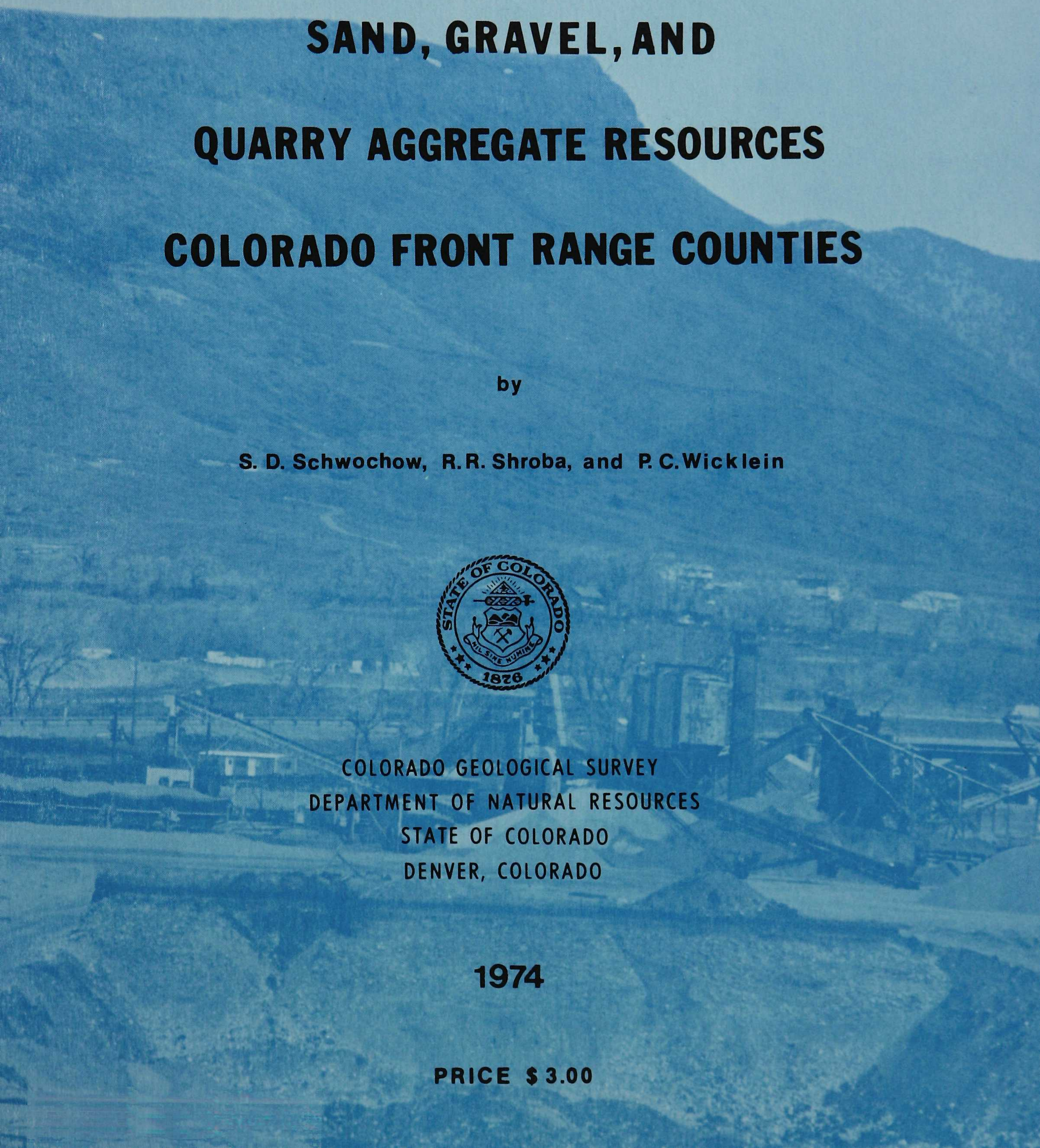

SPECIAL PUBLICATION 5-A

SAND, GRAVEL, AND QUARRY AGGREGATE RESOURCES COLORADO FRONT RANGE COUNTIES

by

S. D. Schwochow, R. R. Shroba, and P. C. Wicklein

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

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1974

Post Office Box 2645
Denver, Colorado 80201
June 30, 1974

LETTER OF TRANSMITTAL

Mr. John W. Rold
State Geologist and Director
Colorado Geological Survey
1845 Sherman Street
Denver, Colorado 80203

Subject: Completion of the report "SAND, GRAVEL, AND QUARRY AGGREGATE RESOURCES, COLORADO FRONT RANGE COUNTIES."

Dear. Mr. Rold:

This report and the 3 enclosed 1:250,000-scale resource maps are hereby transmitted to the Colorado Geological Survey by the contractor geologists, Stephen D. Schwochow, Ralph R. Shroba, and Phillip C. Wicklein, as authorized by the 1973 Colorado House Bill 1529. The contract was administered by Mr. A. L. Hornbaker, Mineral Deposits Geologist, Colorado Geological Survey. The maps in this report were compiled from the 212 maps in Special Publication 5-B, "Atlas of Sand, Gravel, and Quarry Aggregate Resources, Colorado Front Range Counties," by S. D. Schwochow, R. R. Shroba, and Phillip C. Wicklein.

Sincerely,

Phillip C. Wicklein

Phillip C. Wicklein
Project Consultant

Stephen D. Schwochow

Stephen D. Schwochow
Consultant

Ralph R. Shroba

Ralph R. Shroba
Consultant

PCW/psb

PREFACE

This report is in direct response to the charge given to the Colorado Geological Survey by H.B. 1529 to make a study of sand, gravel, and quarry aggregate deposits in the populous counties, including maps that may be generally circulated. The maps and accompanying text are designed to serve as aids to city and county planning commissions in studying the location of commercial mineral deposits and in developing master plans for the extraction of such deposits, consistent with the overall land-use plan and incorporating the multiple sequential land-use concept.

The report on sand, gravel and aggregate resources, phase 1 of H.B. 1529, is only a prelude to phase 2, the development of the master plan. Ideally, there should be continued input from the Colorado Geological Survey to the planning commissions concerning interpretation of map data and recommendations related to aggregate demand projections, future resource areas, and mineral economics. Unfortunately, adequate staffing for such input is not presently available.

The Survey will prepare, with input from various disciplines including the planning commissions, guide lines that should be considered in developing the master plans for extraction. Liaison among neighboring counties and regional councils of government is essential to resolve problems of regional and mutual concern.

A.L. Hornbaker
Mineral Deposits Geologist
Colorado Geological Survey

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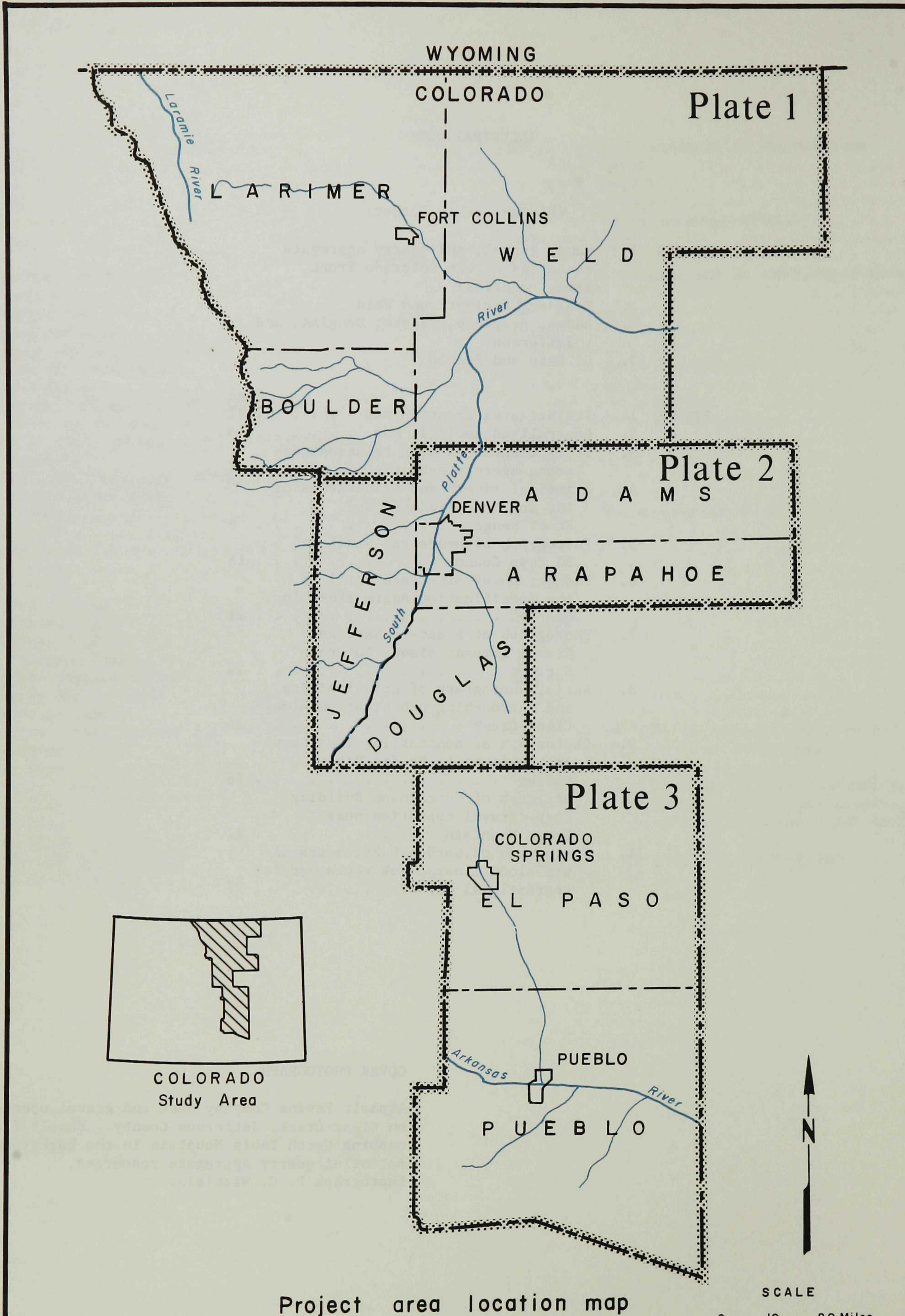
ILLUSTRATIONS

(Plates are in pocket)

COVER PHOTOGRAPH

Asphalt Paving Company sand and gravel operation on Clear Creek, Jefferson County. Basalt flows capping North Table Mountain in the background are potential quarry aggregate resources. Photograph P. C. Wicklein.



Project area location map

Figure 1

SUMMARY AND CONCLUSIONS

Sand and gravel deposits in the Front Range counties are associated with alluvial-fan, upland-mesa, dune, valley-fill, stream-terrace, and flood-plain landforms. Deposits of clean sand and gravel lie in flood plains and stream terraces along the South Platte and Arkansas Rivers and their principal tributaries. These flood-plain and terrace deposits generally are mined for concrete and asphalt aggregates. Upland gravels and alluvial fans, normally sources of road base and fill material, are located along present stream courses, interstream divides, and the mountain front, and contain significant amounts of incompetent rock, calcium carbonate (caliche), silt, and clay.

Most quarry aggregate is produced in the mountains of western Jefferson and El Paso Counties and consumed in metropolitan Denver and Colorado Springs. These Metropolitan growth areas will probably continue to use even more crushed rock in the future.

Adams, Boulder, El Paso, Jefferson, Larimer, Pueblo, and Weld Counties have sufficient reserves of sand, gravel, or quarry aggregate at present to meet future needs, but all these counties experience problems in integrating aggregate production with other land uses. The continual loss of aggregate resources by urbanization is the principal cause for problems in mineral conservation in these counties.

Arapahoe, Denver, and Douglas Counties do not have significant reserves of gravel or quarry aggregate. Most of the aggregate they consume will come from outside these counties.

Sand and gravel are basic to the construction of our homes, schools, hospitals, churches, shopping centers, streets and highways, airfields, and bridges. In addition, sand and gravel play an important role in the areas of sewage treatment, water pollution and filtration, agriculture, landscaping, transportation, manufacturing, recreation, and petroleum production. We, the consumers, cannot take for granted that our supplies of these materials are inexhaustible. The input of technical, governmental, and environmental groups is required to establish a workable master plan that will conserve adequate supplies of aggregate to meet future demands.

