greatly in recent years, the averge price has risen. According to U.S. Bureau of Mines figures, the 1977 average price of sand and gravel has doubled since 1967. That for crushed stone increased 44 percent in the same period. Inflation, quarry economics, transportation constraints, land availability, longer and more inclusive technical and environmental studies, and rising energy costs all will contribute to higher prices for these traditionally low-unit-value materials.

9) Unfortunately the predictions made many years ago have apparently come true--the gravel reserve has reached a critically low level. Metro producers have exercised all their alternatives to a certain degree, but two options have become most popular--1) develop lower-grade gravels farther from the metro markets, and 2) develop quarry aggregate deposits closer to the Denver markets. Ultimately, after depletion of the lower South Platte River reserve, the use of unit trains and manufactured aggregate likely will become more viable. However, these latter two alternatives are rather selective and involve unusual economic and logistical conditions.

THE REST OF THE STATE

Although the shortage problems and significant shifts in industry activities have not been felt in other areas of the State, other producers have been caught up in the paperwork required by the last revision of the mining and reclamation laws (HB 1065). Slight relief and somewhat speedier permit processing is granted to a) operations affecting less than 10 acres and extracting less than 70,000 tons annually, and b) short-term aggregate operations supplying road construction materials under government contracts and affecting less than 10 acres.

House Bill 1041 is another piece of legislation that deserves some discussion. This rather cumbersome land-use law passed in 1974 charged the Survey to assist the counties in identifying important mineral resource areas so that they could "designate" such areas in a way as to limit uses on or maintain access to the deposits. Under the bill's provisions, aggregates would be managed the same way as all other minerals outside the HB 1529 area. Mineral resource maps have been prepared for at least 12 counties, but they have not shown all the detail that we would have liked. The Survey's model study for Mesa County, released this spring, dealt heavily with aggregate deposits in the Grand Junction area--the center of western slope population and activity. Economical flood-plain gravels along the Colorado River there currently support gravel mining, open space, orchards and other agriculture, and vacant land. Very little of the flood-plain deposits has been lost to development. The County has successfully diverted growth onto the terraces and other higher ground. If the County continues this practice (for whatever reasons), it can maintain adequate aggregate resource lands to support its anticipated growth and avoid the shortage problems that have plagued other metro areas. In the last few years Mesa's population reached 65,000, which would qualify it for inclusion into HB 1529. However, whether or not the bill would retroactively apply in this case has not been legally determined. Once the County incorporates our mineral resource maps and information into its plans, under the label of HB 1041 or anything else, I believe it shall have satisfied whichever of the two laws may apply.

CLOSING

Overall I believe that HB 1529 was a strong and specific law, but its one or two weaknesses were quite detrimental to its effectiveness at the local level. Perhaps the law came too late, and the alternatives that industry has put into action could not have been avoided. Certainly the earlier predictions would suggest that. However, this act and HB 1041 will, I think, be successful on Colorado's western slope, and the problems I have outlined can be avoided if protective measures are adopted early in the planning process. For the Denver area in the 1970s, we have seen drastic shifts in the aggregate industry in terms of locating and securing long-term supplies of construction raw materials. As we look toward the 1980s, Colorado will enter a new era in its mining heritage and history.

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Production and Marketing of Rotary Kiln Expanded Shale Lightweight Aggregates

by

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I would like to begin my presentation with a brief outline of the history of lightweight aggregates before going on to the production and marketing aspects of our modern-day products.

Many of you may think of lightweight aggregates and lightweight concrete as fairly new developments in the construction industry, but the fact is that lightweight concretes have been used in construction since before the days of the Roman Empire (Expanded Shale, Clay and Slate Institute, 1971). Grecian and Italian pumice were used as aggregate with ordinary hydrated burned lime serving as the binder in the mix. Although the early lightweight concretes were obviously not of great structural value, they were amazingly durable, and examples of these early lightweight concretes can still be found in the Mediterranean area.

Up until the discovery of Portland cement in 1824 by Joseph Aspdin, an English bricklayer, cements were so weak that the aggregates, both lightweight and normal-weight, were stronger than the cement binder used to hold them together. Until this time, lightweight and normal-weight concretes were roughly comparable in performance. However, with the advent of modern Portland cement manufacturing, lightweight concretes made with natural aggregates could no longer provide the structural strength matching that of normal-weight concrete.

Stephen J. Hayde, of Kansas City, Missouri, is universally recognized as the founder of the rotary-kiln expanded-shale lightweight aggregate industry. Mr. Hayde was a brickmaker and contractor in the early 1900s and was familiar with a perennial problem of the brickmaking industry--that of abnormal bloating of some of the brick as the shale used to make them expanded when subjected to high temperatures of a brick kiln.

Mr. Hayde reasoned that the bloated bricks that were then being discarded had the characteristics of a high-quality lightweight aggregate: low density due to the microscopic nonconnected air cells produced by the expansion of gases during bloating, and a glasslike hardness that would provide high particle strength.

Mr. Hayde's ideas were put to the test by the entry of the United States into World War I. In order to save steel for other essential purposes, the federal government decided to try to make ship hulls from concrete. The National Bureau of Standards was directed to begin research on this project, but they soon found that normal-weight concrete was too heavy, and any of the commonly available lightweight concretes made from pumice, cinders or scoria, lacked the strength or impermeability required for this unusual application. The researchers learned of Mr. Hayde's product, which was still in the development stage. With further research, he was granted a patent on the product, and Mr. Hayde in return granted free use of his product for the shipbuilding program.

The result of these efforts was the christening in June 1919, of the USS Selma, by far the largest concrete vessel ever built in the United States, and the first built with concrete made of rotary-kiln expanded-shale lightweight aggregate. With a length of 434 ft, she weighed 7,500 tons and had a 13,000-ton full cargo displacement (Willson, 1953).

The lightweight aggregate for the Selma project was produced in rotary kilns operated by Atlas Portland Cement Company of Hannibal, Missouri, using Mr. Hayde's process. The hull was 5 in. thick on the bottom and 4 in. thick on the sides. The structural design used 1,165 lb of smooth reinforcing bar per cubic yard of concrete.

Although the war was over by the time the Selma was christened, she did have a short but satisfactory career transporting crude oil into Galveston, Texas.

The Selma was the predecessor of many more concrete ships that saw duty in battle zones in World War II, but, more importantly, the Selma proved the performance of rotary-kiln expanded-shale lightweight aggregates and put the material into production on a large scale. The first private commercial plant for producing expanded-shale aggregate was built in 1920 in Kansas City, Missouri. It was called the Haydite Company, and to this day Haydite is a commonly used term referring to expanded-shale lightweight aggregates produced by the rotary-kiln process.

PRODUCTION OF BUILDEX AGGREGATE

Today rotary-kiln lightweight aggregate plants are located all over the world; 35 plants operate in the US alone. The Buildex plants are located in Ottawa and Marquette, Kansas, and serve a trade territory covering all or parts of Kansas, Missouri, Colorado, Nebraska, New Mexico, Texas, Oklahoma and Arkansas.

Our plants are sited on very large uniform deposits of shale. The Marquette plant is on the Kiowa Shale Formation. The Ottawa plant is on the Weston Shale. Figure 1 is a view of the shale pit at Ottawa. The Weston Shale is a member of the Stranger Formation of Middle Pennsylvanian age and is a grayish-blue to medium-gray marine shale. The clay mineralogy is remarkably uniform vertically with illite, kaolinite and illite-mixed layer clay minerals present. Quartz is the major nonclay mineral impurity.

Figure 1.

At our Marquette plant the shale is a unit in the Kiowa Formation of Early Cretaceous age, much younger than the Weston. Another marine shale, it varies in color from light-gray to black. The clay mineralogy is mostly illite with the presence of some montmorillonitic clay minerals that create an extremely plastic material when wetted.

Buildex lightweight aggregate is made by heating shale at very high temperatures in a kiln. The properties of the shale are of primary concern when determining the location for a lightweight-aggregate plant. Very few shales will bloat properly, and the extent of bloating and thus the density of the finished product will vary significantly among different deposits.

The shale is mined with either a power shovel and truck (Figure 2) at Ottawa or a self-loading scraper at Marquette and is hauled about 3/4 mile to surge piles at the plant site. We have found it important not to allow the Weston Shale (at Ottawa) to air-slake by being exposed to the atmosphere for long periods of time. The Weston Shale has a normal moisture content of 17 percent as it is being mined. If the shale is loosened and left exposed to the atmosphere for any length of time, it will lose this moisture and begin to break down into smaller particle sizes. This makes the shale harder to bloat and produces too many fines in the kiln clinker.

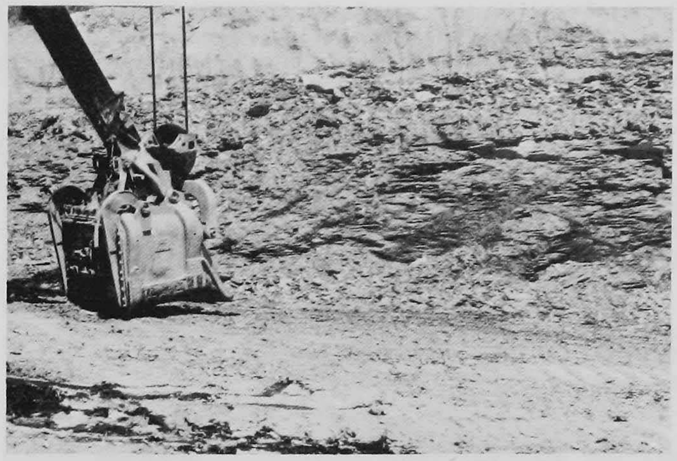


Figure 2.

The opposite is true with the Kiowa Shale at Marquette. The Kiowa Shale is very plastic when it is mined at its natural moisture content of 22 percent. To obtain good handling characteristics and the best bloatability, the shale is left exposed to the air for approximately 3 days before further processing.

Figure 3 shows the surge piles that feed the shale into the rotary kilns where it is heated to over 2000°F in approximately one hour. Our plants employ a total of seven rotary kilns, which are 8 ft in diameter and 125 ft long. Annual production capacity is 400,000 cu yd of expanded shale.

Figure 3.

As the shale travels down the kiln toward the bloating zone, it is expanded by the heating of gas-forming compounds in the shale. Figure 4 is a close-up of the expanded shale, which has been broken open to show the internal air-void structure. Properly bloated shale is heated to the point of incipient fusion, which is white hot and in a plastic state. If the shale is heated too hot, the particles will melt and begin to stick to each other and to the walls of the kiln. The kilns operate continuously and must be monitored closely to insure that the shale is bloated properly.

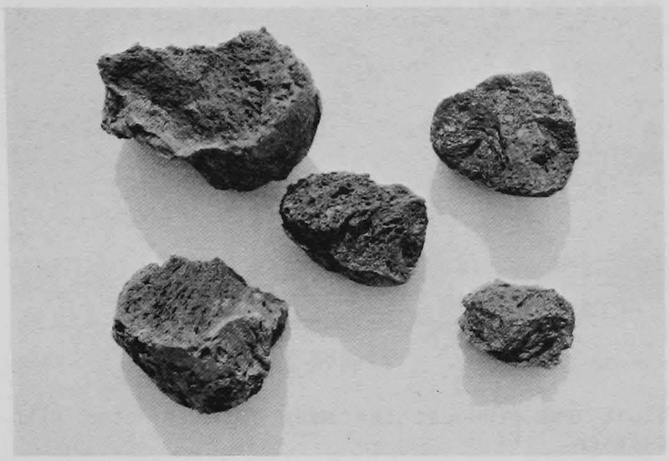


Figure 4.

After being fired, the material is discharged from the kiln and allowed to cool and solidify. However, it still retains the mass of small, unconnected air cells that formed during expansion and that cause the aggregate particles to be light in weight. Chemically the material is about 65 percent silica (SiO_2) and 20 percent alumina (Al_2O_3), with minor amounts of other oxides, and is very hard, almost glasslike, in composition. Figure 5 shows the expanded shale clinker as discharged from the kiln. The aggregate particles are generally rounded or cubical in shape and have fairly smooth surfaces. The specific gravity ranges from 1.0 to 1.7, with the larger particle sizes having the lower specific gravity. Loose density is 40 to 60 lb/cu ft, again depending on particle sizes. This is less than half the density of normal sand and rock aggregates.

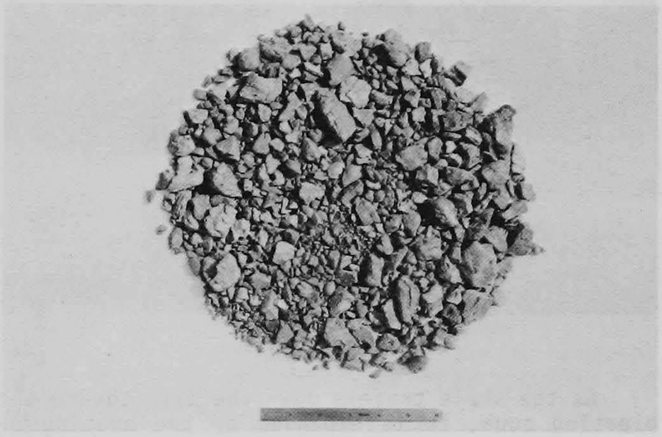


Figure 5.

Figure 6 is a general view of our production plant at Ottawa. I have not included pictures of our Marquette plant since they are both similar in layout and methods of operation. The flow of material in Figure 6 is from right to left. The raw shale is held in the silo and surge pile on the right and then fed into the rotary kilns, which are covered by the long metal building. The ductwork and fans for our stack scrubber are visible in front of the kiln building. The kiln clinker is stored in the middle silos, and the finished product sizes are stored in the silos at the left, with the screening system on top of the silos in the metal building. The clinker surge pile is visible on the far left.

Figure 6.

The "expansion factor" in the rotary kilns is about 66 percent, meaning that for every cubic yard of shale fed into the kiln, 1.67 cu yd of clinker is produced. A cubic yard of shale weighs 2,375 lb before burning and 1,150 lb as the expanded clinker. After being discharged from the kilns and cooled, the clinker is crushed as needed and screened into four production sizes as shown in Figure 7. They are (counterclockwise from upper right) 3/4 in. to 3/8 in., 3/8 in. to 1/4 in., 1/4 in. to 1/8 in., and 1/8 in. to pan.

The individual production sizes are reblended as they are shipped to the customer, depending on the intended use. For instance, most block plants use 3/8-in. to pan blend, while a 3/4- to 1/4-in. blend is used for coarse aggregate for ready-mixed concrete. The screening and reblending give us good control over the actual gradation of the blended material we ship, and help insure the customer receives uniform material from load to load.

The energy consumption of the Buildex production process is around 2.5 million Btu/cu yd of clinker. Burning natural gas makes our lightweight aggregate an "energy-intensive" product. However, since concrete made with Buildex aggregate has a higher thermal insulation factor than normal-weight concrete, an analysis shows that the energy consumed to produce a cubic yard of aggregate is recovered in 1.3 years when the aggregate is used to produce lightweight concrete blocks. That's an energy payback of over 22 times, assuming a 30-yr life of the building. This analysis compares heat flow of lightweight block construction to

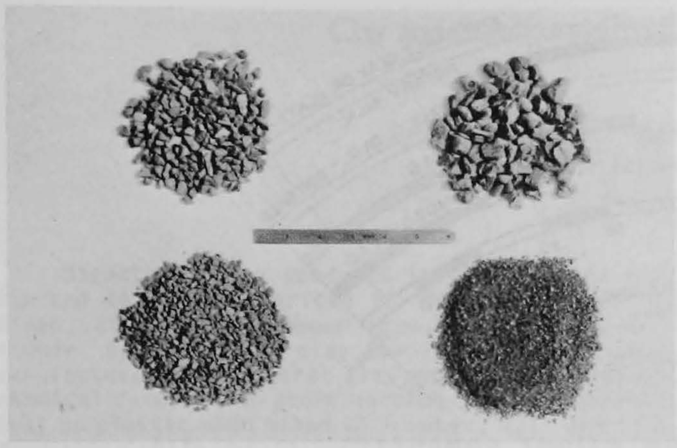


Figure 7.

normal-weight block construction and is calculated on the difference in "U" factors for an 8-in.-thick wall using the Degree Day method for the heating season only for a theoretical exterior wall of a heated building in Kansas City, Missouri. The analysis uses the traditional steady-state U factor and does not include a thermal mass correction.

We are constantly striving to reduce the energy consumed in the manufacture of Buildex aggregate. With energy costs becoming an increasingly significant part of our selling price, we must continue to improve the energy efficiency of our manufacturing process.

MARKETING ADVANTAGE AND USES

The primary use of expanded-shale lightweight aggregate in the United States is in the manufacture of lightweight concrete blocks. A typical 8-in.-thick lightweight block will weigh about 22 lb while the same block made of sand-gravel will weigh about 40 lbs. Lightweight blocks meet the same strength and quality requirements as regular normal-weight blocks, as specified by ASTM C-90, "Standard Specification for Hollow Load-Bearing Concrete Masonry Units." Their lower weight helps reduce the manufacturers' costs by allowing a larger load to be carried by the truck delivering the block to the jobsite. Also, they are easier and faster for the mason to lay up in the wall, meaning that the project can be completed sooner. Lighweight blocks reduce the dead loads on a building's foundation and have a higher fire-resistance rating and a more improved acoustical absorption than normal-weight blocks.

One of the most significant advantages of lightweight blocks over normal-weight blocks is their higher thermal insulation values. The U factor of a typical 8-in. lightweight block wall is 0.17 Btu/hr-sq ft-F°, which is less than half the heat transmission of a normal-weight block wall having a U factor of 0.36. These figures are for a block wall with cores filled with loose-fill insulation; the relative difference is similar for walls with empty cores.

This savings in heat transmission of a lightweight block wall is significant, especially for exterior walls in a heated building. Using the Degree Day method of analysis for the heating season only in Kansas City, the savings in heat flow would amount to 5.4 cents/block per year, at current energy cost levels using natural gas forced-air heating. Again, steady state U factors were used with no thermal mass correction. The differential price of a lightweight block over a normal-weight block can vary widely in different areas of the country.

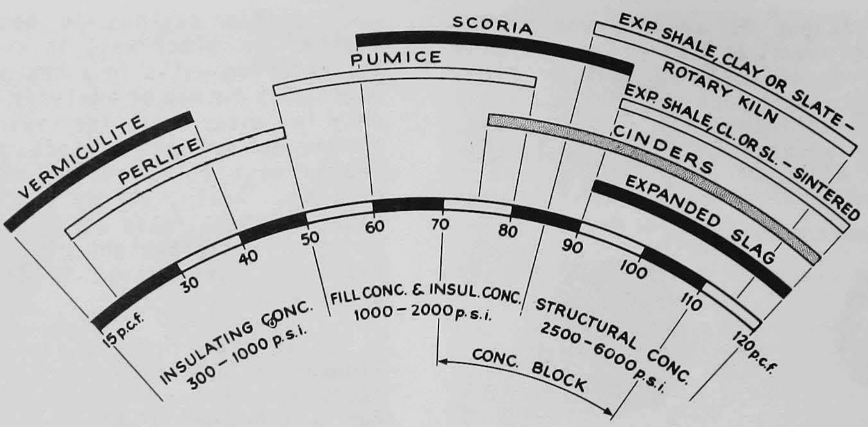
In some cities, such as Kansas City, the lighweight and normal-weight blocks are priced exactly the same. In other areas the premium price for a lightweight block may be as much as the recently reported price of 30 cents in Los Angeles (Engineering News-Record, 1979). An average calculated in 18 North American cities and reported in the May 10, 1979, Materials Prices Section of Engineering News-Record was 7.0 cents/block.

Comparing the average premium price of 7 cents/block with the savings of 5.4 cents/block per year shows that the pay-back period on the investment for lightweight block is less than a year and a half. Looking at it another way, that is a 77-percent annual rate of return on the invested money, and that rate will increase as energy costs continue to escalate.

While lightweight concrete masonry comprises the majority of use of Buildex aggregate, with around 80 percent of our production going into block, another important and highly visible market for our product is in lightweight structural concrete. From the San Francisco-Oakland Bay Bridge to the World Trade Center in New York City, many significant structures that have been built take advantage of the excellent strength and reduced weight of expanded-shale lightweight concrete. The recently completed parking garage addition at Stapleton Airport, here in Denver, as well as many of the high-rise office buildings being built downtown, use Buildex lightweight concrete.

To give you an idea of how expanded-shale lightweight aggregate concrete relates to other lightweight concretes that are currently available, I would like to present the "spectrum" (Figure 8) of lightweight concretes available today.

As you can see, a wide range of strengths and weights are possible with lightweight concrete made from different aggregates--from low-density insulating concretes weighing as little as 15 lb/cu ft up to the structual lightweight concretes weighing over 80 lb/cu ft. These structural lightweight concretes are essentially equal to normal-weight concrete in strength, but weigh only 80 to 120 lb/cu ft while normal-weight concrete weighs about 145 lb/cu ft. The insulating and fill concretes are much lighter than concretes made with expanded shales, but to obtain this extremely low density, one sacrifices strength; none of them could be considered structural concretes capable of 2,500-psi compressive strengths.



WEIGHT SPECTRUM OF LIGHTWEIGHT CONCRETES

Figure 8.

The reduction of up to 50 percent of the weight of the concrete is important to a structural engineer designing a building because the reduced weight means less dead load on the bearing walls and on the foundation. In many cases the size of supporting columns can be reduced, thereby allowing more useable interior space. Similarly the number and/or size of reinforcing bars can be reduced.

All of these factors can provide economies in construction that will more than pay for the $6.00 to $8.00 premium price charged in most areas for a cubic yard of expanded-shale lightweight concrete with a design weight of 110 lb/cu ft. Other advantages, such as improved fire resistance and better insulation, will provide even more savings for the designer and building owner.

Another use for expanded-shale lightweight concrete that has become very popular over the years is in precast and prestressed concrete products. Design strengths of 5,000 psi and more are easily met, and the reduced weight of the concrete often allows longer spans to be achieved that were not possible with normal-weight concrete. Considerable savings can be realized in the expense of hauling the products from plant site to the job, and of setting them in place once they are on the jobsite.

By their very nature, expanded-shale lightweight aggregates are excellent for use in refractory concrete, since they are stable at service temperatures of up to 2000°F. Thermal insulation values are also very good. In cases where temperatures will exceed 1000°F, a calcium-aluminate-type cement should be used as the binder rather than normal Portland cement.

Uses for expanded-shale lightweight aggregate in other applications are a small but growing part of our industry. Our lightweight aggregate provides excellent skid resistance when used as the aggregate in concrete or hot-mix asphalt pavements and in asphaltic seal coats used to rehabilitate highways.

Due to the cellular nature of Buildex expanded-shale aggregates the asphalt wearing course will not "polish" as it would when constructed with some normal-weight aggregates. So the road surface retains excellent skid resistance as it is being worn. In certain areas of the country, most notably Texas and Louisiana, the lightweight aggregates for this use have been very popular, due mainly to the scarcity of high-quality normal-weight aggregates. This use should become more popular throughout the country as good-quality normal-weight aggregates become less available and more costly.

The use of expanded-shale aggregates in horticulture is another growing market. The cellular structure provides high moisture absorption and retention when the lightweight aggregate is mixed into the soil. This also aids in the aeration of the soil, which is especially important in tight, clayey soils that can become highly compacted.

In closing, I would like to reemphasize that expanded-shale lightweight aggregate is a versatile, high-quality product for use in concrete, concrete masonry, and many other applications. Our industry has seen significant growth since its inception almost 60 years ago, and today lightweight concrete is widely known and used in design by architects and engineers to provide long-term economy for the owners of structures built with expanded-shale lightweight concrete products.

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Clay and Structural Clay Products in the Denver Area

by

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Structural clay products include but are not limited to building bricks of all types, roofing tiles, floor tiles, sewer pipe, flue liners and flower pots. The clay bodies used in the manufacture of structural clay products vary as to chemical composition and mineralogy, but in general must be plastic when mixed with water, must dry to a hard state while retaining their shape, and must be capable of being converted to a stable mineral assemblage upon firing in a kiln. No attempt will be made in this paper to define clay or clay body other than to require that one of the constituents be a clay mineral. It would be possible to make up a body capable of being converted into a structural clay product without any clay minerals. However, clay bodies are almost always made from sediments or sedimentary rocks that contain, in the mineralogy, important percentages of clay minerals.

Considering that a clay body must be formed, dried, and fired and that the resultant product must meet color, physical and/or chemical specifications, it is not difficult to understand that a single naturally occurring clay will probably not meet all these requirements. This is most true in the Colorado region of the Rocky Mountains. While one or two clays may be blended to give the desired properties, generally five or six clays are required, and it is not uncommon to blend up to ten or twelve clays.

A sewer pipe must pass specifications as to the permeability of water under pressure through the walls of the pipe. Brick specifications are less stringent and require that porosity be kept under the maximum allowed. In contrast, a flower pot must be permeable to water. These varying specifications as to the action of water on the products have been mentioned to illustrate only one of the physical differences among structural clay products. The physical state of the fired product will depend on the clays used in the manufacture of that product and also just as strongly on the processing of the clays.

MINERALOGY

One of the most important characteristics of a clay is the mineralogy, both quantitative and qualitative. The chemical composition, given in weight percent of the oxides, offers some information as to how the clay will respond to a rate of temperature change or a final firing temperature. It will offer virtually no information on plasticity when mixed with water. If a body from the oxides or simple compounds was chemically equivalent to one of the clays listed in Table 1 and then processed identically with the clay, several differences would be apparent. The body made of oxides would exhibit no plasticity when mixed with water, would be difficult if not impossible to extrude through a die, and would have little strength when dried, probably crumbling when picked up. Plasticity is one characteristic that makes clay so versatile as to the shapes and forms it can be molded into after mixing with water. Plasticity is related to the external morphology of the clay crystals and to the particle size of both the crystals and the larger particles due to comminution processes.

Table 1. Chemical analyses of clays used in the manufacture of vitrified clay sewer pipe. Results are reported in weight percent.

	Dawson Formation (Elbert County)	Dakota Formation (Pueblo County)
SiO_2	64.4	64.1
Al_2O_3	20.2	19.7
Fe_2O_3	3.0	3.6
TiO_2	0.7	0.5
MgO	0.6	0.3
CaO	0.8	0.7
Na_2O	0.1	0.1
K_2O	1.3	0.8
loss on ignition (LOI) (1000° C)	9.4	10.5

The two products would also differ in color and physical properties after firing in a kiln. These differences would be related to the differences in the newly formed mineralogy, both kind and amount. The state of the final materials will depend on the starting materials and the path taken to reach the final firing temperature. If the two bodies remained at a sufficiently high temperature for a sufficient time to attain phase equilibrium, then the final products would be essentially equivalent. However, due to the rather rapid firing rate in commercial kilns, equilibrium is seldom attained.

Clays are quite complex, and their mineralogy is one of the important characteristics in understanding and predicting the behavior of the clay in the manufacturing process. Bricks and other clay products have been made for centuries without any knowledge of mineralogy or chemical composition. This is true of the industry today, but with increasing demands being made on the products and with present-day manufacturing technology, a complete understanding of the materials has been totally neglected. For example, most manufacturers are aware of the alpha to beta transition of quartz and adjust their kiln heating rate accordingly.

Chemical analyses of two clays used in the manufacture of vitrified clay sewer pipe are shown in Table 1. The two clays came from localities over 100 miles apart and were deposited in different geologic periods. Nonetheless, they exhibit a remarkable similarity in chemical composition. It must be admitted that the analyses are not complete; for example, carbon is not listed separately from the LOI. Carbon is found as a finely disseminated element in many clays and cannot be ignored as an important ingredient in the clay. However, the oxides as listed still show a remarkable similarity. There exists a great difference in their physical and thermal properties. The Dakota Formation sample has a Pyrometric Cone Equivalent (PCE) of 23-24 and is semiplastic when mixed with water. The Dawson Formation sample has a PCE of 19-21 and is quite plastic. Furthermore, the Dawson clay has a tendency to bloat at a fast heating rate.

X-ray diffraction analyses of the two clay samples (Dakota and Dawson) are listed in Table 2. There is a difference of ten percent kaolinite between the clays and only two percent in the amount of quartz. The remaining minerals may be treated as fluxes that will react with themselves and with the quartz to form a glassy or vitreous phase when heated to 2000°F or greater. Kaolinite will decompose and then recrystallize to form mullite and crystalline silica. In a greatly simplified mineralogical explanation, the fired clay will consist of mullite, quartz and other solid phases with a vitreous phase acting as a bond between the crystalline phases. In general, the kaolinite forms solid phases and adds refractoriness while the other minerals, excluding quartz, act as fluxes in forming a siliceous glass. Quartz is, to a great extent, inert and will react with the fluxes depending on their amount and the amount of silica the fluxes themselves contain. The mineralogical explanation of the differences in clays and their reaction to heat is beneficial in understanding and predicting the behavior of clays in the manufacturing process.

Four clays from four geologic formations reported in Table 2 show the mineralogy of some of the more important clays used in structural clay products east of the Front Range in Colorado. Of the clay minerals kaolinite, illite and montmorillonite, the dominate one is kaolinite. Quartz is a major constituent in each of the formations. The remaining minerals can be considered as minor but are a major influence on overall manufacturing processes.

Table 2. X-Ray Diffraction analyses of bulk clay samples used in the manufacture of brick and pipe clay products. Results are reported in weight percent.

	Benton Fm.	Dakota Fm.
Kaolinite	50	56
Quartz	40	38
K-Feldspar	3	3
Illite or Muscovite	2	2
Gypsum	2	---
Calcite	---	---
Montmorillonite	---	---
Unidentified	3	1
	Dawson	Laramie
Kaolinite	46	30
Quartz	40	48
K-Feldspar	6	5
Illite or Muscovite	2	3
Gypsum	2	---
Calciye	0.5	2
Montmorillonite	2	8
Unidentified	1.5	1

Laramie Fm. - Jefferson County
Dawson Fm. - Elbert County
Dakota Fm. - Pueblo County
Benton Fm. - Jefferson County

Benton Formation

The analysis of this sample gives a high kaolinite content, 2 percent illite and no montmorillonite. Beds of montmorillonite are known in the Benton, particularly in the lower section that is mined. Lenses of iron oxides also are visually apparent but were not detected in this diffraction analysis. Iron oxide compounds are frequently found in an amorphous state in clays and would not be detected by X-ray diffraction. This clay exhibits a characteristic of blisters or "iron spots" that develop on the surface of the product when fired in a reducing atmoshere. Analysis of the blisters has shown high concentrations of iron. This clay is used in both brick and pipe products, exhibiting good drying properties. It should be mentioned that the drying process is one of the least understood phenomena in structural clay products, reflecting the complex nature of the clay-water system in regard to chemistry, mineralogy and mechanics. The Benton has a PCE of 15-16, which is not consistent with the X-ray diffraction analysis. However, one must realize that noncrystalline compounds not detected by X-ray diffraction techniques can significantly affect the PCE value.

Laramie Formation

Kaolinite is the dominant clay mineral with a significant amount of montmorillonite. Montmorillonite, along with illite, has been reported by Gude (1950) in the lower part of the Laramie. Montmorillonite is associated with lignite zones in the clay. This sample was taken by cutting across near-vertical veins for a distance of 100 ft or more. The veins consist of clay, siltstone, and sandstone. In this particular section of the Laramie, no attempt is made to selectively mine the clay as the veins are too narrow. A high quartz content is the result of mining the sandstone and siltstone. The PCE of 14-15 is the lowest of the four clays summarized in this paper. The PCE value will fluctuate widely as the relative amounts of clay and sandy material change. In spite of the low clay content, the material has a red color when fired and is useful for bricks and "filler" clay.

Dakota and Dawson Formations

Both of these formations have been discussed earlier as to mineralogy and chemical compoosition. Plasticity is good, and the high kaolinite and low flux content give both clays excellent fired strength.

GEOLOGY AND MINING

A generalized section of the rocks in the Golden-Morrison area is presented in Figure 1. Of these rock units, six are reported by Crosby (1976) to be productive clay units: Dakota Group, Benton Shale,Pierre Shale, Laramie Formation, Arapahoe Formation, and the Dawson Arkose. The Dawson Arkose is not listed in Figure 1. It was deposited contemporaneously with the Arapahoe Formation and the overlying Denver Formation. The formation lies to the east and south of the Denver-Golden area. Waage (1952) reports brick and tile clay being mined at one time in the Lykins, Morrison, and the Lytle Formation of the Dakota Group.

As one travels west from Denver toward the Front Range, the rock strata lie horizontally. Near the hogbacks the strata are sharply upturned, dipping toward the east at 55° to 60°. The younger strata lie on the east, and successively older strata crop out as one moves west. In places the strata have been overturned and 80° to 90° to the west. The upturned beds that are exposed in this area make mining of the clays feasible as immediately to the east they lie at considerable depth. Clay mined in the upturned beds includes the Dakota, Benton and Laramie. The Laramie is also mined farther to the northeast in horizontal beds. This is also true of the Dakota in Pueblo County.

The Dawson Arkose lies to the south and east of the Golden-Morrison area. The sediments are horizontal and mined in two localities. In the Parker-Castle Rock area the sediments were deposited by laterally shifting streams moving eastward from the Front Range. The clay occurs in local pockets of arkosic sandstone and conglomerate rich in mica and feldspar. Even farther to the southeast near Kiowa, the clay is finer grained and appears to be lake deposited. At present, more structural-grade clay is probably mined from the Laramie than from any other formation. Veins of sufficient thickness to be mined selectively are present as well as thin veins interbedded with sandstone and siltstone that are nonselectively mined. Zones rich in montmorillonite that are not now mined are a

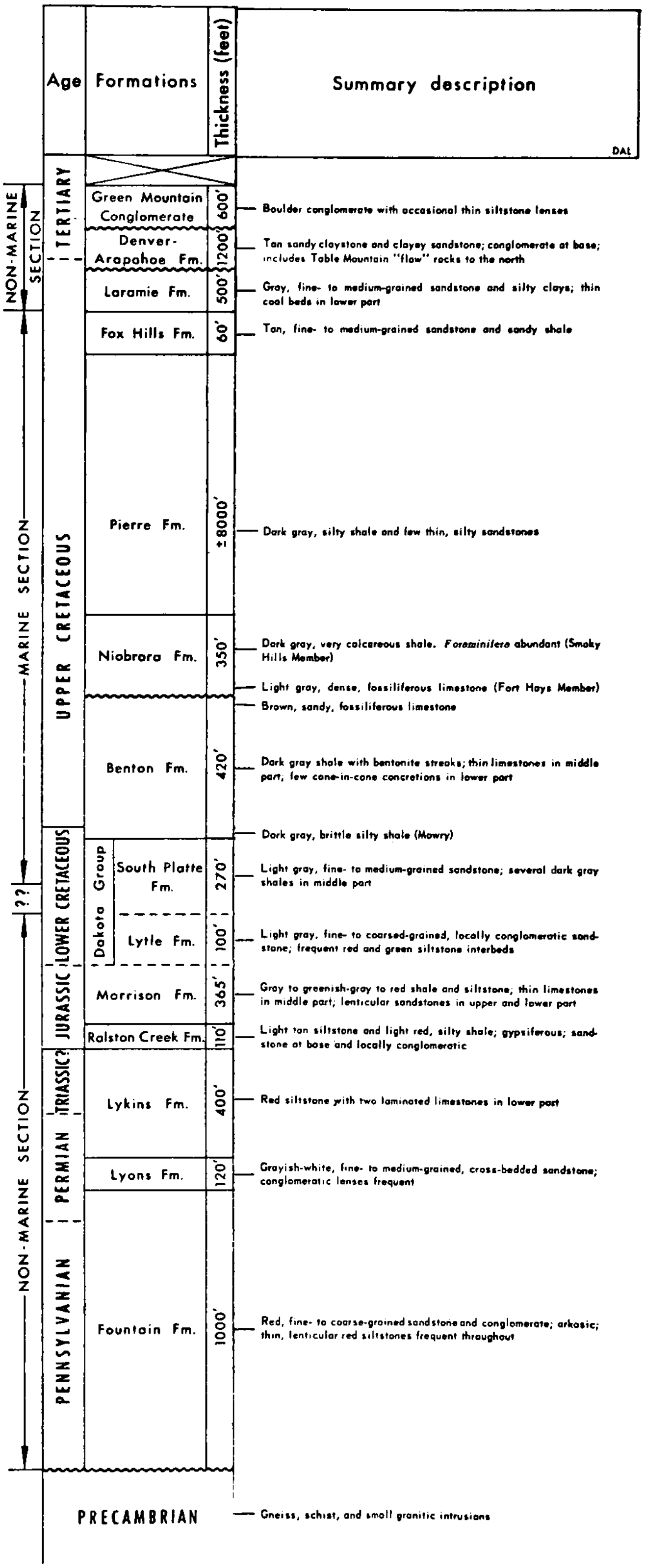

Figure 1. Generalized section of the Golden-Morrison area (adapted from LeRoy and Weimer, 1971).

potential future source of low-firing clays. Due to the large amount of fluxing minerals such as montmorillonite, these low-firing clays can be fired at a lower temperature than most structural grade clays, thereby conserving significant amounts of energy.

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Raw Materials for Technical Ceramics

by

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Kingery and others' (1976) Introduction to Ceramics notes that the annual production in the ceramic industry amounts to nearly $20 billion. The major raw materials for the production of technical ceramics account for 90 percent of the earth's crust--compounds of silicon, oxygen, and aluminum. The dominant minerals used in the ceramic industry are inorganic, nonmetallic, crystalline solids that were formed by complex geological processes. Since these aluminum silicates are widely distributed, they are relatively inexpensive and thus provide the high-tonnage products for the ceramic industry. These are abundant sources of low-grade clays to manufacture technical ceramics. These fine clays require more control than the low-grade clays and are normally beneficiated by mechanical concentration, froth flotation and other relatively inexpensive processes.

MAJOR RAW MATERIALS

The most widely used raw materials are clay minerals. These fine-grained hydrous aluminum silicates develop plasticity when mixed with water. They are found in nearly every state of the United States and in all countries of the world. The world production (Sutton, 1979) of this one raw material exceeds 50 million tons of which more than 1 million tons is the high-grade material required for the manufacture of ceramics. The demand for these high-grade kaolins, ball clays, fire clays, and bentonites will increase as the ceramic industry grows.

The most common clay minerals, the kaolinites, are of primary interest to the ceramist. They are the major components of high-grade clays and are based on the struture $Al_2(SiO_2)\ (OH)_4$.

The clays, as complex oxides, are necessary materials to ceramic manufacturing because of the following physical properties: softness, lubricity, and easy cleavage. Clays perform two important functions in ceramic bodies. First, they impart a characteristic plasticity to the body that not only serves as the basis of most of the common forming techniques but also assures that the clay/water mixture will maintain its shape and strength during drying and firing. Secondly, the kaolinites fuse over a wide temperature range, depending on their particular composition, in such a way to become dense and strong. They aid in the firing mechanism to attain economic temperatures for production.

The most abundant kaolin or "china clay" deposits are found in the southeastern United States (Jones and Berard, 1975). The most important deposits are located in the Carolinas, Georgia, and northern Florida. The ball clays, which are the very fine-grained kaolins, have unusual plasticity and stickiness and are found in Kentucky and Tennessee. These require a larger amount of water to get the plasticity but are more easily formed. Because they exhibit higher shrinkage in drying, they cannot totally replace kaolin in the ceramic body formulation.

The fire clays are the kaolinites that contain such minerals as diaspore, which raises the total alumina (Al_2O_3) content. These are fairly plastic and normally fire to a buff color due to impurities. They are important because of their refractory nature. Fire clays help stabilize the fired properties of the ceramic system and reduce warpage and slumpage in the fired ware. The most abundant fire clays are found in central Missouri, although numerous other deposits are scattered over the country. The kaolinites become the backbone of the ceramic formulas. They have many and varied characteristics that can be utilized to tailor the system to the needs of the finished product.

Alumina is used extensively in the manufacture of technical ceramics. It is an excellent electrical resistor and abrasive and has a high melting point. Alumina (Al_2O_3) is produced from the minerals bauxite and disapore, which are mined in Arkansas and Missouri and offshore (Africa, South America).

This basic ceramic raw material is produced by the Bayer Grain Process. The final product is 99%+ pure Al_2O_3. Recent articles in "Ceramic Industry" state that the United States has a sufficient amount of alumina to last at least the next 500 years. The limiting factor in the supply of this item will be the cost of energy to produce it. Alumina takes only 10 percent of the energy required to produce the metal aluminum. A great deal of effort now goes into other sources of manufacturing alumina, such as the acid leaching of alumina from anorthosite, alunite, and dawsonite.

This is the single most used item for the production of high-alumina technical ceramics, having body compositions of 80 to 99.9 percent pure alumina. The end application is the limiting factor of the purity of the system. Ceramic compositions are the result of tailoring a material for a specific application. As new applications for alumina ceramics become available, specialty systems will be developed.

Silica (SiO_2) in the form of quartz is utilized as a ceramic raw material. Silicon and oxygen, the most common elements, account for 75 percent of the earth's crust. It can be safely said that there is no shortage of this material. It must be qualified that only the pure grade can be used for technical ceramics. Large deposits (Sutton, 1979) of this material can be found in Pennsylvania, Illinois, and Oklahoma. These locations should be able to produce the high quality needed for technical ceramics. Transportation costs will continue to be the major portion of the purchase price of sand.

The production of technical ceramics requires fluxing materials, namely the feldspars, nepheline syenite, and aplite. The feldspars are a group of minerals that form glass at moderate temperatures. The pure spars used are albite ($NaAlSi_3O_8$), orthoclase ($KAlSi_3O_8$), and anorthite ($CaAlSi_3O_8$). These minerals often occur together in nature, and large deposits are found in New England, North Carolina, and Canada.

Talc, which is a hydrated magnesium silicate ($Mg_3Si_4O_{10}$) (OH_2), is also used as a fluxing material for ceramic formulas. Because of its low coefficient of thermal expansion, it is useful in many electrical applications. The deposits of this material in the United States should last for the next 100 years.

Organic binders is another class of raw materials essential to the production of technical ceramics. These are often petrochemical materials whose cost will increase as the supply of these items becomes shorter. They are used to impart the necessary green strength during forming operations. In the manufacture of the high-alumina technical ceramics, these become an important part of the basic formula.

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Development of a Metallurgical Limestone Deposit

by

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CF&I Steel Corporation is a fully integrated steel company that mines all of its principal raw materials from captive operations--three underground coal mines, two open pit and one underground iron mines, and one limestone and one dolomite quarry. The combined output from all of these operations is about 3.7 million tons annually. The mining engineering staff consists of eight persons, one of whom handles environmental matters. What this paper deals with is how CF&I, a relatively small mining company, is handling a particular mineral development in a controversial environmental situation, and some of the engineering aspects that are being planned.

The steel plant uses about 350,000 tons of metallurgical limestone each year at its operations in Pueblo, Colorado. The present source of this limestone is Monarch Quarry, located near the top of Monarch Pass at an elevation of 11,000 ft. In the mid-1950's, it was recognized that in 20 to 30 years this deposit would be exhausted from an economic mining standpoint, and the search for a replacement was begun.

Since limestone is a very common rock in the western United States and it is especially abundant along the Colorado Front Range, it was not expected that this would be an especially challenging assignment for our exploration department. It did, in fact, turn out to be a very formidable challenge.

Some clue to the difficulties to be encountered should have been gotten from considering the past record. (Figure 1 shows the location of the Pueblo steel plant in relation to past sources of limestone). In the beginning, which goes back to 1872, stone was mined from deposits adjacent to the steel plant, then from near Howard, Colorado, some 80 miles west of Pueblo, and from 1930 to the present from Monarch Quarry 120 miles away.

The problem arises not so much from depletion of the deposits, but from increasingly tough specifications dictated by economic steel making. The reserves adjacent to the Pueblo Plant, which have 4 to 5 percent silica, are still there in enormous quantities, but today's specifications call for 0.5 to 1 percent silica. This, combined with other chemical and physical requirements, and also the requirements that the deposit be suitable for economic mining, close to rail transportation, and located in a socially and environmentally acceptable area, made the finding a 25-yr process. A good part of the company's exploration efforts each summer was devoted to the search.

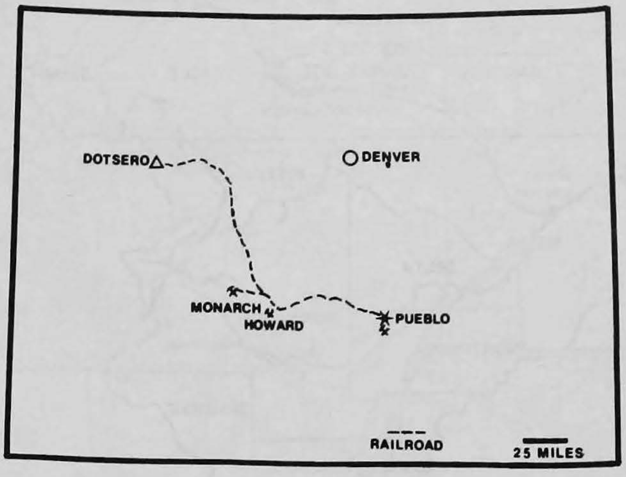

Figure 1. Sources of CF&I Limestone in Colorado.

In the early 1970's a deposit of Leadville Limestone near Dotsero, Colorado, 11 miles northeast of Glenwood Springs, was finally identified as a suitable new source. (Figure 2 shows the Leadville Limestone outcrops in western Colorado, and Figure 3 is a larger scale map of the Dotsero area). The deposit was less than 1 percent silica, had good calcining and handling characteristics, and had in excess of a 50-yr reserve with very little overburden. It was in what was thought to be a suitable environmental area, and best of all, it was located on private property only 4 miles from the railroad. The only drawback was its distance from Pueblo, which was 230 miles, or twice the distance from the present supply. (Figures 4 and 5 show scenes of the quarry area). After an initial determination of suitability was made by outcrop sampling, an option for the property was negotiated, and widespaced diamond drilling was begun on about 0.5-sq-mi intervals. This drilling was verified a fairly uniform deposit of high-quality limestone with overburden thicknesses of 0 to 100 ft (Figure 6). Subsequent close-spaced drilling confirmed an area of optimum suitability, and we now had the necessary reserve in a deposit averaging 100 ft thick, with 10 to 12 ft of shale overburden. Having located the deposit, we next began the process of obtaining the necessary permits. The permits that would be required and the agencies that would be dealt with are listed in Table 1. Note that the project is located in two counties.

To begin the permit process, CF&I filed with Garfield County in July 1975, a 37-page

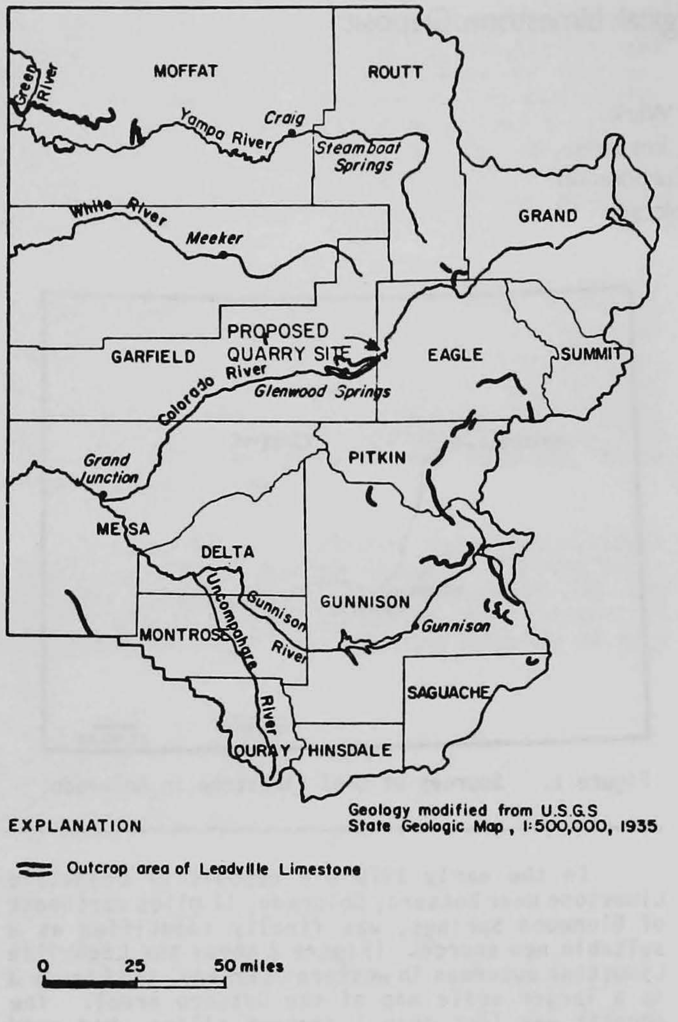

Figure 2. Approximate outcrop areas of the Leadville Limestone.

environmental report which the company felt would satisfy the requirements for a county special-use permit. This initial application was rejected as insufficiently supported, and a small group of local people banded together to oppose the project. The principal concerns of the opposition were:

1. Visual impact
2. Potential damage to caves in the area
3. Wildlife impact
4. Water impact

As for the visual impact, the initial proposal was for a 7-mile-long, 65-ft-wide haul road to accommodate a fleet of 75-ton trucks. The local people were very concerned over the impacts of the road, not only from the visual standpoint, but also for its potential dust and noise pollution. It was also seen as a barrier to wildlife migration. At this point, an independent consultant was hired to investigate alternative haulage methods. Three haulage methods were considered: trucks, conveyor belts, and aerial tram. The results of this study are summarized in Table 2.

As one can see, the tram won hands down. The only areas where trucks held an advantage were operating problems and socioeconomics. Trucks were better from an operating problem standpoint because a problem with the tram shuts down the entire haulage system. From the socioeconomic point, they are better because they make more jobs. One thing that is not shown in the table is capital cost, which was estimated to be about equal for each method. The tram should prove to be a good choice, not only from an environmental standpoint, but from a good engineering and economic standpoint as well.

The visual impact of the tram can be directly compared to a gondola ski lift, and this was something that local people could relate to and understand. As for the other visual aspects, we were able locate both the quarry and the plant site in areas that were out of site to the casual public observer.

The next big issue was the existence of nearby caves. Four known caves lie within a 2-mile radius of the quarry site, and one known as "Groaning Cave" is considered by local spelunkers to be filled with many fragile formations. The cave entrance is hidden and kept under lock and key. It is on public land and is probably visited no more than once a year by the same five or six people. The cave is 1 1/2 miles from the quarry site, and several hundred feet stratigraphically below the quarry rock formation. Figure 7 shows a typical cave environment.

A very concerted attempt was made to stop the project on grounds that it might damage this cave. Seismic testing, using quarry-scale blasts at both Dotsero and at the Monarch Quarry, was performed to determine if any potential hazards existed. These tests, done by two independent consultants, showed no possibility of cave damage. It was also pointed out that earth tremors, some of which exceeded the potential blasting vibrations by as much as twenty times, occurred an average of ten times each year in this area. The maximum recorded vibrations from blasting were under 0.05 in./sec vs the 2 in./sec that the U.S. Bureau of Mines considers as the threshold point at which damage might occur; and the 1 in./sec that federal surface mining regulations specify as the maximum allowable in surface coal mining.

The debate over wildlife was concerned mainly with the haul road presenting a barrier to the migration of deer and elk. This argument was negated by the selection of the aerial tram. The one remaining wildlife question that is being addressed concerns the peregrine falcon. No sightings of this bird have been confirmed anywhere close to our area, but the country is considered a good potential habitat. This spring CF&I put a wildlife consultant in the field for two weeks to look for signs of the falcons. This report is not in yet, but if the bird, which is protected under the Federal Endangered Species Act, is thought to inhabit the immediate area, it could be a problem. Figure 7 shows a potential falcon habitat.

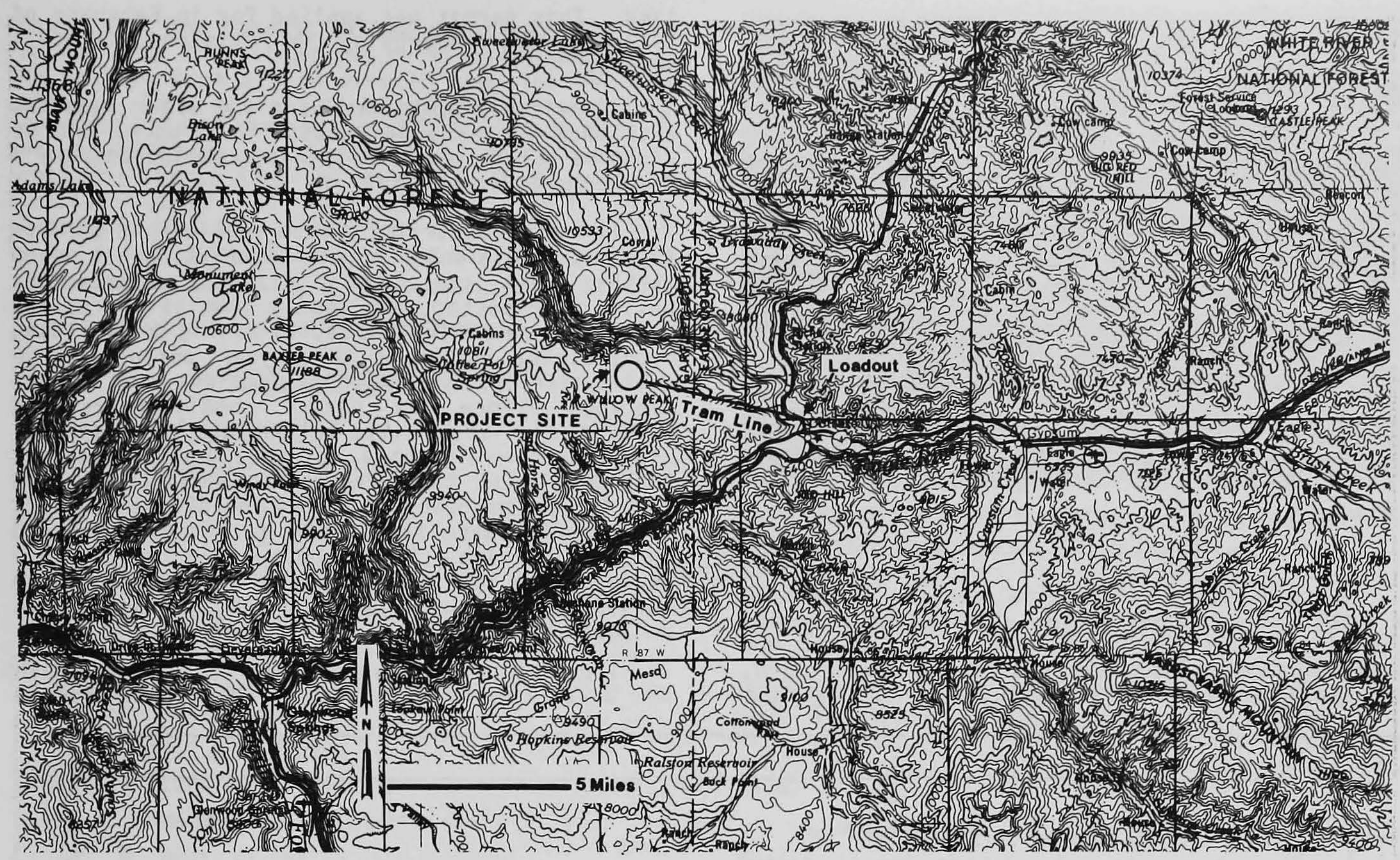

Figure 3. Location map of CF&I Steel Corporation Dotsero Project.

Figure 4. General view looking south to the quarry area. Deep Creek Canyon is in the foreground.

The last point of major concern was water, and a great amount of time, effort, and money was spent to prove the nonexistence of ground water in a geologic situation where its occurrence was very unlikely.

The principal contention of those opposing this project was that CF&I could and should go somewhere else to get their limestone. This group presented a professionally produced and narrated slide show around the State to anyone who would listen--town councils, cave clubs, hiking clubs, elementary school classes, and so on. The Town of Vail, with its dozens of ski lifts and thousands of people, would surely, by comparison with the Dotsero project, have to be considered an environmental devastation. Yet the Town Council of Vail, which is 50 miles from Dotsero, presented to the county a unanimous resolution condemning the project, without any investigation of what the project entailed.

The main theme of this presentation was that CF&I, at the time, and by the standards they chose to use, was the most profitable steel company in the country. CF&I could, therefore, afford to go to practically any expense to get limestone from some other source.

As a result of over 20 years searching, it is known that such a source of equal quality limestone in Colorado could only be found in an environmentally less acceptable area, and if it came from outside Colorado, it would be three to four times the distance from Pueblo than is Dotsero. Using this outside source would have the environmental and economic impacts of tripling the energy required to move the stone to Pueblo from Dotsero (an additional 2,000,000 gal of diesel fuel annually).

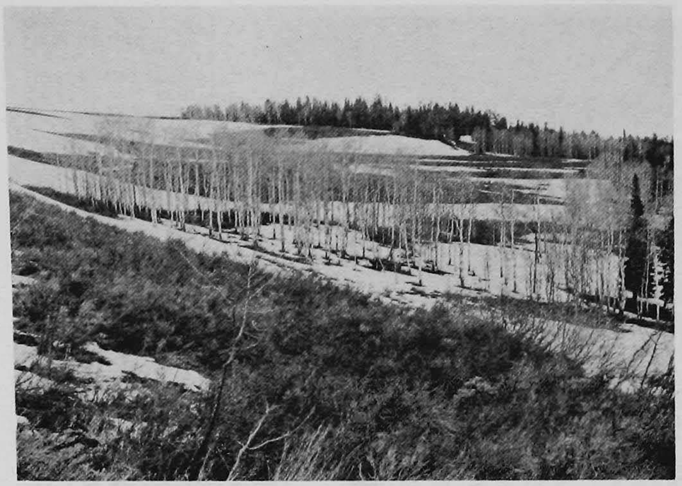

Figure 5. Proposed quarry area, looking north.

At this point the principal concern is getting a Bureau of Land Management right-of-way permit. Even though the quarry and all of its plant and terminal facilities are situated on private land, the aerial tram will cross about 2 miles of public land. This permit was applied for in February of 1977 and after undergoing two revisions, is still pending.

Previously mentioned were the other agencies with whom it has been necessary to work, and it might be helpful to briefly describe the company's involvement with each.

It was necessary to secure special-use permits from both Eagle and Garfield Counties. This meant working with the County Planning Commission, building inspector, and county commissioners, and thoroughly reviewing the county zoning and building regulations. During a three-year period, three public hearings, three public meetings, and 24 open meetings before the county commissioners and planning commissions were held before these special use permits were granted. It should be pointed out that even though the three years seemed like a long time for the granting of these special-use permits, the counties were faced with a controversial and unique situation. Both sides worked through this period with a true cooperative spirit, and undoubtedly a more environmentally acceptable project resulted.

The State of Colorado's involvement began with the State Land Use Commission (LUC) who became

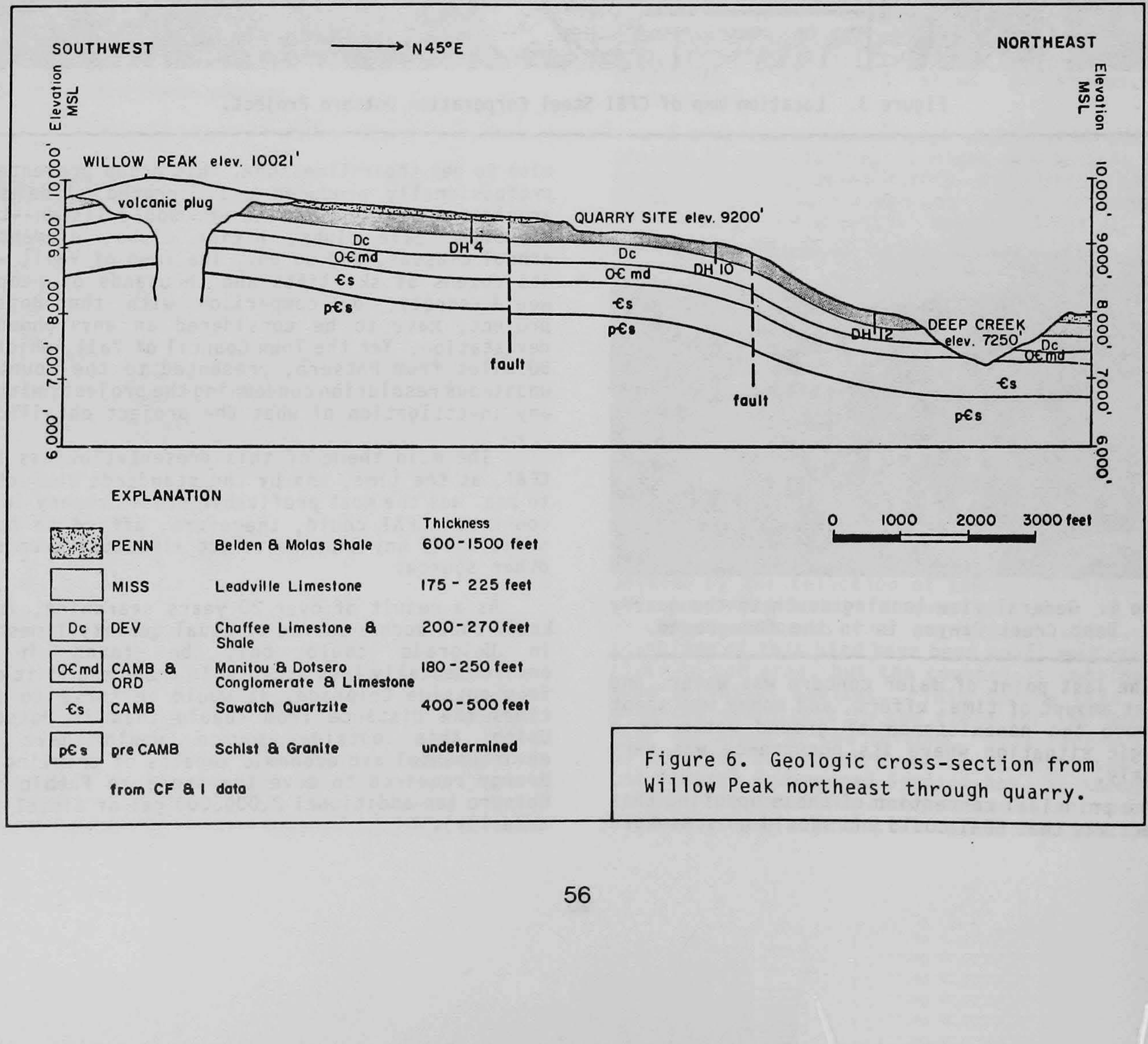

Figure 6. Geologic cross-section from Willow Peak northeast through quarry.

involved at the request of the counties. The LUC responded by soliciting and receiving comments on the project from all interested agencies and the public. This solicitation played an extremely important role in the project development in that it brought to light just about all of the forseeable problems. These problems were then dealt with as a package rather than individually over an extended period of time. Public hearings before the LUC can be held, but none are anticipated for this project.

Table 1. CF&I Dotsero Project.

AGENCIES DEALT WITH

Garfield County
  Planning Commission
  County Commissioners
  Health Department
Eagle County
  Planning Commission
  County Commissioners
  Northwest Colorado Council of Governments
State of Colorado
  Land Use Commission
  Mined Land Reclamation Board
  Dept. of Health, Air Quality
  Dept. of Health, Water Quality
  Division of Water Resources
  Division of Wildlife
  Geological Survey
  State Historical Society
United States
  Bureau of Land Management
  Forest Service
  Soil Conservation Service
  Army Corps of Engineers
  Geological Survey
  Environmental Protection Agency
  Federal Power Commission

PERMITS REQUIRED

1. Garfield County Special Use
2. Eagle County Special Use
3. BLM Right-of-Way
4. State Mining Permit
5. State Emissions Permit
6. PSD Permit to Construct
7. State Water Discharge (or no-discharge) Permit

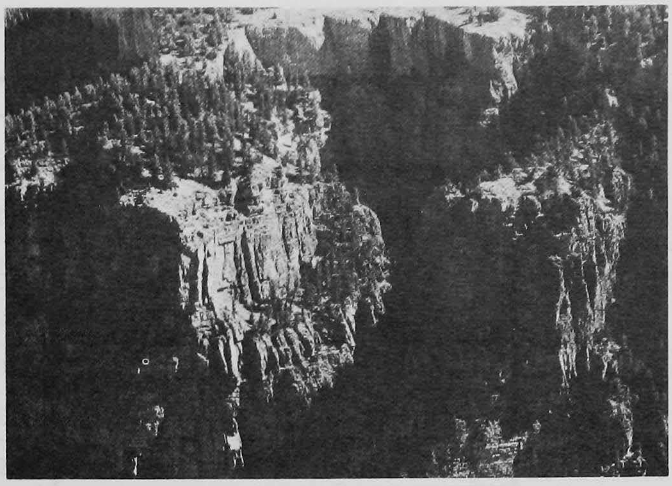

Figure 7. Typical limestone cliffs in Deep Creek Canyon near the quarry site. These cliffs are where caves are located and are potential peregrine falcon habitats.

The Colorado Mined Land Reclamation Board requires that a comprehensive mining and reclamation plan be submitted and approved. This plan must receive public notice and review, and with sufficient justification, public hearings may be held.

The Air Quality Division of the Department of Health issues permits for all point-source and fugitive particulate-matter emissions. The Water Quality Division of the Department is responsible for issuing effluent-discharge permits for all water discharges. The parameters for these permits are determined by an EPA-approved state plan. The State Division of Water Resources is responsible for assuring that any proposed water use is proper under State water law. The State Division of Wildlife was consulted regarding the wildlife species present and the project's potential wildlife impacts. The Colorado Geological Survey was consulted with regard to the potential for damage to the area's nearby caves. The State Historical Society was involved in determining if any archeological or historic sites existed in the area. In this regard, it was necessary to contract a private firm for an archeological survey.

At the federal level, the Bureau of Land Management's involvement is by far the greatest. A very comprehensive environmental report covering every conceivable phase of the operation, including impacts, mitigtions and alternatives, has been required. Even though the only facility on public land is a portion of the tramway, the BLM is required under the Organic Act of 1976 to include the total operation in its review and approval process. According to the Organic Act, the BLM must be reimbursed for its expenses in reviewing right-of-way applications. To date, this review has cost CF&I in excess of $20,000. It should be mentioned that even though this BLM report exceeds 500 pages, it is not considered an Environmental Impact Statement.

Table 2. Dotsero Project alternative haulage method analysis decision matrix.

PARAMETER		HAUL ROAD		CONVEYOR		AERIAL TRAM	
	R	Q	Q x R	Q	Q x R	Q	Q x R
Annual Cost	1.00	1.00	1.00	0.50	0.50	0.31	0.31*
Operating Problems	1.18	0.80	0.94*	0.80	1.18	1.00	1.18
1. Fuel and Energy Use	1.18	1.00	1.18	0.01	0.01	0.00	0.00*
2. Surface Disturbance	1.30	1.00	1.30	0.28	0.36	0.24	0.31*
3. Air Quality	1.37	1.00	1.37	0.90	1.23	0.90	1.23*
4. Visual	1.53	0.80	1.53	1.00	1.38	0.90	1.07*
5. Water Quality and Use	1.63	1.00	1.63	1.00	1.63	1.00	1.63
6. Noise	1.73	1.00	1.73	0.75	1.30	0.53	0.92*
7. Irretrievable Resources	1.86	1.00	1.86	0.81	1.51	0.54	1.00*
8. Reclamation	1.86	1.00	1.86	0.16	0.30	0.10	0.19*
9. Socioeconomics	1.86	0.28	0.52*	1.00	1.86	1.00	1.86
10. Property	2.00	1.00	2.00	0.18	0.36*	0.37	0.74
11. Wildlife	2.17	1.00	2.17	1.00	2.17	0.90	1.95*
12. Geologic Stability	2.36	1.00	2.36	1.00	2.36	1.00	2.36
Summation A All factors considered		21.14		16.06		14.75*	
Summation B Factors in reverse order		21.15		14.27		13.68*	
Summation C Environmental factors only		19.21		14.62		13.26*	

R = Relative Importance Factor

Q = Quantified Impact: 1.00 = Greatest impact, other numbers as proportionally less.

QxR = Impact: Lowest number = least impact = best choice.

Best* Worst

Involvement with the Forest Service was necessary because of the project's immediate proximity to the White River National Forest and the fact that the access road into the area is maintained by the Forest Service. No actual permits from this agency will be required. The U.S. Soil Conservation Service has been of great assistance in providing a very thorough and comprehensive soils investigations of the entire project area. This agency always seems eager and able to provide this kind of information to both private citizens and industry. Inquiry with the Army Corps of Engineers was required because the tram line will cross the Colorado River--a navigable stream. The Corps determined that full review and permitting was not necessary because none of the tram structures encroached upon the river itself, and the tram, being 100 ft or so above the river, presented no hindrance to navigation. The U.S. Geological Survey and Federal Power Commission were involved at the request of the BLM to review their appropriate aspects of the project.

Finally, the EPA is indirectly involved in the issuance of emission and discharge permits and directly involved with the new PSD (Prevent of Significant Deterioration) Regulations, which, under the Clean Air Act of 1977, require a permit to

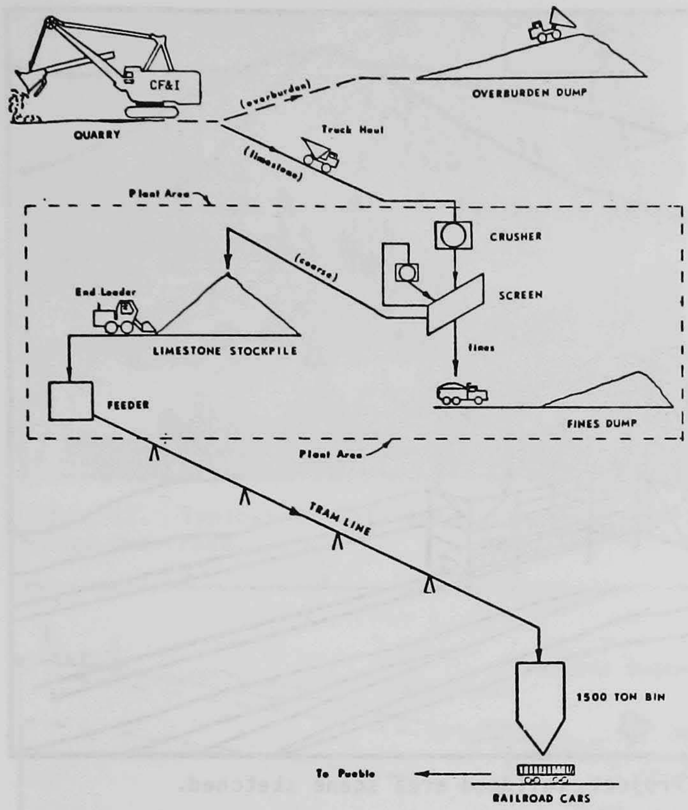

Figure 8. Dotsero limestone operation facility flowsheet.

construct for all major industrial operations. If uncontrolled emissions can be kept below 250 ton/yr, or controlled emissions below 50 ton/yr, then no significant regulatory requirements are brought to bear. If these limits are exceeded, then very difficult preconstruction monitoring, modeling, and postconstruction control measures enter the picture. Even though this project is not expected to exceed the 50-ton/yr limit, CF&I set up an air-quality and meteorological monitoring program 18 months ago that will precede construction by about four or five years.

The following brief description of the project emphasizes the proposed aerial tramway. Figure 8 is a flow sheet of the operation, which is quite conventional except for the tram. Quarry operations will be at 9200 ft elevation and will begin by removing about 5 ft of topsoil and 10 ft of shale overburden, which will be placed on separate dumps. The limestone will then be quarried by conventional open-pit mining methods in 25-ft-high benches. Figure 9 shows the topographic layout of the quarry and its facilities. The run-of-mine limestone will be hauled about 3/4 mile to a crushing and screening plant. The plant will produce crushed and screened products to meet steel-mill specification at the time, with the fine material (-3/8 in.) being rejected. The coarse screened material will then be placed in open stockpiles and reclaimed by front-end loader to feed the tram system. The material will then be transported 4 miles by aerial tram to a rail-loading facility on the D&RGW Railroad, which parallels the Colorado River. The loading facility will consist of two 1,500-ton silos for conventional

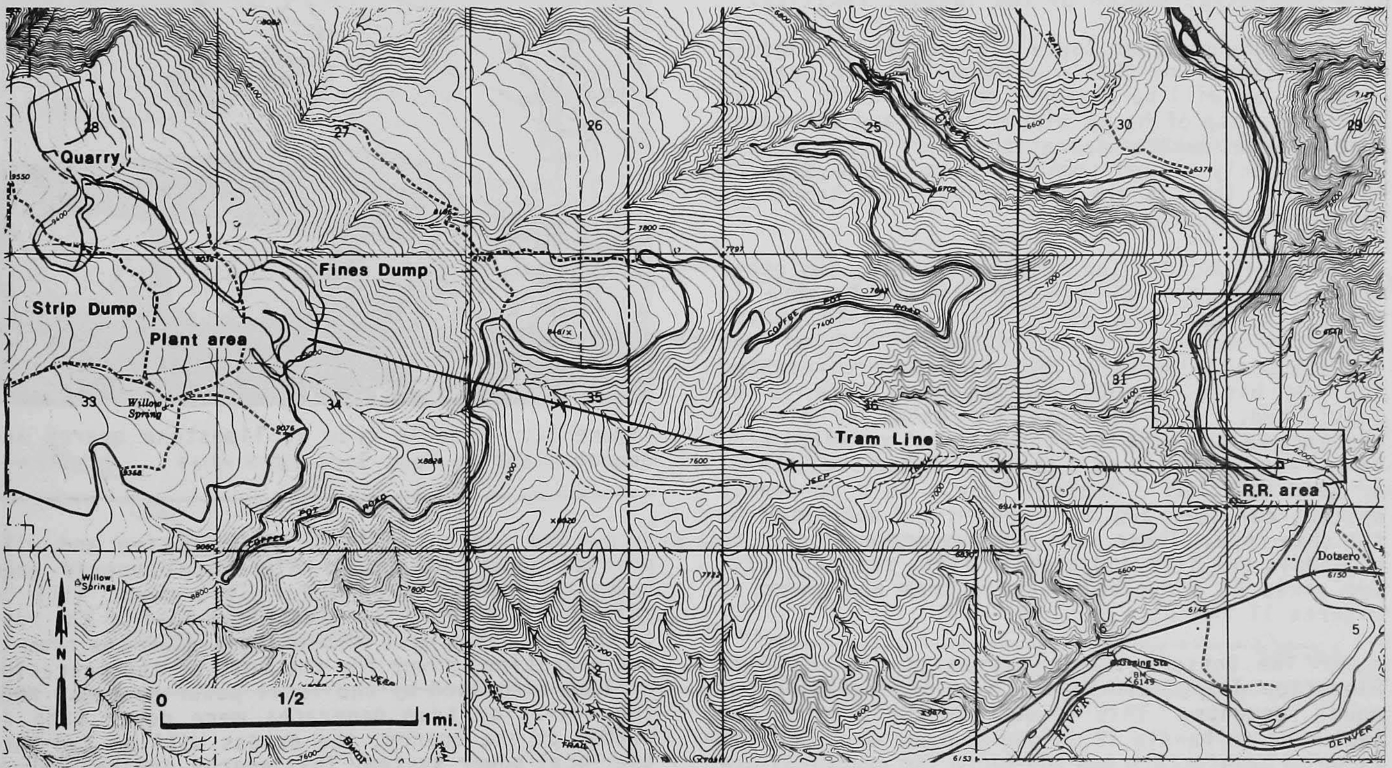

Figure 9. Location map of Dotsero area, CF&I Steel Corporation.

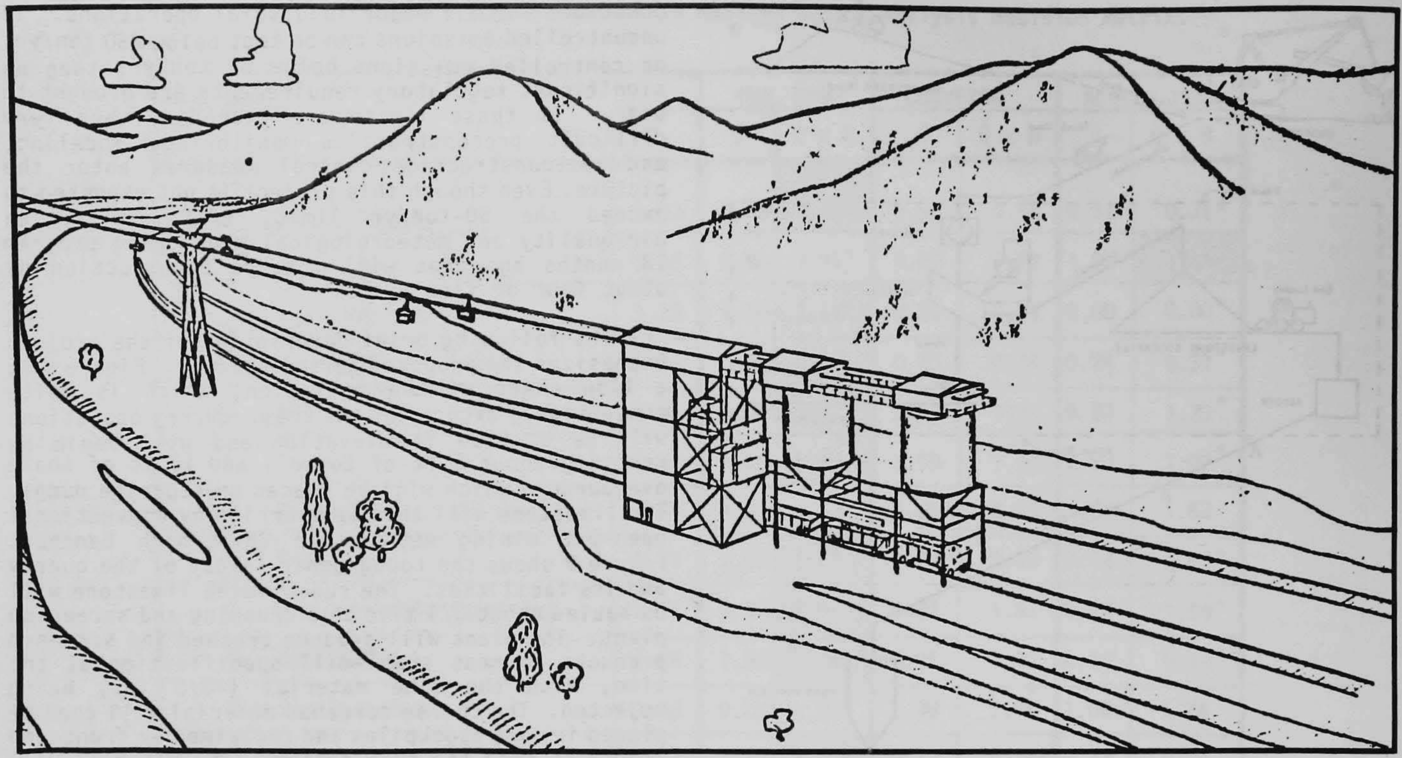

Figure 10. CF&I Steel Corporation Dotsero Project, railroad area scene sketched.

loading into open-hopper rail cars. The normal production will be about 2,500 ton/day. Figure 10 is a conceptual sketch of the loadout facility.

The quarry labor force and operating schedule will be similr to CF&I's present Monarch Quarry. About 30 men will be employed on a one-shift, 40-hr week. Because of heavy winter snows and attendant problems in remote operations, the quarry will operate only seven months each year--May to November. This is the same operating schedule as the Monarch Quarry.

Before deciding on the aerial tram, two other tram locations, each very similar to Dotsero in terrain and climate conditions and with almost identical design capacities, were visited and investigated. These two locations also represented the two basic tramway designs that were to be considered. Both systems are known as bicable systems, which means that the material carriers ride on and are supported by a track rope and are pulled, or held back, by a haulage rope. In a monocable system, carriers are both hauled and supported by the same rope. These same systems are analogous to a gondola ski lift and a chair lift, respectively. Two views of a typical bicable tram are shown in Figures 11 and 12.

The Dotsero tram, because of its 3,000-ft elevation drop, must be designed and built in two equal segments. This is because the size of the haul rope to handle it in one segment would be too large to manufacture and too large for practical use if it could be made.

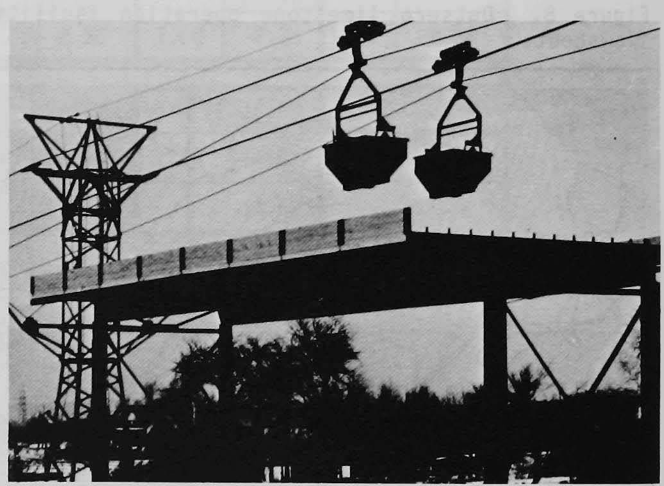

Figure 11. Bicable tram at limestone quarry and cement plant in West Germany.

The system would be regenerative and will provide about 500 kw of electrical energy when operating under full load. This power will be sufficient to carry the electrical load of the rest of the operation most of the time. When the tram is not operating, power for the rest of the operation will be furnished by the local power system. When the operating tram generates more power than is needed at the quarry, the excess will be fed into the local power system. This energy-saving feature was a key point in gaining environmental acceptance

Figure 12. Typical bicable tram with protective bridge over road.

of the project. The truck haul would have used about 200,000 gal/yr of diesel fuel vs a net gain of about 500,000 kwhr from the tram. This represents an annual savings of about $165,000 at present prices.

The tram will have a capacity of 350 ton/hr and will operate at a speed of about 850 ft/min. Actual operation of the tram will require only two men vs the eight or nine men needed for truck haulage. The low manpower requirement plus the positive energy feature will make the tram operating costs relatively insensitive to inflation.

A few words should also be said about postmining reclamation plans. Figure 13 shows a typical cross-section of what the final quarry reclamation will look like. The quarry floors will be revegetated as soon as they are free from active use by making a subsoil of reclaimed overburden and limestone fines covered with reclaimed topsoil and suitable mulches and fertilizers. This will provide

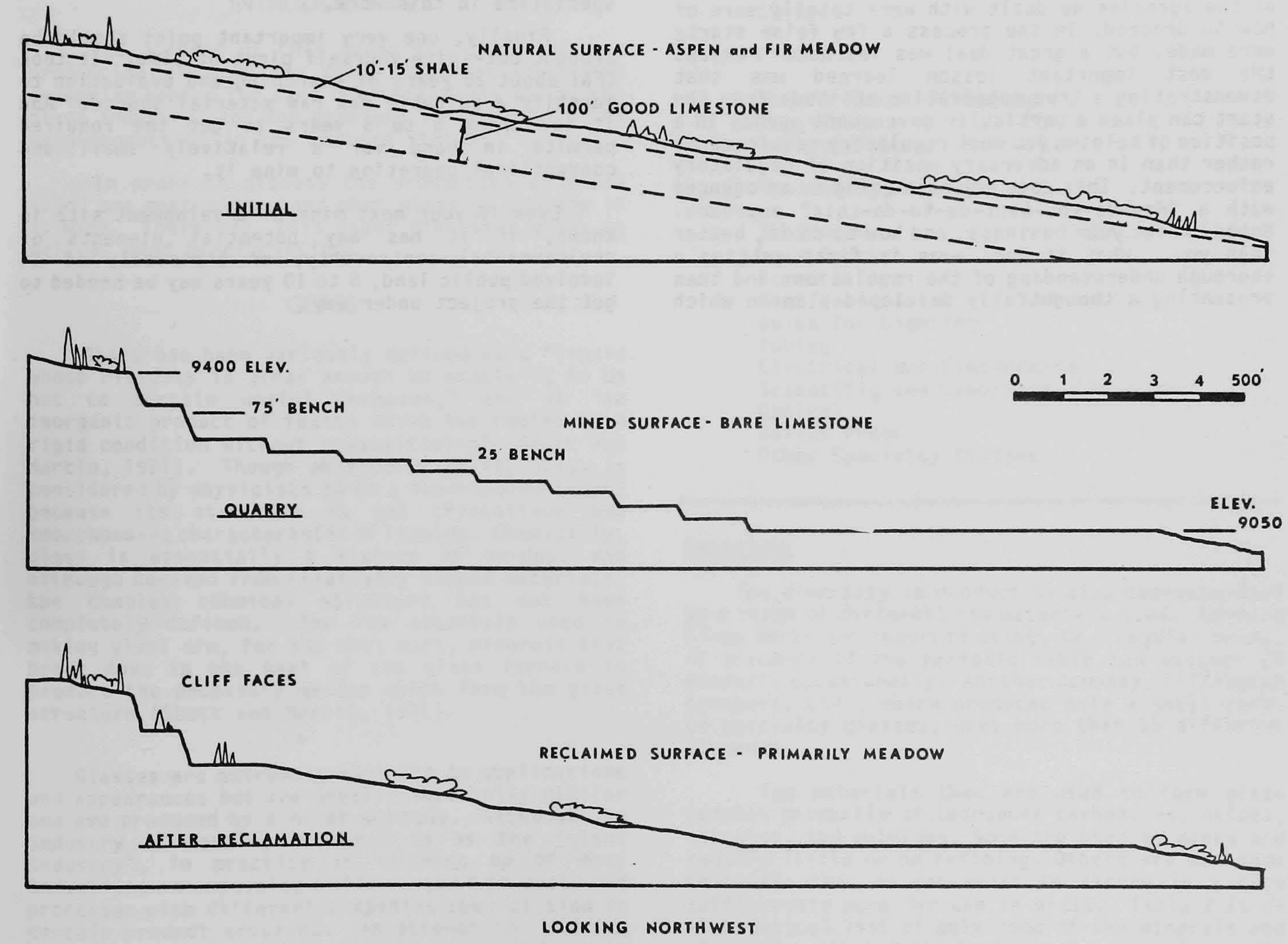

Figure 13. Land profiles, before, during and after mining operations--CF&I Steel Corporation, Dotsero Project.

a good vegetation base and make use of all of the spoil or waste materials from previous mining. The quarry walls will be left bare and will appear much the same as many natural cliff faces in the area. In the end the reclaimed site will be natural and pleasing in appearance and will be more useful for livestock or wildlife grazing than was the preexisting terrain. This revegetation plan is backed up by the CF&I-funded Colorado State University field experimentation program that has been in progress at the two operating CF&I quarries since 1976.

Unquestionably this project will be constructed and operated in a manner that conforms with both the letter and spirit of environmental regulation. The only significant impacts on the area will be positive ones on the local economy and tax base.

In conclusion a few general comments should be made. When we first got into this project more than four years ago, it was at the threshold of a whole new set of county, state, and federal regulations regarding such development. Neither CF&I nor many of the agencies we dealt with were totally sure of how to proceed. In the process a few false starts were made, but a great deal was learned. Perhaps the most important lesson learned was that demonstrating a true cooperative attitude from the start can place a particular government agency in a position of helping you meet regulatory requirements rather than in an adversary position of regulatory enforcement. This does not mean going to an agencey with a "How-do-you-want-us-to-do-this" approach. Nobody knows your business, and how to do it, better than you. What it does mean is first getting a thorough understanding of the regulations and then presenting a thoughtfully developed plan in which both the content of the plan and the proposed operation itself conform to the applicable regulations. From this point, the government people can help you fill in the gaps and make the minor changes that will be needed.

It is my personal belief that, with the exception of some data-gathering and specialized functions, you are better off doing the permit work in-house. As said before, nobody knows your business better than you do, and if you do not know the regulations, or how to comply with them and the people behind them, then you would be well advised to get acquainted. If you feel that you must contract for the permit application, be sure that you understand it completely and be especially wary of cookbook approaches that can result in permit conditions difficult or even impossible to comply with.