INTRODUCTION

Authorization

This study was authorized by article 36 of chapter 92, C. R. S. 1963, known as the "Colorado Open Mining Land Reclamation Act." Article 36 provides:

> *"92-36-3. Geological survey to make study. After July 1, 1973, the Colorado geological survey shall contract for a study of the commercial mineral deposits in the populous counties of the state in order to identify and locate such deposits. Such study shall be of sand, gravel, and quarry aggregate, and shall be completed on or before July 1, 1974, and shall include a map or maps of the state showing such commercial mineral deposits, copies of which may be generally circulated. Any commercial mineral deposits discovered subsequent to July 1, 1974, may be, upon discovery, included in such study."*

Purpose and Scope

The purpose of this report is to provide the populous Colorado Front Range counties with regional resource maps and an explanatory text to be used with 1:24,000-scale sand, gravel, and quarry aggregate land-use maps.

This part of the study was started on September 4, 1973, and completed June 28, 1974. The study area of approximately 16,000 sq mi includes Adams, Arapahoe, Boulder, Denver, Douglas, El Paso, Jefferson, Larimer, Pueblo, and Weld Counties (Fig. 1).

Previous and Present Studies

In 1961, the Inter-County Regional Planning Commission, now Denver Regional Council of Governments, published a drainage-course plan for the Denver Region that discussed future sand and gravel requirements of the area, conservation of sand and gravel, and the economics of transportation. Sheridan (1967) reported the impact of urbanization and outlined many problems of the aggregate industry in Denver. Several Colorado Water Conservation Board Basic-Data Reports and university theses are valuable information sources for parts of the study area.

The U. S. Geological Survey has prepared many water-supply papers and geologic maps within the study area over the past century. Varnes and Larrabee mapped the sand and gravel deposits of Colorado in 1946 at a scale of 1:500,000. Colton and Fitch (1974, in press), and Trimble and Fitch (1974a, 1974b, in press) show the distribution of gravel and crushed-rock aggregate in the Front Range Urban Corridor on 1:100,000-scale topographic maps. A report by J. M. Soule (1974, in preparation) analyzes the economics of aggregates in relation to transportation and urbanization in the Front Range Urban Corridor. The U. S. Geological Survey gravel maps and economic report are being prepared in cooperation with, and are financed in part by the Colorado Geological Survey. W. P. Rogers and D. C. Shelton are presently preparing an aggregate resource map as part of a Colorado Geological Survey land-use study for the Fort Collins-Loveland-Greeley area, Weld and Larimer Counties, Colorado.

Method and Techniques

On the basis of interviews with several sand and gravel producers and with the staff members of the Colorado Geological Survey, the authors decided that:

1. The sand and gravel resources mapping should be primarily geologic so that the work will remain current and useful over any time period.

2. The study should include the mapping of every landform with which significant amounts of aggregate are associated.
3. The deposits shown on the maps should be designated according to land form and the quality of the aggregate.
4. The quality designations should be independent of the location of the deposit.
5. Maps should be designed in such a way that they may be used both as geologic maps and as resource quality maps.
6. Maps should be prepared at one scale for planning and at another scale so that a county or region may be presented on a single map.
7. A text should be prepared that discusses the geology of sand, gravel, and quarry aggregates; the deposits in their geologic setting; and the distribution and nature of deposits within each county.

Photogeologic methods are well suited to the identification and inventory of landforms associated with aggregate deposits. Landforms and their associated aggregate deposits are easily identified on air photographs, and extremely large areas may be evaluated over a very short period of time. Landforms such as flood plains, valley fills, stream terraces, upland mesas, alluvial fans, and sand dunes were identified on aerial photographs and their outlines transferred onto 1:24,000-scale 7½-min quadrangle base maps. Field observations and supplemental data were printed directly on maps. Photogeologic base maps were field checked and individual landforms were evaluated for associated aggregate.

Each landform type shown on the maps is marked with an appropriate letter. Upland landforms are marked with a *U*, alluvial fans with an *A*, flood plains with an *F*, stream terraces with a *T*, valley fills with a *V*, and wind-blown sand dunes with an *E*. Numbers following the landform letter designation indicate aggregate quality. Clean, sound, coarse gravel deposits are marked with the number *1*. Coarse gravel deposits containing significant amounts of incompetent rock, silt, clay, and calcium carbonate (caliche) are marked with the number *2*. The fine-aggregate sand deposits are marked with the number *3*, and unevaluated aggregate deposits with the number *4*.

In developing the numbered quality grading system used in our explanations, representatives from several large sand and gravel companies were interviewed and asked to define the current physical and economic limits of commercial sand and gravel deposits. Although opinions differ among the companies, and all the factors affecting commerciality were not considered, we utilized the following general criteria for identifying commercial deposits:
1. Five-acre tracts with at least 15 ft of gravel can be considered to be economic.
2. The maximum stripping ratio for commercial valley deposits approaches one unit of overburden for each three units of resource (1:3).
3. The maximum stripping ratio for terrace and upland deposits can be one to one (1:1).
4. Large tracts of high-quality aggregate without overburden may be as little as 2 ft thick and still constitute a commercial deposit.
5. Commercial gravel deposits should contain a minimum of 30 percent gravel-size material by weight.

The above factors are intended only as guidelines and do not represent the only standards used to determine commercial mineral deposits as defined in section 92-36-2, C. R. S. 1963.

All Front Range aggregate deposits are potentially commercial. Commerciality of a deposit depends upon the supply, location, and demand for the aggregate, as well as existing and intended land use, population distribution, and road maintenance requirements. For example, an upland gravel deposit with a high concentration of calcium carbonate (caliche) may not be commercial to a producer of concrete aggregate but quite desirable for use as road-base material by the county highway department in areas of highly expansive soils. Likewise, a sand dune field covering several hundred square miles is not commercial over the entire area but may be a valuable source of material for local highway construction. Commerciality of deposits may change with time, zoning, and urban growth patterns. Therefore, we have mapped all the potential aggregate resources along the Front Range and graded individual deposits so that each county can select those principal resources required for the future.

Only areas with the geologically most suitable rock for quarry aggregate are shown on field maps. Although operating stone quarries lie within these potential resource areas, some quarries operate in areas of less suitable rock for economic or environmental reasons.

Two hundred ten of the 271 quadrangles examined for aggregate resource were prepared and distributed as basic-data resource maps to the planning commissions of the appropriate cities and counties. These maps are available from the respective counties or the Colorado Geological Survey. The enclosed 1:250,000-scale resource maps (Plates 1, 2, and 3) were compiled from the basic-data maps.

To supplement well data in the Lone Tree Creek and Big Thompson River valleys, 37 holes were drilled in cooperation with the Colorado Geological Survey's Windsor Environmental Geology Project during January 1974. The drill was a truck-mounted 4-in. auger. Samples were examined and logs written on the drill site. Drilling data appear on the basic-data resource maps.

The boundaries of deposits that are shown on the 1:24,000-scale basic-data maps are subject to change. Any deposits discovered subsequently to July 1, 1974, may be included in this study (section 92-36-3, C. R. S. 1963). As additional data becomes available, some deposits may be proved to be noncommercial. In such cases, boundaries can be changed on the original Colorado Geological Survey maps.

Acknowledgments

The authors are indebted to several persons and organizations without whose help this report could not have been completed.

Robert H. Gast supervised the graphics, reproduction, and publishing phases of this report. His suggestion of a desk-size atlas and his continuing attention to details, methods, and costs were instrumental in completing the project on schedule and within budget limitations.

The Colorado Geological Survey staff advised, assisted, and encouraged the authors throughout the study. Mr. A. L. Hornbaker, Mineral Deposits Geologist, administered the contract and advised in the preparation of the report. Mr. D. C. Shelton provided valuable information about the aggregate resources of the Cache la Poudre River valley. John W. Rold, Colorado State Geologist, and D. K. Murray, Mineral Fuels Geologist, critically reviewed the manuscript. Susan H. Allen and Pamela Sue Bryarly typed the manuscript.

We are particularly indebted to Wallace R. Hansen, the Front Range Urban Corridor Project staff, Messrs. Glenn R. Scott, Norman M. Denson, Bruce Bryant, and Edward T. Ruppel of the U. S. Geological Survey for technical data and consultations.

The Colorado Division of Highways, the Colorado Division of Mines, the Colorado Division of Water Resources, and the Colorado Land Use Commission provided us with services and pertinent data on sand and gravel quality, location, and thickness.

Personnel from all the Front Range Counties and Regional Councils of Governments provided suggestions and data helpful to this study.

The following companies aided our study by reviewing our mapping and answering questions about deposits, economics, and production: Asphalt Paving Company, Golden; Barker Sand and Gravel Company, Fort Collins; Brannan Sand and Gravel Company, Denver; Broderick and Gibbons, Inc., Colorado Springs; Castle Concrete Company, Colorado Springs; Certified Concrete Company, Pueblo; Cherry Creek Sand Specialties Company, Denver; Colorado Lien Company, Livermore; Consolidated Rock, Inc., Denver; Cooley Gravel Company, Arvada; Daniels Sand Division of the Transit Mix Concrete Company, Colorado Springs; Flatirons Gravel Company, Boulder, Fort Collins, and Greeley; Fountain Sand and Gravel Company, Colorado Springs and Pueblo; Golden Gravel Company, Longmont; Greeley Sand and Gravel Company, Greeley; Mobile Pre-Mix Sand and Gravel Company, Commerce City; Mountain Aggregates, Inc., Platteville; Platte Valley Sand and Gravel Company, Northglenn; Peter Kiewit Sons Company, Littleton; Rio Grande Company, Denver; Schmidt Construction, Inc., Colorado Springs; Specification Aggregates, Inc., Golden; Sterling Sand and Gravel Company, Fort Collins; United Minerals Corporation, Greeley; Valley Concrete Company, Rocky Ford; and Western Paving Construction Company, Denver.

A special committee composed of producers, planners, consultants, and interested citizens was established to advise the authors on land-use planning, zoning, reclamation, and production problems. The individual members of this committee will also be concerned with implementing article 36 of chapter 92, C. R. S. 1963 at the county and local level after July 1, 1974. Members of this committee are: Al Abner, Pueblo Regional Planning Commission; Earl Brubaker, Certified Concrete; Jim Cooley, Cooley Gravel Company; Gene Fisher, Pueblo City Planning; Gary Fortner, Weld County Planning Commission; Celia Fuller, Pueblo Regional Planning Commission; Mac Graham Jr., Western Paving Construction Company; Bruce Hanna, Flatirons Gravel Company; Tim Heins, Denver Regional Council of Governments; Merle Hoeft, Adams County Planning Dept.; John Ivey, Amuedo and Ivey; Dave Klotz, Denver Regional Council of Governments; Burman Lorenson, Weld County Planning; State Representative Larry O'Brian, a consulting geologist and principal author of House Bill 1529; Vince Porreca, Boulder County Planning; John Sawyer, Colorado Springs Transit Mix; Patrick Skinner, Pikes Peak Area Council of Governments; Tom Sundaram, El Paso County Planning Department; Bob Wolf, Western Paving; Fred Woodring, Managing Director of the Colorado Sand and Gravel Producers Association; and Fran Yehle and Annelou Neunzert, Jeffco Gravel Committee.

We are grateful to Tom Gray, Colorado Division of Highways District Geologist at Pueblo; and Messrs. James Martin and A. W. Rueff, Missouri Geological Survey, for many valuable suggestions during the planning stage of the study.

PHYSIOGRAPHY AND GEOLOGY OF THE COLORADO FRONT RANGE COUNTIES

The project area encompasses approximately 16,000 sq mi of mountains, foothills, and plains in east-central Colorado and lies within the Southern Rocky Mountains and Great Plains physiographic provinces. The major streams draining the region are the South Platte, Arkansas, and Laramie Rivers (Fig. 1).

The Front Range, which is the easternmost mountain range in Colorado, extends from the Arkansas River northward into Wyoming, where it is known as the Laramie Range. In the Colorado Springs area the name Rampart Range often is applied. Most of the Front Range reaches over 7,000 ft in elevation, with numerous rugged peaks over 12,000 ft high. Many of the higher valleys and peaks in the northern portion of the Front Range were extensively modified by intense alpine glaciation during the Quaternary (Thornbury, 1967). (Refer to the generalized geologic time scale at the end of this section.)