If your company does not have legal personnel that are experienced in these matters, you should go outside for this help. Competent legal assistance is absolutely essential, and some law firms do specialize in this work.

Finally, one very important point should be brought out--give yourself plent of time. It took CF&I about 20 years of searching and evaluation to identify a suitable new raw material source. And it is taking 5 to 6 years to get the required permits in hand for a relatively small and conventional operation to mine it.

Even if your next mineral development site is known, if it has any potential elements of environmental controversy, or especially if it involved public land, 5 to 10 years may be needed to get the project under way.

Production and Processing Problems of Western Glass Sands

by
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ABSTRACT

The production of glass and glass sands is discussed, with emphasis on sands from the five-state region of the Rocky Mountains (Arizona, Colorado, New Mexico, Utah, and Wyoming). Although a large market potential exists for glass and, therefore, glass sands, only one large glass manufacturer is located in this region. The present production of glass-grade sands is limited to supplying this single manufacturer.

INTRODUCTION

The purpose of this paper is to explain the production of sand for glass manufacturing, the reasoning behind the sand specifications set by the glass industry, and the problems relating to glass sand production in the Western States.

In order to discuss the production of glass sand, one must understand what glass _is_ and how it is made. Therefore, this paper discusses glass as well as sand beneficiation.

GLASS

Glass has been variously defined as a "liquid whose rigidity is great enough to enable it to be put to certain useful purposes," and as "an inorganic product of fusion which has cooled to a rigid condition without crystallizing" (Shutt and Martin, 1971). Though physically solid, glass is considered by physicists to be a supercooled liquid because its structure is not crystalline but amorphous--a characteristic of liquids. Chemically, glass is essentially a mixture of oxides, and although derived from relatively simple materials, the complex chemical structure has not been completely defined. The raw materials used in making glass are, for the most part, minerals that break down in the heat of the glass furnace to produce the necessary oxides which form the glass structure (Shutt and Martin, 1971).

Glasses are extremely variable in applications and appearances but are usually chemically similar and are produced by similar methods. Although the industry is usually referred to as the "glass industry", in practice it is made up of many industries encompassing a wide range of products and processes with different companies specializing in certain product sections. An attempt to show the breakdown of the glass industry by product is presented in Table 1.

TABLE 1

Types of Glasses

- Flat Glass
    - Sheet
    - Float
    - Rolled
- Glass Containers
    - Colorless
    - Colored
- Glass Fibers
    - Reinforcement Filaments
    - Insulation
    - Optical Fibers
- Other Speciality Glasses
    - Tableware
    - Lead Crystal
    - Fused Silica
    - Heat Resistant
    - Bulbs for Lighting
    - Tubing
    - Electrical and Electronics
    - Scientific and Laboratory Glassware
    - Optical
    - Bullet Proof
    - Other Specialty Glasses

Materials

The diversity in product is also characterized by a range of different raw materials used. Corning Glass Works has reported using, on a regular basis, 47 elements of the periodic table and another 20 elements occasionally. Another company, Pilkington Brothers, Ltd., which produces only a small range of specialty glasses, uses more than 35 different elements.

The materials that are used to form glass consist primarily of inorganic carbonates, oxides, nitrates, and sulfides. Some are used as-mined and require little or no refining. Others are man-made chemicals that do not exist in nature in a form sufficiently pure for use in glass. Table 2 is an alphabetical list of only some of the minerals and chemicals employed regularly in glass manufacturing (Virgoe, 1979).

In addition most glasses contain sand, soda ash, and lime as their major constituents. Glass requires the following as a raw material mix (Phoenix Glass Co.):

1) RO_2 compounds such as silicon dioxide or germanium dioxide,
2) R_2O compounds such as sodium oxide or potassium oxide,
3) RO compounds such as calcium oxide or magnesium oxide.

Other materials also are added to improve specific qualities of the glass. Some of these materials are:

1) sulfates, to speed melting,
2) arsenic, to accelerate release of entrapped gases,
3) selenium, to control color in clear glass.
4) lead, to increase the refractive index and thereby improve brilliance,
5) fluorides, to form soft white glass,
6) phosphates, to form hard white glass,
7) boron, to reduce thermal expansion,
8) cullet, or broken glass, to aid melting,and
9) other metallic oxides, such as those of iron copper, cadmium, chromium, cobalt, and nickel, to produce colors.

TABLE 2

Some Materials Used in Glass Manufacturing

Alumina-hydrate
Alumina-calcined
Antimony oxide
Arsenic oxide
Anthracite
Anhydrite
Barium carbonate
Barium sulfate
Borax
Boric acid
Calumite
China clay
Ceria
Cobalt oxide
Colemanite
Dolomite
Feldspar
Fluorspar
Gypsum
Kaolin
Limestone
Litharge
Magnetite
Nepheline syenite
Petalite
Potassium carbonate
Pyrite
Quartz
Rare earths
Red lead
Rouge
Salt cake
Silica sand
Silica flour
Selenium
Soda ash
Sodium nitrate
Spodumene
Strontium carbonate
Titania
Ulexite
Zirconia
Zircon flour
And various colorants such as iron, copper, cadmium, chromium, cobalt, and nickel.

The majority of glasses contain approximately 70 percent SiO_2, 13 percent Na_2O, and 13 percent CaO. The remaining 4 percent consists of one or more of the above ingredients (Shutt and Martin, 1971). The raw material mix for a typical soda-lime container glass consists of approximately 60 percent silica, 16 percent soda ash, 16 percent limestone, 7 percent feldspar, and 1 percent other ingredients (Shand, 1958). Table 3 indicates the approximate compositions of some commercial glasses.

Manufacturing Processes

Almost all of the raw materials for glass manufacture are granular and are shipped in either bags, drums, or hopper cars. The uniformity of the chemical composition and of the physical size is closely controlled by the raw material manufacturer and generally is rechecked at the glass factory. Deviation from specified limits can result in the rejection of the shipment by the glass manufacturer. Materials such as sand, soda ash, and lime that are shipped in hopper cars are generally stored in silo bins to minimize manual handling.

The raw materials are weighed to a prescribed formula and then dumped into a rotary mixer. Mixing is necessary to minimize preferentail melting in the glass furnace. The resultant mix is referred to as a "batch". The size of a normal batch is approximately 2 tons. After mixing, the batch is fed either into a storage bin or into "batch cans."

From storage, the batch is charged into a glass melting unit. There are three types of melting units: (1) day tanks, (2) pot furnaces, and (3) continuous tanks (Phoenix Glass Co.). Discussion of the construction and operation of the different types is beyond the scope of this paper.

The batch is melted by heating the materials to a temperature high enough to create a chemical reaction. Typical temperature used for various glasses are shown in Table 4.

The melted batch or "liquid" is withdrawn and formed into glass shapes by either blowing, pressing, or drawing, and then cooled.

Consumption

The U.S. Department of Commerce has estimated the annual per capita consumption of the three most abundant types of glass as:

0.045 tons of container glass
0.015 tons of flat glass
0.005 tons of fiber glass

Multiplying these estimates by the projected population (1980) of the five-state Rocky Mountain region (Arizona, Colorado, New Mexico, Utah, and Wyoming) should indicate the future size of the glass markets. Table 5 presents the results of this calculation. The data indicate a potential annual consumption of 506,000 tons. Assuming that a glass batch is 60 to 70 percent sand, manufacturers would require 304,000 to 354,000 tons of sand to fulfill the glass needs of the people in this region.

TABLE 3

Approximate Compositions of Commercial Glasses (Shand, 1958)

Glass Designation	Oxide Constituents, % SiO_2	Na_2O	K_2O	CaO	MgO	BaO	PbO	B_2O_3	Al_2O_3
Fused Quartz	99.99	$<1X10^{-2}$							
96% Silica Glass	96.3	<0.2	<0.2	--	--	--	--	3	0.4
Soda-Lime (window)	71-73	12-15	--	9	2.5	--	--	--	1
Soda-Lime (plate)	71-73	12-14	--	11	3.0	--	--	--	1
Soda-Lime(containers)	70-74	13-16		10-13		0.5	--	--	2.0
Soda-Lime(light bulbs)	74	16	0.6	5	4	--	--	--	1
Lead-Alkali	63	8	6	0.3	0.2	--	21	0.2	0.6
Lead-Alkali	35	--	7	--	--	--	58	--	--
Alumino Borosilicate	75	6	0.5	1	--	2	--	10	6
Borosilicate	80	4	0.4	--	--	--	--	13	2
Borosilicate	70	--	0.5	--	--	--	--	28	1
Borosilicate	67	5	1	--	0.2	--	--	25	2
Aluminosilicate	57	1	--	6	12	--	--	4	20

TABLE 4

Glass Melting Temperatures (Shand, 1958)

Glass	Melting Temperature at Surface of the Glass °C
Lead-Silicate	1,450
Soda-Lime	1,500
Borosilicate	1,600
Aluminosilicate	1,600

GLASS SAND

Classification

In practice, glass sands do not contain 100 percent SiO_2 but include small amounts of feldspar, clays, carbonates, organic material, iron minerals, and a variety of other heavy minerals. The deposits containing a high percentage of feldspar are referred to as silica sands, whereas the almost pure quartz sands are referred to as silica sands. The silica sands usually contain greater than 97 percent SiO_2, and the feldspathic sands may contain 80 to 93 percent SiO_2 with 2 to 7 percent Al_2O_3.

TABLE 5

Population and Glass Markets for the Five-State Rocky Mountain Region

State	1980 Projected Population	Glass Markets, tons Container	Flat	Fiber
Arizona	2,358,000	106,000	35,000	12,000
Colorado	2,705,000	122,000	41,000	14,000
New Mexico	1,038,000	49,000	16,000	5,000
Utah	1,264,000	59,000	19,000	6,000
Wyoming	328,000	15,000	5,000	2,000
Total	7,693,000	351,000	116,000	39,000

Specifications

In order to sell the sand to the glass companies, the material must meet semirigid specifications. For example, more emphasis is placed on uniform quality than on the maximum limit allowable. This is especially true of chemical specifications.

TABLE 6

Typical Chemical Analysis of Sand Used in Glass Manufacturing

Chemical Analysis, %

Glass Type	SiO_2 (min)	Al_2O_3 (max)	Fe_2O_3 (max)	TiO_2 (max)	CaO + MgO (max)	Na_2O + K_2O (max)	Cr_2O_3 (max)	LOI (max)
Fused Quartz	99.99	<IX10^{-2}						
Crystal	99.81	0.045	0.03	0.012	0.01	--	0.0008	0.012
Special	99.5	--	0.03	--	2.5	--	0.0008	2.5
Optical	99.5	0.30	0.015	--	--	--	--	0.20
Containers:								
Flint	92.0	5.0	0.03	--	--	3.0	0.0008	0.15
Flint	99.3	0.3	0.03	0.03	0.2	--	0.0008	0.15
Green	99.84	0.06	0.10	--	--	--	--	--
Green	83.5	8.7	0.10	--	--	6.0	--	--
General	93.5	3.5	0.04	0.04	--	2.85	--	0.25
Opaque	99.3	Low	0.03	--	--	--	0.0008	0.15
Lime	99.4	0.5	0.1	0.02	0.04	--	0.0010	0.20
Flat (window)	99.77	0.15	0.025	0.018	Trace	--	--	0.08
Borosilicate	99.7	0.1	0.03	0.01	0.02	--	0.0010	0.2
Fiberglass	98.5	0.5	0.10	--	--	--	--	--
Light Bulbs	99.5	0.5	0.06	--	--	--	--	--

Chemical

Chemical specifications are considered as tolerances rather than as absolute values. Exceptions to this rule are elements such as chromium, nickel, manganese, cobalt, and copper, which produce color. Iron, although a colorant, has a somewhat greater tolerance level, especially in the manufacture of amber and green glass. Table 6 outlines some of the general chemical specifications for glass sand.

It should be noted that the values shown in Table 6 are subject to negotiation between buyer and seller because some adjustment can be made in the glass batch compositions to compensate for minor variations from the quoted limits. However, uniformity is nonetheless stressed as being more important than the exact value. A factor called "range" is sometimes used to define the maximum acceptable variance for a given constituent. Range is the difference between the highest and lowest recorded analytical values calculated for each individual constituent. This is predicted by sufficient analytical data to approximate the actual variance that exists in the processed sand. An example of the acceptable variance is given in Table 7 (Goldman and Reining, 1975).

TABLE 7

Allowable Variation Between Sand Deliveries

Constituent	Symbol	Range % (maximum)
Silica	SiO_2	±0.3 when SiO_2 >99.0
Alumina	Al_2O_3	±0.2 when Al_2O_3 <0.5
Calcia	CaO	±0.1
Magnesia	MgO	±0.1
Total Iron	Fe_2O_3	±0.005 when Fe_2O_3 <0.1

In addition to these specifications, the amount of allowable iron varies from glass to glass. Table 8 shows some of the limits set on total iron content according to glass type.

TABLE 8

Fe_2O_3 Variation in Glass Sand According to Glass Type

Glass Type	Maximum Fe_2O_3 %
Optical	0.0010
Tableware	0.010
Flint Glass	0.030
Flat Glass	0.10
Colored Container Glass	0.10-0.25
Fiberglass	0.10-0.30

Size

The object of glass melting is to convert all the various raw materials in the batch to a homogeneous liquid; therefore, the grain size of the materials is very important. The finer the particles, the faster the material will melt, the less fuel will be required, and the greater the throughput will be for a given size furnace.

Sand is fairly refractory and is also the last material to dissolve into the glass. Therefore, its upper grain size is closely controlled. However, if the material is too finely divided, it may cause trouble by retarding the elimination of gas bubbles from the soft fluid glass. Because silica is also a strong acid, its presence in the checker chamber, or heat-recovery system, causes rapid deterioration of the brick; therefore, particles small enough to be carried over in the exhaust gases are not allowed (Shand, 1958). Inasmuch as the economics of production and the availability of various sand products are significant factors in the manufacture of glasses, a wide latitude exists in size limits. Table 9 illustrates some of the extremes found in size specifications given by glass manufacturers. In general, sand is suitable for glass manufacturing if it contains not more than one piece on 16 mesh (Tyler), less than 0.1 percent on 20 mesh, less than 10 percent passing 100 mesh, and less than 2 percent passing 200 mesh (A.S.G. Indusries, Inc.).

Trace Contaminants

In addition to the above-mentioned chemical and physical requirements, the glass manufacturer is also concerned with other constituents that will affect the quality of his product. Certain types of foreign agents are objectionable to the glass technologist, either as individual particles or as minute percentages. These contaminants usually fall into four categories (Libbey-Owens-Ford Co.):

1) Colorants,
2) Metallic,
3) Refractory spalls, and
4) Refractory minerals.

Colorants are considered to be minerals that contain the elements cobalt, chromium, or manganese. These very strong colorants may affect both the color and the light-transmission characteristics of the glass. For some types of flat glass, limits have been set at 0.0020 percent maximum for MnO_2, 0.0002 percent maximum for Cr_2, and 0.0002 percent maximum for Co_3O_4.

Metallic particles can be particles of aluminum, copper, brass, bronze, Monel, or stainless steel. These particles do not melt in the glass furnace and are prohibited from the delivered product. Such particles can come from copper blasting components, aluminum foil or wire, bronze or stainless steel pumps, bronze brazing rods, or stainless steel welding rods. Extreme care should be exercised to exclude metallic particles from the sand product.

Refractory spalls can cause serious glass losses if they enter the glass furnaces. Refractory linings of dryers, kilns, or reaction vessels should be of the highest quality and be regularly inspected to insure that they do not report with the sand product.

Refractory minerals may be naturally occurring minerals contained in trace quantities in the raw material, the result of contamination from mining or process equipment, or the result of chemical interaction during drying or calcining. Some of the refractory impurities that have been found in glass sand are listed below (Libbey-Owens-Ford Co.; Mills, 1975).

Sillimanite	Al_2SiO_5
Kyanite	Al_2SiO_5

TABLE 9

Sand Size Specifications of Some Glass Types

Mesh Size:	+16	+20	+30	+40	+50	+70	-100	-140	-200
					Cumulative %				
Containers	--	0.1	5.0	2.0	--	--	25	-	--
Containers	None	None	0.1	1.0	4.0	--	50	-	--
Flat Glass	None	0.01	--	0.1	--	--	--	8	0.5
Flat Glass	None	None	2.0	--	30.0	25	6	2	--
Fiberglass	--	0.1	3.0	--	--	--	15	-	--
Fiberglass	--	None	None	None	2.0	20	--	-	15.0

Andalusite	Al_2SiO_5
Zircon	$ZrSiO_4$
Spinel	$RO.R_2O_3$
Corundum	Al_2O_3
Chromite	$FeCr_2O_4$
Kaolin	$Al_2O_3(SiO_2).2H_2O$
Zirconia	ZrO_2
Cassiterite	SnO_2

Numerous methods have been used to determine the amount of refractory heavy minerals (RHM) present in a sample, but time and space do not permit detailed descriptions. In general the sample to be tested can be as large as 22.68 kg (50 lb) or as small as 0.4 kg. The heavy minerals are separated from the sand by using tetrabromoethane (TBE) in open vessels or in separatory funnels. The total heavy minerals are then examined under a microscope or are fused with Na_2CO_3, dissolved in dilute HCl, and then examined under a microscope to determine the amount of RHM. One glass manufacturer uses the following criterion as a basis for acceptance or rejection (Joy Manufacturing Co., 1962).

Sample Size = 400 g

Weight Basis

Maximum +60 mesh RHM = 0.0003%

Particle Count Basis

+40 mesh RHM =2 particles maximum
-40 +60 mesh RHM = 20 particles maximum

Another flat-glass manufacturer had a specification of a maximum of 0.00044 percent of +70-mesh RHM but, due to the high quality of sand obtainable locally, has since lowered it to 0.00001 percent of Total Heavy Minerals.

PROCESSING OF GLASS-GRADE SAND

For many years in the past, sand for the glass industry was simply mined, screened, washed, and shipped to the glass plant with little concern about quality control. It was the glass companies' responsibility to adjust the batch mixture to accommodate the sand. Now the emphasis has shifted to the sand producers to maintain the quality of the product.

Nowadays few sand deposits are of sufficient chemical purity to be used in glass manufacturing without beneficiation. It also is rare to find a natural deposit of sand that contains just the proper distribution of sand grains to be suitable as glass furnace feed. In the United States sand is obtained from a variety of rock types and geologic ages. The principal sources are found along existing or ancient river channels, in glaciated areas, in marine and lake deposits, and in altered geologic formations (Goldman and Reining, 1975). Generally sand deposits are classified as follows:

Stream channel deposits consist of sand and gravel in beds along present or ancient stream courses.

Flood plain deposits consist of material deposited on plains bordering streams by the periodic overflow of the streams from their channels.

Terrace deposits are beachlike deposits of sand and gravel that border streams but lie about the level of the present flood plain.

Terrace deposits are beachlike deposits of sand and gravel that border streams but lie about the level of the present flood plain.

Alluvial fan deposits were formed when streams carried large volumes of sand and gravel down a steep mountain slope and entered an adjacent valley or plain. The abrupt change in slope caused a decrease in speed of the stream and a settling out of the transported sand and gravel.

Glacial and glaciofluvial deposits such as outwash, kame, esker, and moraines were all created by the action of the glaciers that moved back and forth over the midwestern and northeastern parts of the United States.

Beach deposits were formed by the windrowing action of currents and waves on beaches along lakes and oceans.

Older geologic formations of pre-Quaternary age that are partly consolidated sedimentary beds of sandstone and conglomerates.

Of the above type of deposits, the most important commerical sources of sand for glass manufacturing are river channels, beach deposits, and consolidated and unconsolidated sandstone formations.

Locating a Deposit

Surface geology is perhaps the simplest and most common method used to locate sand deposits. Data can be obtained by examining stream banks, road cuts, excavations for building foundations, and any other natural or man-made exposures. With the aid of aerial photographs, topographic maps, state and federal geological survey reports, and a knowledge of the type of land forms commonly underlain by sand and gravel, a geologist can pinpoint potential areas for detailed field examinations (Ketner, 1973).

After a deposit is located, the thickness, lateral extent, possible tonnage, and overburden depth need to be determined. Representative samples of the entire deposit must also be obtained for laboratory testing and evaluations.

Evaluation

Representative samples collected from drilling, trenching, or pit excavation can be tested in the laboratory. Grain-size distribution, chemical analysis, and heavy-mineral determintions conducted on samples collected from potential sand deposits are necessary to delineate "ore." Bench tests, including but not limited to grinding, screening, scrubbing, desliming, flotation, thickening, and filtering, can be conducted to determine the response of the sample to beneficiation. This testing also will give data useful in determining the need for by-product markets and tailing disposal problems. In order to be successful in a glass-sand venture, the operator must be aware of all possible markets. No silica operation can afford to consider glass sand as its only product because of the large stockpile of oversized or undersized products that would require handling and disposal.

Mining

The industry utilizes a variety of methods and a great assortment of machinery to mine the ore. Power shovels, draglines, bulldozers, power scrapers, slackline cableways, dredges, and high-pressure waterjets are among the many types of excavation equipment used to mine sand. In dry pit operations material is loaded into trucks or onto conveyor belts for transfer to the processing plant. In wet-pit operations sand is recovered from below the water table, usually by dredges, and pumped to processing plants on shore.

Feed Preparation and Sizing

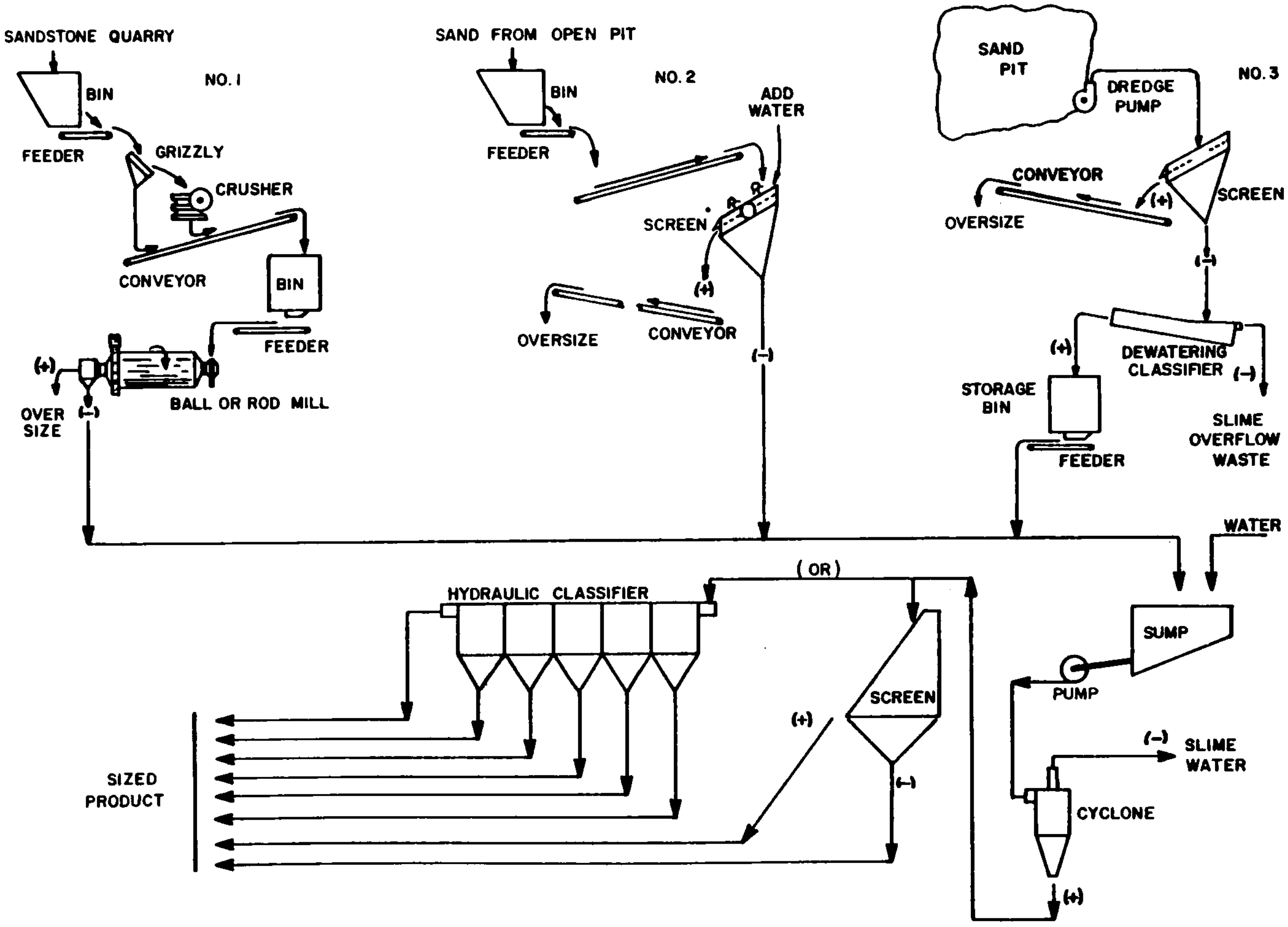
Because few, if any, glass plants are willing to take run-of-mine sand, the ore must be cleaned and sized. Figure 1 (Joy Manufacturing Co., 1962) outlines the general manner in which sands are cleaned.

In the case of a hard rock or a cemented sandstone, the mined rock is crushed and ground to liberation, or to natural grain size. In cases where the cementing material is weak, crushing and breaking in a trommel screen may be all that is necessary.

In dry- and wet-pit operations, the material is scalped to remove rocks and vegetable matter. In wet-pit operations, the undersize from the scalping screens usually must be dewatered due to the large quantities of water used in the dredging operations.

The material from size reductions and from scalping operations is then sent to a primary

FIGURE I



desliming step. This desliming can be performed with cyclones or, in some cases, screw classifiers. The slimes from this step are sent to settling ponds to reclaim the water. The deslimed sand is further sized to remove oversized material unsuitable for glass sand. Depending on the quantity of oversized material present, the material can be sized by stationary or vibrating sloped screens or by hydraulic classifiers that produce several sized fractions. The sized fractions can be sold as produced or blended to meet the customer's requirements. If too much oversize is present and no markets are developed for the oversize, the material can be fine ground in ball mills to produce a size for other markets. At this point if the operator is fortunate or if Mother Nature smiled upon the formation of the deposit, he has a silica sand that meets all the glass-sand specifications, and he can dry it and sell it as is. If he is not so lucky, or if he is among the vast majority of silica producers, he must further beneficiate the sand, probably by froth flotation.

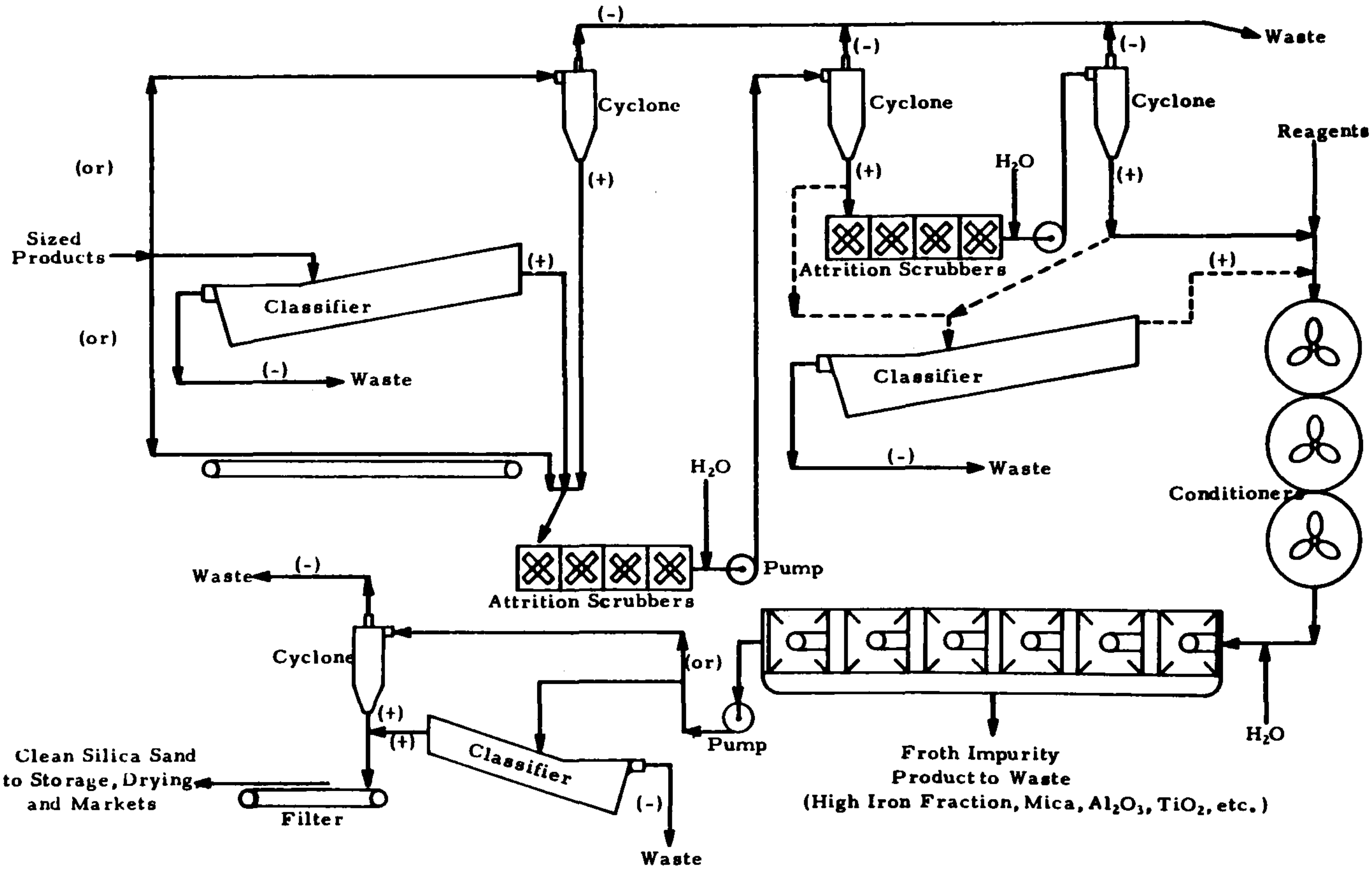
Froth Flotation

Figure 2 (Joy Manufacturing Co., 1962) illustrates a suggested method to process silica by flotation to produce glass-grade sand. This flowsheet can be used on quartz sand or on feldspathic sand and, when accurately designed and properly operated, it will result in a sand product acceptable to any glass manufacturer.

Sized products from the feed preparation circuit are densified to 70 to 80 percent solids and fed to attrition scrubbers. Typical operations use from 1.5 up to 6.5 kw of energy per metric ton (t) of feed (1.9 to 8 hp/short ton) to scrub the grains and remove any surface coating. Between 0.56 kg and 2.5 kg/t (1 lb and 5 lb/short ton) H_2SO_4, NaOH, or sodium silicate is usually added to the scrubber to assist in cleaning the surface of the grains and to assist in dispersing any slimes generated. Scrubbing time can range from 3 to 20 min, depending on the amount of clay and slime in the sand. The scrubbed pulp is then diluted and deslimed by cycloning. The slimes go to waste, and the sands are sometimes rescrubbed and deslimed again to insure clean mineral surfaces.

After the sands have been thoroughly scrubbed and deslimed, they are conveyed at 60 to 80 percent solids to the conditioners. In the conditioner, the pulp is adjusted to 60 to 70 percent solids, and the flotation reagents are added. At this point it is important not to generate any additional slimes that would consume flotation reagents.

FIGURE 2



Conditioning with the flotation reagents takes place in vertical tanks agitated with impellers or propellers. The tanks are either of wood or steel construction and are sometimes rubber lined. Conditioning tanks must have sufficient volume to allow from 5 to 15 min conditioning time without allowing the material to "short-circuit." The flotation reagents used depend on the system developed for the particular ore. Two types of flotation circuits are generally employed in the industry to float the contaminant from the sand--those using fatty acid at a basic pH and those using petroleum sulfonate at an acid pH. A generalized description of the reagent system for each circuit is described below.

Fatty acid is added to a pulp in which the pH has been adjusted to approximately 9.5 ± 0.5. The amount of fatty acid necessary varies from ore to ore but is generally approximately 0.5 kg/t (1 lb/short ton). A frother is added just before the end of conditioning. The frothers used in industry range from soluble glycols to pine oils to alcohol-type frothers, with the glycols finding more use. After conditioning, the pulp is diluted to 20 to 40 percent solids for flotation.

Petroleum sulfonate is added to a pulp in which the pH has been adjusted to approximately 2.0 ± 0.5. The amount of sulfonate necessary varies from approximately 0.25 to 1 kg/t (0.5to 2 lb/short ton), depending on the ore and the amount of impurities present. A frother is added just before the end of the conditioning. Water-soluble glycols are also finding wide use in this system. Reagent requirements for frothers range from 0.05 to 0.10 kg/t (0.10 to 0.20 lb/short ton) of feed. Fuel oil has been added, in some cases up to 0.5 kg/t (1 lb/short ton), to control the froth when slimes are excesive. After conditioning, the pulp is diluted to 20 to 40 percent solids for flotation.

Again the operator should take care that additional slimes are not generated in the conditioning step. If the scrubbing operation is not performed properly, additional slimes can be generated in a high-solids conditioner. The slimes so generated will consume reagents. Slimes in the conditioners are a major cause of poor quality sand and high reagent cost.

The choice between a fatty-acid circuit and a sulfonate circuit is dependent on the quality of product required and on the results of laboratory testing. Although both systems may work

After conditioning, the treated pulp is diluted and charged to flotation cells. The pulp at this point has very few fines to help support the coarser particles, and the pulp density must be carefully adjusted to prevent sanding in the cells. Several manufacturers produce flotation cells, and each can supply technical data on the operational characteristics of its equipment. Depending on the operating pulp density and the retention time required, a plant might be able to operate using as little as 0.28 m^3 (10 cu ft) of cell volume per ton of feed hourly. However, recently constructed plants have installed large 5.66- to 14.16-m^3 (200- to 500-cu-ft) cells that operate at 0.62 m^3/t/hr (20 cu ft/ton/hr).

The froth from the flotation contains the iron minerals, heavily stained quartz, and the refractory heavy minerals. This stream is sent to waste in most plants but is being considered as a possible by-product by some large producers.

The clean sand, which is the nonfloat product, is dewatered and sent to storage and drying. The dry sand may require secondary screening to insure meeting the customer's specifications.

Table 10 was prepared with data from a general survey of the mining industry conducted in 1975 by the U.S. Bureau of Mines. The table summarizes the operations of 22 plants producing glass sand by flotation.

GLASS SAND PRODUCTION

The methods described above should not be considered to constitute all the knowledge necessary to construct a glass sand plant. Nor should it be construed that these are the only methods that can be used economically. Other flotation reagent combinations and different washing and sizing procedures are in use, but by and large the bulk of the sand produced for glass manufacturing involves the basics described in this paper.

According to the federal government (Ketner, 1973; Pajalich, 1976; Evans, 1977), the production of glass sand in the United States averaged 10,500,000 tons/yr from 1973 to 1976. Table 11 summarizes the production of glass sand for these years together with the values and average values per ton.

If the present rate of increase continues, by 1980 the value of glass sand will be $8.00/ton, and production will exceed 13,000,000 ton/yr. In comparison the total production of sand and gravel for the United States in 1976 was 885,156,000 tons valued at $1,774,030,000, for an average value of $2.00/ton. The five-state region of the Rocky Mountains produced approximately 6 percent of this output or 53,942,000 tons. Colorado alone produced 2.3 percent of the total sand and gravel output for 1976, or 20,160,000 tons.

As previously noted, the demand for glass sand for the five-state region, based on the projected glass consumption, is approximately 304,000 to 354,000 tons. Now the U.S. Bureau of Mines reported that the total production of glass sand in the five-state region was:

"WITHHELD"

A guess would be 95,000 tons, all coming from one source and all supplying one manufacturer. This is only approximately 30 percent of the projected demand. However, only three manufacturers of primary glass products in the five-state region are listed in 1979 Glass Industry Directory Issue:

TABLE 10

Froth Flotation of Glass Sand in 1975

OPERATING DATA

Plants:

Number	22
Capacity, tons per day	40,000
Raw Sand Treated, tons	7,348,000
Clean Sand Produced, tons	6,068,400

CONSUMPTION OF FLOTATION REAGENTS

Function and Name	kg Per Metric Ton	Cost Per Metric Ton	lb Per Short Ton	Cost Per Short Ton
Modifier:				
Caustic Soda	0.366	$ --	0.731	$ --
Sulfuric Acid	0.750	--	1.499	--
Other (Alum, $CaCl_2$, CaO, Sodium Silicate)	0.565	--	1.129	--
Total	0.706	0.081	1.411	0.074
Depressant:	0.500	0.424	1.000	0.385
Collector:				
Aero Promoters 801, 825, or 840	0.299	--	0.598	--
Fatty Acid	0.422	--	0.843	--
Other (Aerofloat 31, Amine, Fuel Oil, Miscellaneous)	0.342	--	0.684	--
Total	0.425	0.244	0.850	0.222
Frother:				
Aerofroth	0.038	--	0.076	--
Other (Dowfroth 250, Miscellaneous)	0.086	--	0.171	--
Total	0.080	0.074	0.160	0.067
Flocculant (Polyhall, Stein Hall, Superfloc)	0.006	0.009	0.011	0.008
Other	0.045	0.013	0.089	0.012
Total Reagents	1.093	$0.371	2.186	$0.337

Coors Container Co. Glass Div. Wheat Ridge, Colo.	Container
Pikes Peak Manufacturing Co. Colorado Springs, Colo.	Art & Novelty
Rocky Mountain Glass Co. Durango, Colo.	Art & Novelty

No other primary container, flat, or fiberglass manufacturing plants exist in the region. If there are no glass manufacturers, there is no need for glass.

Therein lies the basic problem of glass sand producers in the five-state region--no markets for glass sand. Other markets do exist for specialty sands of glass-sand particle sizes, such as foundry, sand blast, filtration, and oil fracturing sand. These markets also bring a higher price in the market place. Table 12 summarizes the production and value of these specialty sands for the year 1976 (Evans, 1977).

TABLE 11

Glass Sand Production in the United States

Year	Production tons	Value	Value Per Ton
1973	10,158,000	$41,485,000	$4.08
1974	10,040,000	46,632,000	4.64
1975	10,211,000	54,703,000	5.36
1976	11,467,000	65,551,000	5.72

TABLE 12

Specialty Sand Production and Value for 1976

Sand Type	U.S. Production tons	Value	Value Per Ton
Molding	6,896,000	$37,264,000	$5.40
Blast	1,498,000	9,946,000	6.64
Grinding and Polishing	76,000	304,000	4.00
Engine	752,000	2,213,000	3.08
Filtration	183,000	1,060,000	5.79
Hydrafrac	660,000	4,759,000	7.21

Although the glass manufacturing industry has not increased in the five-state region over the last 3 years, the oil-well hydrafrac, foundry, and filtration markets have. An examination of these tonnages, markets, and prices reveals why only one new company has entered the glass sand business, at the expense of one other company that ceased production of glass sand.

SPECIFIC PROBLEMS OF PRODUCING WESTERN GLASS SANDS

If, indeed, an individual or company decided to enter into the glass sand business to serve existing or any new glass manufacturers, formidable problems would be faced. These problems are described in the following paragraphs.

Deposit Type

The sand deposits in the five-state Rocky Mountain region are characterized primarily as feldspathic sand. Most of the glass manufacturers prefer silica sand and are paying premium prices for it. However, these high prices are not returned to the producer; rather, the railroad industry derives the bulk of the charge, up to three times the f.o.b. price. To produce a silica sand of more than 95 percent SiO_2 from a feldspathic sand would require a flotation plant employing hydrofluoric acid. Hydrofluoric acid is an environmentally unacceptable reagent. Such a plant would require 100 percent water recycle and a maze of permits.

Although pure silica deposits do exist in the five-state region, only one produces silica for the glass industry.

Beneficiating

To produce a beneficiated sand for the container, flat, or fiberglass markets, the naturally occurring sands would require a substantial investment--one that the small sand and gravel producers could not afford. Without the assistance and encouragement of potential glass manufacturers, it is unlikely that a new glass sand operation will open in this region during the next few years. However, with increasing energy and transportation costs for raw and finished products, this conjecture could change. New technology now under development at the Colorado School of Mines Research Institute and by individual glass manufacturers could lead to more glass plants nearer the markets. Cities such as Phoenix, Denver, or Salt Lake City may possibly see the creation of small glass manufacturing operations.

CONCLUSIONS

In conclusion, the following observations may be made:

1. If already a member of the sand and gravel industry, do not rely on producing glass sand.
2. If already a member of the exploration industry, do not allocate appreciable time identifying glass sand deposits, unless they are the silica types, very large, and near transportation, fuel, and electric power facilities.
3. If not already a member of the sand industry but wish to start on a large deposit, examine other specialty sand markets for sale, not glass sand!

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Refractory Clays: Prospecting, Mining, Reclamation

by

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The origin of most types of refractory clay minerals is the intense weathering of igneous rocks. The products of weathering are either left in place as relatively pure deposits or transported by water and deposited as sediments. The primary minerals of refractory clays are kaolinite ($Al_2Si_2O_5(OH)_4$) and halloysite ($Al_2Si_2O_5(OH)_4.2H_2O$). Minor quantities of other hydrous aluminum silicates may occur in refractory clays.

Refractory clay is a term given to clays that may vary in chemical and physical characteristics, but can withstand high temperatures without softening. A clay's refractoriness is directly related to its purity. A clay with impurities such as ferric iron, lime, alkalies or silica will be much less refractory then a clay containing none of these impurities.

The pyrometric cone equivalent (PCE) is the measure of a clay's refractoriness. The standard method of testing for the PCE is described in detail in ASTM designation C24, published by the American Society for Testing Materials.

Clays having a PCE of 33 or higher are used in the manufacture of super-duty refractories. Those with a PCE of 31-32 classify a brick as high-duty. Those with a PCE from 29-30 are labelled intermediate-duty, and those with a PCE from 19-28 are called low-duty refractories. Table 1 shows the range in PCE of the different classes of refractories and the equivalent cone temperatures (American Society for Testing Materials, 1978a, 1978b). Of the many types of refractory clays, the only types A. P. Green is concerned with in the Colorado area are the plastic and the flint clays. Table 2 describes the principal types of refractory clay (Van Sant, 1959).

PROSPECTING

The first step in prospecting for clay in a given area is to review all available publications on that area. This material is usually obtained from various state and federal agencies such as the USGS or the individual State Geological Survey. Other sources might include colleges, universities or private companies. The geologic map is probably the one most valuable resource for locating outcrops of the formation one is looking for. The geologic map will usually show the locations of other mines in the area as well as strike and dip of the rock units.

After the outcrop has been located, field reconnaissance is initiated to collect samples from the area. Samples are usually taken from old mines, road cuts, or the outcrop itself. In conjunction with the field reconnaissance, extensive courthouse work is done to obtain ownership maps and to determine if any leases are currently held on the properties in the area. As soon as the test results for the samples are known, those testing satisfactorily are pursued. The landowner is contacted, and an attempt is made to secure the clay

Table 1. Classification by Pyrometric Cone Equivalent of refractories made from fire clay

Type of Refractory	Minimum PCE	Temperature °C	°F
Super-duty	33	1743	3169
High-duty	31 1/2	1699	3090
Medium-duty	29	1659	3018
Low-duty	15	1430	2606

Table 2. Description of principal types of refractory clays

Clay Types	Principal Mineral and General Description
Semiplastic	Large quantities of kaolinite; smaller quantities of halloysite, quartz, and other impurities
Plastic	Mostly kaolinite with some halloysite and illite, and variable quantities of quartz and other impurities
Semiflint	Halloysite and kaolinite with appreciable quartz
Flint	Halloysite, kaolinite, and some quartz
Burley Flint	Halloyiste; contains small oolites of halloysite and kaolinite. Some diaspore may be present.
Burley	Oolites and nodular varieties of diaspore clay with some halloysite and kaolinite
Diaspore	These clays vary in texture, color, and composition but are primarily composed of diaspore and have an alumina content exceeding 60%; they often contain titania in doubtful mineral form

in a binding agreement. A core drill is then brought in to determine areal extent as well as quality of the deposit. Drilling is usually done on a grid pattern, and the cores are sampled and sent in for further testing.

While the samples are being run, the drill holes are surveyed and plotted on a map. Then the test results of the core samples are posted on the map and a pit outline is drawn. With this outline and an average thickness of the clay, an estimate of the reserves is calculated.

Depending on the plant's usage and the existing stockpile reserves, the property may be mined immediately, or it may be left for several years before it is mined.

UNDERGROUND MINING

With the acquisition of the Standard Fire Brick Co. of Pueblo around 1960, A. P. Green also acquired the Rock Creek underground mine. Located in the Beulah district of Pueblo County, this mine has been active since 1939. Entry is by an incline of approximately 10° through 36 ft of sandstone. Flint clay is mined from the Dry Creek Canyon Member of the Dakota Sandstone and ranges in thickness from 6 to 24 ft. A stratum of plastic clay immediately overlies the flint clay, but it is not of sufficient quality for refractories and is sold to another brick company. Using the room-and-pillar method of mining, the clay is drilled with electric drills and the holes loaded with explosives. The shot is made at the end of the day and loaded out the next day. The clay is carried to the surface using a Wagner Scooptram and placed in layered stockpiles to await transport to the Pueblo plant some 15 miles away. Air is circulated through the mine through two huge shafts and ventilating fans. Core drilling is conducted on 100-ft centers prior to mining to determine clay quality and to thereby plan the mining operation.

OTHER OCCURRENCES OF FLINT CLAY

The occurrence of flint clays in Colorado is not limited to the Rock Creek area, but production, even in other areas, still comes from the Dry Creek Canyon Member of the Dakota Sandstone.

The Wilson Creek area, located about 4 miles due north of Canon City, has in the past yielded considerable tonnages of flint clay. It is believed, however, that the estimated reserves in this area are relatively small (Van Sant, 1959, p. 70).

The Turkey Creek district, located approximately 18 miles northwest of Pueblo around the settlement of Stone City, was also an area of extensive flint deposits. This district is divided into two smaller areas. The Stone City area exposures extend west into Fremont County and include the clay-bearing Dry Creek Canyon Member. Clay reserves in this area are not known, but it is believed that due to the dip of the beds, future mining will be through shafts. The Hell Canyon area of the Turkey Creek district lies north and northeast of Stone City. Flint clay here is found in the Dakota, which has been dissected by Hell Canyon and many small tributaries (Van Sant, 1959, p. 89). Reserve estimates in this area are high but still unknown. Undoubtedly other areas might yield refractory flint clays, but prospecting the thick Dakota Sandstone with a core drill is extremely expensive, if not prohibitive.

SURFACE METHODS

High-fusion plastic clay for the Pueblo plant currently comes from the Rockvale area approximately 10 miles south of Canon City. These are coal-measure clays from the Vermejo Formation. Clay from our Alvidrez and Caldirola pits is mined by contour stripping, the overburden being placed in the adjacent mined out cut. The clay is then loaded into trucks with a front-end loader and hauled to the stockpile site to await transport to Pueblo as needed.

A WORD ON STOCKPILES

Quality control is an important part of producing refractories. All stockpiles are layered and sampled for quality control and unformity of physicl properties. Bad sections are either removed prior to loading and transport or are wasted as the pile is loaded out and shipped.

OTHER OCCURRENCES OF PLASTIC CLAYS

The possibility of finding plastic clays with a PCE high enough to be classified as refractory is slim outside the Rockvale area. A. P. Green has mined plastic clays in Las Animas, El Paso, Fremont and Huerfano Counties, but all of these clays were low in fusion and not suitable for present refractory use.

RECLAMATION

As mentioned before, by using the contour stripping method, overburden that is being stripped is placed in the pit that has just been mined out. When this pit is backfilled and graded to its approximate original contour, the topsoil that has been set aside is spread and the area seeded with natural grasses. We have encountered a few problems in the area of reclamation. A. P. Green has found it very difficult to remove and stockpile topsoil when the surface consists of solid sandstone. Also, due to high winds, the lack of precipitation and seeding the area seems rather futile. In the long run, these reclaimed areas appear to return to their original state without much help from man.

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Alunite–A Potentially Economic Source of Aluminum and Potash?

by

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ABSTRACT

Alunite, $KAl_3(SO_4)_2(OH)_6$, traditionally has been considered as an industrial or nonmetallic mineral because of its historic use as a raw material for making potash alum and aluminum sulfate. During World War I, alunite veins at Marysvale, Utah, were mined to make potassium sulfate fertilizer. Prior to and during World War II, alunite was investigated in the U.S. and other countries as a potential ore of aluminum and so achieved a tenuous status as a metallic mineral as well as nonmetallic. By 1965 the Soviet Union was using alunitic rock as an ore of aluminum, producing cell-grade alumina with potassium sulfate fertilizer and sulfuric acid as by-products. In 1970 large deposits of alunite-bearing rock were discovered in southwest Utah, 140 km west of the Marysvale deposits. A private consortium headquartered in Golden, Colorado, conducted pilot-plant tests on Utah alunite ore and in 1974 announced plans to erect a full-scale alumina-from-alunite plant. This project has not yet materialized because of lingering questions of economic viability.

Alunite deposits large enough to be commercially exploitable are found in volcanic terranes where hydrothermal-solfataric processes have strongly altered ash-flow tuffs, breccias, ignimbrites and porphyries of rhyolitic to dacitic composition. Deposits of this kind occur in Utah, southern Nevada and Arizona, southwestern Colorado, and New Mexico. Alunite as an ore of aluminum, with by-product K_2SO_4 and H_2SO_4, has not yet been proved commercially feasible. Cost-saving technological advances or curtailment of foreign bauxite supply could generate an alumina-from-alunite industry in the U.S. by the end of this century.

INTRODUCTION

Historical background

Alunite, $KAl_3(SO_3)_2(OH)_6$, as an industrial mineral has a certain ambivalence. Ladoo and Myers in their volume, Nonmetallic Minerals (1951, 2d ed.), devote a chapter, albeit brief, to alunite or alum stone as it was popularly called by some in times past. Robert L. Bates in his book, Geology of the Industrial Rocks and Minerals (1960, p. 371), devotes exactly one sentence to alunite. The brevity of treatment given to alunite by Bates contrasted with Ladoo and Myers a decade earlier reflected the decline of alunite into a state of near-total disuse. Nevertheless alunite does have a long history, and in past centuries it held a higher place among the industrial minerals than some minerals considered essential today. The classic deposits of alunite at Tolfa, Italy, were mined almost continuously for five centuries from 1460 until fairly recent times. The alunite was used to make potash alum ($KAl(SO_4)_2.12H_2O$) and aluminum sulfate $Al_2(SO_4)_3$; the potash alum made from Tolfa alunite was called "Roman alum" and was a prized commodity in international trade, being used in textile dyeing, leather tanning, paper-making, and other industries. The Tolfa alunite-alum industry was controlled by the Vatican and was an important income producer for the Papal State until recent times (Lombardi and others, 1977). Similarly a large alunite deposit in China was mined for several centuries as a raw material for making alum, and alunite was mined for this purpose in France, Spain, Australia, and other countries during the 19th century.

During the First World War, potash fertilizers from the famous Stassfurt deposits in Germany were cut off from the Allied Powers, and this led to development of alunite veins on Alunite Ridge southwest of Marysvale, Utah, for making potassium sulfate fertilizer. It has been estimated that more than 250,000 short tons of vein alunite were mined and processed for this purpose during World War I (Callaghan, 1973, p. 67). Alunite deposits in Australia also were mined for potash fertilizer during both World Wars. The end of the World War I emergency and the renewed availability of potash fertilizer from cheaper sources soon led to the virtually complete shutdown of alunite mining at Marysvale. However, the Second World War brought a revival of interest in Marysvale alunite, this time as a prospective ore of aluminum with potassium sulfate fertilizer as a by-product. By then the domestic aluminum industry was already outgrowing the capability of domestic bauxite deposits to meet its raw material needs and was becoming more and more dependent on imported bauxite. But German U-boats began to wreak havoc with the ore boats coming up from Dutch Guiana (Surinam). This was before development of Jamaican bauxite resources. The alunite deposits of Marysvale had already been recognized as a possible source of aluminum as well as potash, and wartime necessity stimulated the effort to develop a process using alunite as a nonbauxite ore. It may be appropriate to point out another element of ambivalence about alunite: as a raw material for making alum and potash fertilizer it clearly merits classification as a nonmetallic industrial mineral, but when considered as an ore of aluminum it crosses over into the metallic classification. However, bauxite is "nonmetallic" when used to make refractories, as is manganese ore used to make dry-cell batteries and chemicals, or iron ore used in mineral pigments. Other examples of this metallic-nonmetallic ambivalence can be cited from the latest edition of Industrial Minerals and Rocks (Lefond, 1975).

The alunite veins at Marysvale are high grade but have a limited tonnage, too small to support an alumina plant of economic size. Larger but lower grade replacement-type deposits in the Marysvale district represent a greater total resource base than the veins, but also present formidable problems of extraction. During World War II an experimental plant in Salt Lake City, sponsored by the Defense Plant Corporation, developed the "Kalunite" process (Fleisher, 1944) for extracting cell-grade alumina and potash salts from alunite ore. This development, although promising, did not achieve an economic breakthrough, and so by the end of the war alunite again was relegated to the status of a noneconomic "potential" resource. Furthermore it was recognized by industry that the Marysvale deposits, including the replacements, were not great enough to serve as a viable raw-material resource base.

Later, during the 1950s and 1960s, the Soviet Union, following a policy of raw-material self-sufficiency, investigated its domestic aluminum resources including nonbauxite materials such as nepheline syenite and alunitic rock with which that nation is well endowed. The USSR, like the USA, has limited bauxite resources. By the mid-1960s an alumina-from-alunite plant was established in the state of Azerbaijan, having a productive capacity of 200,000 ton/yr of cell-grade alumina with by-product potassium sulfate fertilizer and sulfuric acid, the first commerical-scale plant of its kind in the world. Meanwhile other countries also were taking a hard look at alunite as a prospective ore of aluminum. Following up on their successful use of alunite as an emergency wartime source of potash, the Australians attempted to develop a process to extract alumina from alunite. This effort was abandoned with development of Australia's enormous bauxite resources in the 1950s. Japan had an active research program prior to and during World War II to utilize its own and Korean alunite deposits as a sorely needed wartime source of aluminum. Mexico initiated a research program along similar lines in the 1950s, culminating in the early 1970s in a proposal to establish a commercial alumina-from-alunite plant at Salamanca, in the state of Guanajuato. However, this project never got past the planning stage, presumably for economic reasons.

The Alumet Project

Closer to home, alunite received what appeared to be a new lease on life in 1970 when representatives of Earth Sciences, Inc, of Golden, Colorado, discovered very large low-grade bodies of alunite-bearing altered volcanic rocks of Tertiary age. The deposits are located in the southern Wah Wah Mountains of Beaver County, Utah, 90 km northwest of Cedar City and 140 km west of the deposits at Marysvale (Walker and Stevens, 1974; Parkinson, 1974). This discovery was quickly followed by exploration drilling (Figures 1 and 2) under a partnership comprising Earth Sciences, Inc., National Steel Co. of Pittsburgh, Pa., and Southwire of Carrollton, Ga. Further investigation in other western states, notably Nevada, Arizona, Colorado, and New Mexico confirmed the presence of additional large low-grade alunite-bearing deposits, some of which had been known for many years, others recognized for the first time by geologists of Earth Sciences, Inc. An alumina-from-alunite pilot plant with nominal feed capacity of 10 ton/day was erected in Golden, Colorado, at a reported cost of $3,000,000 (Parkinson, 1974, p. 76) and operated from November 1973 until the end of 1976 (Thompson, 1976). Meanwhile results of exploration of the Beaver County, Utah, alunite-lease areas were published by the consortium and showed a proven reserve of 100 million short tons of ore containing 35 to 40 percent alunite (equivalent to 12.9 to 14.8 percent Al_2O_3) and a combined additional indicated-inferred reserve totalling 600 million short tons of material of about the same grade (Walker and Stevens, 1974; Parkinson, 1974). At the same time, the consortium announced its plan to construct a full-scale plant near the Beaver County deposits which would have the capacity to produce 500,000 ton/yr of cell-grade alumina plus 250,000 ton/yr of fertilizer-grade potassium sulfate and 450,000 ton/yr of industrial-grade sulfuric acid. The sulfuric acid would be used to acidulate phosphate rock shipped to the site by rail from southeastern Idaho. Under this plan two valuable fertilizer products, in addition to the alumina, would appreciably compensate for the low alumina tenor of the alunitic rock (Walker and Stevens, 1974; Parkinson, 1974; Thompson, 1976). However, to date the Alumet project has not materialized, owing primarily to the very large investment required and the intent to employ a technology untried and unproven on a large commercial scale in a free market economy.

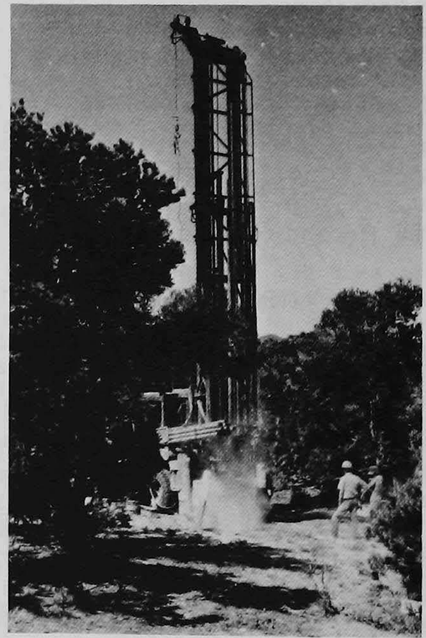

Figure 1. Exploration drilling in the southern Wah Wah Mountains of Beaver County, Utah, by the Alumet consortium has demonstrated reserves of 30-percent alunite ore sufficient to support 500,000-ton/yr alumina plant for several decades.

Figure 2. Alumet's open pit, southern Wah Wah Mountains, Beaver County, Utah, where alunite ore was mined and shipped to 10-ton/day pilot plant at Golden, Colo., for metallurgical testing between 1973 and 1976.

GEOLOGY OF ALUNITE DEPOSITS

Types of Deposits

Three main types of alunite deposits are recognized: (1) veins, (2) sedimentary deposits, and (3) replacements. The first type, veins, is well exemplified by the high-grade lenticular veins on Alunite Ridge near Marysvale in Piute County, Utah, first described by Butler and Gale (1912), and later in greater detail by Callaghan (1938, 1973). The veins are composed of nearly pure alunite and, as previously mentioned, were a signficant source of potash fertilizer in World War I, and supplied much of the raw material to the experimental "Kalunite" alumina-from-alunite plant during World War II. Unfortunately the total resource in veins at Marysvale is estimated at only about 2 million tons (Hall, 1978, p. A10). Other vein deposits in the western states are less promising; similar veins elsewhere in the world also do not constitute a resource large enough to support an aluminum industry. The second type, sedimentary deposits, is surprisingly common and geographically widespread, but like veins, the total resource is not great enough or concentrated enough to serve as an industrial raw-material base. Most deposits of this type consist of thin local layers of nodules in argillic sediment and are not economically minable. Sedimentary deposits of an unusual type have been mined successfully in Australia during wartime emergency, but even these are too small to serve as a long-term economic aluminum resource. Because veins and sedimentary deposits show comparatively little commercial promise, they will not be discussed further.

The third type, replacements, are of lower grade than the veins or even sedimentary nodules, but some deposits of this type are very large (100 million tons or more); this class of deposit constitutes the bulk of alunite resources, both in the United States and elsewhere in the world (Hall, 1978, p. A3).

Characteristics of Alunite Ore

Pure alunite has the formula $KAl_3(SO_4)_2(OH)_6$ and its theoretical composition is 11.37 percent K_2O, 36.92 percent Al_2O_3, 38.66 percent SO_3, and 13.05 percent H_2O. However, "pure" alunite of this composition is very rare in nature. Some Na almost invariably substitutes for K in the mineral lattice; when the atomic (not weight) ratio of Na is equal to or greater than K, the mineral is called natroalunite. K-rich alunite is of greater commercial value than the Na-rich variety because K_2SO_4 fertilizer brings a higher price than salt cake, Na_2SO_4. The two varieties differ little in the Al_2O_3 content. The material under consideration is a fine-grained rock containing other minerals in addition to alunite, and bears little resemblance to textbook descriptions of the pure mineral. Typical alunite ore in large replacement deposits is a hydrothermally and solfatarically altered volcanic rock, commonly ash-flow tuff or ignimbrite of rhyolitic to andesitic composition. It consists of 60 to 65 percent microcrystalline quartz, 30 or more percent alunite, and minor amounts of iron and titanium oxides. If more than a few percent of mica or clay mineral is present, the material may not be a usable ore. In general a deposit should contain 100 million tons or more of this kind of rock, averaging 30 or more percent of alunite, in order to merit consideration as a potentially economic nonbauxite ore (W. W. Walker, Earth Sciences, Inc., oral comm., 1974). Because the rock typically is very fine grained, X-ray powder diffractometry is the most useful method for determining bulk composition. The upper part of Figure 3 is a reproduction of the X-ray pattern of high-grade alunite ore.

The lower part of Figure 3 is a reproduction of the differential thermal analysis curve of the same material. Figures 4, 5, 6, and 7 show some of the microscopic characteristics of quart-alunite rock. Not uncommonly, the metasomatic replacement process takes place in such a way that the original texture of the volcanic rock is surprisingly well preserved in spite of the profound change in chemical and mineral composition (Figure 8).

Zoning of Replacement Deposits

A characteristic zoning is exhibited at large alunite replacement deposits (Figure 9) as follows:

(1) Siliceous core or cap. The rock here is composed mainly of white to grayish chertlike microcrystalline quartz or, less commonly, of milky flintlike opaline cristobalite. Native sulfur may be present as coatings or fillings in spongelike openings. The original volcanic rock has been thoroughly leached of alkaline components and alumina, and this zone is believed to mark the principal vent or channel for strongly acidic hydrothermal fluids that rose through the volcanic edifice.

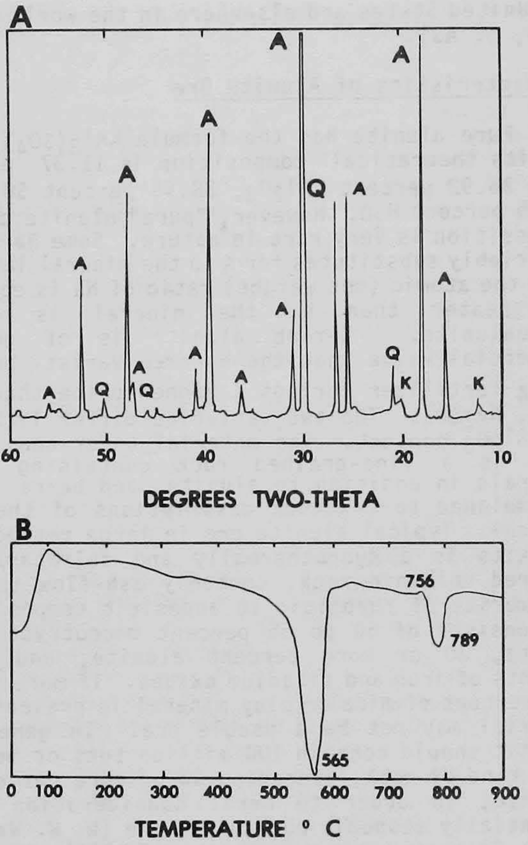

Figure 3. A. X-ray diffraction pattern of high-grade alunite ore from Earth Sciences, Inc., pit, southern Wah Wah Mountains, Beaver County, Utah. A, alunite, Q, quartz, K, kaolinite.

B. Differential thermal analysis (DTA) curve of same material. Only alunite shows response on the DTA.

(2) Quartz-alunite zone. The siliceous core is enveloped by a broad zone consisting of microcrystalline quartz interspersed with abundant small shreddy crystals and flakes of alunite. Minor amounts of iron and titanium oxides are ubiquitous, commonly producing a reddish or purplish mottling. Small amounts of kaolinite or dickite and other alteration minerals may be present, but quartz and alunite typically dominate. This zone is most likely to constitute ore because alunite tenor may be 30 percent or greater.

(3) Inner argillic zone. The quartz-alunite zone grades outwardly to the inner argillic zone--"argillic" because of the prominence of clay minerals, especially kaolinite, $Al_2Si_2O_5(OH)_4$, although its polymorph dickite also is common (Figure 10). The rock has a whitish bleached aspect but may be stained with hematite or goethite. Microquartz is still the dominant mineral phase with kaolin minerals and alunite roughly subequal. Other minerals found in subordinate amounts include: pyrophyllite ($Al_2Si_4O_{10}(OH)_2$), diaspore ($AlO(OH)$), sericite ($KAl_3Si_3O_{10}(OH)_2$), and rarely sparse zunyite ($Al_{13}Si_5O_{20}(OH,F)_{18}Cl$).

(4) Outer argillic zone. This zone differs from the inner argillic zone, which it surrounds, mainly in intensity of alteration. The bleached appearance is subdued and the primary rock texture less blurred than in the inner zones of alteration. Alunite is sparse or absent. Kaolinite may be an important

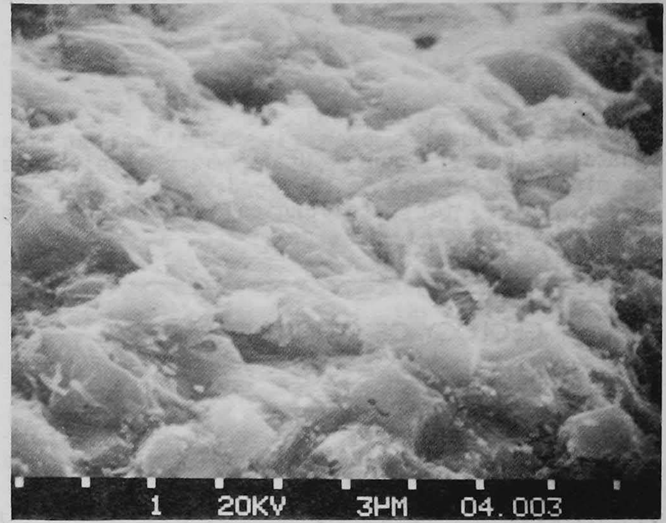

Figure 4. Scanning electron micrograph (SEM) of high-grade alunite ore from Alumet lease, southern Wah Wah Mountains, Beaver County, Utah. Scale 3 µm between ticks. Rock consists of alunite, quartz, and very minor halloysite (?). Larger subhedrons mostly alunite; tiny whisker-like elongate particles probably halloysite.

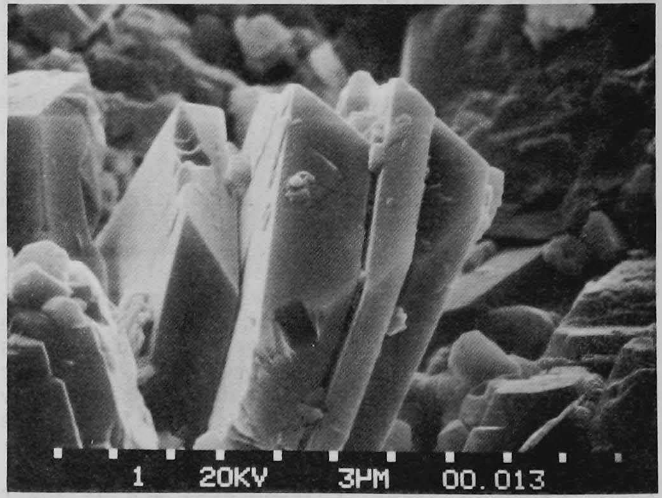

Figure 5. Scanning electron micrograph (SEM) of alunite rhombs in altered latite porphyry from near crest of Calico Peak, Dolores County, Colorado. Scale 3 µm between ticks.

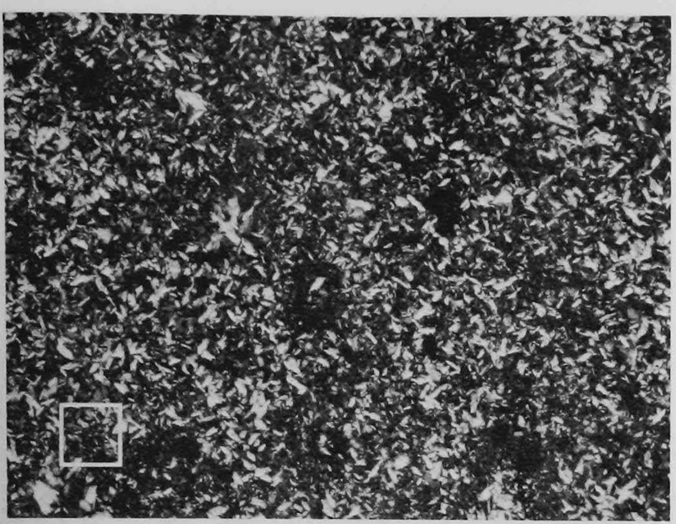

Figure 6. Photomicrograph of high-grade alunite ore from east slope of Red Mountain, Hinsdale County, Colorado, 5 km south-southwest of Lake City. Square 0.1 mm across. Crossed polarizers. Elongate shreddy flakes are alunite; dark matrix (low birefringence) is microcrystalline quartz. Curious runic arrangement of elongated alunite crystallites is characteristic of metasomatically altered alunite-rich rock.

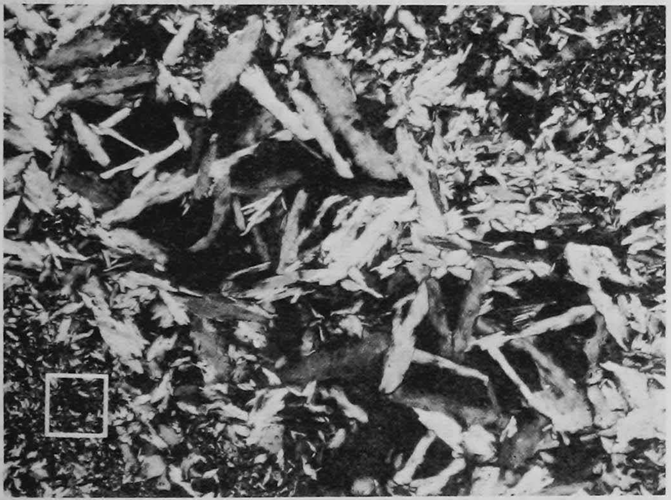

Figure 7. Photomicrograph of same specimen as in Figure 6. Coarser elongate alunite crystals (light) and microquartz (dark) metasomatically replacing feldspar phenocryst in quartz-latite porphyry. Crossed polarizers. Square 0.1 mm across.

constituent but commonly is subequal with or subordinate to sericite. At least a part of the sericite may be illite or so-called "hydromica." It is difficult to precisely distinguish species in these mineral mixtures, either by X-ray diffraction or in thin sections.

(5) Propylitic zone. The outer argillic zone is succeeded by a still more mildly altered zone, the propylitic zone, characterized by a dull, dark grayish-green color and generally by a fairly well preserved primary texture. Feldspars are sericitized; quartz usually is present, both as a primary constituent and as a secondary alteration mineral; epidote, chlorite, zeolites, calcite, and pyrite are characteristic members of the alteration mineral assemblage. Propylitized rock grades into relatively unaltered rock if traced outward far enough, but this zone is so broad and pervasive and gradation so insidious that boundaries may be difficult to map, particularly with a weathering overprint on outcrops.

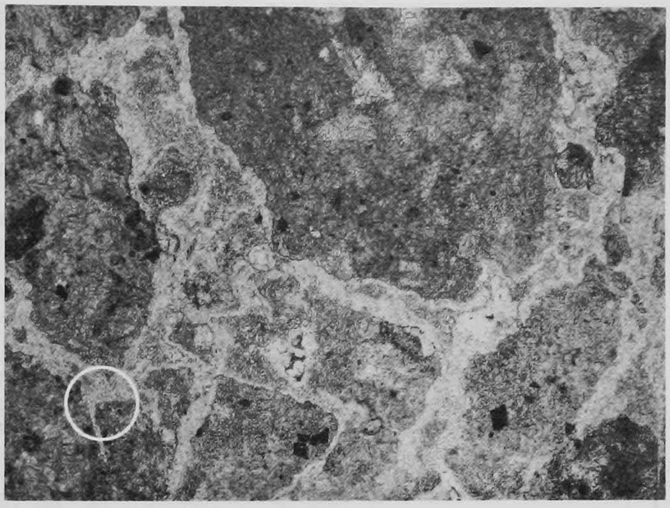

Figure 8. Photomicrograph of lithic ash tuff metasomatically altered to high-grade alunite ore, Marble Mountain, Rio Grande County, Colorado, 10 km east of Summitville. Plane light. Circle 0.1 mm across. Lithic ash fragments (gray) composed of extremely fine-grained microquartz and alunite; matrix (light gray) very fine-grained alunite with subordinate microquartz. Original texture well preserved in spite of profound change in chemical and mineral composition by hydrothermal-solfataric alteration.

Origin

The large replacement deposits in Utah and elsewhere in the western states are the product of hydrothermal and solfataric processes during late stages of an extensive episode of volcanism. The bulk of altered rocks composing the deposits are volcanic. The characteristic zoned pattern indicates that sulfuric acid-charged fluids rising through a vent leached acid-soluble constituents from the rock immediately surrounding the vent, destroying the lattices of the component minerals and permitting metasomatic volume-for-volume replacement by minerals of the alteration suite. Curiously, except in the siliceous core or cap, the primary texture of the rock may be preserved well enough to be readily recognized in thin section (Figure 8), if not in hand specimen or outcrop. With lowering of temperature and rising pH of the hypogene fluids as they react with rock nearest the main conduit, the alteration-mineral suite changes outwardly from the center in accordance with the stability fields of the respective mineral constituents (Hemley and others, 1969). Thus, we see alunite near the center yielding to kaolinte-dickite, then sericite-illite, then to montmorillonitic species, and finally culminating toward the periphery in the relatively mildly altered propylitic zone with chlorite, epidote, calcite, and zeolites--minerals that cannot exist in the acidic environment that caused the alunitization near the center. The sulfurc acid-charged water is though to be a product of the near-surface oxidation of volcanic H_2S arising from below. Both H_2S and and SO_2 are common constituents in volcanic gases emanating from solfataric fumaroles. The water and steam may be partly magmatic ("juvenile") but probably is mostly resurgent deep-circulating meteoric water, more or less in accord with the model suggested by White and others (1971).

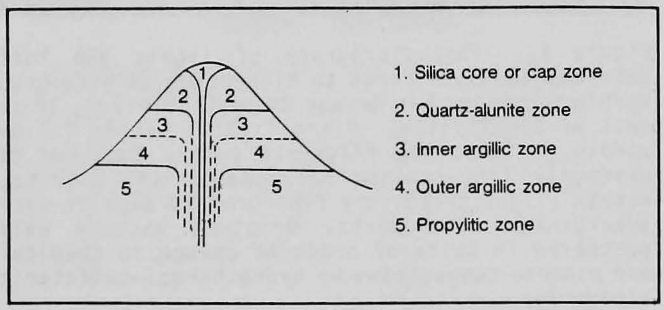

Figure 9. Idealized diagram showing characteristic zoned alteration at replacement alunite deposits in western United States. See text for explanation.

ALUNITE RESOURCES

Domestic

Any undeveloped resource like alunite must be shown to exist concentrated in deposits large enough to serve as a long-term industrial raw material. Below are mentioned some deposits in the United States, at least some of which satisfy this requirement. Figure 11 shows the locations of known alunite resources in the United States.

Utah

The Earth Science, Inc., discovery in 1970 of very large deposits in the southern Wah Wah Mountains of Beaver County and the subsequent exploration and pilot-plant testing by the Alumet consortium have already been mentioned. The lease areas held by the partnership contain the best explored and most promising alunite resources so far recognized in the United States, with more than 600 million tons of estimated resources containing about 30 percent alunite. These deposits are adequate to supply a 500,000-ton/yr alumina plant for several decades.

The longer known resources at Marysvale in Piute County are estimated to amount to less than one-tenth of those in Beaver County, but if an alumina-from-alunite plant were to be built and operated successfully in Beaver County, one may reasonably expect that the Marysvale district would receive renewed attention.

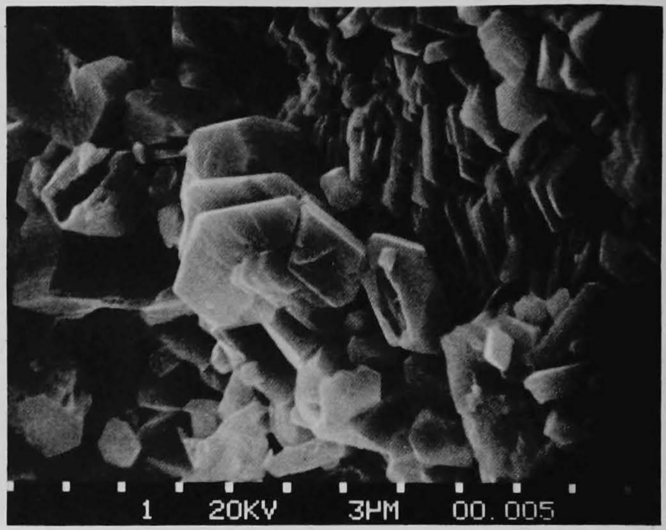

Figure 10. Scanning electron micrograph (SEM) of dickite crystallites in altered quartz latite at Red Mountain, Hinsdale County, Colorado, 5 km south-southwest of Lake City. Scale 3 µm between ticks. Sample from argillic zone immediately east of quartz-alunite zone. Entire upper mass of Red Mountain is composed of quartz-alunite rock (Figures 6 and 7), but lower flanks grade into argillic rock, shown here. Dickite and other phyllosilicate minerals are undesirable contaminants in alunite ore.

Nevada

Alunite deposits are numerous and widespread in southern Nevada, especially in Lincoln, Clark, Esmeralda, Mineral, Nye, and Lyon Counties. However, none of these appear to be as promising as those in Utah. The deposits with high alunite content are small, and the large deposits tend to be nonhomogeneous and low-grade with pockets of ore surrounded by subore-grade highly siliceous masses. Nevertheless a successful alunite plant in Utah would probably lead to more intensive exploration in Nevada.

Arizona

At present only one deposit in Arizona appears to have commerical potential--Red Mountain, 5 km southeast of the small town of Patagonia in Santa Cruz County. The pervasively altered upper part of Red Mountain has been drilled for alunite. The drill data are propietary, but my own resource estimate of 200 million tons of alunite-bearing rock probably is conservative (Hall, 1978, p. A14). There is uncertainty as to the average alunite tenor, and the quality of the ore probably is not equal to that in Utah. Interestingly another company has discovered low-grade porphyry

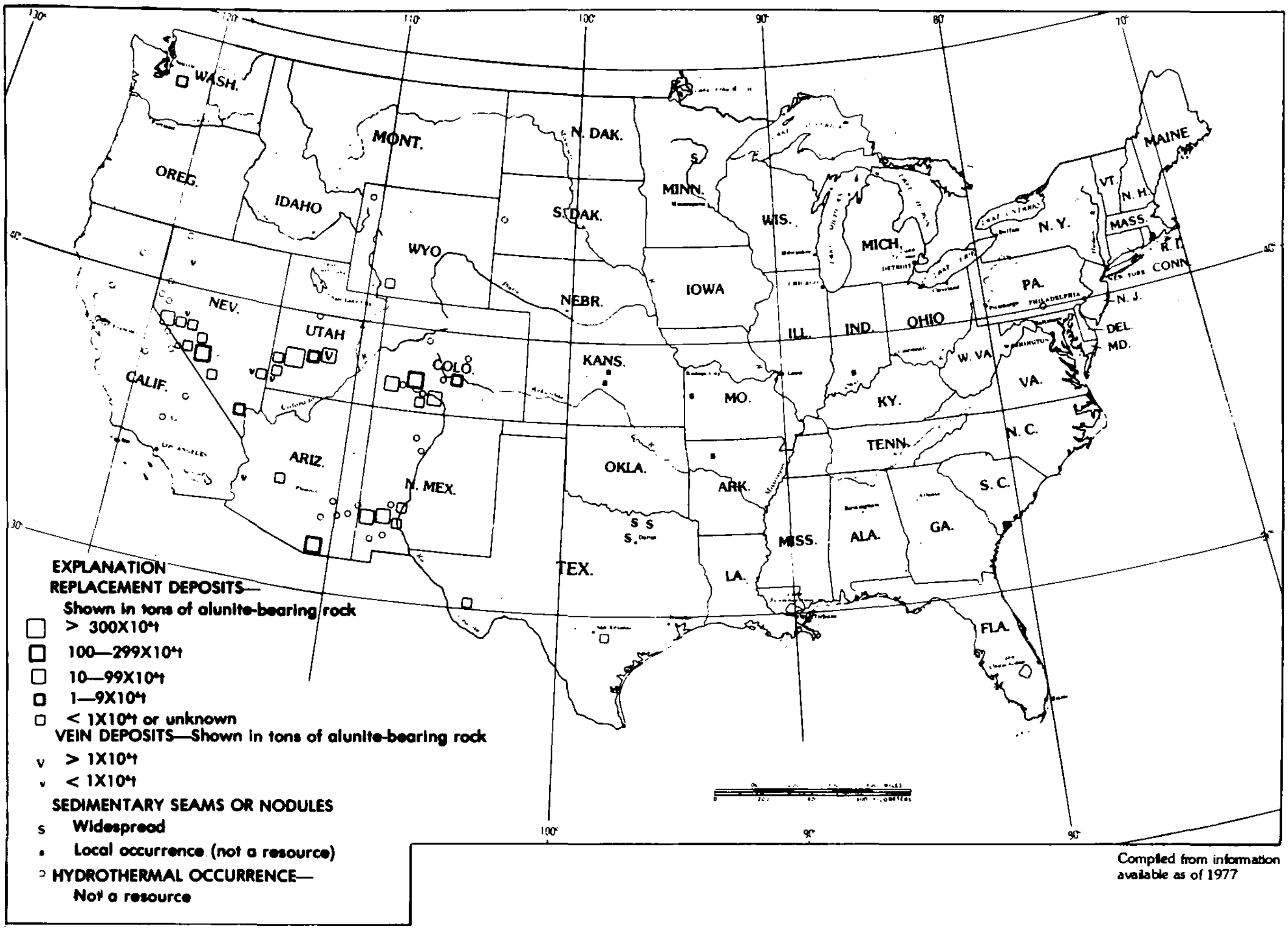

Figure 11. Map showing location of alunite resources in the conterminous United States. Symbols designating the three largest categories include deposits or districts with commercial potential. Smaller deposits are mainly of geological interest. Adapted from Hall (1978).

copper-type mineralization by deeper drilling extending below the alunitized part of the mountain (Corn, 1975). This has led to speculation that Red Mountain might someday be the site of two mining operations, one open-pit on top of the mountain for alunite, the other deep underground for copper. However, neither of these is likely to take place very soon.

Colorado

Alunite was recognized in Colorado many years ago by geologists of the U.S. Geological Survey. Significant bodies of alunitized Tertiary volcanic rock were reported in the Rosita Hills, Custer County, by Whitman Cross in 1891 (Cross, 1891, 1896); at Calico Peak near Rico in Dolores County by Cross and Spencer (1900); and in parts of Hinsdale County near Lake City by Larsen (1913). Small localized alunite-rich bodies later were reported in the Summitville district in southwestern Rio Grande County (Steven and Ratte, 1960), and a deposit of Marble Mountain, 12 km east of Summitville, was examined during World War II (L. S. Gardner, USGS unpub. data, 1943). However, only one deposit in Colorado clearly shows commercial potential--that at Red Mountain, 5 km south-southwest of Lake City, Hinsdale County (Figure 12). (This is not to be confused with the previously mentioned Red Mountain in Santa Cruz County, Arizona, nor with the other "Red" Mountains in Colorado.) The Red Mountain near Lake City is a volcanic neck of quartz latite porphyry of Miocene age that has been pervasively altered by hydrothermal-solfataric processes. Virtually the entire upper portion of the mountain mass from the peak 3,909 m down to an elevation of about 3,700 m is composed of quartz-alunite rock, probably averaging at least 30 percent alunite. A potential resource of 250 million tons probably is a conservative estimate; a representative of Earth Sciences, Inc., has suggested that the deposit could

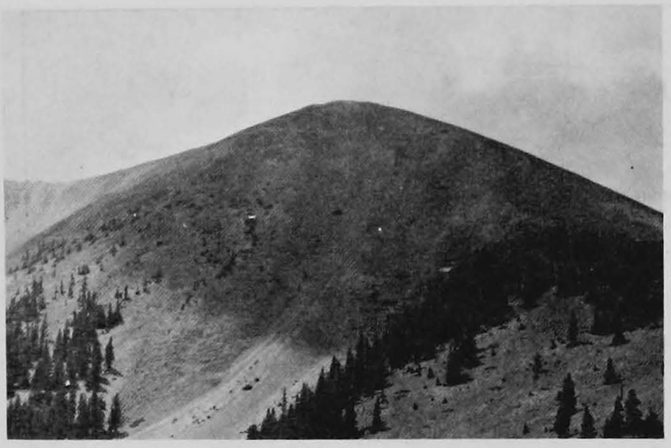

Figure 12. Red Mountain, 5 km south-southwest of Lake City, Hinsdale County, Colorado. Entire mass above timberline is quartz-alunite rock; argillic zone boundary is at upper edge of trees on ridge at right of photo. Red Mountain is the most promising body of alunite in Colorado.

hold 2 billion tons of rock containing 35 to 40 percent alunite (Lyle, 1977). The reserve is unproven, but currently available data suggest that Red Mountain may be one of the largest alunite deposits in the world, comparing very favorably in size and grade with the more thoroughly explored deposits in the southern Wah Wah Mountains of Utah. However, formidable obstacles will have to be overcome if the Red Mountain deposit is ever to be developed commercially. It is located in rugged terrain of the San Juan Mountains volcanic complex, remote from a railroad, in a region lacking an industrial infrastructure. Year-round mining on a high mountain would be a tough challenge, and environmental objections to an operation of this size in a scenic recreational area would be difficult to overcome. Nevertheless if an alumina-from-alunite plant were successful in Utah, one could reasonably expect that the Red Mountain deposit would receive serious consideration as a basis for an expanded alunite industry.

New Mexico

Several alunite deposits in altered Tertiary volcanics occur in New Mexico; two in Grant County are large enough to be considered as potential commercial prospects. One deposit on the south side of the Gila River at Alum Mountain and Alum Canyon, 56 km north of Silver City, was reported first by C. W. Hayes (1907) but has not been fully evaluated; it is immediately adjacent to to Gila Wilderness Area. The material is of variable quality and might not be economical to process with present technology. Another alunite deposit at Saddleback Mountain in extreme western Grant County, adjacent to the Arizona boundary, was recognized first by geologists of Earth Sciences, Inc., in 1974. The altered rock here is a quartz-alunite mixture containing about 30 percent alunite, and a possible resource of 60 million tons has been estimated, although further exploration is needed for proper evaluation.

Other States

Numerous additional deposits of alunite occur in other states, including Washington, California, and Texas. None of these are as promising as those already mentioned.

Foreign

Alunite deposits have global distribution, and some certainly are of a size and grade that should encourage development in the future, if they can be proven as an economic ore of aluminum, with potassium sulfate and sulfuric acid as by-products. Only the briefest summary of foreign resources is given here; a more comprehensive summary can be found in a recent review of worldwide alunite resources (Hall, 1978).

Union of Soviet Socialist Republics

The USSR is the only country in the world to have an established alumina-from-alunite industry. The Soviet plant, which has a capacity of 200,000 metric tons/yr of alumina, is located in Azerbaijan and fed by ore composed mainly of quartz and alunite, a product of hydrothermal-solfataric alteration of tuffaceous volcanics of Late Jurassic age. This plant has been operating since 1966, and has set a precedent. The world has its first commercial-scale alumina-from-alunite plant after decades of laboratory and pilot-plant testing in a number of countries. The deposit in Azerbaijan that feeds the plant is not the only alunite resource available in the USSR. Many other deposits occur inside this vast nation, which may be better endowed with alunite resources than any other country in the world.