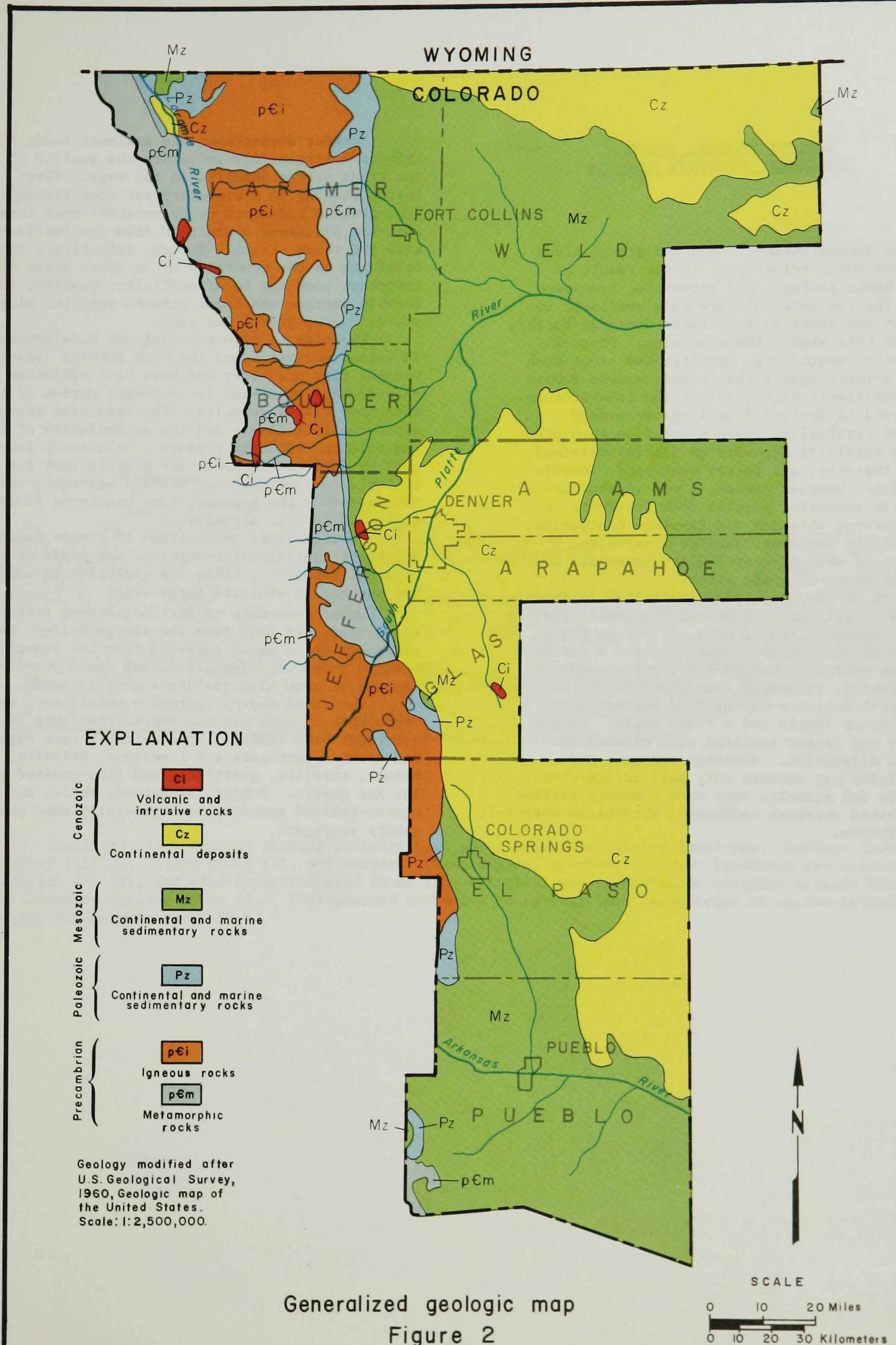
The core of the Front Range consists of Precambrian meta-sedimentary and layered meta-igneous crystalline rocks that include gneiss, schist, and quartzite; these, in turn, have been intruded by a series of massive granite plutons and smaller Tertiary intrusive bodies of varying composition (Lovering and Goddard, 1950). Draped over these basement rocks are the steeply eastward-dipping sandstones, shales, and limestones of Paleozoic and Mesozoic ages that form the north-south trending foothills belt (Fig. 2).

The Great Plains east of the hogbacks can be divided into 3 regions: 1) the Colorado Piedmont, 2) the interstream uplands between the South Platte and Arkansas Rivers, and 3) the High Plains along the Wyoming border. These regions range in elevation from about 4,300 ft along the broad Arkansas River Valley at Fowler to about 5,500 ft, where the gravel-capped pediments abut against the foothills, to over 7,500 ft in the Black Forest area near Colorado Springs. The region east of the mountain front once was mantled by an extensive Tertiary alluvial plain that blanketed the entire Great Plains area. In the Colorado Piedmont this thick sedimentary cover has been removed by the action of the South Platte and Arkansas River systems, exposing vast areas of Upper Cretaceous (latest Mesozoic) shale, claystone, and interbedded sandstone and limestone. North of this area the Tertiary cover remains beneath the High Plains surface. Gently sloping late Tertiary formations of sand and gravel, sandstone, clay and siltstone crop out along the prominent escarpment that separates the Colorado Piedmont from the High Plains (Weist, 1965).

The bedrock within the interstream area between the South Platte and Arkansas Rivers consists of a thick sequence of early Tertiary sediments that range from claystone to coarse-grained arkose and conglomerate; extrusive volcanic rocks occur in the vicinity of Castle Rock.

During the Quaternary, surficial processes related to stream erosion and deposition, glaciation, slope movement, and wind action produced a wide variety of deposits that include moraines, outwash terraces, talus, and colluvium in the mountains and flood plains, terraces, pediment gravels, colluvium, dune sand, and loess in the plains region.

Millions of years ago	Era	Period
2	Cenozoic	Quaternary
		Tertiary
70	Mesozoic	
225	Paleozoic	
570	Precambrian	



Generalized geologic map
Figure 2

GEOLOGY OF SAND, GRAVEL, AND QUARRY AGGREGATE DEPOSITS

The accumulation of sand and gravel along rivers and their tributaries is the result of several basic geologic and geomorphic processes. Most of the raw materials are made available to rivers in the upper part of their drainage basins, or, as in this study, the mountains. Physical and chemical weathering, gravity, and slope wash are the primary agents that supply coarse debris to the relatively high-gradient mountain streams. This debris is derived from large fractured masses of crystalline bedrock and from such preexisting surficial deposits as glacial moraines, outwash terraces, and deeply weathered, loosely consolidated bedrock masses. Once in the narrow stream channels, angular rock fragments or clasts undergo abrasion and in-place weathering, which lead to rounding, smaller clast size, breakdown of weak or poor-quality material, and a greater range of grain sizes.

Much of the coarser sediment load is deposited as alluvial fans and upland (pediment) gravels near the mountain front, (Fig. 3), where the lowering of the stream gradient causes a decrease in stream energy. Through time, valley widening and deepening, reworking and deposition of the valley-fill deposits may produce successively lower terrace levels and a flood plain. Upland deposits may become isolated with renewed erosion and dissection. Although terraces and flood plains may contain only well sorted channel sands and gravels, they more commonly include fine-grained overbank sediments, wind-blown material, and colluvium.

Farther downstream, the sediment loads of tributary streams may influence the quality of the trunk stream deposits in two ways. First, tributaries heading in sedimentary terranes transport fine-grained sediments or incompetent rock fragments that are dispersed downstream from the confluence with the trunk stream. Second, tributaries that originate in the mountains or in other areas of competent rock may be of sufficient gradient to locally upgrade the trunk streams deposits with sound, coarse gravel and sand.

The effects of weathering are more pronounced in upland sediments and the high terrace deposits because they are older and have been subjected to soil-forming processes for a longer period of time than most valley deposits. The resulting decomposition of rock clasts and the accumulation of fines and calcium carbonate produce a relatively low-quality aggregate. Sands and gravels that are more suitable for concrete and asphalt aggregate can be obtained from the younger, less weathered flood-plain and terrace deposits.

Photogeologic recognition of simple landforms and their spatial relationships, and study of their physical appearance allow the geologist to rapidly and accurately evaluate large areas.

Under favorable conditions, strong prevailing winds transport sand from the stream valleys and redeposit it as dunes downwind from the source. Locally these wind-deposited sand dunes provide sources of some high-quality specialty sands.

The ideal quarry aggregate should be a sound, tough rock of such mineral composition that it will not react with cement. Some suitable rock types for crushed aggregate are limestone, dolomite, basalt, rhyolite, quartzite, and fine-grained granite and gneiss. Schist, sandstone, shale, and coarse-grained granitic rock generally make poor quarry aggregate.

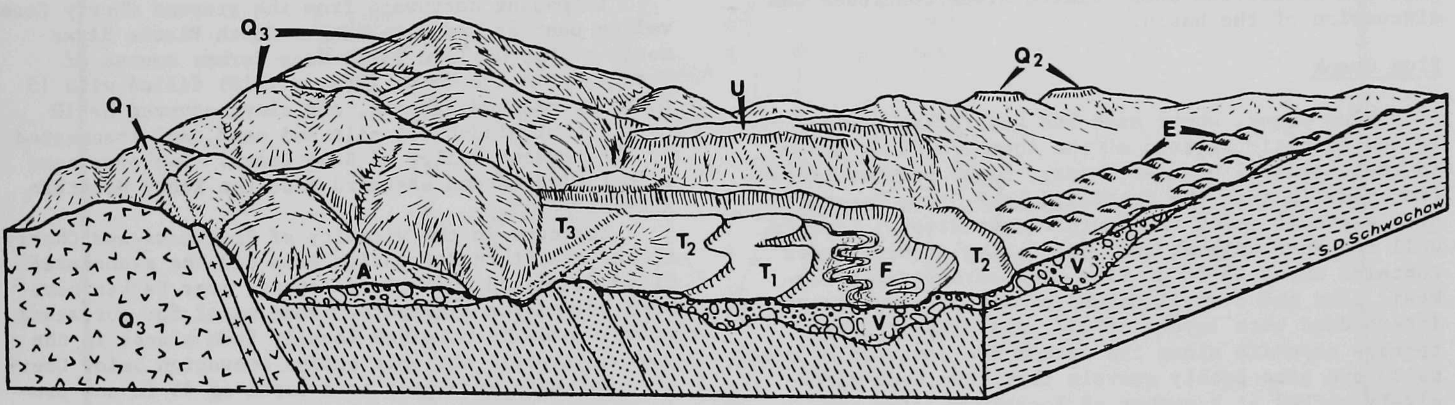


Figure 3. Idealized block diagram showing relationships among aggregate-bearing landforms. Lowland forms include valley fill (V), flood plain (F), and terraces (T_1-youngest; T_3-oldest). Other landforms are upland gravels (U), alluvial fan (A), and wind-deposited sand dunes (E). Potential quarry-aggregate deposits include fine-grained intrusive igneous rocks (Q_1), fine-grained extrusive rocks (Q_2), and large areas of coarse-grained igneous and metamorphie rocks (Q_3).

SAND AND GRAVEL RESOURCES OF THE SOUTH PLATTE RIVER BASIN

The South Platte River Basin includes those parts of Weld, Larimer, Boulder, Denver, Adams, Arapahoe, Jefferson, and Douglas Counties drained by the South Platte River and its tributaries. The principal tributaries of the South Platte River within the study area are, from the headwaters downstream, Plum Creek, Bear Creek, Cherry Creek, Sand Creek, Clear Creek, St. Vrain Creek, Big Thompson River, Cache la Poudre River, Lone Tree Creek, Beebe Draw, Crow Creek, Box Elder Creek, Lost Creek, Kiowa Creek, Bijou Creek, Pawnee Creek, and Cedar Creek (Fig. 4). The sand and gravel deposits within each principal tributary drainage are discussed starting with Plum Creek and progressing down the South Platte River. A discussion of sand and gravel deposits associated with the mainstream South Platte River concludes the discussion of the basin.

Plum Creek

Plum Creek, whose east and west branches head in the granitic terrain of the southern Front Range in south-central Douglas County, flows northwestward from Sedalia into the Chatfield Lake State Recreation Area where it joins the South Platte River. Limited well log data suggest that the valley of Plum Creek contains about 45 ft of fine- to coarse-grained arkosic sand and a small amount of fine-grained gravel interbedded with layers of silt and clay. Thick terrace deposits along the stream are composed of clean sands and some pebbly gravels that have been extensively worked at a number of locations. The substantial amount of fines in the upland deposits west of Plum Creek will limit their potential uses to subbase and road metal for local use.

Bear Creek

Bear Creek, which heads in the mountains of Clear Creek County, flows eastward through Jefferson County and emerges from the foothills at Morrison. It continues eastward and joins the South Platte River at Sheridan, a southwest Denver suburb. East of the hogbacks at Morrison, Bear Creek is joined by Turkey Creek, another stream heading in the mountains to the southwest.