Europe

The historically important deposits in Italy have been mentioned already. Deposits in Spain, France, Greece, and Bulgaria have been considered at various times for use as a nonbauxite aluminum ore.

Asia

The People's Republic of China may have the most promising alunite resources in the Far East (Yih, 1931; Ikonnikov, 1975). Smaller deposits in Japan and the Republic of Korea were wartime sources of aluminum and potash (Allen, 1947). A recent article in World Mining (1977, p. 57) reported a tentative arrangement between Russian technicians and Iranian entrepreneurs to investigate and develop a "billion-ton" alunite deposit in Iran. Recent events in that country make it unlikely that this project will materialize at any time soon.

Australia

Alunite deposits in Australia were mined for raw material to make alum during the 19th century and were emergency sources of potash fertilizer during both World Wars. With development of their enormous bauxite resources, commencing in the 1950s, the Australians' interest in alunite as a source of aluminum quickly waned.

Central and South America

Mexico has a number of alunite deposits of modest size (Yris Rovirosa, 1964). As recently as 1974 a proposal to establish an alumina-from-alunite industry in the state of Guanajuato was being considered seriously, but the proposal has since been suspended. Several porphyry copper deposits in the Argentinian and Chilean Andes are capped with large bodies of alunite-bearing rock, and potentially minable deposits may someday be discovered in the Andean Cordillera.

Other countries

Significant deposits of alunite are known to exist in a number of other countries, for example, Pakistan and Turkey. Unlike Australia most countries with potentially exploitable alunite resources are generally poor in bauxite resources. Consequently, if an alunite industry were to be developed successfully in Utah, establishing the viability of this kind of an operation under a free-enterprise system, similar developments might well follow in these countries.

TECHNOLOGY

Mining

Open-pit mining on a scale comparable to that at Southwest porphyry copper deposits appears to be the only feasible extraction method for the large but low-grade alunite deposits. It seems reasonable to suppose that open-pit mining costs at 100+-million-ton alunite deposits should be no higher than at Arizona's porphyry copper mines. Barren overburden is virtually nonexistent, but savings here might be offset somewhat by the abrasiveness and tenacity of the quartzose alunite rock, which is said to resemble taconite in crushing and grinding properties (Thompson, 1976). Also, the alunite deposits are not homogeneous, and the cost of selective mining to avoid subore-grade rock or to remove it to waste would be similar to the cost of removing overburden at porphyry copper deposits. Mining a replacement-type alunite deposit in the western states would consist essentially of removing the top of a mountain (or a whole mountain) because the siliceous alunite-bearing rock is resistant to erosion and stands as a topographic high.

Metallurgical Processing

The Alumet Process

Several methods of separating alumina, potassium sulfate, and sulfuric acid have been tried in the past. The process presently favored by the Alumet consortium and tested at their Golden, Colo., pilot plant, is based in part on a roasting technique purchased from the Russians. Crushing is followed by grinding to minus 16 mesh, and then by dehydration roasting to drive off water of crystallization. Dehydration is followed by a fluidized-bed roast in a reducing atmosphere to drive off SO_2 associated with aluminum in the alunite molecule. This roasting step must be carried out under narrow and complex restraints on both temperature and velocity of feed-flow (Thompson, 1976). The SO_2 offgas is converted to sulfuric acid in a conventional acid plant. It is intended that the acid would be used to acidulate phosphate rock brought down from Idaho to make triple superphosphate fertilizer. The roasted ore is leached in alkaline water to remove K_2SO_4 that is rendered water soluble during the second roast. The filtered leach liquor is piped into precipitator vessels where crystalline K_2SO_4 is precipitated, then dried and bagged for fertilizer. The sulfate is preferred over the muriate variety of potash in some agricultural applications. The filter cake with K_2SO_4 removed consists of amorphous aluminum trihydrate and quartz plus a small amount of other insoluble mineral matter in the original rock. This residue contains about 23 percent Al_2O_3 and is a kind of low-grade synthetic bauxite (Thompson, 1976) that is treated by a modified Bayer process to extract cell-grade alumina.

The Alumet modification differs from the conventional Bayer process used on bauxite ores in the following two important respects. (1) The alumina in the roasted and leached alunite residue is soluble in caustic solution at atmospheric pressure and at a temperature of 95°C, whereas most conventional Bayer plants use pressures of 200 psi or thereabouts, and temperatures approaching 200°C. The energy saved by lower pressure and temperature offsets somewhat the disadvantage of lower alumina content in the alunite-rock feed. (2) There is much less iron oxide in alunitic rock than in most bauxites; therefore, the "red mud" problem that plagues conventional Bayer plants is nearly negligible in the Alumet process. The filtered tailing is essentially a fine quartz powder.

The sodium aluminate liquor from digestion is purified by desilication and passed to conventional Bayer-type precipitator vessels where a nearly pure aluminum trihydrate (synthetic gibbsite) is precipitated. The $Al(OH)_3$ precipitate is washed, filtered, and calcined, leaving a high-purity alumina sand that is suitable feed for Hall-Heroult type electrolytic cells that reduce alumina to aluminum metal.

The credits from by-product K_2SO_4 fertilizer and from H_2SO_4 (or preferably from the added value of phosphate fertilizer made with the by-product acid) appreciably offset the disadvantage of the lower grade of alunitic rock in comparison to imported bauxite. In the opinion of Alumet engineers, alumina from alunite could compete with that made from imported bauxite (Thompson, 1976). This premise may only be proven by construction and successful operation of a plant employing the Alumet process.

The Problem of Ore Quality

The Alumet process (or any similar process) would appear to be an acceptable solution to the problem of metallurgical extraction, providing that the alunite ore meets the two following important criteria: (1) Alunite content is at least 30 percent. (2) The material is composed essentially of microcrystalline quartz and alunite. Small amounts of iron and titanium oxides can be tolerated, as these are vitually ubiquitous in alunitic rock, and in bauxites as well. However, if the rock contains phyllosilicate minerals such as kaolinite, dickite, halloysite, sericite, illite, or pyrophyllite, or an alkali-soluble form of silica such as opaline cristobalite, a problem arises that can seriously affect the economics of the operation. The phyllosilicates and soluble silica are undesirable in the synthetic bauxite produced by the roast-leach step for the same reason that they are undesirable in natural bauxites. The clay, mica, and cristobalite break down in the caustic digestion, thereby contaminating the aluminate solution with an excessive amount of silica. In contrast, quartz is a "benign" gangue, not soluble in the relatively mild conditions of the modified Bayer process. Removal of silica from the solution entails a costly desilication step that results in loss of alumina and soda. Since 30-percent-alunite rock contains only about 11 percent Al_2O_3 to begin begin with, compared with 45 to 50 percent in bauxites, the losses in desilication become intolerable if the raw alunite ore contains more than a very small amount of phyllosilicates or cristobalite. "There's the rub," to quote Hamlet.

Finding alunitic rock free of soluble silica is not easy because of the nature of the deposits. Although zoning of the hydrothermal alteration is characteristic, the individual zones generally are not homogeneous. There commonly are enclaves of argillic rock in the quartz-alunite zone and pockets of quartz-alunite rock in the argillic zone. Hence, large uniform bodies are uncommon. Nonhomogeneity may be due to variations in the spacing of fractures through which the altering solutions pass, and to differing chemical activity, rate of flow, and temperatures of the solutions themselves, as well as to variations in permeability, grain size, and composition of the rock that is altered. Heterogeneity is a common characteristic of hydrothermally altered terranes, regardless of any broad-scale zoning that may be evident. This is clearly a limitation to be taken into account when considering alunitic rock as a nonbauxite aluminum ore (Hall, 1978, p. A6).

This limitation could be overcome if it were possible to economically concentrate alunite by separation from associated minerals. Unfortunately, so far as I am aware, no satisfactory concentration method has yet been demonstrated. Experiments by the U.S. Bureau of Mines years ago, including differential flotation, did not prove practicable (Gabriel and Dasher, 1942). I do not know of recent research on the concentration problem other than laboratory experiments in Turkey using a selective flocculation technique to separate alunite from kaolinite in both artificial mixtures and a natural alunitic kaolin (Ustaer and Gurgey, 1975). This latter method appears to have doubtful utility on a commercial scale. Nevertheless if an effective and economical technique for concentrating alunite from alunitic rock could be developed, it would greatly increase the likelihood of using alunite as a nonbauxite ore of aluminum and might also produce valuable by-products such as paper-grade kaolinite or dickite.

SOME ECONOMIC CONSIDERATIONS

The recent price of copper has been close to \$1/lb (Metals Week, May 7, 1979, issue quotes a New York dealer price of \$0.967/lb), and some major porphyry copper mines in Arizona have been successfully mining ore containing 0.4 percent Cu, that is 8 lb of metal having a final value of \$8/ton of ore. Concurrently, the price of aluminum ingot has been quoted at 73 cents/lb (Metals Week, May 7, 1979). Rock containing 30 percent alunite holds about 5.86 percent Al, or 117.2 lb of aluminum metal having a final value in ingot of \$85.55/ton of ore. Why then, if Arizona copper producers can work ore with a contained metal value of \$8 per ton, cannot an alunite miner work ore with a contained metal value of \$85 per ton? The answer, of course, lies in the enormously greater processing costs involved, first in extracting 222 lb of cell-grade alumina from a ton of 30-percent-alunite rock, and then reduction of that alumina to the 117.2 lb of metal, compared to cost of extracting 8 lb of Cu from a ton of 0.4-percent-Cu ore. For the alunite operator the critical value is that of alumina, not metallic aluminum.

Established aluminum companies are, for the most part, completely integrated from raw bauxite to finished metal products, and because the alumina made in their own Bayer plants is an internally produced intermediate product, the industry can assign to its alumina whatever price that may be convenient for accounting purposes. The cost of cell-grade alumina has been rising steadily over the past decade owing to long-term inflationary trends plus the effect of sharply increased severance taxes and other levies imposed on the companies that are importing bauxite or alumina from members of the International Bauxite Association (IBA). Calcined alumina recently was quoted at about \$200/short ton (Chemical Marketing Reporter, May 7, 1979, quotes \$193/ton bulk, f.o.b. plant; \$200/ton is used in this discussion).

Consider the gross value of products that can be extracted from one ton of 30-percent-alunite rock:

(1) Al_2O_3, 222 lb @ \$0.10/lb	\$22.20
(2) K_2SO_4, 111 lb @ 0.049/lb (Agricultural 52% K_2O quoted @ \$1.88 per "unit-ton," equivalent to \$99.76/short ton or \$0.0489/lb, Chemical Marketing Reporter, May 7, 1979)	5.42
(3) H_2SO_4, 200 lb @ \$0.015/lb (Acid from alunite is not likely to	3.00

command a price much higher than nonferrous smelter-fume acid which is sold at a sharp discount below "virgin" acid made from Frasch-produced sulfur. Prices quoted for smelter acid currently range from \$6 to \$18/ton, that is, \$0.003 to \$0.009/lb of H_2SO_4, Chemical Marketing Reporter, May 7, 1979.) Assuming a price of \$30/short ton for acid from alunite gives \$0.015/lb.

Total \$30.62

Thus the gross value of products from 30-percent-alunite rock is but a little more than \$30/ton, reckoned at current prices. Would a new "green-field" alunite plant in Utah be profitable today with a gross return of \$30/ton of rock? We do not know, but I have serious doubt. We do know that our nation's aluminum industry, the largest in the world, is more than 90 percent dependent on foreign bauxite. Nonbauxite ores undoubtedly will be looked at more closely than ever in the years ahead. Domestic alunite resources are adequate, at least quantitatively, to support an industry based on this material. The question is not one of availability but of cold marketplace economics. Any cost-reducing technological breakthrough on one hand, or embargo or inordinate escalation of price by IBA suppliers of bauxite and alumina on the other, would greatly increase the probability of eventually establishing an alumina-from-alunite industry in the United States. Such a plant could become a reality by the turn of the century. This does not imply that alunite rock or any other nonbauxite ore is likely to replace bauxite as the main source of the world's aluminum, but our earth's bauxite resources, while enormous, are not inexhaustible.

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Development of Nahcolite-Rich Oil Shales

by

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ABSTRACT

Nahcolite-rich oil shale can supply the world with: superior building materials for low-cost housing and commercial construction, insulation, alkaline chemicals, aluminum, pollution-control reagents, containers, and other products necessary for our industries. Its least valuable use will be to convert its contained kerogen to oil. Its most valuable use will be for materials for low-cost housing. Development of the resource is underway.

INTRODUCTION

Our energy and economic problems are of such a scale that they demand bold solutions. The Senate Energy Committee has finally taken an action in scale with the energy problem. The committee is proposing massive subsidies for oil shale development. Let us hope that the United States does not forget that energy is where you find it. The conversion of nahcolite- and dawsonite-rich oil shale to energy self-sufficient raw materials, to energy-saving housing and to pollution-control reactants will be even more important than producing oil. Fortunately the resource is so vast, all options can be done.

My paper will describe those non-oil uses of nahcolite-rich oil shales and review the current activity in development.

Figures 1, 2, 3, and 4 are self-explanatory index maps of the deposits.

DEVELOPMENT OF NAHCOLITE-RICH OIL SHALE

Nahcolite- or sodium bicarbonate-rich oil shales occur in a section of the Green River Formation called the saline section in Rio Blanco County. It is 800 to 1,000 ft thick and lies 200 ft below the Mahogany Ledge oil shale that is normally considered mineable for purposes of retorting to recover synthetic crude oil.

This saline section contains about 25 percent sodium bicarbonate in beds, nodules, and disseminated nahcolite and about 10 percent disseminated dawsonite or dihydroxy-sodium aluminum carbonate.

These resources constitute the richest, most valuable and most useful mineral deposit in the world.

A very exhaustive study of these resources has been published by Jim Mains and Cliff Farris of the Colorado School of Mines Research Institute for the Department of Energy, Reference IDO- 1683-1. If you desire technical information regarding the deposit, you should refer to that publication--all 15 volumes.

This deposit is unique in the world and has a variety of potential uses that can aid the United States in solving its energy problems and its economic problems. Products that can be made from this resource are in order of their importance:

- Housing
- Commercial building materials
- Containers
- Aluminum
- Nahcolite for SO_2 control
- Industrial chemicals
- Process energy
- Oil

I will discuss each of these potential products and what is being done, or has been done, to bring these particular products to the market.

Housing

If one were to analyze the needs for housing throughout the world, he would come to the conclusion that the universally ideal dwelling would be highly insulated, strong, waterproof, fireproof, vermin-decay proof, lighweight, low-cost, and buildable by unskilled labor. Such a dwelling would also need to be produced in the style of any indigenous architecture.

The maximum utility of the nahcolite-rich oil shales will be to provide such housing the U.S. and for that matter, the world's populations.

Several researchers have demonstrated that the mineralogy of nahcolite-rich oil shale is such that it can be melted with sand to produce lime-soda glass--the same kind of glass found in a beer bottle. Nahcolite-rich oil shale has a value of about $65/ton to a glass plant located in a population center. If a ton of this material is mixed with 1.5 tons of sand, it will yield two tons of molten glass, and that in turn can be made into 5,000 board ft of structural foam glass. Blocks of structural foam glass are glued together with new adhesives and sandwiched with stress skins to form self-supporting wall, ceiling, roof, and floor panels. These panels can then be fabricated into panelized housing to duplicate any style housing one can imagine. A typical three-bedroom suburban home will require 10 to 12 tons of foam glass to form all walls, ceilings, roofs, and floor sections.

Cost at the mine for 12 tons of raw materials is expected to be $120. The cost of producing a board foot of foam glass in a large-production

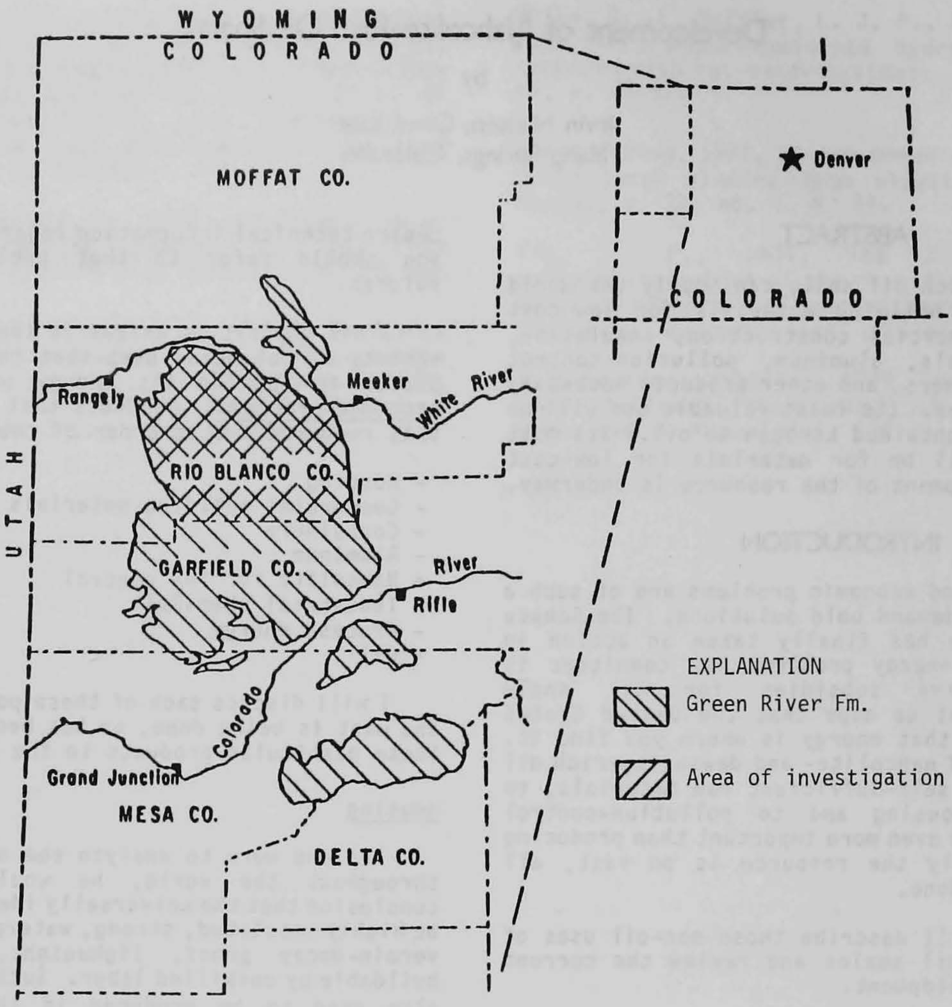

Figure 1. Index map of the Piceance Creek Basin, Colorado.

facility is expected to be $0.15, and the retail price will be about $0.25/board ft. A house requiring 40,000 board ft of foam glass will have a basic material cost of $10,000. To make a long story short, the house can be built for 30 percent less than conventional housing. These houses can be built without the use of any structural lumber and, if sprayed with cement plasters, can be totally fireproof, waterproof, decay- and vermin-proof in addition to being highly insulated (8 in. = R22), low-cost, constructed with unskilled labor and panelized in factories. The savings in capital cost, energy, maintenance, insurance and taxes over a 40-yr period is estimated at $150,000 per house. The savings of $150,000 enjoyed by a family owning a foam glass house could provide for the owner's retirement income. Each ton of foam glass will save approximately the energy equivalent of 400 bbl of oil during its lifetime use.

A mine producing nahcolite-rich oil shale would ship mine-run rock to glass plants throughout the world. No processing would be necessary in Colorado.

Markets for building materials in the U.S. are in the order of $100 billion/yr. Markets in the world must be three or four times that amount. We have a marvelous opportunity to ship energy self-sufficient materials to other countries to offset the cost of our oil imports and lessen their dependence on Mideast oil.

Commercial Building Materials

Commercial buildings can and are being made of foam glass panelized walls and other components. If foam glass becomes a low-priced common building material rather than a high-priced specialty building material, it will find a large market in commercial building construction. The lightweight, high-insulation values and indestructible nature of foam glass panels will reduce construction and maintenance costs appreciably.

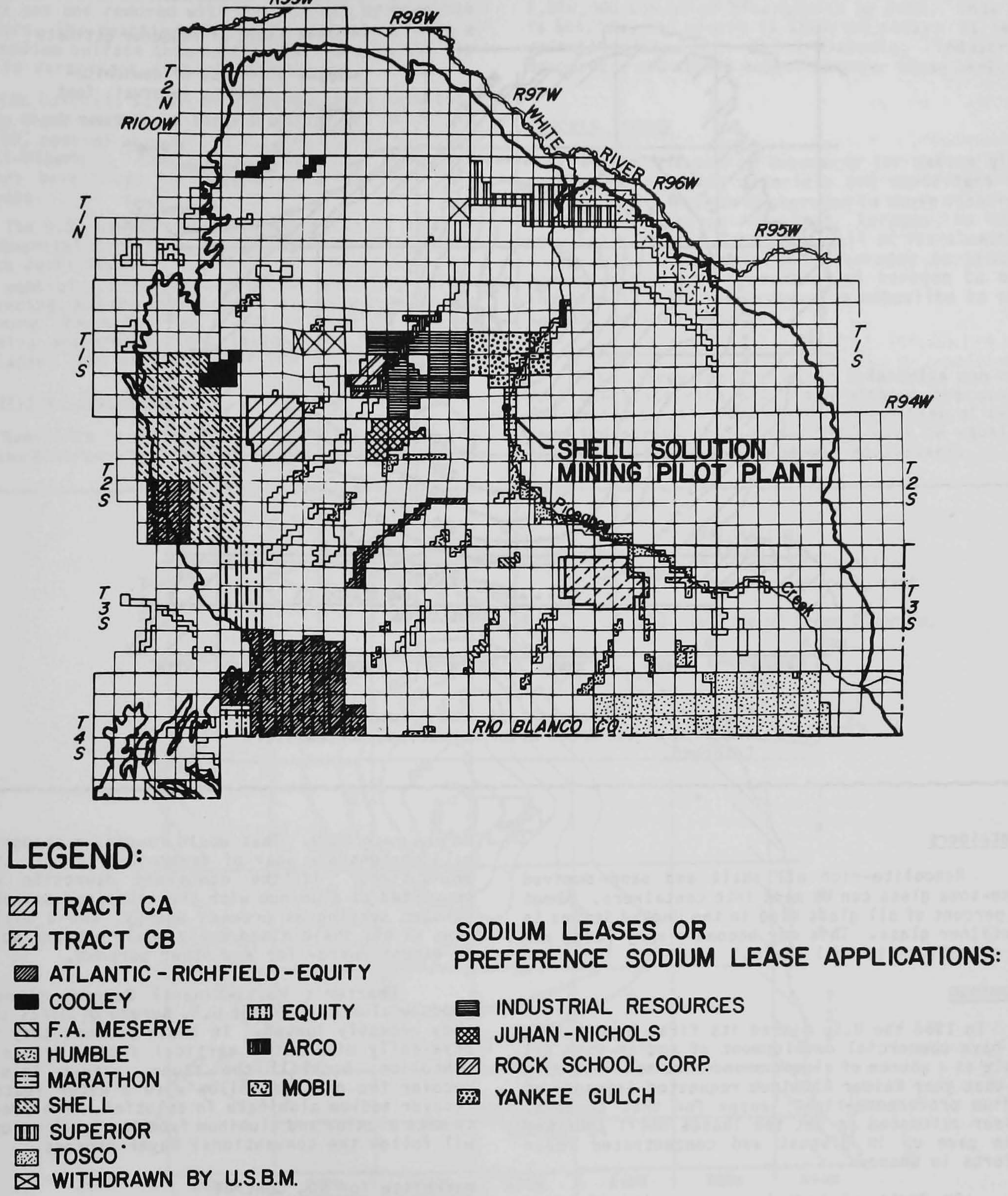

Figure 2. Location of oil shale and sodium leases in the Piceance Creek Basin.

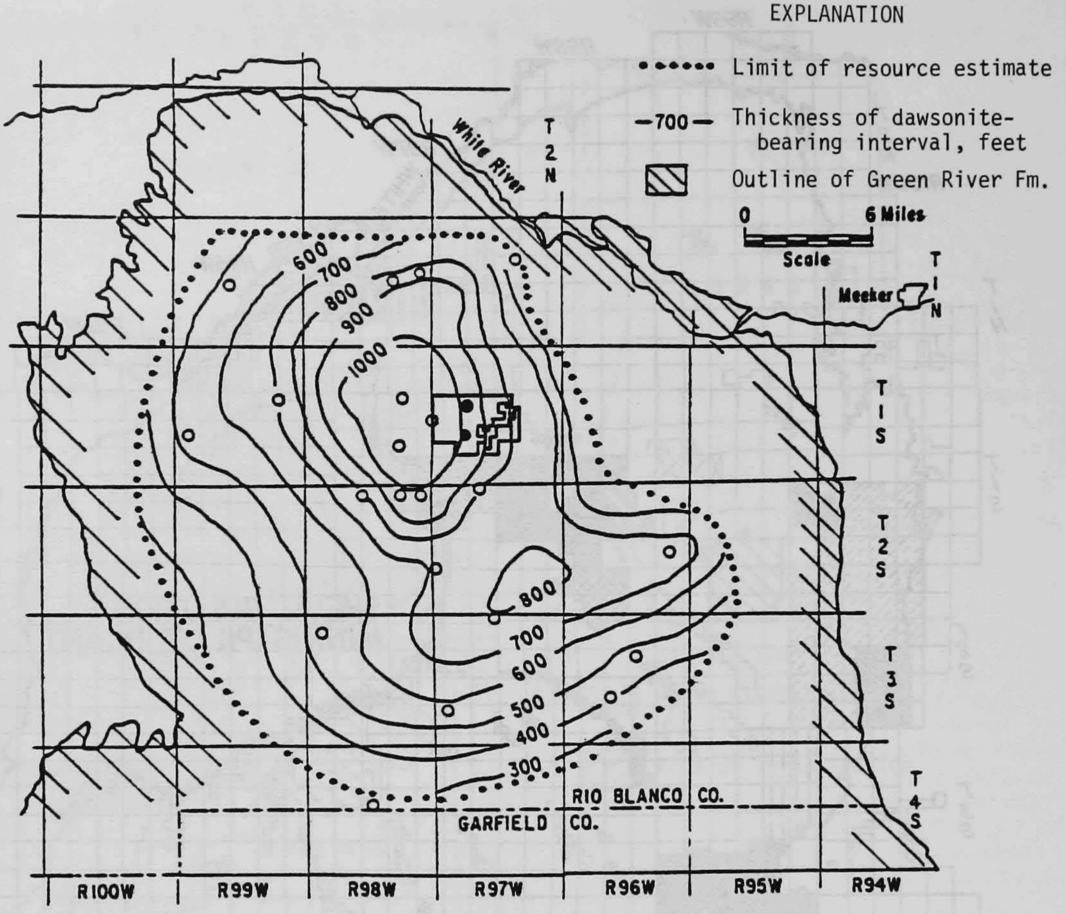

Figure 3. Thickness of the dawsonite-bearing interval of the Green River Formation, northwestern Colorado.

Containers

Nahcolite-rich oil shale and sand-derived lime-soda glass can be made into containers. About 60 percent of all glass made in the United States is container glass. This may become a very large use of nahcolite-rich oil shale.

Aluminum

In 1966 the U.S. missed its first opportunity to have commercial development of sodium-rich oil shale as a source of aluminum and soda ash--not oil. In that year Kaiser Aluminum requested issuance of sodium preference-right leases for that purpose. Kaiser attempted to get the leases until 1967 and then gave up in disgust and concentrated their efforts in Ghana.

In light of today's energy situation and economics, it is time to reconsider dawsonite as a source of alumina and aluminum. CSMRI's study revealed that 115 million tons of dawsonite would be necessary to supply all the U.S. needs for aluminum in the year 2000. That would require a staggering billion tons per year of dawsonite-rich oil shale production. If the contained dawsonite were converted to aluminum with the contained oil-shale kerogen serving as process energy, the 3 million tons of oil shale mined daily would produce no oil or excess energy for any other purpose.

Charter's Multi-Mineral Company plans to produce alumina from the U.S. Bureau of Mines shaft they recently leased. In their process they will physically mine out a vertical stope, remove the nahcolite, backfill the stope, retort in-situ, recover the oil and follow with a water leach to recover sodium aluminate in solution. The process to make alumina and aluminum from the leach solution wil follow the conventional Bayer process.

Nahcolite for SO_2 Control

Nahcolite has been determined to be the only naturally occurring alkali that can be used directly in a totally dry system to remove SO_2 from industrial and power industry flue glases. In that process, powdered nahcolite is injected into the stack gas and removed with the fly ash by baghouse filters. The reaction of $NaHCO_3$ with SO_2 yields a dry sodium sulfate that is then buried with the fly ash in watertight disposal areas.

The Colorado School of Mines Research Institute study shows that the potential market for nahcolite for SO_2 control will be 130 million ton/yr by 2000. Multi-Minerals, Industrial Resources, Inc. and others have plans to produce nahcolite for this purpose.

The U.S. missed its second opportunity to have a commercial operation in this resource when Yankee Gulch Joint Venture formed to mine nahcolite for SO_2 control. Northwestern Mutual was to provide financing, and the Cleveland Cliffs Iron Company was to mine the nahcolite. BLM refused to act on pending preference-right leases, and the venture collapsed just as the Kaiser project collapsed.

Industrial Chemicals

Nahcolite is a potential source of soda ash and sodium bicarbonate. Markets for these chemicals is expected to be 25,000,000 ton/yr of soda ash and 1,000,000 ton/yr of bicarbonate by 2000. Soda ash is $66/ton, and bicarb is $220/ton today. It is my understanding that Multi-Minerals, Industrial Resources, and others expect to enter these markets.

Process Energy

All of the energy necessary for making glass insulating building materials and containers can conceivably come from the kerogen in these resources without conversion of that kerogen to oil. Similarly, the U.S., to supply all of its aluminum, could process dawsonite with kerogen as process energy without the conversion of kerogen to oil. The same is true for processing nahcolite to soda ash and refined bicarb.

Thus, energy for four major industries can come from nahcolite-rich oil shale without the costly conversion to oil. The energy consumption of these four industries in the year 2000 will be equal to about 5 million bbl/day of oil equivalent.

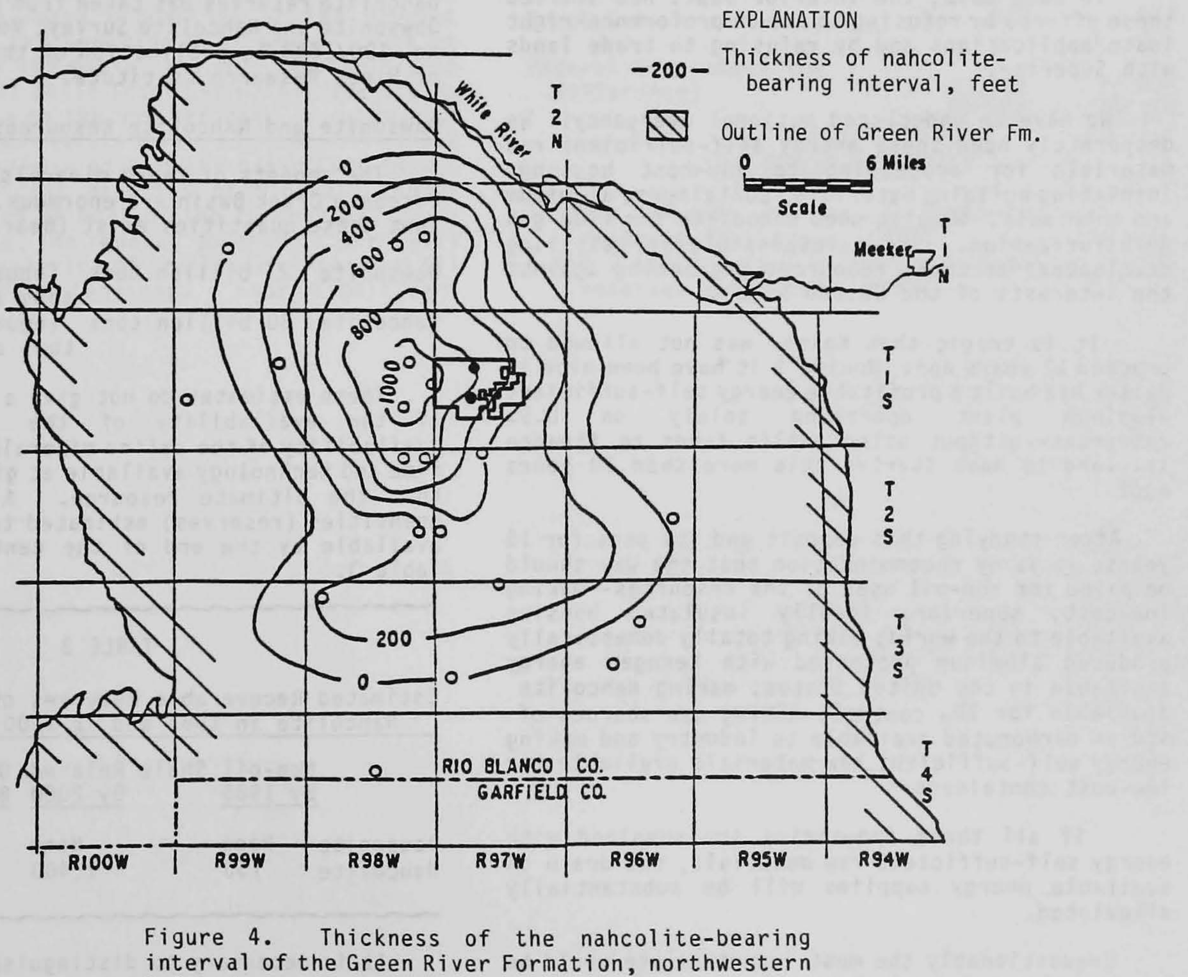

Figure 4. Thickness of the nahcolite-bearing interval of the Green River Formation, northwestern Colorado.

Conversion of Nahcolite-Rich Oil Shale to Oil

Nahcolite-rich oil shale will be processed to yield oil along with nahcolite and alumina in the Multi-Mineral and Industrial Resource proposed projects. Both companies are seeking DOE funding for their projects.

Nahcolite-rich oil shale has a low oil content because of diluting nahcolite. Therefore, its least valuable product is oil. One could not afford to mine this resource for oil shale alone, even at today's prices of oil. Hundreds of thousands of acres of richer oil shales can be exploited at much more accessible depths.

CONCLUSION

Industry has attempted to open commercial development of nahcolite-rich oil shale three times in the past 13 years. Kaiser proposed a dawsonite-to-alumina aluminum plant in 1966; Yankee Gulch, Northwestern Mutual, and Cleveland Cliffs proposed a nahcolite mine in 1976; and Superior Oil Co. has proposed a multimineral plant for the past decade.

In each case, the Interior Dept. has stifled these efforts by refusing to act on preference-right lease applications and by refusing to trade lands with Superior.

We have an undeclared national emergency. We desperately need these energy self-sufficient raw materials for processing to low-cost housing, insulating building materials, containers, aluminum and chemicals. We also need nahcolite for flue-gas desulfurization. Those responsible for stifling development of these resources are acting against the interests of the United States.

It is tragic that Kaiser was not allowed to proceed 12 years ago. Wouldn't it have been nice if Kaiser had built a profitable energy self-sufficient aluminum plant operating solely on U.S. resources--without using public funds to finance it...and to have started this more than 10 years ago?

After studying this deposit and its uses for 15 years, it is my recommendation that the way should be paved for non-oil uses of the resources--making low-cost, superior, ideally insulated housing available to the world; making totally domestically produced aluminum processed with kerogen energy available in the United States; making nahcolite available for SO_2 control; making new sources of sodium carbonates available to industry and making energy self-sufficient raw materials available for low-cost containers.

If all these industries are supplied with energy self-sufficient raw materials, the drain on available energy supplies will be substantially alleviated.

Unquestionably the most important use would be to ship the rock throughout the world for use as a low-cost housing material in the 21st-century energy crisis era.

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APPENDIX

The following information on dawsonite and nahcolite reserves was taken from pages 23-25 of the Dawsonite and Nahcolite Survey, Volume I, Reference No. IDO/1683-1, publication of the Colorado School of Mines Research Institute.

Dawsonite and Nahcolite Resources

The amounts of these minerals contained in the Piceance Creek Basin are enormous. It is estimated that these quantities exist (Beard, et al., 1974):

Dawsonite	27 billion tons	(equals 9.5 billion tons alumina)
Nahcolite	30 billion tons	(equals 19 billion tons of soda ash)

These estimates do not give a complete picture of the availability of the resource. The availability of the saline minerals as a function of time and technology available at given times is less than the ultimate resource. A summary of the quantities (reserves) estimated to be economically available by the end of the century is given in Table 3.

TABLE 3

Estimated Recoverable Reserves of Dawsonite and Nahcolite in 1985 and in 2000 (tons x 10^6)

	Non-oil Shale Related		Oil Shale Related	
	By 1985	By 2000	By 1985	By 2000
Dawsonite	None	None	490	10,400
Nahcolite	750	2,400	190	15,100

It is necessary to distinguish between non-oil shale and oil shale-related reserves. Dawsonite cannot be recovered with present technology without pyrolizing the shale oil first. Nahcolite occurs intermixed with oil shale which can be mined for nahcolite, oil, and in some cases dawsonite.

Ownership of Resource

Six categories of mineral interest exist in the Piceance Creek Basin:

1. Federal ownership of oil shale and saline mineral rights.
2. Private ownership of oil shale and saline mineral rights.
3. Private leases or ownership of oil shale values.
4. Private leases or ownership of saline mineral value.
5. Federal ownership of natural gas resources under oil shale.
6. Private leases or ownership of natural gas resources under oil shale.

These are mutually exclusive unless specifically agreed to otherwise. Both Figures 2 and 3 show the locations of these mineral interests and of oil shale where they coincide. Dawsonite, nahcolite, and oil shale resources are known to coincide at two lease properties at the present time. They are the Superior Oil Company tract at the north edge of the basin, and to a limited extent in the federal oil shale Tract C-b within the basin. Federal Tract C-a on the western edge is outside of the major mineral locations. All the oil shale tracts on the southern edge of the basin (not shown) lack any significant deposits of minerals though they are the sites of most of the current oil shale activities. Thus, the federal government presently holds the great majority of the lands containing oil shale and minerals together. Four significant saline mineral leases occur near the center of the basin belonging to the Yankee Gulch Venture, Rock School Corp., Industrial Resources, Inc., and Juhan-Nichols. These lease agreements specifically preclude any mining of oil shale over 25 gpt (gallons per ton) and require stockpiling 10 to 25 gpt shale if disturbed.

Detailed estimates of the mineral resources on the active private company leases were not determined in this study. The following tabulation should be considered only as gross estimates developed from open-file reports (notably Beard, et al., 1974) on nearby core holes.

TABLE 4

Ownership of Dawsonite and Nahcolite Resources (tons x 10^6)

	Dawsonite	Nahcolite
Superior Oil	490	190
Industrial Resources	1,400	4,600[1]
Joe Juhan	300	690
Yankee Gulch and Rock School	1,100	2,400[2]
Tract C-a	340	--
Tract C-b	270	120
Federal Government (by difference)	23,100	22,000
	27,000	30,000

(Estimated by CSMRI)

[1] 100 x 10^6 tons are proven, economic reserves (Tassicker, 1976).

[2] 650 x 10^6 tons are proven, economic reserves (Tassicker, 1976).

Market Potential of the Green River Nahcolite / Dawsonite in Colorado

by

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ABSTRACT

Recovery of the saline minerals, dawsonite and nahcolite, which are codeposited with portions of the Piceance Creek Basin oil shale is potentially of special economic importance for an oil shale industry. The paper assesses the size of the mineral resource, production potential, effect of production on related oil shale operations, economics, and market assessment to the year 2000.

Dawsonite and nahcolite are rare in nature outside the Piceance Creek Basin of northwestern Colorado. There, it is estimated that 27 billion tons of dawsonite and perhaps 30 billion tons of nahcolite are intermingled with portions of a vast oil shale deposit. The future of the saline minerals is closely tied to U.S. energy trends through energy costs, oil shale development, fuel costs for competing commodities, and developments in flue-gas scrubbing. Forecasts of these factors are made from 1980 to 2000.

Corecovery of alumina from dawsonite, nahcolite, and oil from shale offers some opportunity for lowered overall production costs. While the incremental costs of alumina and nahcolite production are roughly equal to competing processes, the three-product complex offers an opportunity to achieve economics of scale, to take advantage of a strong market in up to three areas rather than one, and will be better positioned to control energy costs as compared to individual plants producing the three products separately.

Dawsonite and its derivatives can be used in the aluminum, alumina, water-treatment catalyst, and plastics industries. Nahcolite and its derivatives can be used in the flue-gas scrubbing, glass, soda-ash, and dawsonite-recovery industries.

BACKGROUND

The complex intertwining of economic, energy, and environmental issues is clearly illustrated in the potential processing of oil shale and its coproducts into commodities of commerce for the United States economy. This paper explores some of these issues for dawsonite, nahcolite and oil shale at a macro level under these headings:

Energy and Oil Shale to 2000
Dawsonite and Nahcolite Resources
Chemistry and Processing
Production to 2000
Markets to 2000

Portions of this analysis were sponsored by the Department of Energy under contract EC-77-S-07-1683. The full report from that project will be available from NTIS shortly.

ENERGY AND OIL SHALE TO 2000

The United States is currently in its third energy transition. Earlier transitions were from wood to coal between 1850 to 1890, from coal to petroleum between 1930 and 1950, and now from petroleum to coal and other sources extending from about 1970 to 2000. In contrast to earlier transitions, the current one is from relatively low-cost to high-cost sources of energy. Table 1 is a United States energy balance from 1975 to 2000. It is from CSMRI estimates, based partly on an exhaustive study prepared by the Congressional Research Service, Project Interdependence, 1977, and partly on other sources. Several points are notable. The growth in energy demand assumes considerable conservation and use-efficiency efforts, coupled with a significant rise in real energy costs. The required imports continue to rise significantly until the latter part of the 1980s. Domestic production, even at the levels shown, will require considerably more effort than currently evident.

TABLE 1

U.S. energy balance (in quads) - 1975 to 2000

		1975	1980	1985	1990	2000
Demand		70	83	95	109	139
Supply	Imports	13	20	23	25	27
	Fossil	52	55	58	65	83
	Nuclear	2	5	9	13	20
	Other	3	3	4	5	7
	Oil Shale	-	0.002	0.2	0.5	2

The oil shale contributions, while relatively small in the total energy demand picture, are certainly needed. Shale oil should find a market, subject to certain problems. For the year 2000 the level of 2.1 annual quads corresponds to about 1 million bbl/day. This is roughly the maximum level that could be developed and sustained by 2000.

An ancillary consideration to oil shale production level is the projected costs of fuels.

Figure 1 is a plot of energy costs from 1980 to 2000 and a plot of the general price level inflated at an even 6 percent annually. Should the general price level fluctuate or increase faster than 6 percent, the inflation in fuel costs could be higher. The energy costs are very significant in the competitive position of alumina from dawsonite and soda ash from nahcolite. Rising energy costs will probably make the oil shale-based production more competitive.

DAWSONITE AND NAHCOLITE RESOURCES

Both dawsonite ($NaAl(OH)_2CO_3$) and nahcolite ($NaHCO_3$) are rare minerals in nature outside of the Piceance Creek Basin in Colorado. Nahcolite is somewhat more frequently seen than dawsonite. The minerals are associated in certain portions of the deposits and are asssociated with oil shale as well.

Dawsonite

Dawsonite has been found in only very small quantities and in a limited number of locations around the world. It was initially discovered near McGill University in Montreal. Figure 2 is an isopach map of the dawsonite-bearing oil shale within the Piceance Creek Basin. The zone is up to 800 ft thick over an area of two townships at the depositional center of the basin. The concentration of dawsonite is estimated by Nielsen (1969) to be up to about 12 percent in this region. The total resource is estimated to be as high as 27 billion tons according to Beard and others (1974). This corresponds to 9.5 billion tons of alumina.