On the south side of the valley downstream from Mount Carbon are several long, narrow remnants of terrace deposits of marginal quality probably not exceeding 12 ft in thickness. Equivalent terraces lying north of the creek upstream from Mount Carbon contain excellent pebbly gravels but with significant fines. The low terrace between Bear Creek and Turkey Creek also contains about 10 ft of cobbly and bouldery gravel. Mount Carbon is an old high remnant of Bear Creek gravels and interbedded sands more than 15 ft thick. The flood-plain and valley-fill deposits contain 8 to 36 ft of good quality gravels.

Except for several inactive operations on the Bear Creek flood plain in Lakewood, most of the gravel pits are located on the terrace edges between the hogbacks and Mount Carbon. Gravel from most of these pits has been used as concrete aggregate.

Cherry Creek

Cherry Creek, whose upper tributaries head in the Black Forest region of El Paso County, flows northward past Franktown and northwestward into Denver where it joins the South Platte River. The Dawson Arkose crops out extensively in the drainage basin and constitutes the main source of sediment carried by the stream. The valley of Cherry Creek between Franktown and Cherry Creek Lake State Recreation Area contains 35 to 50 ft of fine- to coarse-grained arkosic sand and a small amount of fine-grained gravel all overlain by 10 to 15 ft of nonresource. Below Cherry Creek Lake State Recreation Area, the valley fill is reported to contain 20 to 90 ft of sand and gravel. Although only sand has been extracted in this area, well logs indicate that some gravels occur at depth.

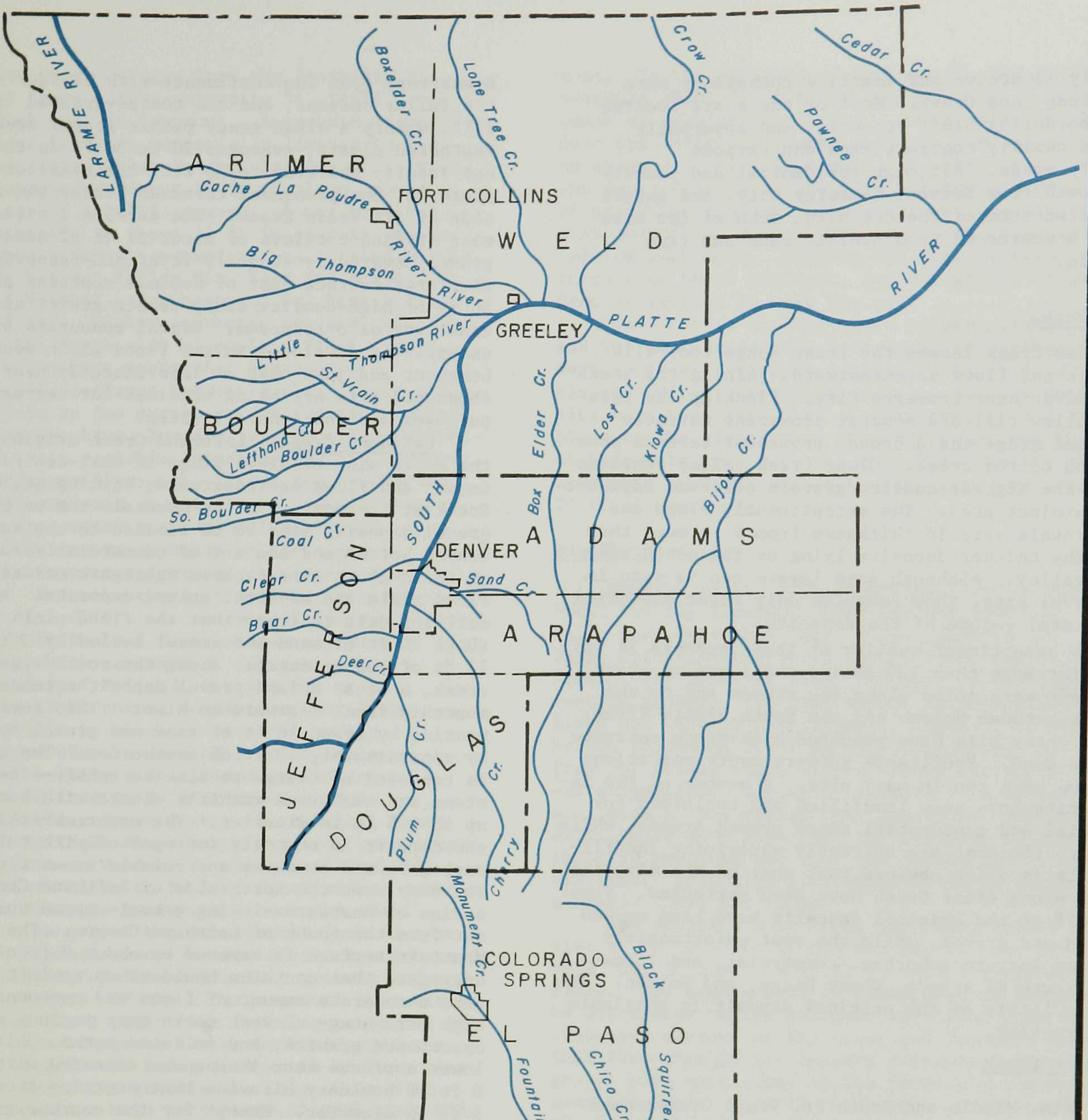
Extending northward from the present Cherry Creek valley east of Glendale to the South Platte River north of Dupont is a 90-ft-deep former course of Cherry Creek (De Voto, 1968, p. 118) filled with 15 to 80 ft of sand, gravel, and clay, covered by 10 to 40 ft of wind-blown silt and sand, and transected by the present valley of Sand Creek. Two prominent tributaries extend eastward into the Rocky Mountain Arsenal.

Terraces in the vicinity of Franktown and Cherry Creek Lake State Recreation Area and the associated flood plain and one upland deposit near Parker have been worked for aggregate. Road metal for surfacing gravel roads is obtained locally from places in the Dawson Arkose. The only active operation below Cherry Creek Lake excavates to a depth of 45 ft and produces high quality concrete sand and a variety of specialty sands used for plastering, filtration, sandblasting, stucco, and golf course trap sand. Along Cherry Creek, at University Boulevard in Denver, a large site that had been mined for sand and subsequently used as a sanitary landfill now supports Cherry Creek Shopping Center. Another reclaimed sand pit on Leetsdale Drive at Quebec Street now supports new condominiums.

Generally recognized as an excellent source of sand, the Cherry Creek valley in Denver County has been completely lost to urbanization, and that part of the valley in Arapahoe County below Cherry Creek Dam is rapidly undergoing residential development.

Sand Creek

Several miles east of Aurora, in Arapahoe County, Coal Creek and Murphy Creek join to form Sand Creek, which flows northwestward and joins the South Platte River at Commerce City northeast of Denver. The prominent bluffs bordering the valleyfill on the south contain more than 35 ft of relatively clean sands with some interbedded gravel lenses. The flood-plain and valley-fill deposits contain from 12 to more than 25 ft of sand and gravel. Extending from Lowry Air Force Base north to Stapleton Airport is a former tributary valley of Sand Creek filled with 8 to 23 ft of sand and gravel and buried by 8 to 30 ft of wind-blown sand and silt.



Principal Rivers and Tributaries of the Colorado Piedmont and Front Range

Figure 4

Only 13 active and inactive operations were noted along Sand Creek. Most of these are located in the bordering bluff deposits, and apparently produced quality concrete sand and various specialty sands. Although residential and industrail growth from Denver, Commerce City, and Aurora has covered some of the deposits, much of the area remains a source of good quality sand and fine aggregate.

Clear Creek

Clear Creek leaves the Front Range foothills at Golden and flows northeastward, joining the South Platte River near Commerce City. Flanking the principal valley fill are several prominent terraces near Wheat Ridge and a broad, prominent terrace near the mouth of the creek. Clear Creek valley contains some of the highest quality gravels observed anywhere in the project area. The exceptionally clean and sound gravels vary in thickness from 8 to more than 30 ft, the thicker deposits lying on the north side of the valley. Although sand layers can be seen in many gravel pits, they comprise only about one-third of the total volume of the deposits.

The exceptional quality of these gravels is well known, for more than 120 active and inactive gravel operations were noted along the stream and on the terraces between Golden and the South Platte River. Most of these pits have produced high-grade concrete rock and sand. Profitable gold-recovery operations also have been run in many pits. A number of the inactive pits have been landfilled and reclaimed for commercial and residential sites around Arvada, while others to the east are currently undergoing landfilling. It is quite obvious that most of the mineable gravels along Clear Creek have been extracted. Fewer than half of the original deposits have been worked for sand and gravel, while the rest unfortunately have been lost to suburban, commercial, and industrial growth in Arvada, Wheat Ridge, and Golden. Today very little of the original deposit is available for extraction.

St. Vrain Creek

North, Middle and South St. Vrain Creeks head in a series of small lakes along the Continental Divide in northwestern Boulder County. These streams merge to become St. Vrain Creek, which flows eastward toward its confluence with the South Platte River about 4 miles northwest of Platteville.

Alpine glaciation in the upper reaches of St. Vrain Creek provided the material that was reworked by running water and deposited as terrace gravels along the main tributaries in the vicinity of Riverside, Allens Park, and Peaceful Valley. The gravels downstream near Lyons were derived from glaciated and non-glaciated terranes. All the above deposits tend to be from one to several miles in length and are composed of high quality coarse aggregate derived from granitic and gneissic bedrock. The flood plain of St. Vrain Creek from Lyons to the junction with Boulder Creek contains about 12 ft of unweathered granitic pebbles and cobbles in a matrix of clean sand. Overburden thickness is about 1 or 2 ft. Downstream from the confluence with Boulder Creek, the valley deepens, and the coarse-grained alluvial fill, mainly a clean sandy pebble gravel free of weathered clasts, averages 20 to 30 ft in thickness but locally thickens to 50 ft. Northeast of Interstate 25, two prominent terraces border the east side of St. Vrain Creek. The terrace 2 miles northeast of Rinn consists of about 27 ft of sand and gravel covered by about 19 ft of non-resource, and the large terrace east of Gowanda contains about 50 ft of high-quality, sandy pebble gravel and several feet of overburden. Gravel resources have been extensively developed in the flood plain south of Longmont and just west of Interstate 25 near Rinn. Abandoned pits are being utilized for recreational purposes and for landfill sites.

Lefthand Creek: Lefthand Creek originates along the north side of Niwot Ridge in west-central Boulder County and flows northeastward, joining St. Vrain Creek at Longmont. In the mountain region sand and gravel deposits tend to be limited to the narrow canyon bottom and are not of commercial value. East of the hogback area, coarse aggregate occurs in the flood plain and adjacent upland deposits. Available well-log data indicate that the flood plain contains about 20 ft of sand and gravel buried by 2 to 13 ft of non-resource. Along the south side of the creek, a broad upland gravel deposit extends from the mountain front eastward to Niwot. This surface is mantled by about 20 ft of sand and gravel concealed by approximately 10 ft of overburden. The gravel is composed of coarse pebble- to cobble-size sandstone and weathered granitic clasts with boulders up to 1.5 ft in diameter. The upper several feet of the deposit is strongly impregnated with calcium carbonate and contains appreciable amounts of silt and clay. On the north side of Lefthand Creek, a series of eastward-sloping gravel-capped uplands fan out from the mouth of Lefthand Canyon. The Table Mountain surface is covered by about 8 ft of coarse aggregate that contains boulders up to 1 ft in diameter, a moderate amount of fines and carbonate, and a high percentage of weak rocks that include sandstone, decomposed granite, and foliated metamorphics. The lower surfaces near Altona are veneered with about 6 ft of bouldery alluvium that contains stones up to 5 ft in diameter. Except for the coarser grain size and absence of carbonate, these deposits resemble the material on Table Mountain. Due to the limited thickness and low quality of these upland gravels, few pits have been developed. The only active operation is located at the northeastern end of Table Mountain.

Boulder Creek: Middle and North Boulder Creeks originate along the eastern slope of the Continental Divide in southwestern Boulder County. At Boulder Falls, about 6 miles northeast of Nederland, these streams join to form Boulder Creek. The valley of Middle Boulder Creek between Eldora and Nederland contains a massive deposit of outwash gravel at least 100 ft thick. This material is high quality coarse aggregate and has been commercially extracted at two localities. Significant deposits of sand and gravel along North Boulder Creek are restricted to the area near Lakewood Reservoir.