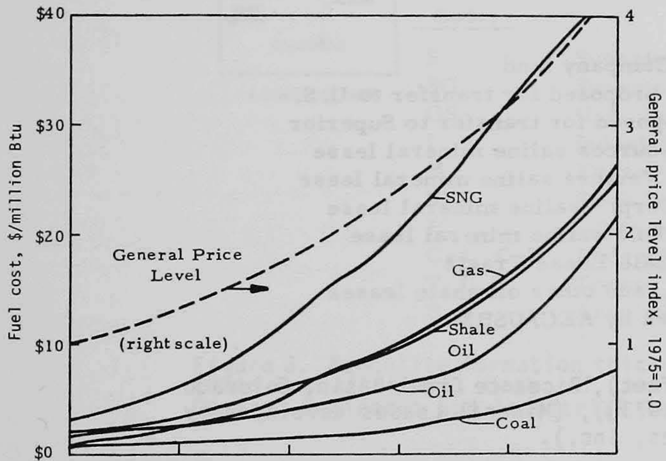


Figure 1. Price of fuels from 1975 to 2000

Nahcolite

Nahcolite is a natural sodium bicarbonate. It was initially discovered in Naples in the 1870s. Boring for a railway tunnel in a volcanic mountain opened up an ancient Roman cuniculus that was used to move hot spring waters to the Roman baths. The nahcolite has formed on the walls of the cuniculus due to a combination of the hot mineral waters and the CO_2-saturated atmosphere. The mineral was positively identified in 1929 (Bannister) from occurrence in Lake Magadi, east Africa. It has also been seen in other places in Africa including Olduvai Gorge, site of the early anthropological discoveries. Figure 3 is an isopach map of the nahcolite-bearing oil shale in the Piceance Creek Basin. It overlaps the region containing dawsonite both horizontally and vertically. Nahcolite occurs in three forms. The first is as a white crystalline variety, bedded in zones up to 17 ft thick and, in many cases, intimately mixed with halite (Beard and Smith, 1976). This zone can be mined directly for nahcolite without disturbing large amounts of oil shale. The second form of occurrence is a brown microcrystalline variety dispersed within the oil shale. The third is as a crystal mush. The latter two forms must be recovered from mined oil shale due to their relatively limited particle sizes. The main nahcolite-bearing zone is above the main dawsonite zone but overlaps it to some degree.

The total resource is estimated to be about 30 billion tons by Beard and others (1974), corresponding to about 19 billion tons of soda ash.

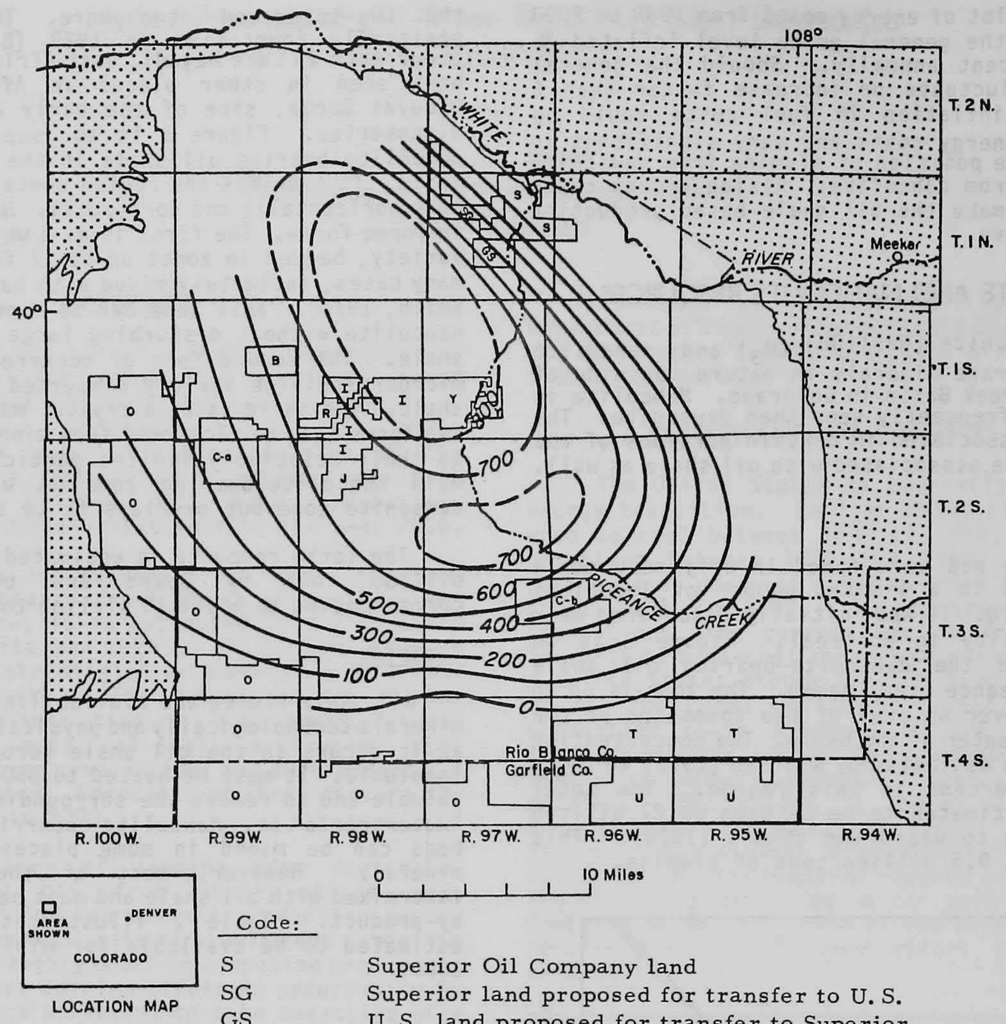
Reserves

Oil shale limits the availability of the saline minerals technologically and physically. Dawsonite, as it occurs in the oil shale kerogen matrix, is insoluble. It must be heated to 350°C to render it soluble and to remove the surrounding kerogen that "waterproofs" it. Nahcolite occurring in the white beds can be mined in some places as a primary mineral. However, most of the resource is intermixed with oil shale and must be separated as a by-product. Table 2 illustrates the reserves estimated to be available for mining by 1985 and 2000.

While the saline minerals and oil shale are intimately intermixed within the resource proper, this is not the case with the leaseholder's properties. The mineral leases in the depositional center of the basin shown in Figures 2 and 3 contain terms that specifically prohibit mining of the related oil shale. The oil shale tracts C-a and C-b leased by the Federal Government lack any known significant concentrations of nahcolite and contain only very low (about 1 to 2 percent) concentrations of dawsonite buried deeply on the lease. The present operators have no plans to attempt dawsonite recovery. Other oil shale properties, with the exception of Superior Oil's property on the northern edge of the basin, are completely outside the significant mineral locations. As can be seen in Table 3, the Federal Government controls the bulk of the mineral deposits and practically all the areas where they overlap oil shale.

CHEMISTRY AND PROCESSING

Dawsonite, a sodium aluminum hydroxy carbonate, was probably formed in an ancient lake from CO_2-saturated solution (Smith, 1974). Sodium bicarbonate was first formed from organic matter:



Code:

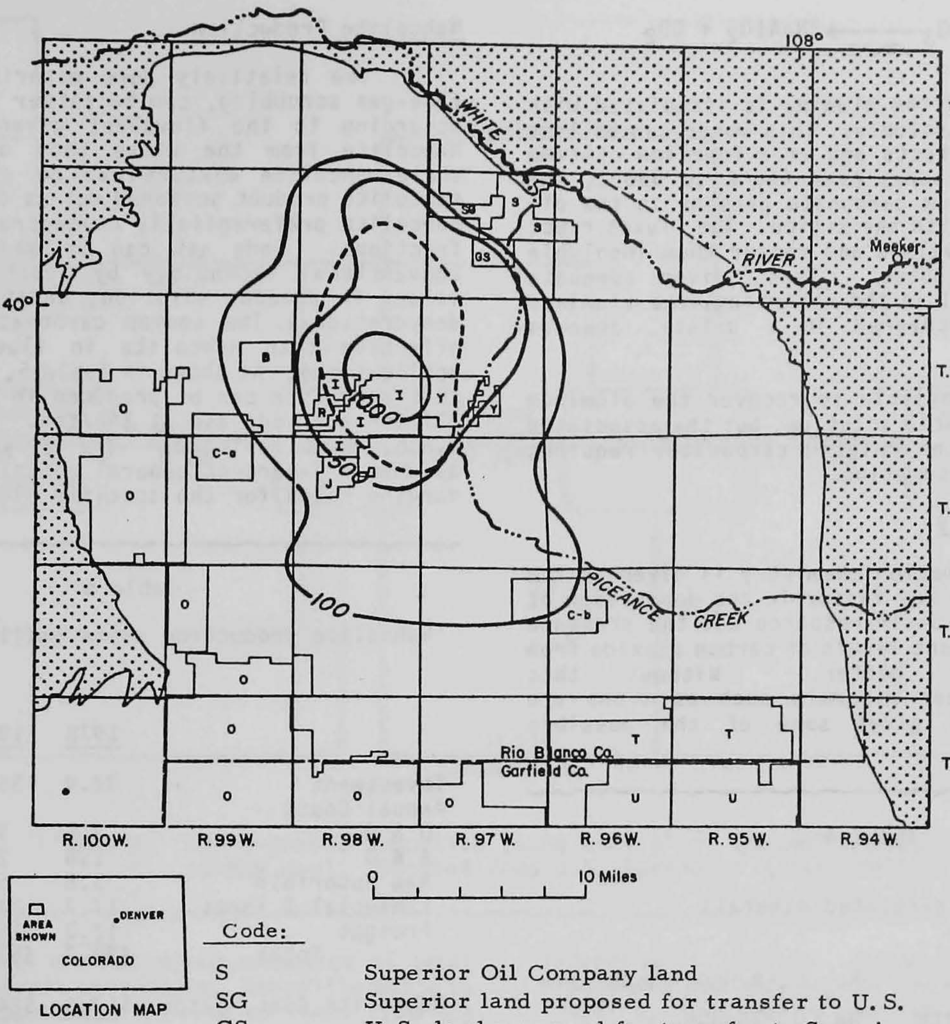
Code	
S	Superior Oil Company land
SG	Superior land proposed for transfer to U. S.
GS	U. S. land proposed for transfer to Superior
I	Industrial Resources saline mineral lease
Y	Yankee Gulch Venture saline mineral lease
R	Rock School Corp. saline mineral lease
J	Juhan and Nichols saline mineral lease
C-a, C-b	Federal Oil Shale Lease Tracts
T, U, O	Tosco, Union, and other oil shale leases
B	Area withdrawn by AEC/USBM

Figure 2. Dawsonite formation thickness (feet), Piceance Creek Basin, Colorado (Base Map after U.S. Dept. of Interior [1973]), (Mineral Leases developed by Cameron Engineers and Industrial Resources, Inc.).

TABLE 2

Saline mineral reserves
(million tons)

	Non-oil shale-related reserves		Oil shale-related reserves		
	1985	2000	1985	2000	Ultimate
Dawsonite	0	0	490	10,400	27,400
Nahcolite	750	2,400	190	15,100	30,000



Code:

S	Superior Oil Company land
SG	Superior land proposed for transfer to U. S.
GS	U. S. land proposed for transfer to Superior
I	Industrial Resources saline mineral lease
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R	Rock School Corp. saline mineral lease
J	Juhan and Nichols saline mineral lease
C-a, C-b	Federal Oil Shale Lease Tracts
T, U, O	Tosco, Union, and other oil shale leases
B	Area withdrawn by AEC/USBM

Figure 3. Nahcolite formation thickness (feet), Piceance Creek Basin, Colorado (Base Map after U.S. Dept. of Interior [1973]) (Mineral leases developed by Cameron Engineers and Industrial Resources, Inc.).

TABLE 3

Control of dawsonite and nahcolite resource (million tons)

	Dawsonite	Nahcolite
Private Mineral Leases	3,410	7,910
Private Multimineral and oil shale	490	190
Federal Government	24,100	21,900

$$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3$$

The sodium bicarbonate then reacted futher:

$$\underset{\text{nordstrandite}}{NaHCO_3 + Al(OH)_3} \rightleftharpoons \underset{\text{dawsonite}}{NaAl(OH)_2CO_3} + H_2O$$

Temperature causes the decomposition of dawsonite:

$$2NaAl(OH)_2CO_3 \xrightarrow[350°C]{} Na_2CO_3 + \underset{\text{chi form}}{Al_2O_3} + 2H_2O + CO_2$$

$$Al_2O_3+Na_2CO_3 \xrightarrow[700^\circ C]{} 2NaAlO_2 + CO_2$$

The chi form of the alumina is associated with water and is quite soluble. This water can be lost due to chemical effects and as a function of time and higher temperatures over 450°C to 550°C, the nahcolite and sodium carbonate present in the oil shale form fluxes with the silica. The fluxes react with the aluminum values and render them insoluble for practical purposes. Thus, given adequate temperature control in the retorting, the aluminum values can be recovered in a dilute, aqueous solution.

It is also possible to recover the aluminum values in a dilute acid solution, but the associated decomposition of the related carbonates requires excessive acid consumption.

Nahcolite Chemistry

Nahcolite formation chemistry is given on the previous page. The key factor in the deposition of the Piceance Creek Basin resource was the presence of high and consistent levels of carbon dioxide from decaying organic matter. Without this concentration, other minerals such as trona are formed. Table 4 gives some of the possible varieties.

TABLE 4

Nahcolite-related minerals

Trona	$Na_2CO_3\cdot NaHCO_3\cdot 2H_2O$
Wegscheiderite	$Na_2CO_3\cdot 3NaHCO_3$
Shortite	$Na_2CO_3\cdot 2CaCO_3$
Northupite	$Na_2CO_3\cdot MgCO_3\cdot NaCl$
Searlesite	$Na_2CO_3\cdot Si_2O_6\cdot H_2O$

Sulfur dioxide may be removed from flue-gas streams according to the reaction:

$$2NaHCO_3 + SO_2 + 1/2O_2 \xrightarrow[110^\circ C]{} Na_2SO_4 + 2CO_2 + H_2O$$

This process works well at temperatures above 100°C and on a completely dry basis. With the use of sufficient reagent (nahcolite) high sulfur contents are no problem. The process inherently removes practically all particulates and may remove about half of the nitrogen oxides. Sulfur contents in flue gas as low as 0.4 lb/million Btu can be obtained. Concentrations of 0.2 lb/million Btu are difficult to achieve.

Nahcolite can also be calcined to soda ash, Na_2CO_3, for use in the traditional soda ash markets.

Nahcolite Production

The relatively pure material, for use in flue-gas scrubbing, can be rather simply produced according to the flowsheet given in Figure 4. Nahcolite from the white beds or from an oil shale/nahcolite mixture can be crushed and the nahcolite product screened out as the more brittle nahcolite preferentially concentrates in the fine fractions. Soda ash can be made according to conventional technology by leaching the sodium values in aqueous solution, crystallization, and dehydration. The sodium carbonate is much less effective than nahcolite in flue-gas scrubbing applications. As shown in Table 5, it is estimated that nahcolite can be produced in 1978 dollars at $17/ton and soda ash at $48/ton. These costs are f.o.b. main railroad. The 20-yr average cost assumes a 6-percent general annual inflation with varying rates for the specific elements of cost.

Table 5

Nahcolite production costs (million dollars)

	1978	1983	20-yr Average
Investment	32.9	35.4	38.1
Annual Costs			
O & M	3.6	5.5	9.4
A & G	1.6	2.2	3.4
Raw Materials	3.5	5.7	10.0
Financial & Taxes	17.7	24.7	37.7
Freight	12.3	15.7	20.4
Total	$38.7	$53.8	$80.9
Nahcolite Cost, $/ton	$17.0	$24.0	$36.0
Soda Ash Cost, $/ton	$48.0	$70.0	$105.00

DAWSONITE AND NAHCOLITE PRODUCTION (IN OIL SHALE COMPLEX)

Recovery of the aluminum values in dawsonite requires prior retorting of the oil shale in which it is distributed as microscopic crystals. The retorting renders the aluminum values soluble and removes the kerogen, which allows the leach solution access to the mineral. The flowsheet in Figure 5 shows the processing of spent shale required. Spent shale from a commercial operation is leached with a dilute caustic solution. The aluminum values are precipitated and calcined to a high-grade alumina, which can be used for aluminum metal manufacture or as a source of alumina.

Sodium values are recovered from raw shale fines by leaching. The fines are then retorted and the spent shale directed to the above alumina section. The sodium carbonate is recovered from the leach liquor by crystallization and is calcined to the product soda ash. Some of the sodium-containing liquor is used for pH control in the alumina plant.

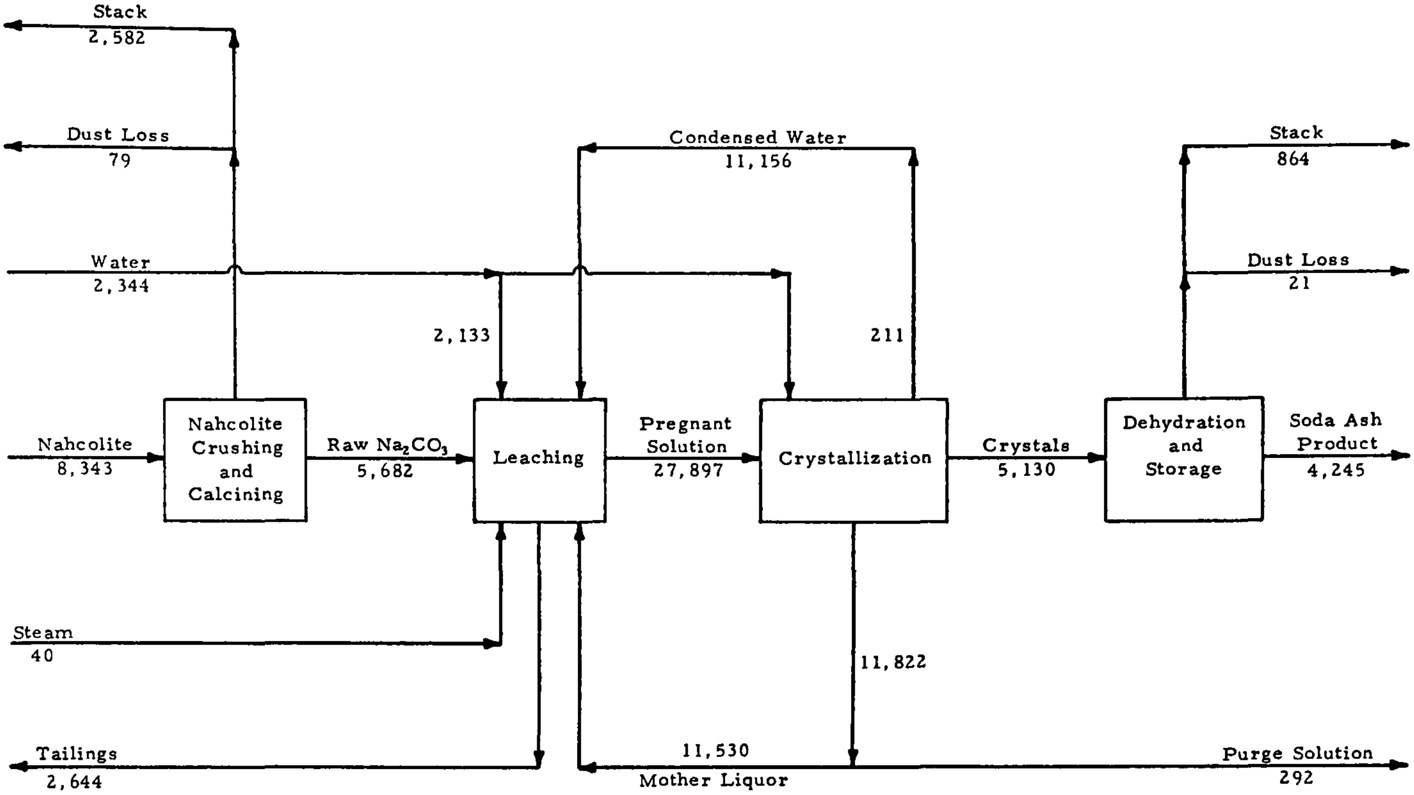

Figure 4. Above-ground nahcolite (soda ash) plant (flows in tons per stream day). Adapted from U.S. Bureau of Mines (1972a).

Table 6 gives the estimated economics of joint alumina and soda-ash production. Nahcolite would be produced by screening nahcolite as fines from the raw shale crushing step. The cost would be approximately that of nahcolite recovery alone (Table 5). The estimated 1978 costs per ton are alumina--$148, soda ash--$48, and nahcolite--$17. Market prices in 1978 were about $160 for alumina and $55 for soda ash. Nahcolite was not a product of commerce in 1978. Estimated costs of alumina per ton from other, nonbauxitic sources in 1978 are (1) HCl-ion exchange-clay, $196, (2) HNO_3-ion exchange-clay, $202, (3) HCl-ether-clay, $216, (4) lime-sinter-anorthosite, $232, and (5) K-alum-clay, $279.

The estimated production costs of alumina and soda ash from oil shale in the Piceance Creek Basin look attractive compared to other new sources. However, the accuracy of the cost estimates is not good as they may be up to 50 percent low. A more thorough plant design under 1980s' conditions and a preparation of a more definitive cost estimate are suggested.

PRODUCTION TO 2000

Potential annual production for each of the minerals was estimated from oil shale operations and independent mineral operations. Oil shale production was matched in total to the levels in Table 1, and was accumulated from individual estimates for Colony, Occidental, Rio Blanco, Superior Oil, and Union Oil companies based on public information. Non-oil shale-related nahcolite production was estimated for Superior Oil, Industrial Resources, and Yankee Gulch. The overall

TABLE 6

Combined alumina and soda-ash costs (million dollars)

	1978	1983	20-yr Average
Investment	307	331	355
Annual Costs			
O & M	17	23	37
A & G	10	12	17
Raw Materials	76	121	215
Financial & Taxes	106	137	200
Total	$226	$315	$497
Alumina Cost, $/ton	$148	$193	$328
Soda Ash Cost, $/ton	$ 48	$ 70	$105

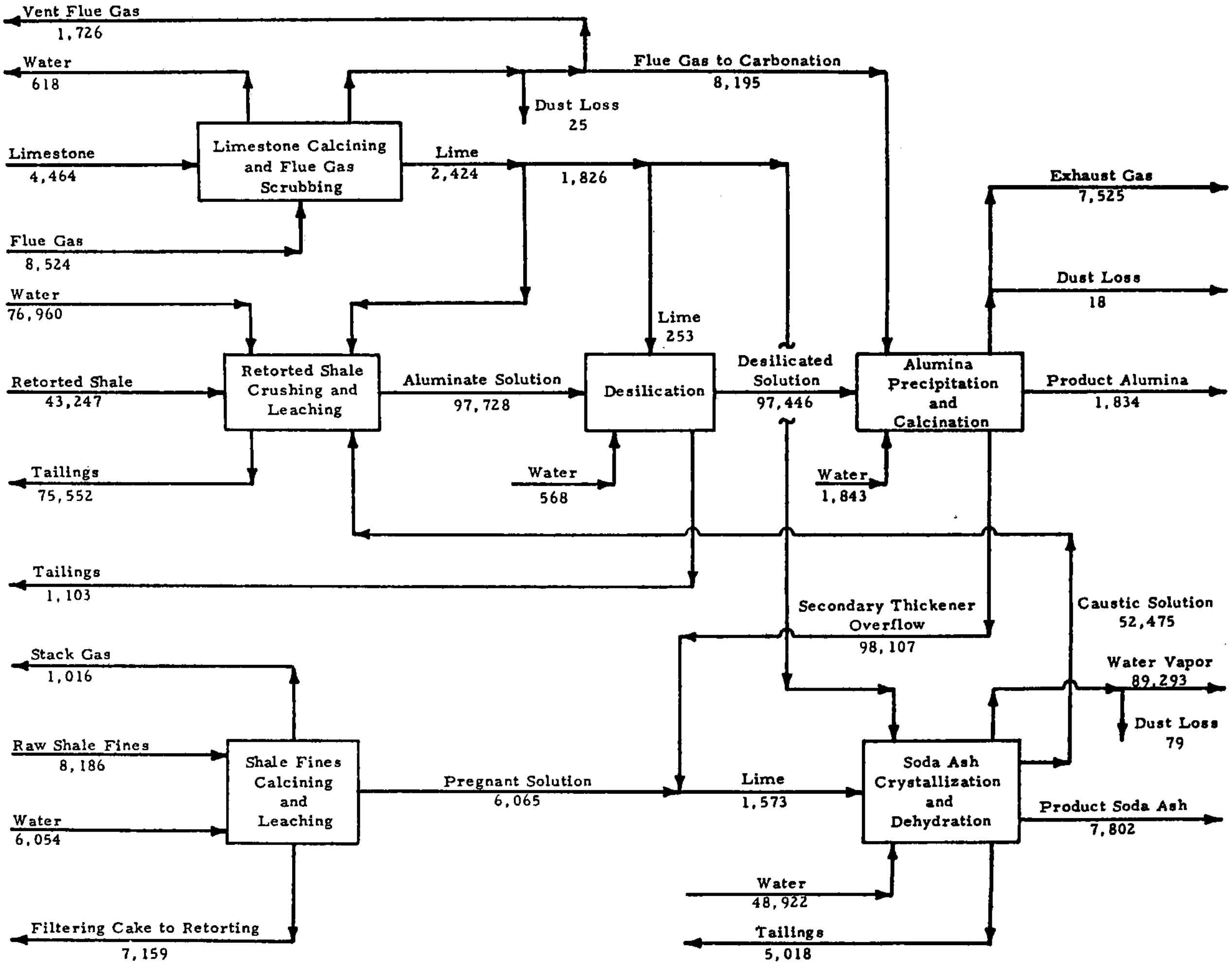

Figure 5. Above-ground minerals recovery as part of oil shale complex (tons/stream day). Adapted from U.S. Bureau of Mines (1972b).

production is shown in Figures 6 and 7 where the totals are compared to potential market outlets. Alumina reaches 8,000 ton/day by 2000, and nahcolite rises to 38,000 ton/day by 2000.

MARKETS TO 2000

Dawsonite

Market outlets for dawsonite-derived products include aluminum, alumina, water treatment, plastics filler, reforming catalyst substrate, and stomach antiacid. The first three are the most promising for large tonnages. As one can see from Figure 6, the growth in these markets would be just sufficient to absorb the maximum likely production of dawsonite-related materials to 2000.

Nahcolite

Nahcolite itself is not presently a product of commerce. However, its effectiveness as a dry flue-gas scrubbing agent looks good. A market level was estimated by assuming that half of the growth in U.S. coal consumption to 2000 would be in high-sulfur coal, amenable to nahcolite scrubbing. Other markets could exist for soda ash in glassmaking, chemicals, pulp and paper, water treatment, and potentially dawsonite manufacture. However, as one can see in Figure 7, soda-ash markets are expected to grow slowly in the next two decades and would be immediately saturated by oil shale-related production. Thus, flue-gas scrubbing appears to be the main potential market for nahcolite at this time.

Market Sensitivity

A match between saline mineral production and its market appears reasonable to expect at this time. Dislocations would not be severe in general, although operators might experience problems. Changes in energy costs and supply could significantly alter this picture. CSMRI estimates

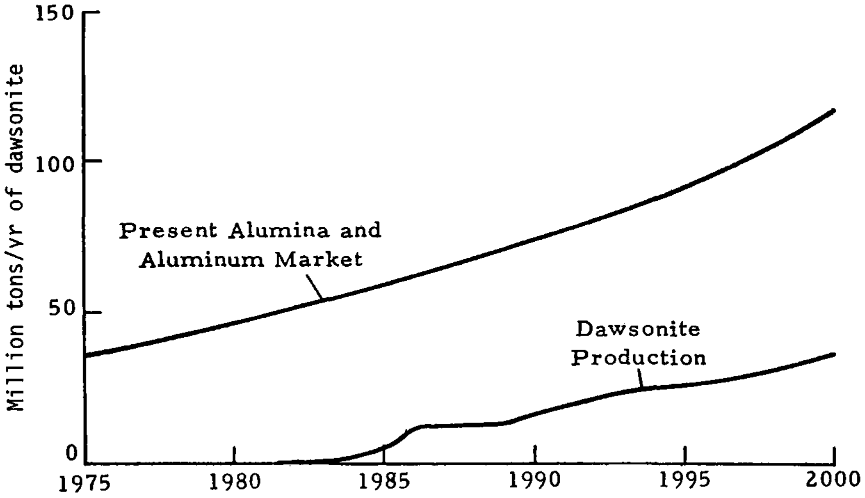

Figure 6. Comparison of dawsonite production and potential market.

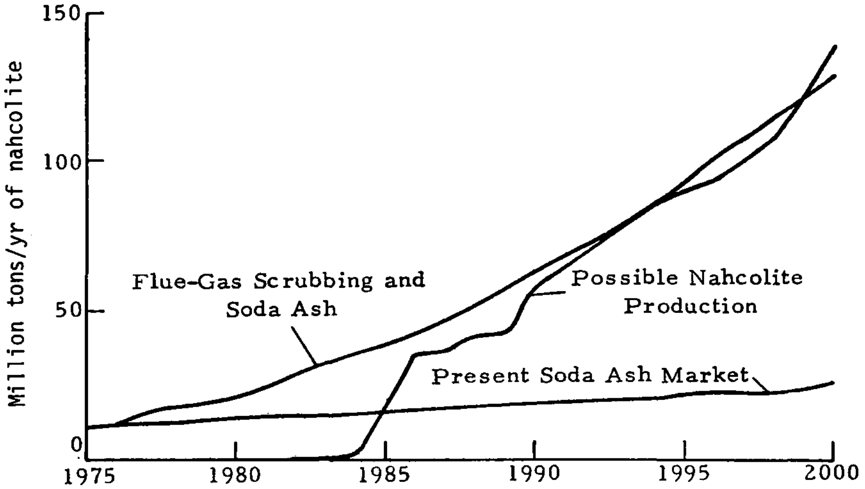

Figure 7. Comparison of nahcolite production and potential markets.

that approximately 27 percent of the current aluminum price is energy related. This could rise to about 50 percent by the end of the century. Current soda-ash costs are also relatively energy intensive, although a separate study was not made. The cogeneration and other energy-use efficiencies possible in an oil shale complex will probably give the related mineral operations a growing competitive advantage. Furthermore the environmental control problems will be more localized and adaptable to effective control, compared to a multiplicity of individual alumina and soda-ash manufacturing operations scattered around the United States.

SUMMARY

The oil shale deposit in the Piceance Creek Basin contains the only large deposits of dawsonite, a source of alumina, and nahcolite known to exist in the world. Most of the current oil shale properties lack significant concentrations of these minerals and thus are not positioned to take advantage of a multiproduct operation. Superior Oil is the exception. Two significant mineral property holders, one with leases and one with preference rights, lack the right to concurrently mine the associated oil shale. The federal government controls the bulk of the saline minerals, as well as the richest oil shale. Estimated production costs look reasonable for alumina, soda ash, and nahcolite from oil shale. Potential markets exist for significant quantities of all these materials.

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Zeolites – Economic Minerals in Colorado's Future

by

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ABSTRACT

Zeolites have been prominent in the 100-year annals of classic mineralogy in Colorado. In 1878 chabazite, heulandite, natrolite, and stilbite were reported from Gunnison County and from the Table Mountain lava flows at Golden. The list of minerals and localities has grown so that collectors of zeolite specimens recognize Colorado as a world renowned source. Since the mid-1950s studies have revealed the presence of prodigious volumes of zeolites present as rock-forming minerals in sediments. These are very fine grained, often nearly monomineralic deposits. Clinoptilolite is the most abundant of the industrially useful zeolites in Colorado and elsewhere. It is present in western Colorado in multimillion-ton deposits that are well documented in recent reports. Other zeolite varieties not currently considered as useful are also present in the state.

The diagenetic process by which vitric tuffs in an alkaline saline environment are altered to zeolites has been studied in detail. Field and laboratory work has provided excellent geologic evidence of patterns of authigenic mineral development. These patterns serve as prospecting guides for the growing zeolite mineral industry.

General Review of Northern Colorado and Southeastern Wyoming Kimberlites, Diamonds, and Related Research Activity

by

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PROLOGUE

Diamonds were first reported in the Colorado-Wyoming region in 1872 in northwestern Colorado near the Utah-Wyoming borders. This "discovery" was later determined to be part of a conspiracy involving the salting of several thousands of dollars worth of uncut diamonds, rubies, and sapphires and became known as the "great diamond hoax" (Woodward, 1967).

More than 100 years later, diamonds were discovered near the Colorado-Wyoming state line in a kimberlite pipe nearly 170 miles (273 km) east of the famous diamond hoax site. This occurrence, situated south of Laramie, Wyoming, represents only the second authenticated occurrence of diamonds found in place on the North American continent (McCallum and Mabarak, 1976b). The first North American discovery of diamonds in kimberlite was at Murfreesboro, Arkansas, in 1906 (Miser and Ross, 1922).

INTRODUCTION

Kimberlite is a relatively rare rock that commonly occurs in crudely conical-shaped pipes that typically merge at depth into dikes. The kimberlite rock itself is demonstrably of magmatic origin and contains xenolits (nodules) of material formed at a variety of depths in the earth's crust and upper mantle. For example, some mantle nodules in the Colorado-Wyoming kimberlites are believed to have been derived from depths in excess of 120 miles (190 km) below the earth's surface; such nodules provide direct evidence of the chemistry and mineralogy of the earth at depth (Eggler and McCallum, 1976; Eggler and others, 1979; McCallum and Eggler, 1976). Some kimberlites are of great importance to the industrial community in that they are the only known primary source rock of economical concentrations of diamond; however, only a few kimberlites worldwide have been known to produce diamonds. According to Lampietti and Sutherland (1978), less than 2 percent of all known kimberlites contain commercial concentrations of diamond, and of those kimberlites that are diamond-bearing, diamond concentrations generally are considerably less than 1 ppm. Thus the chances of funding a commercial diamond pipe are very small.

In June 1975, the Colorado-Wyoming kimberlites became more than just a scientific curiosity when T. Botinelly and B. F. Leonard of the U.S. Geological Survey identified several small diamonds in a serpentinized garnet peridotite nodule collected by M. E. McCallum from the Schaffer 3 kimberlite pipe in Wyoming. Subsequent examination and partial digestion of the nodule revealed the presence of numerous additional diamonds ranging in size up to approximately 1 mm (McCallum and Eggler, 1976). Since the 1975 discovery, diamonds have been identified in 12 kimberlite pipes--seven in Wyoming, four in Colorado, and one straddling the Colorado-Wyoming border (McCallum and others, 1977, 1979). Approximately 90 kimberlite occurrences have been located in the Colorado-Wyoming Front Range region (McCallum and Smith, 1978) (Figure 1). Two placer diamonds were recently discovered by Paul Boden in the Medicine Bow Mountains of Wyoming, but no primary source has been determined for these stones (Hausel, 1977).

Additional regions in Colorado and Wyoming are currently being explored and evaluated for new discoveries by geologists from Colorado State University and the Wyoming Geological Survey. Furthermore, several major mineral resource firms have expressed interest in initiating exploration programs to evaluate the region for its diamond potential, and a few firms are presently engaged in field activities.

Cominco American Incorporated was the successful bidder on a parcel of 2,974 acres in Wyoming offered for diamond potential evaluation by the State of Wyoming and Rocky Mountain Energy Company. This firm is currently operating under an exploration permit for diamonds granted by the Wyoming Department of Environmental Quality and is actively engaged in testing kimberlites in an area immediately north of the Colorado-Wyoming border and south of Tie Siding, Wyoming.

KIMBERLITE DISTRIBUTION

Kimberlite was initially recognized in Colorado when M. E. McCallum of Colorado State University identified the ultrabasic rock in the Sloan 1 diatreme in 1964. This discovery led to the recognition that two Paleozoic "outliers" described

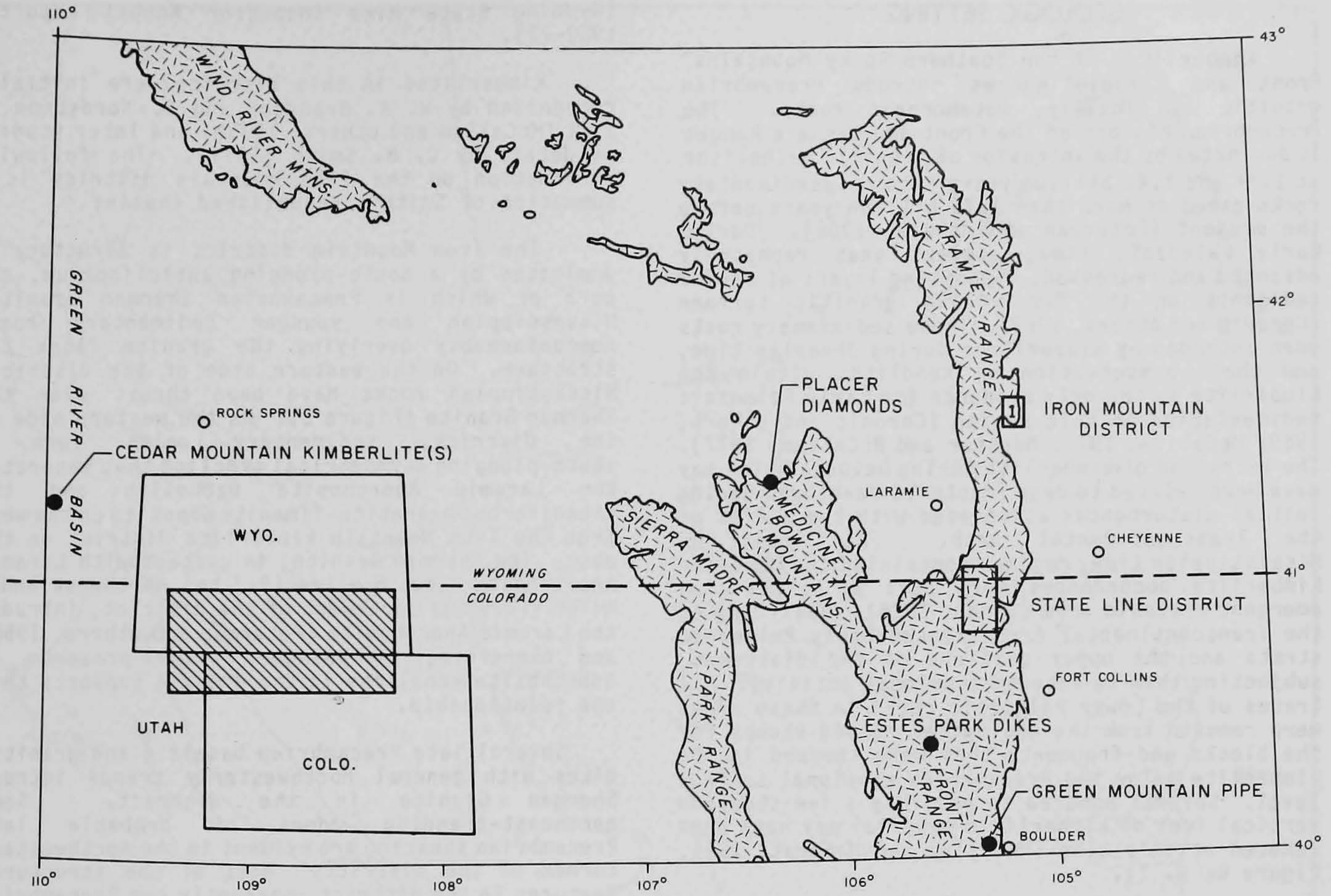


Figure 1. Index map of kimberlite districts and placer diamond locality.

by Chronic and Ferris (1963), located about 14.5 miles (23.5 km) others, 1965). In 1964, D. H. Eggler discovered more diatremes between the Sloan 1 and the two Paleozoic "outliers" (Ferris 1 and Aultman 1 pipes), and the existence of a well defined kimberlite district was established. This district (the State Line district) is located in the Colorado and Wyoming Front Range and extends 2.5 miles (4 km) north and 12 miles (19.5 km) south of the state line. More than 35 kimberlite diatremes have been recognized in this district (McCallum and others, 1977; Smith and others, 1979). Many of these kimberlites have been tested in a preliminary fasion for diamonds and have been determined to be diamondiferous (McCallum and others, 1979).

A second major district, containing 57 kimberlite occurrences (Smith, 1977; McCallum and Smith, 1978) within the Laramie Range, is located near the town of Farthing, Wyoming, nearly 45 miles (72.5 km) north of the state line. This area is referred to as the Iron Mountain district. Kimberlite at Iron Mountain occurs as structurally controlled "feeder dikes" with numerous blows that represent "root zones" of diatremes (Smith and others, 1979). A preliminary examination for diamonds in this district by C. B. Smith (1977) gives negative results, and no diamonds have been recovered in subsequent testing at Colorado State University.

Two additional districts in the Front Range of Colorado are defined by a kimberlite dike near Estes Park, approximately 40 miles (64.5 km) south, and by a single kimberlite pipe (Green Mountain pipe) nearly 70 miles (112.5 km) south of the state line (McCallum and Smith, 1978). No diamonds have been reported from these two districts.

Additionally, placer diamonds were recently reported from the Medicine Bow Mountains, Wyoming. Two diamonds were recovered from stream sediment concentrates from a placer mining operation in the Mullison Park area on the northern flank of the Medicine Bow Mountains where undifferentiated Tertiary rocks overlap Archean granites. Preliminary evaluation of this deposit has been conducted by the Wyoming Geological Survey. However, evaluation of alluvial samples has revealed neither kimberlitic material nor additional diamonds (Hausel, 1977).

GEOLOGIC SETTING

Kimberlites of the Southern Rocky Mountains' Front and Laramie Ranges intrude Precambrian granitic and locally, metamorphic rocks. The Precambrian history of the Front and Laramie Ranges is dominated by the intrusion of granitic batholiths at 1.7+ and 1.4+ billion years into metasedimentary rocks dated at more than 1.75 billion years before the present (Peterman and others, 1968). During Early Paleozoic time, ancient seas repeatedly advanced and regressed, depositing layers of marine sediments on the Precambrian granitic terrane (Chronic and others, 1969). These sedimentary rocks were intruded by kimberlites during Devonian time, and their preservation as xenoliths within the kimberlite is the only evidence for Early Paleozoic sedimentation in this region (Chronic and others, 1969; McCallum, 1976; Naesser and McCallum, 1977). The intrusion of kimberlite during Devonian time may have been related to deep fractures developed during initial disturbances associated with the uplift of the Transcontinental Arch. At least by Mississippian time, regions containing the Devonian kimberlite occurrences were part of a positive emergent cratonic area (Sando, 1975). Uplifting of the Transcontinental Arch exposed Early Paleozoic strata and the upper portions of the diatremes, subjecting them to intense erosional activity. All traces of the Lower Paleozoic rocks in these areas were removed from the geological record except for the blocks and fragments that were trapped in the kimberlite below the Precambrian erosional surface level. Several hundred to possibly a few thousand vertical feet of kimberlitic material may have been removed at this time (McCallum and Mabarak, 1976, Figure 6, p. 7).

Several thousand feet of sediment were deposited when the seas reinvaded southeastern Wyoming and northeastern Colorado intermittently from Late Paleozoic through Late Cretaceous times. These depositional events were followed in Late Cretaceous and Early Tertiary times by tectonic disturbances related to the Laramide orogeny and uplift of the Front Range, which were accompanied by extensive erosion. Additional removal of upper portions of diatremes accompanied Late Tertiary and Pleistocene erosional events that produced the Sherman surface, which is very prominent throughout much of the Front and Laramie Ranges in Colorado and Wyoming (Eggler and others, 1969). The amount of kimberlite removed by erosion during Tertiary time is not known; however, the degree of Tertiary planation in portions of the Front Range suggests that a significant volume of material was removed.

Iron Mountain District, Wyoming

The Iron Mountain kimberlite district is located on the eastern flank of the Laramie Range and marks the northernmost extent of known Front Range kimberlites. This district is named for the titaniferous magnetite-ilmenite deposits located about 4 miles (6.4 km) southwest of the known kimberlites. These iron and titanium deposits were mined in the 1960s and early 1970s by Plicoflex Incorporated and later by the U.S. Aggregate Company (Wyoming State Mine Inspector Annual Reports, 1960-72).

Kimberlites in this district were initially recognized by W. A. Braddock and D. Nordstrom in 1971 (McCallum and others, 1975b) and later studied in detail by C. B. Smith (1977). The following information on the Iron Mountain district is a summation of Smith's unpublished thesis.

The Iron Mountain district is structurally dominated by a south-plunging anticlinorium, the core of which is Precambrian Sherman Granite. Mississippian and younger sedimentary rocks nonconformably overlying the granite flank the structure. On the eastern side of the district, Mississippian rocks have been thrust over the Sherman Granite (Figure 2). On the western side of the district, sedimentary units form a south-plunging asymmetrical syncline that separates the Laramie Anorthosite batholith and the titaniferous magnetite-ilmenite deposits on the west from the Iron Mountain kimberlite district on the east. The Sherman Granite, in contact with Laramie Anorthosite about 6 miles (9.7 km) northwest and 8 miles (12.9 km) southwest of the district, intrudes the Laramie Anorthosite (Peterman and others, 1968) and therefore, is younger. The presence of anorthosite xenoliths in the granite supports this age relationship.

Several late Precambrian basaltic and granitic dikes with general northwesterly trends intrude Sherman Granite in the district. Some northeast-trending zones of probable late Precambrian shearing are evident in the northwestern corner of the district. Most of the structural features in the district apparently are Precambrian in age, although later east-west compressional deformation of Laramide age has complicated the structural trends.

Distribution of the Iron Mountain kimberlites defines a general northeasterly trend, and occurrences have been located over a distance of 5 miles (8 km). This northeasterly trend bisects the anticlinorium. Individual kimberlite dike systems in the southwestern half of the district diverge from the overall trend and align predominantly toward the northwest. Individual dike systems in the northeastern half of the district trend dominantly east to northeast. Kimberlite dikes in the southwestern corner of the district project under the sedimentary cover, the oldest rocks of which are Mississippian.

Although 57 kimberlite occurrences have been mapped in this district, many of them, mapped separately by Smith (1977), are, because of "blow-like" features or enlargements along the dikes, really portions of the same dike system. Even though outcrops are scarce, many of the dikes and "blows" can be mapped as continuous features by the presence of bluish-gray soils (blue ground), typical kimberlitic minerals (pyrope and magnesian ilmenite), rock fragments (serpentinized or carbonatized kimberlite and peridotite), and vegetative and topographical differences. Most dike systems can be traced from a few feet to a few

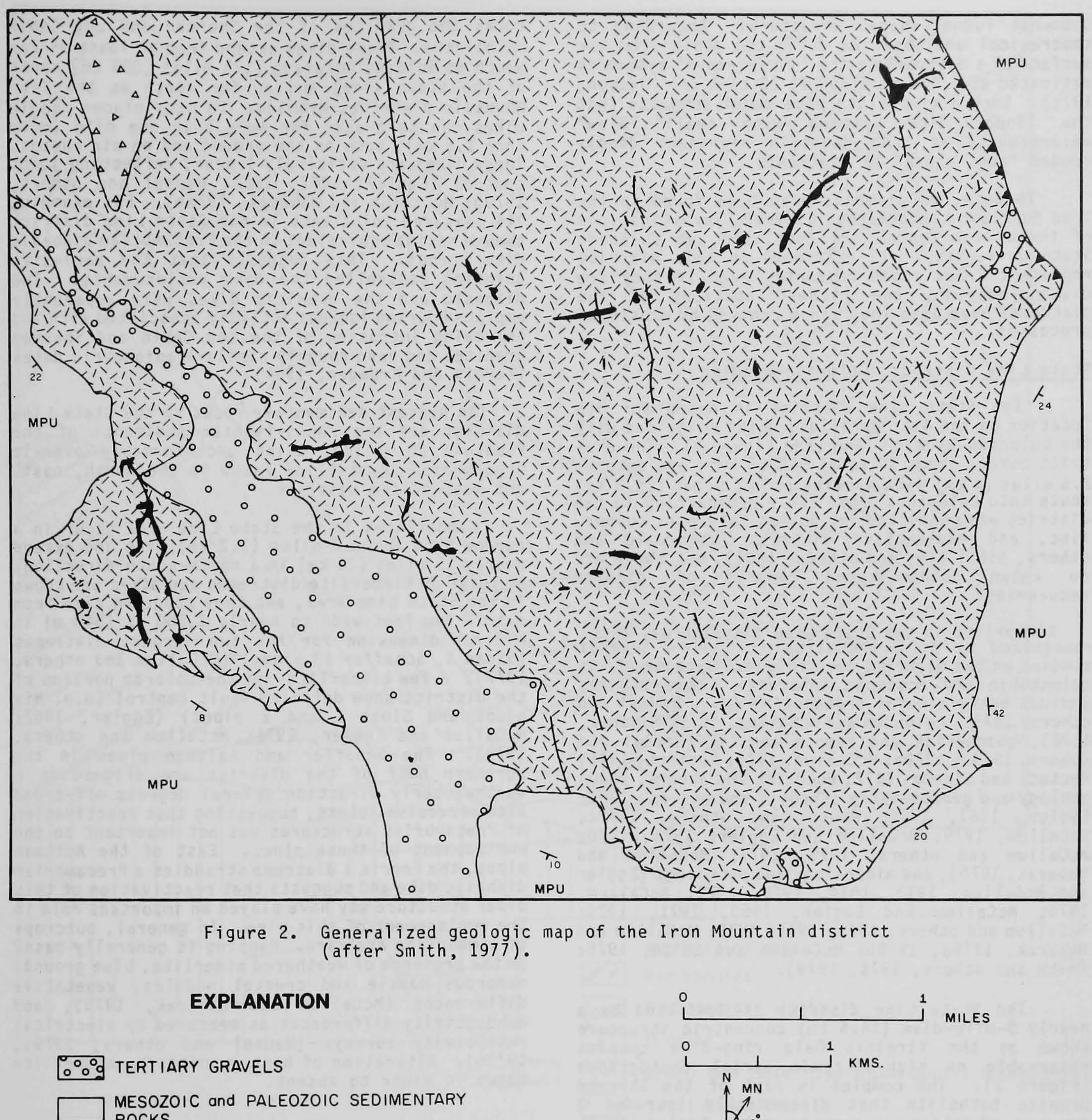


Figure 2. Generalized geologic map of the Iron Mountain district (after Smith, 1977).

EXPLANATION

°o° TERTIARY GRAVELS

☐ MESOZOIC and PALEOZOIC SEDIMENTARY ROCKS

■ KIMBERLITE

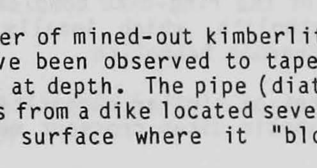
⟋ DIABASE DIKES

▨ GRANITE

△ ANORTHOSITE

▲ THRUST FAULT

20 STRIKE AND DIP OF BEDS



hundred feet in maximum length, although one dike extends nearly one mile (about 1.6 km).

A number of mined-out kimberlite pipes in South Africa have been observed to taper down and merge with dikes at depth. The pipe (diatreme) apparently originates from a dike located several thousand feet below the surface where it "blows out" into a somewhat funnel-shaped structure. According to theoretical and observed data, the depth from the surface of a diatreme to its "dike-feeder" system is estimated at 6,500 to 9,800 ft (2 to 3 km) (Dawson, 1971). Such a kimberlite pipe model suggests that the linear dike systems with small "blow" enlargements at Iron Mountain represent deeply eroded "root zones" of diatremes.

To date, no diamonds have been found in the Iron Mountain kimberlites; however, investigations of these occurrences are continuing at Colorado State University. If diatremes in this district represent "root zone" remnants, even if they are diamond-bearing, the richest portions of the diatremes have been long since removed by erosional processes.

State Line District, Colorado-Wyoming

The State Line district is named for its location on the 41st parallel, which coincides with the Colorado-Wyoming line (see Figure 1). The district covers about 50 sq mi (129.5 km^2) and extends 2.5 miles (4 km) into Wyoming and 12 miles (19.3 km) south into Colorado. Some early prospecting in the district was conducted for potash feldspar, copper, zinc, and radioactive minerals (Osterwald and others, 1966; Sims and others, 1958), but there are no known authenticated reports of diamond recoveries.

Kimberlite in the State Line district was first recognized by M. E. McCallum in 1964. Several studies on the district have followed because of its scientific and economic interest. Some studies include heavy mineral prospecting (e.g. Hausel and others, 1979c; Leighton and McCallum, 1979; Mabarak, 1975), geophysics and remote sensing (Hausel and others, 1979a, 1979b; McCallum, 1974; Puckett, 1971; Puckett and others, 1972; Woodzick and others, 1980) geology and geochemistry (Chronic and others, 1969; Eggler, 1967, 1968; Hausel and others, 1979c; McCallum, 1979; McCallum and Eggler, 1971, 1979; McCallum and others, 1975, 1977; McCallum and Mabarak, 1976), and mineralogy and petrology (Eggler and McCallum, 1973, 1974, 1976, 1979; McCallum, 1976; McCallum and Eggler, 1968, 1971, 1976; McCallum and others, 1975, 1977, 1979; McCallum and Mabarak, 1976a, 1976b; McCallum and Smith, 1978; Smith and others, 1976, 1979).

The State Line district is dominated by a nearly 9-mile-diam (14.5 km) concentric structure known as the Virginia Dale ring-dike complex observable on high-altitude aerial photographs (Figure 3). The complex is part of the Sherman Granite batholith that discordantly intrudes a sequence of folded metamorphic rocks. Eggler (1967, 1968) subdivided the complex into four zones: the biotite hornblende outer ring dike, a complex zone of diorite, andesite (basalt), and metamorphic rocks; two inner ring dikes of biotite quartz monzonite; and to the south of the ring-dike complex, the Log Cabin Granite batholith, which locally intrudes granites of the Sherman batholith.

Diabasic dikes of similar composition to the Iron Mountain diabasic dikes crosscut metamorphic rocks and granites of the Sherman and Log Cabin batholiths. These dikes extend from at least as far south as Golden, Colorado (125 miles [200 km] south of the state line) and as far north as the Iron Mountain district, Wyoming. In many places single dikes can be traced for more than one mile (more than 1.6 km), both on the ground and on air photos. These dikes are strikingly linear, reflecting joint control (Eggler, 1967, 1968; Hausel and others, 1979b; McCallum and Mabarak, 1976b). For example, 744 measured joint sets in the State Line district showed maxima equivalent to the Precambrian diabasic dike trends. This suggests that the pervasive jointing controlled the dike emplacements. The diabasic and the granitic dikes were apparently emplaced during igneous activity associated with and following intrusion of the Log Cabin and Sherman Granites and have roughly similar radiometric dates (Ferris and Krueger, 1964).

The nearest sedimentary rocks to the State Line district are the Pennsylvanian sediments of the Fountain Formation, which unconformably overlie Precambrian crystalline rocks to the north, east, and west of the district.

Kimberlites in the State Line area occur in a narrow band about 2 miles (3.2 km) wide and extend nearly 15 miles (24 km) in a north-south direction. At least 35 kimberlite diatremes and dikes are known in the State Line area, and they range in size from only a few feet wide to nearly 1,800 ft (548 m) in maximum dimension for the two largest diatremes (Sloan 1, Schaffer 13 pipes) (McCallum and others, 1977). A few kimberlites in the Colordo portion of the district show definite fault control (e.g. Nix pipes and Sloan 1 and 2 pipes) (Eggler, 1967; McCallum and Eggler, 1971; McCallum and others, 1975). The Schaffer and Aultman pipes in the northern half of the district are aligned in a northwesterly direction several degrees off trend with pervasive joints, suggesting that reactivation of Precambrian structures was not important to the emplacement of these pipes. East of the Aultman pipes, the Ferris 1 diatreme straddles a Precambrian diabasic dike and suggests that reactivation of this older structure may have played an important role in the emplacement of this pipe. In general, outcrops of kimberlite are rare. Mapping is generally based on the presence of weathered kimerlite, blue ground, numerous mantle and crustal nodules, vegetative differences (McCallum and Mabarak, 1976), and conductivity differences as measured by electrical resistivity surveys (Hausel and others, 1979a, 1979b). Alteration of host granites by kimberlite magma is minor to absent.

The surface exposures of the State Line kimberlites are commonly elongated to ellipsoidal, and the sizes of exposures suggest that they are not as deeply eroded as the Iron Mountain kimberlites. However, a few thousand feet of vertical pipe column and the Lower Paleozoic strata, which at one time covered the Precambrian crystalline rocks, were removed by erosion (e.g. McCallum and Mabarak, 1976b, Figure 6, p. 7). Additional kimberlite material was removed throughout the Tertiary to the Holocene.

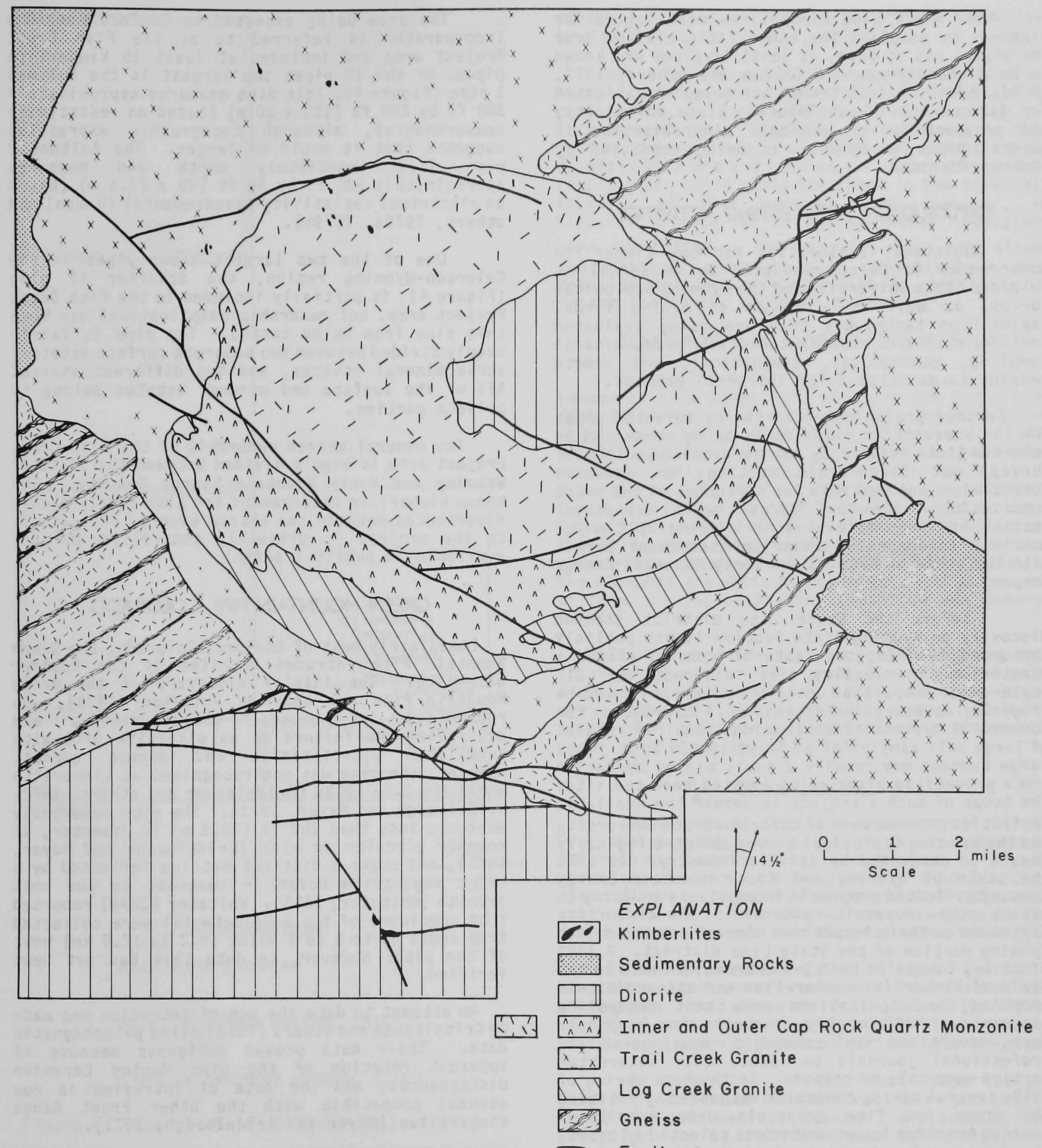


Figure 3. Generalized geologic map of the State Line District, Colorado and Wyoming (after Eggler, 1967).

Many State Line kimberlites were tested for diamonds by sampling the kimberlitic eluvium over the pipes, and to date, at least 12 pipes are known to be diamondiferous (McCallum and others, 1977, 1979). Additional diatremes are being investigated for diamond content at Colorado State University, and prospecting for economic mineralization in several pipes in Wyoming is being conducted by Cominco American.

EXPLORATION AND TESTING ACTIVITIES

Additional exploration for new kimberlite occurrences is being conducted by personnel at Colorado State University and the Wyoming Geological Survey, as well as a number of mining firms. Exploration techniques that are being evaluated include standard eluvial-colluvial heavy-mineral sampling, geochemical, geophysical, and remote sensing (e.g. false-color infrared) methods.

Further preliminary testing of selected pipes for the presence of diamonds is being conducted at Colorado State University and the Wyoming Geological Survey, but large-scale testing for economic potential is not feasible for personnel of the state institution. However, larger scale assessment testing has been initiated in Wyoming by Cominco American Incorporated under an assessment permit with the state of Wyoming and Rocky Mountain Energy Company.

Before the State Line district diamond discovery on Wyoming State Section 16 was publicly announced in 1975, the State of Wyoming placed a moratorium on leasing for diamonds on all state-owned properties until the discovery could be properly assessed. Testing of kimberlites for commercial diamond concentrations requires removal of large bulk samples of at least 10,000 tons. This large tonnage may require a small mining operation and a processing plant to be located near the site. The scope of such a project is beyond the available facilities and manpower of Colorado State University and the Wyoming Geological Survey and more logically should be conducted by private industry. In 1978 the state of Wyoming and Rocky Mountain Energy Company solicited proposals from private industry to assess the economic potential of kimberlite diatremes on their respective mineral estates in the Wyoming portion of the State Line district. A list of mining companies with previous experience in the field of kimberlite exploration and assessment was compiled, and invitations were sent requesting proposals. Additionally, requests for proposals were advertised in strategic newspapers and professional journals to insure that interested parties were able to respond. In the late spring of 1978, several mining companies responded by visiting the area, and five proposals were submitted. Cominco American Incorporated was selected to assess the commercial potential of kimberlites on 2,974 acres of State and Rocky Mountain Energy Company's mineral estate lands. An exploration permit to prospect for diamonds was granted by the Wyoming Department of Environmental Quality in the fall of 1978, and an assessment permit was agreed to by all three affected parties on February 12, 1979.

The area being assessed by Cominco American Incorporated is referred to as the Fish Creek Project area and includes at least 18 kimberlite pipes. Of the 18 pipes the largest is the Aultman 1 pipe (Figure 4). This pipe measures approximately 360 ft by 200 ft (110 x 60 m) (based on resistivity measurements), although topographic expression suggests that it could be larger. The Aultman 2 pipe lies immediately north and measures approximately 320 ft by 90 ft (98 x 27.5 m) (based on electrical resistivity measurements) (Hausel and others, 1979a, 1979b).

One of the two largest known pipes in the Colorado-Wyoming region, the Schaffer 13 pipe (Figure 4), is partially included in the Fish Creek Project area, but ownership complications may keep this pipe from being tested. The pipe is fairly evenly divided between two separate surface estates, three mineral estates, and two different states. All of the surface and mineral estates belong to private parties.

The mineral estate ownership of the Fish Creek Project area is evenly divided between the State of Wyoming and Rocky Mountain Energy Company. The known kimberlite occurrences are also fairly evenly distributed between the estate owners. All access to the project is privately controlled and not available to public traffic!

GREEN MOUNTAIN PIPE, COLORADO

Immediately west of Boulder, Colorado, the Green Mountain Pipe intrudes granites of the Boulder batholith. The initial discovery of the Green Mountain Pipe was made by Whitaker (1898), who recognized its unusual characteristics and classified the feature as an olivinite dike with associated picrotitanite and pyrope garnet. However, the pipe was not recognized as kimberlite until the late 1960s (Kridelbaugh and others, 1972; Kridelbaugh and Meyer, 1973). The pipe reportedly measures less than 100 ft (30.5 m) in diameter, is roughly circular in plan (Kridelbaugh and Meyer, 1973), and shows a distinct outline reflected by a thick vegetation cover in contrast to the host granite (Whitaker, 1898). Whitaker (1898) reported that specimens of the same material were collected from areas up to 6 to 8 miles (9.7 to 12.9 km) west of the pipe; however, to date this has not been verified.

An attempt to date the age of intrusion was made by Kridelbaugh and others (1972) using paleomagnetic data. Their data proved ambiguous because of apparent rotation of the pipe during Laramide disturbances, and the date of intrusion is now assumed compatible with the other Front Range kimberlites (Meyer and Kridelbaugh, 1977).

ESTES PARK DIKE, COLORADO

Very little information is available concerning the Estes Park dike discovered by J. C. Cole. The Estes Park occurrence is being investigated by M. E. McCallum and others at Colorado State University.

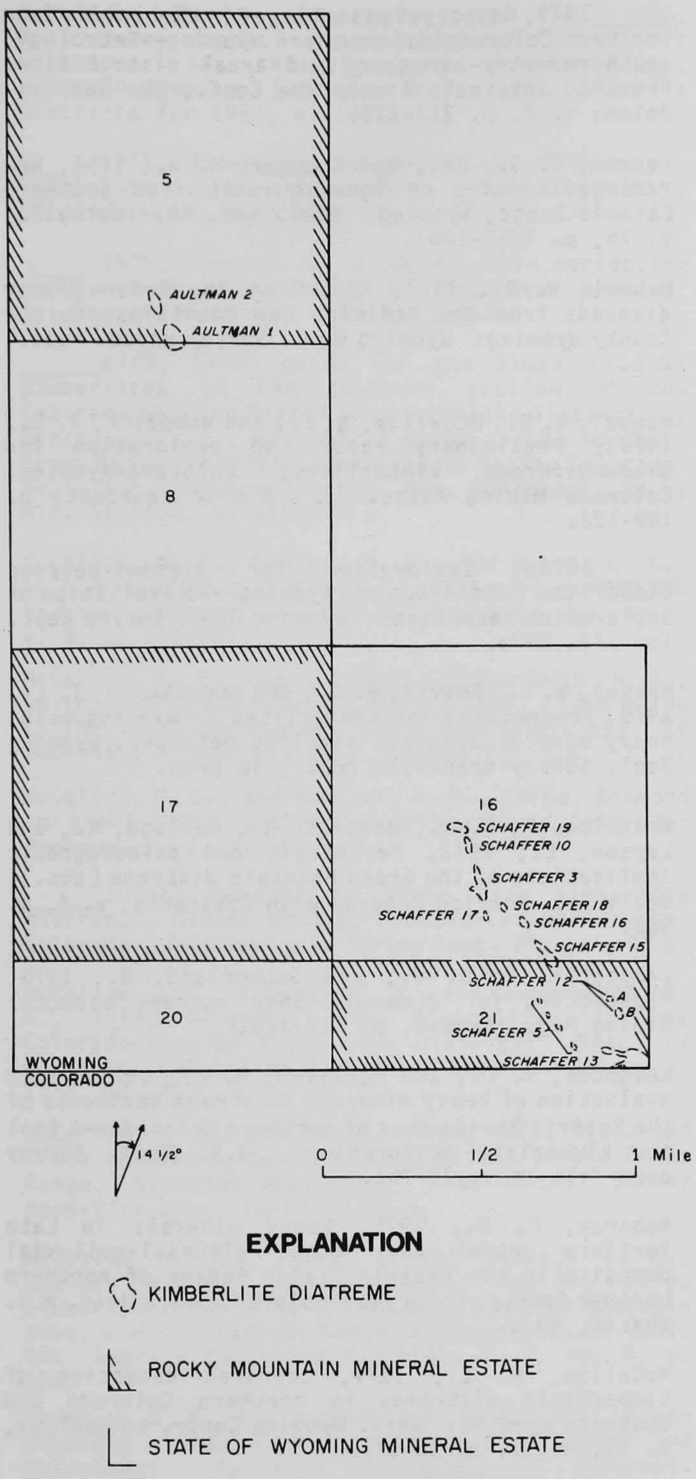


Figure 4. Map of the Fish Creek Project area.

MEDICINE BOW DIAMOND PLACER, WYOMING

Two diamonds, reportedly extracted from stream sediment concentrates on a placer mining operation in the Mullison Park area about 20 miles (32 km) east of Saratoga, Wyoming (Paul Boden, 1977, personal communication) were positively identified by X-ray methods (Hausel, 1977).

In the Mullison Park area, undivided Tertiary sediments derived from the weathering of Precambrian crystalline and metasedimentary rocks onlap the Archean granites. The Tertiary sediments in this region contain loosely consolidated quartzite and diabasic boulders and pebbles. A number of sediment samples were taken along the creek in the immediate vicinity of the reported find; however, no kimberlitic material or heavy-mineral indicators were identified. The sampling from the stream sediments was cursory and, undoubtedly, a more detailed sampling program will be necessary to locate the source of these diamonds.

COLORADO AND WYOMING DIAMONDS

More than 90 small diamonds have been recovered from kimberlite pipes in the State Line district, Colorado-Wyoming, by personnel at Colorado State University (McCallum and others, 1979; McCallum, unpublished data), and two small diamonds were reportedly recovered from a placer operation in Wyoming (Hausel, 1977). The State Line diamonds range in average size from less than 0.3 mm to about 2 mm. The largest recovered diamond is a distorted octahedron measuring 2.8 mm in its maximum dimension and having a carat weight of 0.059. The majority of the diamonds are white to colorless, and 38 percent of them are inclusion-free (McCallum and others, 1979).

The two Medicine Bow placer diamonds are both octahedrons. The smaller crystal measures 1.5 mm in diameter and weighs 0.035 carat, and the larger stone measures 3.0 mm in diameter and weighs 0.100 carat. Both crystals contain inclusions observable under a 10X lens (Hausel, 1977).

CONCLUSIONS

More than 90 Devonian kimberlites intrude Precambrian granite batholiths in the Front Range of Colorado and Wyoming (McCallum and Smith, 1978). Of these occurrences 12 are presently classified as diamondiferous, and the majority of the 90+ diamonds that have been recovered are less than 2 mm in the largest dimension and less than 0.4 carat in weight.

It is not presently known if any of the State Line kimberlites contain economical concentrations of diamonds. This phase of testing possibly will be conducted on several Wyoming kimberlites over the next several years by Cominco American Incorporated.

No kimberlites in the Front Range located outside of the State Line district have yet proven to be diamond-bearing; however, exploration and investigations by Colorado State University, the Wyoming Geological Survey, and private industry will continue.

The identification of two placer diamonds reportedly extracted from stream sediment concentrations on the northern flank of the Medicine Bow Mountains is presently under investigation by the Wyoming Geological Survey. To date, no alluvial samples taken in this investigation have shown any kimberlitic material or additional diamonds. However, a more detailed sampling program is planned in the near future.

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Rare-Earth Provinces of Colorado

by

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ABSTRACT

Groups of genetically diverse rare-earth deposits are concentrated in geographically restricted areas, or provinces. Three major provinces occur in the Rocky Mountains, one along the Idaho-Montana line and the other two in Colorado. All three are time-independent, containing deposits of different ages. The north-central Colorado province contains deposits of Precambrian and Tertiary age: 1) a wide variety of rare-earth pegmatites; 2) rare earth-rich granites, 3) metasomatic disseminated allanite, 4) xenotime- and monazite-rich migmatite, and 5) radioactive fluorite veins. The south-central province includes deposits of Precambrian, Cambrian and Tertiary age: 1) rare-earth pegmatites of several ages, 2) rare earth-rich granitoids, 3) deposits in and related to the alkalic complexes of McClure Mountain and Powderhorn; and 4) RE-apatite-molybdenite breccia, and 5) radioactive fluorite-Cu sulfide veins along faults. The Colorado provinces contrast markedly with that of Idaho-Montana both in types of deposits and in their age distribution.

INTRODUCTION

Early accounts of the mineralogy of Colorado were concerned mainly with listings of sulfides, sulfosalts, and tellurides, owing largely to the exploitation of the numerous spectacular metallic mineral deposits of both base and precious metals developed and mined in the last half of the 19th century. Nevertheless, by the end of the 19th century a number of rare-earth minerals had already been recorded for the state: 1) Devil's Head, Douglas County--allanite, gadolinite, and samarskite and 2) St. Peter's Dome, El Paso County--bastnaesite, xenotime and fluocerite (tysonite) (Dana, 1898; Eckel, 1961).

Prior to, during, and shortly after World War II Colorado experienced an intensive and widespread program of pegmatite prospecting and mining--before the war chiefly for feldspar and to a minor extent for lepidolite; during the war for beryl, mica, and columbite-tantalite-microlite; and after the war for feldspar, grinding-quality muscovite, beryl and rare-earth minerals. This program led to the discovery of many new rare-earth mineral pegmatites (e.g., Heinrich, 1948) and, in particular, to the development of numerous pegmatites in the South Platte district, Jefferson County, which is now known to be the most important and mineralogically most diverse rare-earth pegmtite districts of the world (Heinrich, 1958d; Simmons, 1973; Simmons and Heinrich, 1975).

In addition to the pegmatite deposits, various major rare-earth concentrations also have been discovered in the alkalic- carbonatitic complexes of Colorado largely during the 1950s when prospecting for radioactive mineral deposits was at its height: 1) the Powderhorn (Iron Hill) complex of Gunnison County (Olson and Wallace, 1956; Temple and Grogan, 1965); 2) three allied and clustered complexes in Fremont and Custer Counties (McClure Mountain, Gem Park and Democrat Gulch) (Heinrich, 1966).

Attempts at mining and recovery of rare-earth minerals in the state have been few and short-lived:

1. Hand-picked ore samples (10 to 100 tons) from several of the South Platte pegmatites ranged from 1 to 7.5 percent RE. These yielded a crude concentrate containing 47.9 percent Y, 2.8 percent Gd, 2.3 percent Dy, 3.7 percent Nd, 1 to 2 percent Er, Sm, Ce and 0 to 1 percent Ho, La, Tb, and Pr (Heinrich, 1958d). The ore, consisting mainly of fluorite rich in microscopic inclusions of monazite and xenotime, was obtained from the Big Bear pegmatite.

2. A "carload" of hand-picked gadolinite ore was sold from the White Cloud pegmatite of the same district. A much smaller amount was obtained from the Dazie Bell.

3. The Henry pegmatite, Fremont County, (Heinrich, Borup and Salotti, 1962) was mined for rare-earth fluorite, and a "recovery plant" was begun in Canon City to recover the rare-earth elements. The amount of rare-earth ore proved to be very small and the project was aborted.

4. The Jim 3 pegmatite near Lookout Mountain in Fremont County was developed by G. C. Addey of Canon City in 1955, who leased it to the Minerals Refining Company of Salt Lake City in 1954. This company tried for a year, unsuccessfully, to develop an economic recovery process for beneficiation of the samarskite-bearing ore (Dahlem, 1965).

5. Numerous thorium deposits associated with the McClure Mountain group of alkalic complexes were sampled for thorium, niobium and rare-earth elements, in particular by the Dow Chemical Company of Midland, Michigan, and also by the Cotter Corporation of Canon City, Colorado. Only one mineable thorium deposit was found, and no rare earths were recovered.

6. The Powderhorn complex was explored by Du Pont de Nemours and Company of Wilmington, Delaware, chiefly for niobium in pyrochlore. During the

prospecting program several types of rare-earth concentrations were found (monazite veins, sideritic carbonatite, magnetite-perovskite lenses), but no mining resulted.

During the preparation of a general study of geology of rare-earth deposits (Heinrich and Wells, in press), it became evident that a very high percentage of the rare-earth deposits of the United States are geographically localized; i.e., they occur in provinces. This paper describes the two Colorado provinces and compares them with another major province in the Rocky Mountains, that along the Idaho-Montana border.

GEOCHEMISTRY AND MINERALOGY

The rare-earth elements are conspicuously misnamed, for, as has been often remarked, they are neither earths, but metals, nor are they rare, being considerably more abundant than many other metals of technical importance. They form a relatively homogeneous group of elements related closely by their atomic and chemical properties as well as by their mineralogical and geological characteristics. They include elements 57 through 71, lanthanum to lutecium (commonly called the lanthanide elements), to which yttrium (39) is added. Commonly they are separated into two subgroups: the cerium subgroup, which includes elements 57 through 62 (lanthanum to samarium), and the yttrium subgroup, which comprises the heavier lanthanides, elements 63 through 71 (europium to lutecium), together with yttrium (39) (Heinrich, 1958a, 1958b).

The rare earths form a geochemically allied group, which as a unit is estimated to constitute 0.005 percent of the earth's crust. Several rare earths are more abundant than such widely used metals as lead and cobalt; most are more abundant than silver, mercury, or selenium. The lighter rare earths, particularly Y, La, Ce, and Nd, are the most abundant of the group; Pr, Sm, Gd, Dy, and Yb rank next; the least abundant are Eu, Tb, Ho, Er, Tm, and Lu.

Because of their relatively large ionic radii, rare-earth ions cannot readily participate in the structure of early-crystallizing silicate minerals from magmas, but are successively rejected and become enriched in late residual fractions or in late accessory species (e.g., allanite). Thus they are concentrated especially in pegmatites and hydrothermal fractions.

The mineralogy of the rare earths is extremely diverse and complex, and this is reflected in the great variety of genetic types of rare-earth deposits. Rare earths not only form their own minerals in a variety of groups (oxides, multiple oxides, fluorides, carbonates, phosphates and silicates), but they also occur vicariously in numerous minerals of many other elements (oxides, multiple oxides, fluorides, silicates) in isomorphous substitution, particularly for Ca but also for Th, U, Ti, and Zr. Rare earths are essential elements in over 100 minerals and occur in lesser amounts in substitution in many more. Inasmuch as the total range of stabilities of all the rare-earth minerals is very broad, deposits can be formed under a wide variety of geological environments. Despite this unusually diverse mineralogical representation, only a very few rare-earth species are economically important because of abundance, high rare-earth content, and processability. The two most important are monazite (Ce, La, U, etc. Th) PO_4 and bastnaesite (Ce, etc.) FCO_3. Others of lesser economic significance include:

xenotime YPO_4

apatite $(Ca, RE)_5(PO_4)_3F$

brannerite $(U, Ca, Fe, Th, Y)_3Ti_5O_{16}$.

GEOLOGY OF RARE-EARTH DEPOSITS

Rare-earth deposits occur in all three petrologic-geologic domains: igneous-hydrothermal, sedimentary, and metamorphic-migmatitic. In each of these categories the deposits were formed under specific, unique genetic controls. Igneous-hydrothermal deposits, which are the most diverse, are genetically dichotomous: 1) those related to calc-alkalic rocks, and 2) those related to alkalic rocks. Analogously, sedimentary deposits occur in both clastic and nonclastic types.

Igneous-hydrothermal deposits represent the most complex group, both in mineralogy and geology. To a large extent their distribution depends on the prior emplacement of plutons, either calc-alkalic or alkalic, anomalously enriched in rare-earth elements. Intrusion sites of alkalic plutons are closely guided by large-scale lineaments.

The mineral assemblages of sedimentary rare-earth deposits are much simpler than those of the igneous-hydrothermal group and depend, in the clastic group, on the survivability of such resistance as monazite and xenotime to the destructive actions of weathering and transportation. The accumulation of these resistates is a long, complex, and repetitive process involving usually recyclings into progressively younger sediments to an ultimate marine placer deposit. The Precambrian metastable brannerite (metamict) placers of Blind River, Ontario, are postulated to have formed during a time when the earth's atmosphere was significantly lower in oxygen, preventing oxidation of detrital brannerite and the accompanying pyrite.

Rare-earth mineral assemblages in regional metamorphic deposits are the most simple and are based on the geochemical cycle for monazite (Overstreet, 1967). Detrital monazite in clastic sediments becomes unstable during low-grade metamorphism, and the rare earths enter the structure of other minerals. With increasing grade of metamorphism, monazite again becomes stable and reforms, attaining its maximum abundance in rocks most intensely metamorphosed. Also, the percentage of Th in monazite increases with increasing grade of metamorphism. With migmatization, monazite is further concentrated, and extrinsic monazite may be added.

A genetic classification of rare-earth deposits is presented in Table 1.

Of all these deposits only a few are of direct economic importance. The two most important are the marine monazite placers (e.g., Florida, Brazil, India) and the bastnaesite carbonatite of Mountain Pass, California. With the development of the latter, the United States has become essentially self-sufficient in rare-earth resources. The Sulphide Queen carbonatite of Mountain Pass probably is the largest single rare-earth concentration in the world, with inferred reserves in excess of 25 million tons of carbonatite with 5 to 10 percent RE_2O_3 (<10 billion pounds of RE_2O_3).

Other deposits mined in the past include:

1) the Barringer Hill pegmatite of Llano County, Texas,
2) the monazite vein at Steenkampskraal, South Africa,
3) Idaho euxenite placers, mined for niobium, with extraction of rare earths from the residues,
4) recovery of rare earths from residues from the Canadian Blind River mills that processed conglomeratic brannerite ore for uranium.

Other deposits of potential future economic significance include:

1) the Mary Kathleen, Australia, uraninite-allanite skarn,
2) the rare earth-rich carbonatites of Malawi (Kangakunde, Chilwa Island and Tundulu),
3) by-product rare earths from various thorium-rich veins such as those of Idaho,
4) by-product rare earths from aptite-magnetite skarns of New York and New Jersey,
5) by-product rare earths from treatment of residues from marine phosphorites (Florida, Idaho).

GEOLOGIC FRACTIONATION OF RARE-EARTHS

Both the ratio Y/Y + Ln and the distribution percentage of the lanthanides in RE minerals are strongly controlled by crystallochemical factors. The causes for partitioning include 1) the detailed geometry of the crystral structures, 3) basicity differences, 4) oxidation states, and 5) stability of complexes (Wells, 1977). However these variations also are markedly influenced by differences in the geological environment under which the deposit formed. In general silica-rich igneous rocks favor the concentrations of heavy lanthanides and yttrium, whereas igneous rocks low in silica and high in carbonate favor concentrations of light lanthanides (Fleischer and Altschuler, 1969). Thus yttrium and yttrium-earth metals are concentrated predominantly in pegmatitic differentiates from nepheline syenitic or alkali syenitic magmas. However, granitic provinces may also contain cerium in abundance, particularly in monazite and allanite, thus serving as sources for both yttrium and cerium elements, whereas nepheline syenitic and syenitic provinces yield primarily cerium-group elements (Heinrich, 1958b).

Data on the distributional variation of rare-earth elements with paragenesis have been determined for pegmatitic monazites (Heinrich, Borup, and Levinson, 1960), for monazite and apatite (Fleischer and Altschuler, 1969), for sphene (Fleischer, 1978a), and for bastnaesite (Fleischer, 1978b).

The relationships between rare-earth pegmatites and their parent granites have been investigated by Heinrich, Simmons, and Crook (1978) for two major rare-earth pegmatite districts--Barringer Hill, Texas, and South Platte, Colorado. In this study the sum of the rare-earth elements analyzed for the granites from both districts is approximately 450 ppm. From this it can be extrapolated that the total rare-earth content, including yttrium, is in excess of 1000 ppm or 0.1 percent. Average whole-rock rare-earth values for typical granites are only about 270 ppm, which means that the parent granites of these pegmatites contain over 4 times the average granitic rare-earth element concentration.

In contrast, the outermost wall-zone rocks of the pegmatites are calculated to contain only between 100 and 200 ppm and thus are notably depleted in total rare earths relative to the granites. Farther within the pegmatites the rare-earth elements are concentrated as rare-earth minerals in either intermediate zones or in secondary replacement units. Concentrations of rare earth in perthite and albite reflect the presence or absence of rare-earth minerals in these units. Units that contain rare-earth minerals are rare earth-enriched (Σ350 ppm); whereas units containing no rare-earth minerals are markedly rare earth-depleted (Σ50 to 65 ppm).

Thus the pegmatites are further enriched in rare earths relative to their granites by about an order of magnitude. It is clear that fractionation has contributed significantly to the abundance of these elements in the pegmatites but not to such an extent as to cause a major depletion of rare earths from the parent granite magma. In both districts it appears that the rare-earth mineralogy of the pegmataites was dependent upon an original rare-earth enrichment of the parental magma and then upon late-stage fractionation of these elements during the pegmatitic phase.

A quantitative study of the composition of the Kaatiala pegmatite in western Finland by Nieminen

Table 1. Classification of RE Deposits

Type	RE Mineralogy	Examples
	Igneous-Hydrothermal	
A. Calc-Alkalic Association		
1. Disseminations in granitoid plutons	Monazite, xenotime, allanite, RE-sphene	Several phases of Idaho batholith; Silver Plume granite of Colorado
2. Granite pegmatites	Monazite, xenotime, RE-fluorite, microlite, uraninite, uranothorite, samarskite, euxenite, etc.	South Platte, CO; Llano Co., Texas; Haliburton-Bancroft, Ont.
3. Metasomatic disseminations		
a) Metamorphic rocks and granite	Allanite	North-central Colorado
b) In para-pyroxenites	Uranothorianite	Madagascar
4. Veins and replacement deposits		
a) Tin-tungsten veins	Monazite	Bolivia; South Africa
b) Copper-thorium veins	Monazite (20-75%!)	Steenkampskraal, South Africa
c) Barite-sulfide-quartz veins	Bastnaesite	Karonge, Urundi
d) Davidite veins	Davidite	South Australia; Mavuzi, Mozambique
e) Fluorite veins and replacement breccias	Uranothorite	Jamestown, Colorado
B. Alkalic Association		
5. Disseminations in alkalic plutons	Pyrochlore, thorite	Teria District, Nigeria
6. Pegmatites		
a) Alkalic granite	Thorite, niobian rutile, zircon	Mt. Rosa, Colorado
b) Syenitic	Uraninite, RE-sphene allanite	Haliburton and Renfrew Counties, Ontario
c) Nepheline syenitic	Allanite, sphene, apatite, tritomite, melanocerite, thorite, pyrochlore, xenotime, rinkite, steenstrupine, lovchorrite, loparite	Langesundfjord, Norway; Southern Greenland; Kola Peninsula, USSR
7. Alkalic-carbonatitic complexes		
a) Magnetite-perovskite lenses	Perovskite	Iron Hill, Colorado
b) Carbonatites	Bastnaesite	Mtn. Pass, California
c) Fenites	Perovskite, pyrochlore, thorogummite, brockite, RE-miserite	McClure Mtn., Colorado
8. Veins and replacement deposits		
a) Quartzose-thorium veins (several types)	Thorite, monazite, brockite	Lemhi Pass, Idaho
b) Fluorite replacement bodies	Bastnaesite	Gallinas Mtns., New Mexico

Table 1. Classification of RE Deposits (continued)

Type	RE Mineralogy	Examples
Sedimentary		
A. Clastic Sediments		
1. Eluvial and colluvial deposits (in saprolite)	Monazite	Patrick and Henry Counties, VA
2. Alluvial (fluviatile) placers	a) Monazite, xenotime	a) Coastal plain of Georgia, S.C.; Cascade, Idaho
	b) Euxenite	b) Bear Valley, Idaho
3. Littoral (beach) placers	Monazite, zircon	Jacksonville, FL; Bahia, Brazil; Travancore, India; Ceylon
4. Consolidated (fossil) placers	a) Monazite	a) Goodrich quartzite, Palmer, MI
	b) Brannerite	b) Blind River, Ontario
5. Adsorptions on clay minerals	Clay minerals	Pennsylvania sediments, mid-continental USA
B. Non-Clastic Sediments		
6. Marine phosphorites	RE-apatite	Phosphoria Fm., Idaho and Montana; Bone Valley Fm., Florida
7. Phosphatic concretions	Gorceixite	Dale Co., Alabama; Garland Co., Arkansas
8. Marine evaporites	New Ca-RE borate	Paradox Basin, Utah
Metamorphic		
A. In Regional Metamorphic Rocks		
1. Disseminations in medium to high-grade ortho-and para-metamorphic rocks	Monazite	Monazite belt in Piedmont of VA, NC and SC
2. Veins, pods, disseminations concentrations in migmatites	a) Monazite	a) Kulyk Lake, Saskatchewan; Puumala, Finland; North-central Colorado
	b) Xenotime	b) Music Valley, CA
	c) Brannerite	c) San Bernardino Mtns., CA
B. In Contact Metamorphic Rocks		
3. Hematite skarns	Allanite, cerite, fluocerite, lanthanite, tornebohmite, bastnaesite	Bastnäs, Sweden
4. Magnetite skarns	RE-apatite, doverite, xenotime, bastnaesite, monazite	Mineville, NY; Dover, NJ
5. Uraninite skarns	Allanite, stillwellite	Mary Kathleen, Queensland, Australia

(1978) reveals that the mean content of lanthanoids plus yttrium is only 19 ppm, far below the average contents of the rare earths in granite. Yet apatite and columbite from this pegmatite contain 15,500 ppm La plus 1000 ppm Y, respectively. These two species contain 70 percent of all the rare earths in the pegmatite, with the remaining 30 percent in the feldspars. These data illustrate both the powerful concentration effect of specific mineral structures on rare earths and the lanthanoid-yttrium fractionation by individual minerals.