Boulder Creek emerges from the foothills at Boulder and flows northeastward to St. Vrain Creek several miles east of Longmont. Aggregate resource along Boulder Creek is essentially limited to the broad flood plain, which in the vicinity of Valmont Butte is composed of about 15 ft of clean, sound pebbly to cobbly granitic gravel. Downstream the deposit decreases to about 11 ft in average thickness. Numerous gravel operations are located on the flood plain between Valley View Road and North 75th Street near Valmont. Northeast of Gun Barrel Hill, a series of thin, highly weathered gravels caps the uplands on the north side of Boulder Creek. Only one deposit has been worked for aggregate.

The upland surfaces between Boulder Creek and Mesa Reservoir to the north are covered by alluvium derived from Sunshine, Twomile, and Fourmile Canyons. Because of their variable thickness and high percentage of sandstone fragments, fines, and decomposed granitic and gneissic clasts, these deposits are unsuitable for concrete or asphalt aggregate.

South Boulder Creek heads on the eastern slope of the Continental Divide in western Gilpin County. Near the towns of Tolland, Rollinsville, and Pine Cliff, the eastward-trending valley of South Boulder Creek widens exposing a relatively thick sequence of outwash gravels. In the vicinity of Tolland, the gravels are greater than 17 ft thick; downstream near Pine Cliff, they thin to about 10 ft. The pebbly and cobbly gravels are derived from crystalline bedrock—mainly granites and gneisses—and tend to be free of deleterious material.

South Boulder Creek leaves the mountain front at Eldorado Springs, flows northeastward, and joins Boulder Creek near Valmont Butte east of Boulder. The flood plain of South Boulder Creek widens downstream from Eldorado Springs and contains about 15 ft of coarse gravel beneath several feet of overburden. In places, minor amounts of incompetent sandstone clasts, weathered granitic gravel, and fines are present. Of the 2 large gravel operations active on the flood plain, one is being reclaimed for commercial use. Terraces lie on both sides of the creek, the largest one being just south of Base Line Reservoir. There the gravels are only about 5 ft thick and contain a high percentage of weak rock and fines. Upland gravels similar to those on Davidson Mesa are very thin and of low quality, although some have been worked in the past for base-course in local road construction.

Coal Creek originates in the mountainous terrane of northwestern Jefferson County and flows northward, joining Boulder Creek just north of Erie. In the mountain region, deposits of sand and gravel are restricted to the very narrow valley bottom. Downstream of the hogback region the valley widens, and the creek is flanked by a variety of stream-lain material which include the flood plain, terraces, upland gravels, and alluvial fans.

At the mouth of Coal Creek Canyon, an extensive alluvial fan-like deposit known as Rocky Flats mantles an area of at least 15 sq mi. This alluvium is thickest and coarsest near the apex of the fan and becomes thinner and finer-grained toward the east. In the vicinity of Highway 93, the gravel averages about 15 ft thick and contains an abundance of cobble-size clasts. Seven miles to the east, near the Jefferson County Airport, the deposit thins to about 5 ft of pebbly material. The deposits that cap Rocky Flats and Lake Mesa consist almost entirely of unweathered quartzite gravel, but contain significant amounts of fines, and, in places, considerable calcium carbonate. Despite the vast reserve of aggregate on these surfaces, current gravel extraction is limited to only one pit.

The section of Coal Creek between Highway 93 and the confluence with Rock Creek is flanked by a series of terraces that contain 10 to 15 ft of pebbly and cobbly quartzitic gravel. Several small pits have been developed on the terraces and flood plain in the vicinity of Superior. Between the towns of Lafayette and Erie, the Coal Creek valley contains less than 10 ft of aggregate buried by more than 20 ft of overburden.

Big Thompson River

Heading in the high mountains north of Estes Park, the Big Thompson River emerges from the foothills near Boedecker Lake, flows eastward past Loveland, and joins the South Platte River east of Milliken. The deposits under and east of Loveland do contain gravels, but they appear to have significant fines and caliche development. Because the overburden thickness tends to rapidly increase northward from the valley edge, only a narrow terrace strip was delineated. A similar terrace lies on the southeast side of the valley near Johnstown. Several drill holes here show that the resource is not as thick thick as expected and that the overburden is substantial. This high overburden:resource ratio will probably limit its value.

The deposits seen along the river itself consist of 10 to 20 ft of coarse, sound, granitic gravels, but in most places they contain significant fines. The high amount of fines can, in large part, be attributed to the sediment additions from such tributary streams as Dry Creek and Buckhorn Creek that flow through sedimentary terranes. About 30 gravel pits were noted in the flood-plain deposits near Loveland. Most of these pits are operated by the Flatirons Sand and Gravel Company and Loveland Ready-Mix Concrete Company. Essentially all of the material produced from these pits is used as concrete and asphalt aggregate. Just west of Interstate 25 are several inactive gravel pits now converted to recreational facilities in the Big Thompson Ponds State Wildlife Area. The flood-plain and valley-fill deposits of the Big Thompson River are obviously prime aggregate resources and should be considered for mineral conservation.

Little Thompson River: The Little Thompson River heads near Rocky Mountain National Park in Larimer County and flows out of the mountains and hogback area south of Carter Lake Reservoir. From there it flows northeastward past Berthoud and Johnstown and joins the Big Thompson River at Milliken.

The valley deposits observed at the Boulder-Larimer county line contain significant fines and abundant sedimentary rocks. Based on the poor aggregate observed here, and the fine-grained alluvium seen downstream, no commercial deposits are believed to exist east of Berthoud. However, additional drilling is needed to verify this prediction. Extending southeastward from the mouth of Little Thompson Canyon, a series of gravel-mantled uplands (including Table Top Mountain) rises high above the surrounding terrain and may represent a portion of the ancient channel of the Little Thompson River. These deposits consist of about 10 ft of pebbly and cobbly gravel containing a moderate amount of fines and weak sandstone fragments.

The terraces near the Larimer-Boulder County line also contain abundant fines and sedimentary clasts. Although 2 gravel pits were noted on one of the terraces, the poor quality of the material restricts their use to road dressing and miscellaneous fills. Gravel has been mined at 3 localities on Table Top Mountain. The upland deposits north of the river around Berthoud and on the divide south of Dry Creek do not appear to contain any commercial sand or gravel resources.

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Cache la Poudre River

The Cache la Poudre River heads on the Continental Divide in Rocky Mountain National Park and flows northward to Kinikinik, then eastward from there through the mountains and foothills where it emerges at Laporte. Flowing southeastward past Fort Collins and Windsor, the river joins the South Platte River east of Greeley. For convenience, the river basin has been divided into two portions: 1) upper, extending from the headwaters to the mountain front; and 2) lower, from the mountain front to the South Platte River.

In the mountains most of the significant flood-plain, terrace, and alluvial fan deposits lie between Spencer Heights (4 miles southwest of Kinikinik) and Indian Meadows. Several other terrace deposits occur at Kelley Flats, Fort Collins Mountain Recreation Area, Dutch George Flats, and Big Narrows Campground. Ordinarily these deposits are sound and quite coarse, consisting of granite, gneiss, and schist boulders up to 5 ft in diameter—material that would be set aside as "oversize" in gravel pits on the plains. These gravels, in places, may exceed 30 ft in thickness. The finer grained matrix is very silty but does contain significant amounts of sand. The numerous, small alluvial fans, built out onto the river terraces at the mouths of short tributary streams, consist of abundant silt, some sand, and angular cobbles and boulders.

East of Kinikinik, one large gravel pit was seen in the terrace deposits. A few small borrow pits can be seen in the alluvial fans along the river. Material from these pits probably was used for miscellaneous fills and road dressing on unpaved, secondary roads leading away from the river valley. Numerous small borrow pits have also been dug in the colluvial slopes adjacent to some of these unpaved roads. Along Colorado Highway 14 near the mouth of Joe Wright Creek, the Larimer County Highway Department is crushing bouldery colluvial and talus-slope debris and fractured bedrock for road base.

Although the flood-plain and terrace deposits in the mountains do show potential for aggregate, difficult access, mining in a narrow valley, handling oversized material, and environmental problems probably will limit most mining activities here. Alluvial fan and colluvial deposits are, at best, only suited very locally for miscellaneous fills and road dressing.

In the lower part of the river basin, the major flood-plain and valley-fill deposits consist of clean, sound, cobbly gravels and medium- to coarse-grained sands that range in thickness from 10 to 20 ft at Fort Collins to about 50 ft at Greeley. The overburden may attain a thickness of 9 ft, as at Windsor.

Three terrace levels can be distinguished north of the river between Fort Collins and Windsor. The 6-mile-long lower terrace begins near the mouth of Boxelder Creek and contains 8 to 32 ft of sand and gravels, locally cemented, and quite silty. The intermediate terrace begins near Timnath, widens near Windsor, and extends downstream to Greeley. As much as 30 ft of gravel occurs in this terrace; however, in most places the overburden is quite thick, creating an overburden:resource ratio as high as 7:1. Remnants of the highest terrace lie between Timmath and Windsor and contain about 10 ft of cobbly to bouldery gravels impregnated in the upper several feet by calcium carbonate (caliche). The quality of the sand and gravel in the low terrace over which much of Greeley is built has been influenced by the South Platte River but does contain 20 to 30 ft of clean, sound, pebbly to cobbly gravel and high-quality coarse sand. Deposits at the south end of this terrace are the result of South Platte River deposition and, therefore, contain much finer grained aggregate than the coarser northern part which is the result of Cache la Poudre deposition. Several remnants of a higher terrace, also containing very clean gravel and sands lie south of the river along a 4-mile stretch west of Greeley.

Numerous gravel pit operations were noted in the deposits in this area—33 around Fort Collins, 10 near Timnath, 6 near Windsor, and 39 at Greeley. About two-thirds of these operations are located adjacent to the river. In Fort Collins the finished products include concrete and asphalt aggregate, plaster sand, cement sand, concrete slab bedding, washed rock, base course and subbase, and decorative stone (flagstone, crushed sandstone, feldspar, and quartz sand). Pit run, crusher cleanup, and silt sand are also sold. Much of the material produced in Greeley is used for concrete and asphalt aggregate and for base course.

West of Greeley, in the thick, clean terrace gravels south of the river, are 8 gravel pits operated by the Colorado Department of Highways. To the south are 3 other pits in upland deposits of exceptionally high quality.

The flood-plain and valley-fill deposits of the lower Cache la Poudre River obviously are the prime aggregate resources in this area and definitely should be considered for mineral conservation. North of the river the lowest and highest terraces appear to be significant resources, although not of high-quality aggregate. Even though a number of pit operations are located here, it is doubtful that the gravels can be easily upgraded. The amount of fines and caliche will be significant limiting factors in their use. The deposits in the middle terrace have little likelihood of ever being worked mainly because of the thick overburden. The terraces south of the river at Greeley have great potential although, as implied above, much of the lower terrace has been lost to urbanization.

Altogether, the reserves in the lower river valley are adequate to meet the demands of the area. There is a possibility that some of the materials might be transported by unit train to such aggregate-scarce areas as Denver. The feasibility of this operation, however, will require further study.

Boxelder Creek: Boxelder Creek heads in the southern end of the Laramie Range in Colorado, flows southeastward to Fort Collins, and joins the Cache la Poudre River.

South of Gilman Mountain the stream emerges from the hogback area and has built a massive alluvial fan toward the southeast. The gravels contain significant fines, weak rocks, and, several miles downslope, a caliche. Well logs indicate that the gravels range from 30 to more than 60 ft in thickness, with overburden as great as 20 ft. Across Boxelder Creek from this fan is Rawhide Flats, probably a large alluvial fan of Rawhide Creek origin.

Along the upper reaches of Boxelder Creek are several small terrace remnants containing about 20 ft of silty sand and gravel but with abundant weak (sedimentary) clasts. Somewhat more suitable gravels lie in the high terrace north of Wellington at the confluence of Boxelder Creek and Coal Creek.

Although recorded depths and thicknesses appear erratic in the well logs in the valley north of Wellington, they reveal a rather deep canyon filled with nearly 100 ft of gravel and clay. In areas west of Wellington and north of Black Hollow Junction, the logs show 30 to 100 ft of valley-fill deposits. The overburden here, however, is so thick that these areas were excluded as potential resources.

Very few gravel pits were noted in the Boxelder Creek valley. Two pits were seen in terrace deposits—one southwest of Gilman Mountain and one operated by the Larimer County Highway Department north of Wellington. Two pits were observed on the alluvial fan west of Boxelder Creek. In the flood-plain and valley-fill deposits, one gravel pit was noted east of Buckeye, and one was noted north of Arrowhead. Although the pit near Arrowhead is shown in a Cache La Poudre terrace on the map, the deposits are characteristic Boxelder gravels.