RARE-EARTH PROVINCES

Geographically restricted areas in which rare-earth deposits are concentrated are defined as provinces. Usually a province is time independent, containing a genetic variety of deposits of different geological ages. Among the well-defined rare-earth provinces in North America are:

1. Southeastern United States (VA, NC, SC, GA, FL). Precambrian, Cretaceous and Tertiary deposits. Types: disseminations in metamorphic rocks, pegmatites, all types of placers, phosphorite.
2. North-central Colorado. Precambrian and Tertiary. Types: granites, pegmatites, metasomatic allanite dissemination, xenotime and monazite migmatites, radioactive RE-fluorite-veins.
3. South-central Colorado. Precambrian, Cambrian, Tertiary. Types: granites, pegmatites, magnetite-perovskite lenses, carbonatites, fenites, monazite veins, rare-earth apatite-molybdenite breccia, radioactive fluorite veins.
4. Idaho-Montana border. Silurian, Permian, Cretaceous, Tertiary, Pleistocene. Types: disseminations in granite, pegmatites, carbonatites, Th veins, fluorite replacements, sulfide-parisite veins, marine phosphorite, monazite placers, euxenite placers (Table 2).

Other provincial concentrations occur in San Bernardino County, California (migmatitic deposits and carbonatites) and in southeastern Alaska (carbonatites and various types of RE veins). Malawi, with disseminations in alkalic rocks, in numerous carbonatites very rich in rare earths (Chilwa Island, Tundulu, Kangankunde), and in phosphorite, is an example of a foreign province.

COLORADO RARE-EARTH PROVINCES

North-Central Province

The rare-earth province of north-central Colorado is within the Front Range and includes parts of Clear Creek, Boulder, Gilpin, Jefferson and Douglas Counties. The province trends in general north-south for about 70 miles. The rare-earth deposits are geologically diverse, including rare earth-rich granitoids, their pegmatites, metasomatic disseminations, fluorite veins and migmatitic deposits. All are of Precambrian age except the fluorite veins, which are Tertiary.

Two major Precambrian granitoid plutons are anomalously enriched in rare-earth elements 1) the Silver Plume granite (~1400 my) in the Longs Peak-St. Vrain pluton, and the 2) the Pikes Peak granite (~1000 my), particularly in the northern end of the batholith in the South Platte district. The oldest granite of the province, the Boulder Creek appears to have been introduced metasomatically in Silver Plume time (Hickling and others, 1970). The chief rare-earth minerals of the Silver Plume granite itself are allanite and monazite.

Near Jamestown several small rare-earth pegmatites occur near the northern border of a stock of Silver Plume granite to which they are genetically related (Goddard and Glass, 1940). They contain an unusual suite of rare-earth species--cerite, allanite, brown epidote, tornebohmite, bastnaesite and monazite.

The Pikes Peak granite of the South Platte district contains allanite and bastnaesite formed from allanite (Simmons, 1973; Adams and Young, 1961). The South Platte pegmatites are rich in a varied assemblage of rare-earth minerals (Heinrich, 1958d; Simmons, 1973; Simmons and Heinrich, 1975; Heinrich and Simmons, and Crook, 1978; Adams and Sharp, 1972): (oxides) samarskite, fergusonite, yttrotantalite; (halides) RE-fluorite, yttrofluorite, fluocerite (Heinrich and Gross, 1960); (carbonates) doverite, bastnaesite, yttrian bastnaesite; (phosphates) xenotime, monazite; (silicates) zircon (cyrtolite), thorite, gadolinite, cerian gadolinite, allanite, thalenite.

In addition to these two groups of rare earth-rich pegmatites, pegmatites scattered elsewhere in the province contain rare-earth accessory species (Eckel, 1961; Waldschmidt and Adams, 1942): gadolinite, 3 localities; monazite, 8 localities; allanite, 7 localities; crytolite, 2 localities; euxenite, 1 locality; fergusonite, 1 locality; microlite, 1 locality; samarskite, 3 localities; xenotime, 3 localities.

The disseminated metasomatic allanite occurrences described by Hickling and others (1970) represent a unique type of rare-earth deposit. Allanite metacrystic porphyroblasts replace biotite in 1) comagmatic rocks of the Boulder Creek batholith, 2) associated amphibolite xenoliths and related hybrid rocks and 3) Silver Plume granite over an area about 10 miles wide (E-W) and nearly 20 miles long (N-S).

Migmatitic rare-earth deposits occur in Precambrian biotite gneiss and migmatite at three localities near Central City. Xenotime and monazite are concentrated in zones as much as 5 ft thick and a few hundred feet long. These zones contain 1 to 5 percent of combined rare-earth phosphates in sand-sized crystals (Young and Sims, 1961).

Table 2. Rare-earth deposits of the Idaho-Montana Province

Deposit, location	Type	RE minerals	Age
1. Bull Canyon, Lemhi Co., Id.	Disseminations and shear zones in granite	Allanite, monazite; thorite in shears	Probably Silurian
2. Idaho batholith and outliers.	Disseminations in granitoids and rarely in pegmatites	a. General: monazite, zircon sphene, allanite, xenotime, thorite b. Bear Valley, Id: euxenite, monazite c. Hailey, Id: thorite, sphene	180 my.
3. Lemhi Pass, Id. and Mont.	Thorium veins and fracture zones	Thorite, monazite, allanite brockite, bastnaesite	Laramide (?)
4. Hall Mtn., northern Id.	Thorium veins	Thorite, allanite, monazite, cenosite	Cut Belt Series
5. White Cloud mine, Eight Mile Creek Dist. Ravalli Co., Mont.	Gold vein	Parisite	?
6. Crystal Mtn. Ravalli Co., Mont.	Fluorite replacement body	Fergusonite, thorianite?, thortveitite	Laramide?
7. Salmon River Canyon, Id.	Carbonatites	Monazite, allanite, ancylite, bastnaesite	95 my.
8. Ravalli Co., Mont. and Lemhi Co., Id.	Carbonatites	Ancylite, fersmite, baotite, allanite, monazite, eschynite	95 my.
9. Snowbird deposit, Mineral Co., Mont.	Carbonate-quartz-fluorite "pegmatitic carbonatite"	Parisite, xenotime	70 my.
10. Phosphoria Fm., SE Idaho and adjacent Mont.	Marine phosphorite	Uraniferous collophane	Permian
11. Bear Valley placers, Valley Co., Id.	"Radioactive black" type metastable alluvial placers	Euxenite, brannerite, monazite	Late Pleistocene

Table 2. Rare-earth deposits of the Idaho-Montana Province (continued)

Deposit, location	Type	RE minerals	Age
12. Hailey placers, Blaine, Co., Idaho	Metastable alluvial placers	Thorite, allanite	Late Pleistocene?
13. Cascade placers Valley, Co., Id.	Gold alluvial placers	Monazite	Holocene
14. Sand Basin placers, Granite Co., Mont.	"Radioactive black" type metastable alluvial placers	Euxenite, sphene, zircon, allanite, thorianite	Late Pleistocene to Holocene

Sources: Heinrich, 1958c, 1966; Anderson, 1958, 1960, 1961; Clabaugh and Sewell, 1964; Parker and Havens, 1963; Penfield and Warren, 1899; Staatz, 1972; Staatz and others, 1972.

The Jamestown fluorite deposits of Tertiary age (Goddard, 1946) consist of mainly violet to black fluorite in breccia zones and veins. The deep-violet fluorite contains irregularly scattered minute grains of uraninite and uranothorite. Anomalous concentrations of rare earths have been detected in these ores, but it is uncertain if they occur in the fluorite or in its radioactive inclusions.

South-Central Province

The south-central rare-earth province, occurring in parts of Teller, Fremont, Custer, southern Park, Chaffee and Gunnison Counties, is generally elongated east-west over a distance of about 100 miles from near Rosemont in Teller County to Powderhorn in Gunnison County. The rare-earth deposits are geologically even more diverse than those of the northern district and include a variety of deposits of Precambrian, Cambrian and Tertiary age.

The Precambrian occurrences are related to three main groups of granitic plutons: Boulder Creek granitoids (~1700 my), Silver Plume granitoids (~1400 my) and the Mount Rosa alkalic (riebeckite) granite (~1000 my). The Boulder Creek granite, near Coaldale in Fremont County just east of the Pleasant Valley fault, locally contains large allanite crystals from which supergene autunite mineralization has been developed. Near Parkdale a tonalitic phase of the Boulder Creek is notably enriched in RE-sphene (keilhauite).

Pegmatites associated with Boulder Creek plutons display a dichotomy with respect to rare-earth minerals. In some districts the pegmatites are essentially devoid of rare-earth species (e.g., Eight Mile Park), whereas in other districts the pegmatites contain rare minerals in relative abundance. Examples of the latter include:

1) Guffey area, southern Park County and Fremont County--monazite, euxenite, allanite (Heinrich and Bever, 1957),

2) Cotapaxi area, Fremont County--gadolinite in Pine Ridge pegmatite (Heinrich, 1948); cenosite, RE-fluorite, cyrtolite, doverite in the Henry pegmatite (Heinrich, Borup, and Salotti, 1962); monazite and allanite in the Kuntz Gulch pegmatites,

3) Lookout Mountain area, Fremont County--Jim No. 3, samarskite; Horsepasture, samarskite, allanite (Dahlem, 1965); Jim No. 6, samarskite, monazite; Addey, samarskite.

Although the exact assignment of some of the pegmatites to a granitic period of a particular age (Boulder Creek or Silver Plume) is admittedly uncertain, it does appear the pegmatites of probable Silver Plume affinity in this province are conspicuously low in rare-earth accessory minerals.

Pegmatites of Mt. Rosa age, noted for occurrences of rare aluminofluorides, also contain zircon and thorite in relative abundance and lesser amounts of microlite, monazite, bastnaesite, and doverite (Gross and Heinrich, 1966). Pegmatites of this area associated with the Pikes Peak granite are recorded as having a few scattered occurrences of bastnaesite, xenotime and fluocerite.

Other Precambrian pegmatites with rare-earth minerals but of uncertain age are the Luella (allanite, euxenite) and the Yard (monazite, euxenite) in Chaffee County (Heinrich, 1948). A small pegmatite district that may be part of the south-central province lies on the west side of the Sangre de Cristo Range in Saguache County. The dikes contain euxenite, xenotime, monazite and cyrtolite (Brown and Malan, 1954).

Next in age are the various rare-earth deposits associated with the Cambrian alkalic-carbonatitic intrusions of McClure Mountain and its environs (three complexes) in Fremont and Custer Counties and of the Iron Hill (Powderhorn) complex of Gunnison County. In the McClure Mountain group (McClure Mountain, Gem Park, and Democrat Gulch) rare-earth minerals occur in:

1) internal mafic fenite, Gem Park--RE-perovskite species (Parker and Sharp, 1970). Some Gem Park carbonatites also contain monazite; and
2) various types of external fenites, leucofenites, carbonatites and veins--thorite, thorogummite, brockite, monazite, xenotime, bastnaesite and fergusonite (Heinrich, 1966).

In and around the Iron Hill (Powderhorn) complex of Gunnison County, rare-earth thorium mineralization (Olson and Wallace, 1956; Heinrich, pers. obs.) occurs in:

1) magnetite-perovskite lenses--in perovskite,
2) sideritic carbonatite--bastnaesite, and
3) various veins and shear zones--thorite, thorogummite, xenotime, bastnaesite, synchisite and cerite.

Rare-earth occurrences of Tertiary age include:

1) brannerite in the molybdenite vein of the California mine in the Mount Antero district Chaffee County (Eckel, 1961),
2) a rare earth-bearing apatite-molybdenite breccia body in the Silver Cliff-Rosita district, Custer County (Hildebrand, 1960), and
3) radioactive fluorite-copper sulfide veins along faults in the Cotopaxi district, Fremont County (Heinrich, pers. obs.).

CONCLUSIONS

The Precambrian rare-earth concentrations in Colorado comprise those types of deposits genetically related to granitoid plutons--1) concentrations in the plutonic rocks themselves; 2) rare-earth pegmatites; 3) migmatitic monazite-and/or xenotime-rich gneisses and 4) metasomatic allanite disseminations. In the north-central province the two principal source granitoids have been the Silver Plume (1, 2, 3, 4 above) and the Pikes Peak (1, 2 above). In the south-central district, where Boulder Creek and Silver Plume plutons dominate, the Boulder Creek appears to be the dominant rare-earth source (1, 2 above), but ages of some of the pegmatites remain uncertain. The Mt. Rosa granite also was a significant source in the southern province.

Cambrian rare-earth mineralization is restricted to the two alkalic-carbonatitic complexes of the McClure Mountain group in Fremont and Park Counties and the Iron Hill (Powderhorn) complex of Gunnison County. In these, rare-earth concentrations occur principally in late rock units--fenites, carbonatites and veins. However, at Powderhorn rare earths also are concentrated in a magnetite-perovskite lens, one of the oldest units of the complex. It has been pointed out that both of these alkalic centers lie on the 38th parallel (Heinrich, in press) and that their alignment may represent control by the 38th parallel lineament (Heyl, 1972) now buried by Laramide-Tertiary structures of the Rocky Mountains.

Tertiary rare-earth concentrations, the least numerous and smallest, occur principally in fluoritic and metalliferous veins.

Most of these types of rare-earth deposits also occur in the Idaho-Montana province (Table 2), which in addition also contains several other types, notably rare earths in the Phosphoria Formation and in a variety of alluvial placer deposits. The Colorado provinces further contrast with that of Idaho-Montana in age distribution. In Colorado the rare-earth deposits are principally Precambrian and Cambrian in age, whereas in the Idaho-Montana province the deposits are mainly Laramide, Tertiary, Pleistocene and Holocene.

Except for some of the migmatitic deposits and such secondary deposits as the phosphorites and placers, these provinces exhibit no evidence of rare-earth recycling.

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APPENDIX I

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APPENDIX 2

15th FORUM ON GEOLOGY OF INDUSTRIAL MINERALS

Golden, Colorado

Field Trip Road Log

"Aggregates and Industrial Minerals in the Golden, Morrison, and Lyons Areas"
Wednesday, June 13, 1979

Field Trip Leaders: Steve Schwochow, Colorado Geological Survey
Veryl Larsen, Colorado School of Mines Research Inst.

Mileage	
0.0	Leave Holiday Inn and proceed west on U.S. 40 (W. Colfax Ave.).
0.3	Proceed onto Interstate 70, heading southwest. Oldest rocks in the Golden area consist of folded and faulted gneisses and schists (Idaho Springs Formation) intruded by granitic and quartz monzonitic batholiths and stocks, and pegmatites—all lying within the uplifted Front Range. Above a regional unconformity on the Precambrian sequence lie Pennsylvanian to early Tertiary sedimentary rocks, steeply tilted to overturned near the mountain front and gently dipping farther eastward into the Denver Basin. Prominent hogbacks are formed by the Fountain Formation, Lyons Sandstone, and Dakota Group (see attached stratigraphic column).
2.8	East end of the I-70 roadcut, a spectacular cross-section of Jurassic and Lower Cretaceous rocks (Morrison Fm. through Benton Shale). Top of the cut and hogback is upheld by resistant sandstone in the Dakota Group, also the source of important refractory clays.
3.2	Leave I-70 roadcut. Valleys of Lena Gulch (right) and Mt. Vernon Creek (left) are underlain by red shales and siltstones of the Lykins Formation. Note low outcrops of the Glennon Member—a pink, crinkly laminated algal limestone. Just beneath the Lykins is the light-colored, cross-bedded Lyons Sandstone.
3.5	Pass over the unconformity between the Precambrian and Pennsylvanian, heading west into Mt. Vernon Canyon. In roadcuts, note intense folding and many dikes intruding the Idaho Springs Fm. Major faults and shear zones trend from northwest to southeast approximately parallel to foliation.
6.1	Reclaimed highway department rock quarry on right along the entrance road to Paradise Hills subdivision.
7.3	Highway department rock quarry. Both quarries are located on or near major shear zones.
8.2	Genessee Park exit. Prime developable lots and homes on both sides of the highway sell for $100,000 to $150,000.
9.6	Chief Hosa exit. Now entering the south part of the Clear Creek pegmatite district, one of two districts in Jefferson County and 19 throughout Colorado. The pegmatites strike nearly east-west in contrast to the northwest-southeast trend of bedding and foliation. Pegmatites in this area have yielded economic feldspar, scrap mica, and quartz, with accessory tourmaline, beryl, and garnet.

10.6 Take El Rancho exit, cross I-70, proceed southwest on Colo. 74.

11.7 Hidden Valley. Turn left onto Jefferson County Road 23, heading south and southeast down Kerr Gulch. Primary host rock unit for pegmatites here is interlayered hornblende gneiss, calc-silicate gneiss, and amphibolite.

13.5 Access road to Burroughs pegmatite mine. STOP 1. Deboard and walk about 0.3 mile to mine site. Proceed with caution into excavation. Note large feldspar crystals in the quartz. Also biotite pods and small reentrant showing contact of the dike and country rock.

Reboard and continue down Kerr Gulch. Below the junction with Swede Gulch, valley alignment is fault controlled.

15.7 Cross bridge over Swede Gulch.

16.3 Junction with Colorado 74 near town of Kittredge (elev. 6840). Turn left and head northwest down Bear Creek Canyon toward Morrison. Granulation and discoloration in road cuts denote fractures and faults.

18.8 Valley widening caused by east-west-trending shear zone.

20.1 Town of Idledale (elev. 6466). Townsite is located on wider valley areas at intersection of two shear zones.

23.4 Leave Bear Creek Canyon, cross Precambrian-Pennsylvanian unconformity, enter town of Morrison (elev. 5800). Ahead on left note gradational contact of Fountain Fm. into Lyons Sandstone.

23.8 Turn right onto Colorado 8, heading south. Subdued outcrop of Lyons Sandstone on left. On right, Fountain Fm. is covered by Slocum gravel on high-level erosional surface.

25.1 Access road to Cooley Gravel Company. Turn right. Note isolated erosional remnants of Fountain Fm.--pink conglomeratic sandstone and dark-red mudstones

STOP 2--Strain Gulch quarry. Proceed to south end of quarry. Excavation is located back from canyon mouth in Precambrian gneiss. Location and elevation help screen this site from view.

25.1 Junction of access road and Colorado 8. Turn left and continue log. Hogback on right is held up by Dakota Group overlying brightly colored Morrison Fm. shales.

26.4 Town of Morrison. Turn right onto U.S. 285 (Morrison Road), heading east through the hogback.

27.1 Turn left onto Rooney Road, heading north. Road passes along outcrop of Niobrara Fm. Fort Hays Member, on left, forms low ridge offset by small en echelon faults. Quarries on left yielded argillaceous limestone for lime. Smoky Hill Shale member exposed on right. Valley of Rooney Gulch on right is underlain by Pierre Shale. Golden Fault cuts out succeedingly larger portions of Pierre Shale heading north. On the right, note the Chieftain clay pits in the Laramie Fm.

29.5 Rooney Ranch and junction with Colorado 26 (W. Alameda Parkway). Proceed straight on Rooney Road and cross Golden Fault. Note old clay mine in the Dakota and Benton Shale on left. Road veers to the right around a large landslide from the Dakota dipslope. Note old clay mine adits on the left. Many of the Dakota clay mines began as underground mines. Strainland pit on top of the hogback is operated by Denver Brick & Pipe Co. Road veers to right along the I-70 rado fill. Roadcut on right shows contact of Pierre Shale and Fox Hills Sandstone.

31.2 Access road to Rooney clay pit, operated by Parfet Estate, STOP 3. Here we will contrast the geology of brick clays in the Laramie Fm. with that of the refractory clays in the Dakota in the Strainland pit.

Leaving Rooney pit, roadcuts on the right show vertical to overturned Laramie in contact with basal conglomerate of the Arapahoe Fm.

31.4 Turn left and cross I-70. Jefferson County landfill ahead on the left is built over the Fox Hills-Laramie aquifer. Trailer court ahead is built over reclaimed Laramie clay pit.

32.2 Junction with U.S. 40. Turn right.

32.6 Turn left onto access road. Turn left onto U.S. 6, heading west. Passing the second bend, again cross the trend of the Laramie clay beds.

33.9 Active Laramie clay pit. Road right-of-way essentially lies along the trace of the Golden Fault. Truncated Dakota hogback on left. Golden Fault displaces nearly all of the 6000 ft of Pierre Shale. Abandoned Laramie clay pits on right.

35.0 Junction with 19th Street, Golden. Continue on U.S. 6. Campus of Colorado School of Mines on right. Married-student housing on right is built on old backfilled clay pits.

35.5 Colorado School of Mines Research Institute on right. At the mouth of Clear Creek canyon ahead is the old Bertrand quarry, currently under proposal by Brannan Sand and Gravel for reopening and reclamation. Golden Fault here displaces Pierre Shale against Fountain Fm.

35.9 Cross Clear Creek and turn right onto Colorado 58, heading east into Golden (elev. 5772). Ahead Clear Creek has eroded thru a sequence of three latite lave flows in the Denver Fm. to form North and South Table Mountains. Old quarries on South Table Mtn. have operated for aggregate, road material, and riprap intermittently for 70 years. A proposal is now underway to open a new quarry on the north end of the mountain.

36.6 Take Washington Street exit. Turn left onto Colorado 93, heading northwest. The rock quarry on North Table Mtn. began in the 1920's and was enlarged in 1949 by the Rogers Construction Co. of Indianapolis. Western Paving Construction Co. now proposes a major expansion of the site. Both mountains are famous zeolite localities.

37.8 Cross Tucker Gulch. Junction with Golden Gate Canyon road. Pass the old Golden Fire Brick Co. plant and clay pit on left. Just beyond the first bend in Golden Gate Canyon is another proposed quarry site (Brannan Sand and Gravel).

38.2 Earth Sciences, a geological and minerals consulting firm. Plant in back was pilot for alunite processing to obtain aluminum.

38.5 Access road to North Table Mtn. site. Turn right. STOP 4. We will hear details of the North Table Mtn. proposal from Western Paving and plans for the Golden Gate Canyon site from Brannan Sand and Gravel.

38.5 Junction of access road and Colorado 93. Turn right and continue log. On left is extensive mining of refractory clays from the Dakota.

40.0	Monzonite intrusion on left. Claypit is Pierre Shale on hillside. Beyond the hill and off to the far left is the Ralston quarry operated by Asphalt Paving Co. Site is located on the south end of an oval-shaped monzonite intrusion.
40.8	Access road to Ralston quarry.
41.8	Cross Ralston Creek. An old monzonite quarry is visible on the east limb of the intrusive above the buildings on the left. Road rises onto gravel-covered mesa. The deeply weathered gravel is called Verdos alluvium and is classed as Kansan in age based on a volcanic ash bed found locally at its base.
43.2	Descend from the Verdos surface, cross Leyden Gulch and pass vertical Laramie clay beds on right. In the foothills due west in Colorado's largest uranium mine—the Schwartzwalder—a classic vein-type uranium occurrence. As the road bends left, we rise onto a higher gravel-covered surface called Rocky Flats, of Nebraskan age.
44.8	Junction with Colorado 72. Proceed straight on Colorado 93. Note Laramie clay pits 0.5 mile to the east (right).
46.1	Entrance to Rocky Flats atomic weapons plant—a highly controversial site.
47.8	Inactive Idealite lightweight aggregate plant. Pierre Shale was quarried on the left, trucked beneath the road to the plant where it was heated and expanded in a kiln.
49.2	Junction with Colorado 128. Proceed straight. Pass through the southwestern end of the Boulder-Weld coal field.
51.4	Town of Marshall (elev. 5509). Descend into South Boulder Creek valley. Controversial proposed gravel pit and park site less than 2 miles to northeast (right) on South Boulder Creek at the Boulder Turnpike.
54.9	Baseline Road, City of Boulder. Turn right. On left is campus of University of Colorado. Note buildings constructed of Lyons Sandstone.
55.3	Turn left onto U.S. 36, heading north. In the mountains immediately west of Boulder are several old gold and silver districts, an important tungsten district, and Colorado's most recently active fluorspar district at Jamestown.
60.9	Concrete products plant. Outcrops are the lower shale and Hygiene Sandstone members of the Pierre Shale.
63.2	Exposures of Niobrara Fm.
65.1	Cross Left Hand Creek. In a side canyon just beyond the Dakota hogmack is a north-south-trending intrusion currently being studied by C & M Sand and Gravel Co. as a long-term source of quarry aggregate.
66.5	Note landslide deposits from the Dakota dipslope.
69.6	Junction with Hygiene Road. Continue on U.S. 36. On right is plant and quarry of Martin Marietta Cement Co. Along the road on right are old quarry workings backfilled with overburden and waste rock and successfully revegetated.
70.8	Martin Marietta's silica sand quarry in Dakota sandstone on left.
71.2	Cross St. Vrain Creek, turn right onto Colorado 66, heading east.
72.3	Access road to Martin Marietta plant. Turn right and proceed to office building. Head into quarry area (Niobrara Fm.). STOP 5. View benched workings in the Smoky Hill Shale member, inactive excavations in Fort Hays limestone member, revegetated sites, coal stockpile, plant buildings and kiln.

72.3	Junction access road and Colorado 66. Turn left, continue log, heading west into town of Lyons.
73.5	Pass Dakota hogback and Stone Canyon, underlain by Lykins Fm.
74.1	Enter town of Lyons (elev. 5400). Note anticlinal outcrop of Lyons Sandstone on right, extensive quarrying for dimension stone.
74.9	Turn left onto Colorado 7, heading south up South St. Vrain Creek. Cross railroad tracks and turn right into park. <u>STOP 6</u>. Lunch

During and after lunch, note cross-bedding and other sedimentary structures in outcrop of Lyons Sandstone along railroad tracks. Note samples of crushed rhyodacite along the tracks. This material comes from the Andesite Rock Co. quarry in a sill 2 miles up South St. Vrain Creek canyon.

After lunch, board <u>Bus A</u> for trip to Denver Brick and Pipe Co. <u>or</u> <u>Bus B</u> (preassigned) for trip to Coors Porcelain Co. Leave Lyons via U.S. 36.

Log for Bus B continued on page 6.

<u>Additional log for Bus A route:</u>

79.5	On right are loading silos for Western Paving Construction Co.'s gravel unit train. Gravel is mined and loaded here onto rail cars for a 45-mile trip to the company's asphalt plant in Denver.
81.1	Junction with N. 75th Street, heading into Hygiene. Continue east on Colorado 66.
82.0	Table Top Mountain on left—a long isolated remnant of upland gravel which has been extensively mined.
85.1	Junction with U.S. 287 to Longmont. On the south side of town, along St. Vrain Creek, flood-plain development is conflicting with gravel mining. Plant on the west edge of town manufactured brick from Pierre Shale.
91.6	Turn right onto Interstate 25, heading south for Denver.
93.0	Descend into St. Vrain Creek valley. Note reclaimed gravel pits on right.
95.6	Cross approximate contact of Pierre Shale and Fox Hills Sandstone.
98.0	Begin crossing mined land in the Boulder-Weld coal field. Bumps in the next 6 miles of road are caused by subsidence of underground mined areas.
101.2	Imperial coal mine to the right.
102.3	Eagle coal mine to the right.
104.0	Leave Boulder-Weld coal field.
105.5	Base Line Road exit.
110.0	Cross Big Dry Creek, enter developed areas of Northglenn and Thornton, northern Denver suburbs.
117.5	U.S. 36 interchange. Descend into Clear Creek valley. Extensive gravel mining on both sides of highway. Confluence with South Platte River is 2 miles to left.
121.0	Interstate 70 interchange—"Mousetrap"
121.5	Take 38th Ave. exit, proceed west to Fox Street, turn right. Proceed 7 blocks to Denver Brick and Pipe Co.—<u>STOP 7A</u>.
121.5	38th Ave. ramp onto Interstate 25, heading north. Continue log.

Reclaimed gravel pits in South Platte River deposits beneath railroad tracks on right.

122.5 Proceed through "mousetrap" and head west on Interstate 70.

126.6 Descend into Clear Creek valley. Development on principal gravel deposits here has precluded mining in a 4-mile-long stretch.

128.9 Kipling Street exit. Up on the hill to the right is Colorado's only glass plant, the Columbine, now operated by Coors.

130.1 Reclaimed gravel pits on right.

132.0 Junction with Colorado 58.

132.3 Cross Clear Creek. Extensive gravel mining on both side of highway. Golf course on right is last significant reserve in this section of the valley.

135.7 Take Colfax Ave. exit, turn left onto U.S. 40.

136.0 Arrive at Holiday Inn

END TRIP

Additional log for Bus B route:

74.9 Junction of Colorado 7 and U.S. 36, proceed east out of Lyons.

76.7 Turn right onto U.S. 36, heading south toward Boulder.

Proceed back to Golden via U.S. 36, Colorado 93.

111.3 Cross Colorado 58 in Golden.

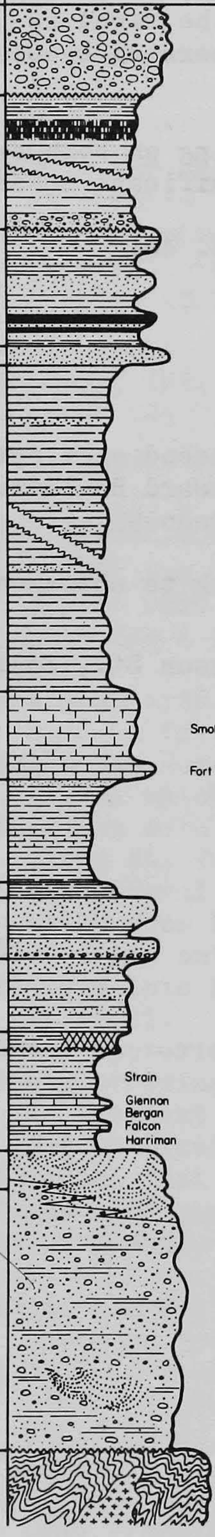
111.5 Turn left on 10th Street. Go around block to entrance to Coors Porcelain Co. STOP 7B.

111.6 Proceed through Golden via Ford St., Jackson St., South Golden Road, and Indiana St.

115.5 Arrive at Holiday Inn

END TRIP

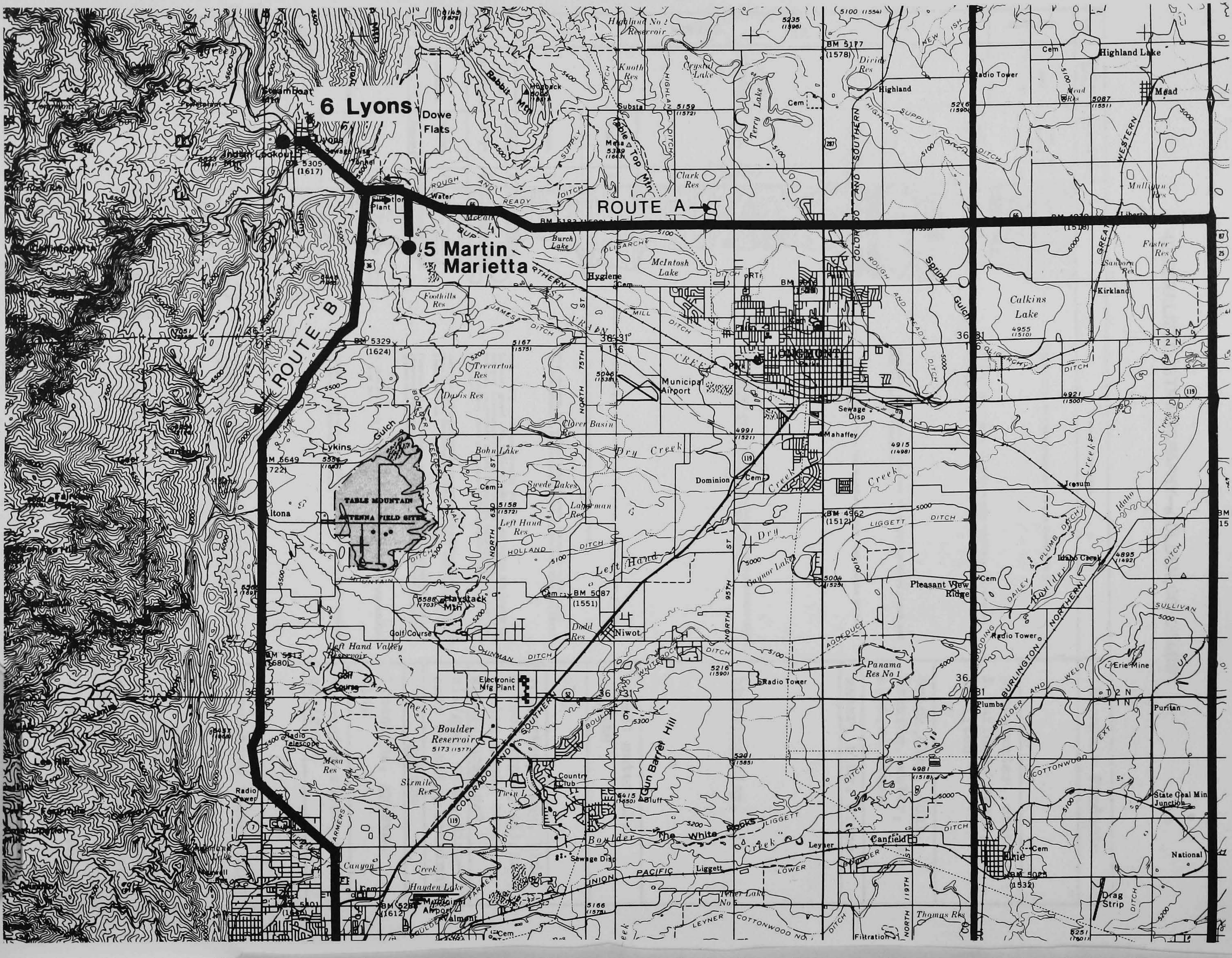
GENERALIZED STRATIGRAPHY—GOLDEN,COLORADO

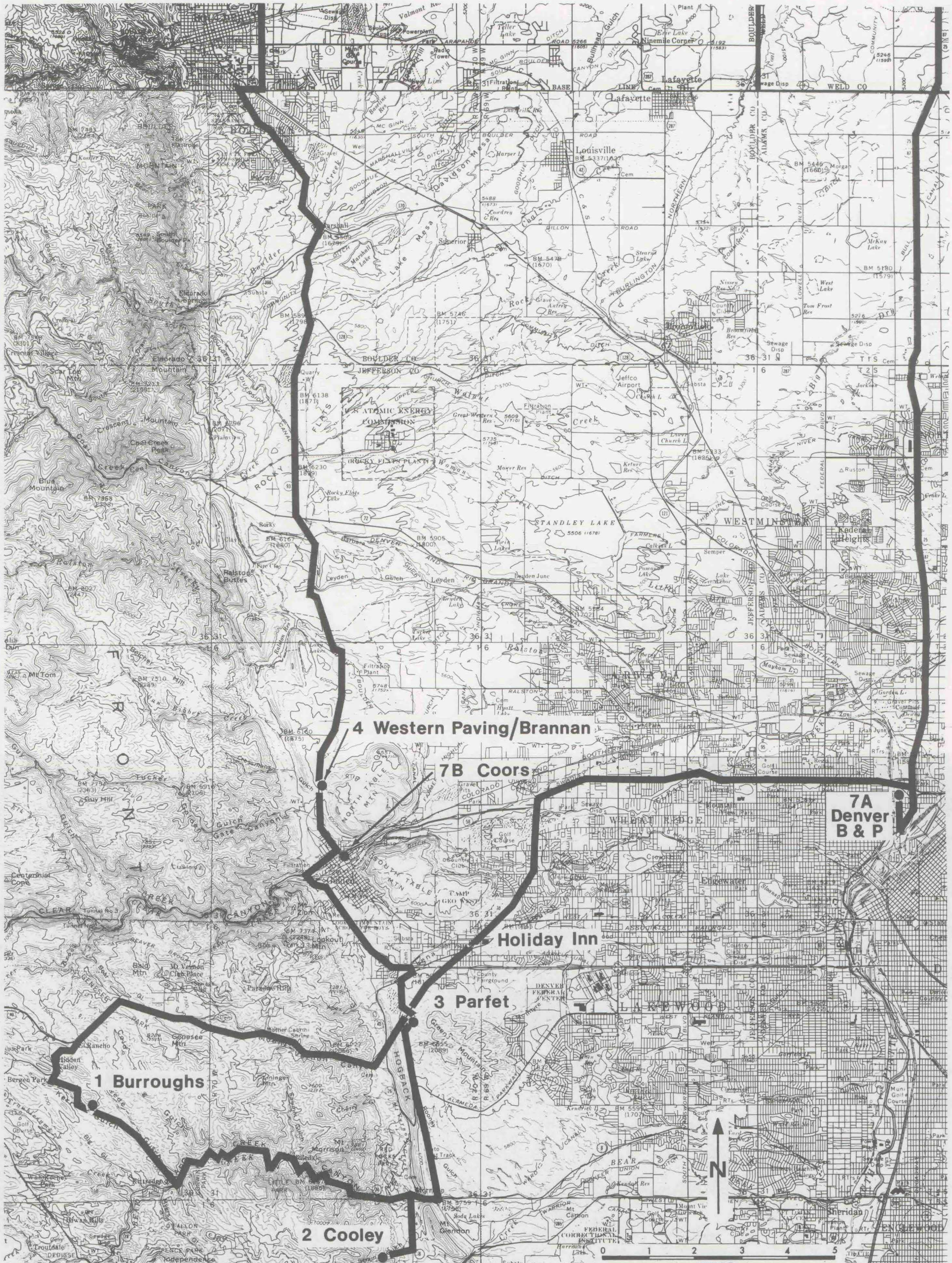


Era	System or Series	Formation	Thk.	Summary Description	Economic Products
CENOZOIC	LOWER TERTIARY	Green Mountain	600′	Boulder conglomerate, some boulders up to 3 feet in diameter. Nonmarine.	
MESOZOIC	UPPER CRETACEOUS	Denver-Arapahoe	1200′	Siltstone, olive-drab, sandy clays, and hard shaly sandstones. Conglomerates locally well-developed in basal part. Table Mountain flows (3) in upper part. Nonmarine.	clay, water, crushed & building stone, zeolites
		Laramie	500-1100′	Interbedded light to dark gray clays and fine-grained sandstones. Lignitic coal beds in lower part. Nonmarine.	brick clay, coal, uranium, water, decorative stone
		Fox Hills	60′	Sandstone, light gray to tan, fine- to medium-grained, friable, notable for being an aquifer. Marine.	water, bldg. stone
		Pierre	6000-8000′	Interbedded dark gray sandy shales and mudstones containing scattered lenses of fine-grained, shaly sandstones and siltstones. Marine.	bloating clay, oil
		Niobrara	330′	Smoky Hill— Shale, dark gray, highly calcareous, fossiliferous. Weathers light tan. Marine. Fort Hayes—Limestone, light gray, thin-bedded, fossiliferous. Marine.	cement materials, oil/gas
		Benton	480′	Shale, dark gray, thin-bedded, locally calcareous, particularly in middle part (Greenhorn limestone), a few large cone-in-cone concretions in lower part. Marine.	clay
		Mowry	15′	Shale, silver gray, siliceous, fish scales. Marine.	
	LOWER CRETACEOUS	Dakota	280′	Sandstone, grayish white, medium-grained, at top and bottom with intervening dark gray, carbonaceous shale, sandy mudstone, and siltstone. Lower sandstone frequently conglomeratic at base. Economically important for its water, oil, gas, and ceramic clay. Forms conspicuous hogback along the mountain front. Marine to nonmarine.	refractory clay, bldg. & dec. stone, oil/gas, silica sand, coal, water, uranium*
	JURASSIC	Morrison	270′	Claystone, light gray, greenish-gray, and pale red, containing few thin, light gray, dense limestones. Sandstones distributed throughout with thicknesses up to 5 feet. Nonmarine.	oil/gas, clay, dinosaur fossils, uranium*
		Ralston Ck.	65′	Claystone and shale, light gray to pinkish-red. Few thin beds of yellowish-tan, calcareous siltstone, occasional dense gray limestone, local well-developed gypsum beds. Nonmarine.	gypsum
PALEOZOIC	PERMIAN	Lykins	400′	Siltstone and sandy mudstone, red. Two thinly laminated pinkish-gray limestones in lower part.	limestone, gypsum, clay
		Lyons	120′	Sandstone, light gray to white, medium-grained, relatively soft, locally conglomeratic. Sometimes conspicuously cross-bedded.	dimension stone, water, oil/gas
	PENNSYLVANIAN	Fountain	1060′	Sandstone and conglomerate, red, containing discontinuous streaks of red sandy shale, mudstone, and siltstone. Nonmarine. Upturned edges weather into conspicuous topographic features. Well displayed in the Park of the Red Rocks.	decorative stone, clay
PRECAMBRIAN				Banded gneiss intruded by granite masses and pegmatites.	base/precious metals, uranium, pegmatites, crushed & dec. stone, titanium*

from Haun, 1960

* reported occurrence


6 Lyons
5 Martin Marietta
ROUTE A
ROUTE B
Lyons
Steamboat Mtn
Indian Lookout
Dowe Flats
Rabbit Mtn
Hogback
Filtration Plant
Water
Table Top Mtn
Highland No 2 Reservoir
Knoth Res
Crystal Lake
Terry Lake
Divide Res
Highland
Clark Res
Burch Lake
McIntosh Lake
Hygiene
Longmont
Municipal Airport
Calkins Lake
Highland Lake
Mead
Radio Tower
Mulligan Res
Foster Res
Sanborn Res
Kirkland
Liberty
Foothills Res
Trevarton Res
Davis Res
Clover Basin Res
Lykins Gulch
Table Mountain Antenna Field Site
Bohn Lake
Swede Lakes
Lagerman Res
Left Hand Res
Altona
Dry Creek
Left Hand Creek
Dominion
Mahaffey
Sewage Disp
Gaynor Lake
Pleasant View Ridge
Idaho Creek
Jresum
Haystack Mtn
Golf Course
Left Hand Valley Reservoir
Niwot
Dodd Res
Electronic Mfg Plant
Radio Tower
Panama Res No 1
Erie Mine
Boulder Reservoir
Radio Telescope
Mesa Res
Sixmile Res
Country Club
Twin L
Gun Barrel Hill
Bluff
The White Rocks
Boulder Creek
Canfield
Leyner
Liggett
Erie
Plumbs
Puritan
State Coal Mine Junction
National
Drag Strip
Hayden Lake
Municipal Airport
Valmont
Canyon
Sewage Disp
Thomas Res
Filtration
Lower Boulder Ditch
Colorado and Southern
Union Pacific
Burlington Northern
Great Western
Boulder and Weld Co Ditch
Rough and Ready Ditch
Supply Ditch
Oligarchy Ditch
Liggett Ditch
Holland Ditch
Dailey Ditch
Plumb Ditch
Sullivan Ditch
Goodling Ditch
Cottonwood Ditch
Spring Gulch
North 75th St
North 95th St
North 119th St
North 63rd St
T 3 N
T 2 N
T 1 N


4 Western Paving/Brannan
7B Coors
7A Denver B & P
Holiday Inn
3 Parfet
1 Burroughs
2 Cooley
N
0 1 2 3 4 5
MILES