It is unlikely that the immense alluvial fans along Boxelder Creek will be considered for more than local needs, such as road base and miscellaneous fills. The potential of the flood-plain and valley-fill deposits south of Wellington is somewhat questionable because of the thick overburden and the proximity of the high-quality gravels along the Cache La Poudre River near Fort Collins.

Lone Tree Creek and the High Plains

Lone Tree Creek heads in the Laramie Range of southern Wyoming, flows eastward to an area near Cheyenne, and then southward into Colorado. The stream turns southeastward and joins the South Platte River several miles east of Greeley. This complex drainage system includes the valleys now occupied by Lone Tree Creek, Eaton Draw, Spring Creek, lower Owl Creek, and upper Spottlewood Creek. To supplement the scarce well information in certain areas of the valley, several lines of holes were drilled in conjunction with the Colorado Geological Survey's Windsor Environmental Geology Project.

Several impressive, southeast-trending upland surfaces flank upper Lone Tree Creek valley. The 2 long surfaces east and west of Carr are covered by 6 to 10 ft of pebbly to cobbly gravels containing substantial fines and calcium carbonate. Across the valley 7 miles southwest of Carr is an 18-mile-long mesa capped by 10 to 15 ft of pebbly to cobbly gravels and relatively clean, coarse-grained gravelly sands partially covering a 6- to 15-ft-thick resistant ledge of cobbly to bouldery conglomerate of the Chadron Formation (White River Group).

More than 10 ft of clean, sandy, cobbly and bouldery gravels are exposed on several terrace levels developed along a 10-mile stretch in the vicinity of Carr.

South of Carr, a large prominent terrace and an upland surface divide Lone Tree Creek valley into two branches. Cross channels connect the two branches at several places between Carr and Greeley. Well logs and drill holes in the valley fills record up to 40 ft of clean sand and pebbly to cobbly gravels, the thicker deposits lying in the western valley. Exposures along the truncated end of the western valley fill just east of Greeley show thick, fine-pebble gravels that probably contain considerable fines. Overburden becomes significant east of Pierce and exceeds 20 ft in thickness at higher levels between Eaton and Greeley.

Between Pierce and the South Platte River are 3 elevated areas that separate the 2 main valleys. These features appear to be loess-covered bedrock highs that acted as islands or interstream divides during one or more stages of the valley's history. The cross channels that probably separate these highs suggest a large-scale braided stream network.

Only 24 gravel pit operations were noted along Lone Tree Creek and its associated streams. One of the largest pits is located on a Lone Tree Creek terrace 6 miles south of the state line. Gravel from this site was used in the construction of Interstate 25 in this area. Other pits occur east of the towns of Carr, Nunn, Pierce, and Ault. Northeast of Pierce are several large pits operated by the Weld County Highway Department. A large operation northeast of Eaton once was a source of concrete aggregate but now produces only road base. North of Nunn are 2 large borrow pits in the west valley fill and central terrace. Most of the material from the small pits in this area probably was used for road base, although some might have been used in the construction of U. S. Route 85 here, or even as concrete and asphalt aggregate in the towns along U. S. 85.

The authors believe that the eastern valley fill and associated terraces in the vicinity of Carr comprise valuable high-quality aggregate resources. On the basis of test drilling, that part of the western valley fill upstream from the first cross channel (southwest of Carr) was denoted as a predominantly fine-aggregate resource (*V3*). A *V1* designation was given to the fill south of the cross-channel on the basis of well logs, test drilling, and the interpretation that this once was the major Lone Tree channel. The *V1* classification was retained on both valley fills downstream from an area 4 miles north of Nunn, where the entire valley noticeably widens and where the predicted braiding or meandering fully develops. Much more drilling will, however, be required to locate the actual channels. Around Eaton the valleys were somewhat arbitrarily given a *V4* designation because of lack of exposures, absence of gravel pits, and the fact that the overburden has thickened to the point where it could be a limiting factor. Where the deposits were observed northeast of Greeley, the small size of the gravels probably will prevent their use as aggregate.

The problems in attempting to evaluate such a vast resource area as that along Lone Tree Creek are indeed difficult. First, the landforms are so large that any one of them could yield a large amount of usable material. Second, much of this area is agricultural land and may prove to be more valuable than the underlying deposits when compared to the high-quality gravels along the Cache la Poudre River. Third, being a thick gravel fill, the Lone Tree deposits represent an important source of water for the stock and crops of the area. The effects of large-scale gravel operations and their reclamation on the ground-water regime cannot be determined without further study. Fourth, the nature of this buried system will require considerably more test drilling and geophysical study to locate the coarse channel deposits and hence, to determine the most attractive pit sites. Land use and economic comparisons with other areas will be required to adequately determine Lone Tree Creek's potential for mineral land conservation.

The point at which Lone Tree Creek enters Colorado marks the division between 2 principal physiographic provinces—the Colorado Piedmont and the High Plains. In Colorado the boundary is marked by a spectacular escarpment on which are exposed sands, gravels, and conglomerates of the Ogallala Formation of late Tertiary age. The High Plains Escarpment is the southern edge of a vast continuous sheet of coarse sediments that extends northward into Wyoming and farther northeastward into Nebraska. Where observed in Colorado, the cobbly and bouldery deposits are more than 100 ft thick and are quite variable in soundness, cementation, and percent fines. Rising above the principal Ogallala mesa are a number of higher isolated mesas of the same general lithology. The only gravel pit noted in this area is on one of these mesas west of U. S. Route 85 near the state line. It is not recommended that the entire Ogallala outcrop area be considered for mineral conservation, but only the higher mesas, because they appear to contain a sufficient volume of gravel to meet all of the local needs, and because they are more easily attainable.

Crow Creek

Crow Creek flows southward into Weld County from Wyoming and joins the South Platte River 4 miles downstream from Kersey. Porter, Little Simpson, Geary, Willow, Coal, and Wildhorse Creeks form the headwaters of Crow Creek.

The upper Crow Creek drainage basin is an area of broad alluvial fans. The middle reaches of the drainage are characterized by narrow upland remnants and the lower reaches by stream terraces and valley-fill deposits. Lower Crow Creek valley is covered by grain and livestock farms. A large area of sand dunes extends from the Crow Creek valley southeastward to the South Platte River. Much of the sand was derived from the broad Crow Creek valley and transported by prevailing northwesterly winds.

Along Porter Creek and Little Simpson Creek lie the dissected remnants of a large alluvial fan complex whose source was ancient Porter Creek in Wyoming. South of these erosional remnants are more recent alluvial fans also of Porter Creek origin. The potential of the younger fans is questionable, but at best, they are fine-aggregate resources. No pit operations were observed in these units.

The upland deposits along Willow Creek and Geary Creek and their tributaries are mostly thin, fine-aggregate resources. In several of the thicker remnants 5 operations have produced coarse sand and fine gravel that apparently were used for road base. Because the flood plains of these streams appear to contain mostly very fine-grained alluvium, they were not mapped.

Stream terraces along Wildhorse and Coal Creeks contain thin, fairly clean sands and gravels that probably do not extend more than 9 miles north of Colorado Route 14. Four small gravel pits were noted in the principal terrace. Again the flood plains consist mostly of very fine-grained alluvium (nonresource). Thin upland gravels on several hilltops and surfaces along Coal Creek 6 to 13 miles north of Purcell were excluded because of their thinness and deep weathering.

In the vicinity of Hereford, massive fan-shaped upland deposits border both sides of Crow Creek. The fan on the east side of Crow Creek originates near Arcola, Wyoming, 13 miles northwest of Hereford. This deposit is a pebbly gravel with moderate amounts of sand. The other major fan heads in Porter Creek 10 miles west-northwest of Hereford and contains large amounts of sand and minor amounts of pebbly material. Very few pits are located on these fan-shaped surfaces south of the Colorado-Wyoming state line.

Although there are no important large commercial operations in the Crow Creek Valley, one sand pit was noted about 2 miles northeast of Barnsville. Aggregate in the Crow Creek drainage is important for local road maintenance, but it is unlikely that it will ever be an important aggregate-producing area of the Front Range. The crop-land and ground-water resources may ultimately be the most favorable uses of the lower Crow Creek valley.

Beebe Draw

Beebe Draw heads in northwestern Adams County as a buried valley, flows northward through Weld County, and joins the South Platte River near Kersey.

Smith and others (1964, p. 119) report that the 70- to 100-ft-deep fill of Beebe Draw consists of cobbles and boulders at depth grading upward to increasingly finer gravel, sand, and clay. Grain and livestock farms are concentrated on the valley fill of Beebe Draw.

The great amounts of sand that were transported southeastward from the South Platte River valley by strong northwesterly winds formed prominent dunes that have migrated across Beebe Draw. The extensive dune sands and low-quality upland gravels west of Beebe Draw apparently have not been utilized for aggregate.

Box Elder Creek

Box Elder Creek flows northward through Arapahoe and Adams Counties and into Weld County, joining the South Platte River 5 miles downstream from Kersey. Large grain and livestock farms have been developed on the valley fills of Box Elder Creek and its tributaries. Smith and others (1964, p. 121) report up to 85 ft of gravel, sand, and clay in the valley fill. As in the case of Beebe Draw, winds have carried sand and fine-grained material out of the valley and across the bedrock uplands, often damming smaller stream valleys. Although the dune areas do not produce clean quality sand, some has been used for road base; however, it is unlikely that the material will be used for more than local needs in the foreseeable future. No gravel operations were observed in the Box Elder drainage. It is likely that the farming and the ground water upon which it depends will be more important and valuable than any commercial aggregate that might be designated.

Lost Creek

Lost Creek heads near Prospect Valley in southeastern Weld County and flows northward to join the South Platte River about 3 miles above Masters. The broad valley fills in the upper reaches of Lost Creek are covered by grain and livestock farms. There are no good exposures of aggregate along stream courses, and extensive exploration will be required to locate any sand and gravel in the thick alluvial fill. The lower reach of Lost Creek between Prospect Valley and the South Platte River is dammed by extensive dune fields that cover many tens of square miles. No sand or gravel pits were observed anywhere in the drainage.

Kiowa Creek

Kiowa Creek heads in southern Elbert County, flows northward through Arapahoe, Adams, and Weld Counties, then turning, flows eastward into Morgan County where it joins the South Platte River. The farm-covered valley fill of Kiowa Creek is not known to have produced any aggregates. Extensive exploration will be required to determine if any gravels are buried in the valley. In Weld County, Kiowa Creek is flanked by several square miles of wind-deposited sands that were probably utilized when Interstate 80 was constructed through this area.

Bijou Creek

The source area of Bijou Creek lies in northern El Paso and southern Elbert Counties. Bijou and West Bijou Creeks flow northward into Arapahoe County and join in Adams County. Bijou Creek enters the South Platte River near Fort Morgan in Morgan County.

Coarse sand aggregate is produced from broad interstream uplands along Bijou Creek in southeastern Arapahoe County. A few large pits have been developed on the eastern edge of an upland deposit between Wilson Creek and Bijou Creek 2 miles southwest of Deer Trail; and a few other small pits have been developed 12 miles south of Strasburg on the eastern edge of another upland bordering West Bijou Creek. Thick deposits of wind-blown silt and sand cover most of this surface and only the eastern edge is shown as a resource on Plate 2.

Farms cover most of the broad valley-fill and stream-terrace deposits along Bijou Creek in Arapahoe and Adams Counties. These deposits consist of fine to coarse sands and have not been developed for aggregate. Concrete aggregate used in this area comes from the South Platte River north of Denver.

Pawnee and Cedar Creeks

Cedar and North Pawnee Creeks head in the Pawnee Buttes area of northeastern Weld County. This extensive upland is bounded by prominent escarpments on its western and southern margins and is mantled by unconsolidated sands and gravels of the Ogallala Formation of late Tertiary age. This material consists primarily of clean sand, with minor amounts of granitic pebbles and cobbles, and measures at least 20 ft in thickness.

Just south of the High Plains Escarpment and somewhat parallel to it are a series of long, narrow, sinuous hills composed of clean sand and minor amounts of fine- to coarse-grained crystalline gravel. These deposits, probably exceeding 20 ft in thickness, represent ancient channel fills that were cut into the underlying siltstone bedrock (Norman Denson, 1974, personal communication; Galbreath, 1953). North of Raymer are several minor south-easterly-trending upland deposits that exceed 6 ft in thickness and are composed of calcareous gravelly sand. Extensive deposits of well-sorted dune sand occur in the area south of Stoneham. The principal use of aggregate extracted in the Pawnee Buttes-Raymer area is the surfacing of county roads.

South Platte River

The South Platte River drains nearly three-fourths of the entire project area. The South Fork South Platte River flows southeastward through South Park to Elevenmile Canyon Reservoir, where it turns northeastward. It leaves the Front Range and enters the Colorado Piedmont province at Kassler, a small town about 25 miles southwest of Denver. The overall drainage is toward the northeast to the vicinity of Greeley, where the river turns eastward, eventually joining the North Platte River 225 miles downstream at North Platte, Nebraska.

In most places the river's flood plain averages about 1 mile in width and is flanked by distinct terraces that are separated by fairly prominent scarps and that usually lie south and east of the river. Former courses of the river and its tributaries are indicated by series of small gravel-capped hills that parallel the present course, by unusually thick deposits recorded in wells located on broad terraces, and by maps of bedrock topography published in water reports. As the river deepened its channel into older valley-fill deposits, considerable fine-grained material was made available for wind transport; consequently, large, conspicuous sand-dune fields blanket much of the area south and east of the river, usually concealing portions of terraces and tributary valleys. For purposes of discussion, the South Platte River is divided into three sections: 1) Denver reach (Kassler to Brighton), 2) Platteville reach (Brighton to Greeley), and 3) Kersey reach (Greeley to Weld-Morgan County line).

In the Denver reach, the river flows directly through Denver and most of its suburbs. The flood-plain and lower terrace deposits generally are composed of sound, clean, pebbly and cobbly gravels and clean, well-graded sands. As much as 50 ft of resource is recorded in the wells in Littleton. Even near the valley margins the thickness may reach 20 ft. Downstream, the deposits become thinner (20 to 40 ft) and finer grained. On the river near Hazeltine, cobbly gravel is rare, and sand is more abundant.

An interesting gravel deposit in the Denver area is the Broadway alluvium (Hunt, 1954, p. 104; Scott, 1960), which forms a high extensive terrace lying almost exclusively east of the river. In the Commerce City area the deposit consists of 10 to 15 ft of pebbly gravel and fairly clean sand. However, overburden, in the form of wind-blown sand and silt, appears to thicken rapidly toward the southeast. Further downstream, in the Henderson area, the percentage of fines increases noticeably, and the gravel size decreases. This decline in quality is also evidenced by the decrease in the number of gravel pits northward from Dupont. Because it overlies the older, principal valley-fill gravels seen along the river, the Broadway alluvium could be considered as overburden where its quality becomes marginal. Indeed, this is the case in the Henderson area, which has complicated the mapping of economic Broadway deposits there. Northeast of Henderson, the terrace widens and continues downstream for many miles; however, because of decreasing grain size, it is mapped as a fine-aggregate resource.

Upland deposits near the river occur in Littleton along Massey Draw and Dutch Creek, and on small gravel-capped hills between Northglenn and Brighton. The thick Massey Draw gravels contain significant fines and some weathered rock but currently are being processed at a plant just south of the creek on Garrison Street. The gravels on the hills southwest of Brighton are thin, deeply weathered, and locally cemented, but have been excavated in several places.

Nearly 100 active and inactive gravel pits were noted along the South Platte River and its terraces in the Denver reach. Most of the material has been used by both private firms and governmental agencies for concrete aggregate and asphalt mix. Until recently, overburden (topsoil), squeegee (coarse sand) and fines had accumulated in some areas. At present, these materials also are in great demand for use as street sand, asphalt sand, backfill, and concrete slab bedding. Many operations along the river also run gold-recovery systems. Although most of the aggregate produced is used in the metropolitan area, some is shipped by rail as far as Limon and Cheyenne Wells, in eastern Colorado.

A number of depleted areas within Denver have undergone sanitary landfilling and subsequently have been converted to industrial sites. Several pits in Sheridan and Englewood currently are undergoing sanitary landfilling. Even though Denver County continues to produce some sand and gravel, most of the high-quality deposits unfortunately have been lost to urbanization. A similar encroachment problem is apparent in some of the suburbs. Although Chatfield Lake, currently under construction on the South Platte River in Littleton, will cover 1150 acres of valuable gravel land and will affect an additional 3350 acres of land, mining is currently in progress there. Possibilities exist for simultaneous underwater excavation and recreational development (Pickels, 1970, p. 50).

The flood-plain and lower terrace deposits in the Denver area obviously are prime sources of high-quality aggregate. As mentioned above, however, much of the resource has been lost to urbanization. Between Denver and Brighton, the valley gravels gradually become finer grained and contain increasing amounts of sand and clay. The limit of definite commercial value was approximated on the basis of field observations, personal communications, and the distribution of gravel pits. The broad, high terrace between Plum Creek and the river near Chatfield Lake is an enormous reserve of good quality fine aggregate.

The Broadway terrace deposits within Denver are largely unevaluated, but the numerous gravel pits on the terrace edge north of Sand Creek indicate that the deposit is a prime resource. Downstream, the gravels are finer grained and contain more sand and fines. In the Hazeltine-Henderson area, the quality is marginal, based on data from several consultants. Therefore, only a narrow strip of commercial material was delineated. Even though good quality gravels exist in the old valley fill beneath the Broadway, the deteriorating quality of the alluvium will be a serious limiting factor for gravel extraction in this area. Where the terrace widens northeast of Henderson, the landform is quite distinct; a sizeable portion of it may, however, be found noncommercial when more data are available.

In the Platteville reach, the flood plain widens to 1½ miles and overlies 25 to 80 ft of valley-fill sands and gravels. The mile-wide Broadway terrace equivalent (Kersey terrace) east of the river overlies 27 to 100 ft of terrace and valley-fill sand and gravel containing interbedded clays and silts. Between Platteville and the St. Vrain Creek confluence, the terrace widens markedly to about 2½ miles. Exposures on the terrace edge show more than 20 ft of clean, fine- to coarse-grained sands and sandy, pebbly gravels. However, the gravels account for only 10 to 20 percent of the exposed deposit. Data from the large terrace between the South Platte River and St. Vrain Creek show that the west side, influenced by St. Vrain Creek, contains coarser material than the east side, which was influenced more by the South Platte River.

The bedrock topographic maps of Smith and others (1964) and exceptionally thick deposits recorded in well logs both indicate several, deep former channels of the South Platte River and its tributaries in this area. One principal channel extends from Fort Lupton to an area southeast of Evans, where it is joined by another channel that emerges from the St. Vrain Creek valley 13 miles upstream. The buried channel of Beebe Draw enters the river valley at Lower Latham Reservoir and joins the main river channel northeast of Kersey. Although the upper 20 ft or more of the Kersey terrace deposits are fine-aggregate resources, coarser gravels probably exist in the ancient channels. Their depth, water-table conditions, and existing land use may make them uneconomic.

A number of sand and gravel pits in the lower Platteville reach occur on the edge of the Kersey terrace. Some of the inactive sand pits east of Wattenberg and around Platteville have been converted to landfills and cattle feed lots. The sand has been used as road salt and could be a component of road base. Sixteen pits in the Greeley-Evans area have produced excellent coarse sand and pebbly gravel. Two other operations currently are extracting gravel on the flood plain at Evans. Although gravels may occur locally near the surface and in buried channels along the river, the overall valley lowlands in this reach probably contain fine-aggregate resources. The Kersey terrace deposits and others just east of Greeley have yielded excellent materials; but because of their small grain size, they will not meet all specifications for concrete aggregate. The channel gravels buried beneath the Kersey terrace have little chance of being utilized for reasons stated earlier.

The South Platte River flows southeastward through the Kersey reach after a curious change in direction east of Greeley. Southeast of Kersey, both the flood plain and Kersey terrace diminish in width to 1 mile or less. Although more than 15 ft of clean, coarse sand was seen on the Kersey terrace, some pebbly and cobbly gravels may occur at depth. Below the level of the Kersey terrace lies the Kuner terrace which also contains clean, coarse sands. The deposits in the flood plain and valley fill may exceed 100 ft in thickness and vary considerably in grain size. South of Kersey, near the mouth of Box Elder Creek, are 2 small upland deposits containing 8 ft of good quality gravel impregnated with calcium carbonate.

Great amounts of sand and finer grained material have been blown out of the stream valleys and deposited across the bedrock uplands on both sides of the river valley as extensive dune fields. In addition to mantling portions of the river's flood plain and terraces, the sand dunes, as much as 100 ft high, have partially buried the tributary valleys of Beebe Draw, Crow Creek, Box Elder Creek, Lost Creek, Kiowa Creek, Bijou Creek, and others east of the project area.

Only 7 sand pits were noted on the Kersey terrace in this reach. The material extracted apparently was used for road dressing. No pits were noted on the Kuner terrace or on the flood plain, but 2 were seen in the sand dunes west of Empire Reservoir.

Because the alluvial deposits of the South Platte River and its tributaries constitute the principal aquifers in this area, grain and livestock farming have been extensively developed on the broad Kersey terrace and valley lowlands. Although additional drilling and geophysical studies are needed to accurately determine the extent of coarse aggregate, it is unlikely that these deposits will be of substantial commercial value because 1) the value and potential of the present farmland may exceed the value of aggregate, 2) coarse gravel is not readily attainable in this area, and 3) good quality coarse sand is in ample supply near the markets upstream.

SAND AND GRAVEL RESOURCES OF THE ARKANSAS RIVER BASIN

The Arkansas River Basin includes those parts of El Paso and Pueblo Counties drained by the Arkansas River and its tributaries (Fig. 4). The principal tributaries of the Arkansas River in the study area are Fountain Creek, St. Charles River, Chico Creek, and the Huerfano River. The sand and gravel deposits within each tributary drainage system are discussed starting with Fountain Creek at Pueblo and progressing down the Arkansas River to the Huerfano River. A discussion of sand and gravel deposits associated with the mainstream Arkansas River concludes the discussion of the basin.

Fountain Creek

The source of Fountain Creek is in the mountains west of Colorado Springs. At Colorado Springs, Fountain Creek turns south and joins the Arkansas River at Pueblo 30 miles away. Fountain Creek and its tributaries drain a north-south strip of El Paso and Pueblo Counties extending from the Palmer Lake area on the north through Colorado Springs to Pueblo.

Within the drainage basin of Fountain Creek are alluvial fan, upland, flood-plain, stream terrace, valley-fill and wind-blown types of sand and gravel deposits. The most important alluvial fan and upland mesa gravel deposits extend from the mountain front eastward to Fountain Creek. Close to the mountains, the upland deposits contain decomposed boulders and large amounts of silt and clay. Generally, these deposits are poor sources of high-quality sand and gravel, but may be important producers of base course or road dressing material. Some aggregate in these deposits might be upgraded to meet asphalt specifications. Upland mesa deposits generally improve in quality with distance from the mountain front, and many of the gravel pits developed on these mesas produce high-quality concrete aggregate. Several mesas contain up to 30 ft of sand and gravel; however, in places up to 10 ft of wind-deposited material (loess) may cap the aggregate. The most important operations on these upland deposits are the Broderick and Gibbons pits located on "The Mesa" in northwest Colorado Springs and the Schmidt Construction Inc. pits located on a large mesa 2 miles southwest of Fountain.

Upland deposits on both sides of Fountain Creek below Security produce aggregate suitable for asphalt, and in some cases these aggregates may be upgraded to concrete specifications. Most upland mesa gravel deposits in the Colorado Springs area have been lost to urbanization or lie within the Air Force Academy and Fort Carson Military Reservation. The only major gravel deposits other than uplands in the Colorado Springs area lie within the flood plain of Fountain Creek and on the stream terraces of Fountain and Monument Creeks.

Colorado Springs lies on broad stream terraces of Fountain and Monument Creeks; only flood plains and terraces of the lower reaches of Fountain Creek contain significant reserves of sand and gravel. The most important sand and gravel operations on Fountain Creek are located between Colorado Springs and Fountain. There are only a few aggregate pits on Fountain Creek between Fountain and Pueblo. Drilling along this stretch has disclosed gravels both in the flood plain and on stream terraces (Tom Ledgerwood, 1973, personal commun.).

Several high quality sand deposits lie east of Monument and Fountain Creeks in the Colorado Springs area. Sand dunes mantle 2 large areas of clean, coarse-grained water deposited (alluvial) sands. One of these areas is southeast of the U. S. Air Force Academy between Cottonwood and Pine Creeks. Fountain Sand and Gravel Company produces 600 tons of *hydrafrac sand* each week from this area for use in hydraulic fracturing operations in oil field reservoirs (Fig. 5). They also produce blast sand, well pack sand, filter sands, pipeline sand, engine sand, and other specialties requiring a clean, dry, close-specification, high-silica sand (R. W. Sack, The Fountain Sand and Gravel Company, 1974, personal commun.). The other area of sand deposits is located between Colorado Springs and Security near the mouth of Sand Creek. These sands are mined and then mixed with coarse gravels and quarry rock to meet various aggregate specifications. About 60 percent of the quarry aggregate mix is made up of this sand-size material. Daniels Sand Company, Schmidt Construction Company, and Castle Concrete Company are the principal operators in the Sand Creek area.

Figure 5. Fountain Sand and Gravel Company hydrafrac sands in El Paso County. This deposit supplies the petroleum industry in the United States and Canada with coarse-grained quartz sands that are used to increase the recovery of oil. The pit is located 1 mile east of the south entrance of the U. S. Air Force Academy. Photograph by P. C. Wicklein.

Northeast of Colorado Springs near the headwaters of Sand Creek, alluvial-fan, upland, valley-fill, and flood-plain deposits of coarse sands derived from the Dawson Arkose highlands of northern El Paso County are commercial and are presently being mined for aggregate. Coarse sand also is being mined from the south end of a large sand-capped mesa 5 miles northeast of the mouth of Fountain Creek at Pueblo.

We suggest that a follow-up study be conducted to determine the origin and extent of the Cottonwood Creek and Sand Creek deposits and how much of these particular aggregates are required for the future needs of Colorado Springs and the petroleum industry.

St. Charles River

The St. Charles River enters southwestern Pueblo County from the west, flows generally northeast, and joins the Arkansas River 2 miles east of Pueblo. Upland deposits are important sources of sand and gravel in the Rye, Colorado City, and Beulah areas.

Upland mesas in the Rye-Colorado City area are capped by deposits of sand and gravel. These deposits commonly range between 5 and 20 ft in thickness with 4 to 6 ft of overburden. The content of calcium carbonate, incompetent rock, silt and clay varies among deposits. The few widely scattered aggregate deposits in southwestern Pueblo County are needed for road maintainance and community development in that area.

Good gravels are found in the upland and terrace deposits along North, Middle, South, and Squirrel Creeks, near Beulah, Colorado. Many of these upland sand and gravel deposits exceed 10 ft in thickness but contain significant amounts of incompetent rock, silt, and clay.

Near Pueblo, high stream terraces on both sides of the St. Charles are important potential sources of sand and gravel. The flood plain of the St. Charles River, generally a poor source of aggregate, contains good quality aggregate west of Interstate 25. Lower terraces along the St. Charles west of Interstate 25 also are sources of good quality sand and gravel, and a few deposits near Burnt Mill have been worked. No significant deposits of sand or gravel were found in the flood plain or in the stream terraces of Greenhorn Creek.

Chico and Black Squirrel Creeks

Chico Creek and its principal tributary, Black Squirrel Creek, drain a large part of eastern El Paso and northeastern Pueble Counties. Northeastern El Paso County is drained in part by Big Sandy Creek and a few other creeks not related to Chico Creek; however, these other areas are so similar to the Chico-Black Squirrel drainage system that they will be included in this discussion. Nearly the entire eastern part of El Paso County and northeastern Pueblo County is covered by fine-aggregate sand resources. Deposits vary from coarse pebbly sands of the flood-plain, stream-terrace, valley-fill, alluvial-fan and upland deposits to fine wind-deposited dune sands. It appears that the sand in these deposits originally was derived from the highlands of Dawson Arkose located in north-central El Paso, southeastern Douglas, and southern Elbert Counties. Upland deposits are up to 20 ft thick and have practically no overburden. These deposits also generally contain a large percentage of silt and clay. Along Colorado Highway 50 near the Arkansas River in northeastern Pueblo County, many pits have been developed on the scarps of these upland deposits. Alluvial-fan deposits consist of reworked aggregate or slope wash derived directly from outcrops of Dawson Arkose. Stream-terrace and flood-plain deposits may represent primary, secondary, or even tertiary deposits of aggregate derived from Dawson Arkose. The large dune fields in this area were deposited by dominant northwesterly winds that transported sand from the flood plain of Black Squirrel Creek. Small individual sand dunes scattered across the coarse-sand upland deposits generally are associated with sand blowouts. The widespread sand aggregates of this region are important in maintaining the road systems in El Paso County and Pueblo County.

Huerfano River

The Huerfano River, nearly 100 miles long, heads in the Sangre De Cristo Mountains 65 miles southwest of Pueblo, flows northeastward and joins the Arkansas River south of Boone. Despite the river's impressive length, mappable sand and gravel deposits in Pueblo County extend only 20 miles upstream from the Arkansas confluence. Further upstream, the river flows through narrow canyons incised as much as 300 ft into sandstones, shales, and limestones.

Although one water well along the river penetrated 32 ft of flood-plain and valley-fill deposits, greater depths were recorded near the river mouth, but these are, in part, due to Arkansas River deposition. Only sand and silt were seen along the river channel, and high quality coarse aggregate is not anticipated at depth because the source materials for a considerable distance upstream consist of fine-grained, incompetent sedimentary rocks.

The high terrace deposits flanking both sides of the river vary from 5 to 10 ft in thickness, although one small remnant measured 15 ft. In most places significant calcium carbonate has developed, and the gravels contain abundant fines and weak rocks. As much as 8 ft of silt and clay is exposed on the lower terrace.

Capping the Hooker Hills 6 miles from the river mouth are deeply weathered, silty upland gravels up to 15 ft thick. Thinner upland remnants lie at a lower level between the Hooker Hills and the river.

Of the 6 sand and gravel pits noted in the Huerfano River valley, all but one are located on the higher terrace level. The best quality material was observed in the two pits nearest the river mouth. Although part of an Arkansas River terrace, the material here undoubtedly was influenced by the Huerfano River at some time in the past.

Compared with the vast amounts of high-quality sand and gravel available along the Arkansas River, the relatively poorer quality deposits along the Huerfano River have little potential for more than local road repair, fills, and earth embankments.

Arkansas River

The Arkansas River, which heads in the mountains of northern Lake County near Leadville, enters the plains at Canon City and flows eastward across eastern Fremont and Pueblo Counties. The flood plain and terraces along the Arkansas River between the western boundary of Pueblo County and the confluence with the St. Charles River contain extensive deposits of sand and gravel. Tributary streams, with the exception of the Red Creek and Turkey Creek drainages which contain limited reserves of sand and gravel, tend to be devoid of commercial quality aggregate. The flood plain of the Arkansas River consists of approximately 25 ft of clean, sound sand and gravel beneath 4 to 12 ft of fine-grained overburden. This aggregate is being recovered from a flooded pit near the junction with Blue Ribbon Creek just west of Pueblo.

Upstream from the town of Goodnight, stream terraces tend to be limited in areal extent and are composed of about 10 ft of pebbly to cobbly granitic gravel that includes a small amount of calcium carbonate, silt, and clay in the upper few feet of the deposit. Overburden thins toward the edge of the terraces. The broad terraces along the south side of the river between Goodnight and the St. Charles River are made up of about 16 ft of sand and gravel lying beneath 5 to 30 ft of wind-deposited silty sand that thickens with increasing distance from the flood plain. The aggregate resource on the terrace segments between Goodnight and Salt Creek has been entirely lost to urbanization.

The wide, prominent terrace lying south of the river extends downstream past the St. Charles and Huerfano Rivers toward Fowler. The deposits beneath the terrace vary from 6 to 20 ft in thickness and consist of fairly clean pebbly to cobbly gravels with equal amounts of sand. The southern or upslope limit of the terrace is uncertain because of thickening deposits of clay, silt, and sand derived from the river valley by wind transport and from several northeastward flowing tributary streams that head in the fine-grained terrain to the south. Two lower terraces lie on the north side of the river and in places contain more than 15 ft of clean sands and gravels.

Between the St. Charles and Huerfano Rivers, about 4 miles south of the Arkansas River, lies a series of small gravel-capped hills, probably the remnants of a former position of the Arkansas River. Although they are old, high upland gravels, these deposits are not so deeply weathered as might be expected.

Most of the 21 active and abandoned gravel operations noted on the high terrace south of the river lie within ¼ mile of the river bluffs. There the overburden is thin to nonexistent, and access to Pueblo is excellent on U. S. Highway 50 and Colorado Highway 96. Seven other operations were noted on the high terrace at and southeast of Boone. The gravels extracted from these areas have been used for concrete and asphalt aggregate throughout the Pueblo area. Even with the abundance of high-quality river terrace gravels, 4 operations have been started on the relatively high-quality upland gravels south of the river. It is likely that these gravels will continue to be of importance in the Pueblo area. Most of the activity will be concentrated on the terraces and probably within the ¼-mile strip described above. The flood-plain and lower terrace deposits appear to have great potential but will require much more testing and evaluation as to ground water depth, grain size limitations, and land use.

SAND AND GRAVEL RESOURCES OF THE LARAMIE RIVER BASIN

Heading in the high glaciated peaks of the Medicine Bow Mountains in western Larimer County (Fig. 4), the Laramie River flows northward into Wyoming and northeastward toward Laramie.

In general, most of the flood-plain, terrace, and alluvial fan deposits along the river are of poorer quality than most seen along other mountain streams and along comparable rivers on the plains. The terraces flanking the river downstream from Stub Creek are more prominent than those upstream. Just above Stub Creek is a valley constriction caused by a series of glacial end moraines. Downstream the higher terraces are well defined and consist of 10 to 20 ft of pebbly, cobbly, and bouldery gravel with significant silt and clay, weak sedimentary clasts and decomposed igneous rock. Field observations suggest that the thickness of the gravels decreases rapidly away from the river.

Numerous small alluvial fans have been built out onto the terrace by tributary streams and may contain up to 15 ft of silt, sand, and angular boulders.

In several exposures along the river, the flood-plain deposits appear to contain some pebbly and cobbly gravels and sands of undetermined thickness.

One gravel pit was noted in sandy, pebbly, and cobbly terrace sediments south of the Stub Creek confluence. In the fall of 1973, the Larimer County Highway Department was borrowing terrace gravel for local road repair just west of Four Corners. East of Gleneyre School, on the southern end of Crazy Mountain, is an operation in deeply weathered and disintegrated granite (grus).

The alluvial fan gravels along the river probably have no potential as sources of aggregate because of their high amount of fines, oversize material, and the necessary upgrading. They can be used locally for road dressing. The terrace deposits are of slightly better quality; but because of the sedimentary clasts and decomposed rocks in them, it is doubtful whether they could be easily upgraded for high-quality aggregate. However, since most of the roads in the valley are gravel-based these terraces and the weathered granite of Crazy Mountain should be excellent sources of road base and subbase. The deposits are more than adequate to meet the local needs in the valley, provided that no rapid growth is projected for the area.

QUARRY AGGREGATE

Quarry aggregate is any crushed rock produced from a bedrock quarry. The principal Front Range rock types that may be suitable for quarry aggregate are granite, gneiss, basaltic rock, quartzite, limestone, dolomite, rhyolite, and conglomerate. Sandstone, shale, and schist are generally unsuitable for quarry aggregate. The major quarries producing aggregate in the Denver area are the Cooley Gravel Company quarry at Morrison and the Specification Aggregate, Inc. quarry at Golden. Both quarries are located in an area of Precambrian gneisses and schists (Plate 2). The only major aggregate producer north of Denver is the Andesite Rock Company quarry located in fine-grained intrusive rock near Lyons (Plate 1).

There are several aggregate-producing quarries in the Colorado Springs area. The Schmidt Construction, Inc. quarry is located in Pikes Peak granite; and Castle Concrete Company's Snyder, Queen's Canyon, and Lennox-Breed quarries are in Paleozoic limestones and dolomites of the Rampart Range (Plate 3).

Gneisses and Schists

The quality of quarry aggregate in the outcrop areas of the Precambrian gneisses and schists varies considerably from place to place. The principal quarries are in Jefferson County.

The Morrison Quarry, operated by the Cooley Gravel Company, lies on a 200-acre tract along Strain Gulch, about 1½ miles south of Morrison. Although intensely fractured in places, the granite, gneiss, and schist that are quarried here do require periodic blasting. Rock products from the quarry include road base, quarry fines (structural fill), and surge rock.

The Specification Aggregates, Inc., quarry is located above the Old Heidelberg Inn, 2 miles south of Golden off U.S. Highway 40(Fig. 6). About two-thirds of the crushed and uncrushed granite and gneiss quarried here is used as riprap for the Chatfield Lake State Recreation Area in Littleton. Other products include concrete aggregate, road base, and asphalt binder.

Highly fractured biotite gneiss, garnet gneiss, and granite lenses are exposed in a 100-ft excavation at the Clear Creek quarry, which is located adjacent to U. S. Highway 6, half a mile west of Golden in Clear Creek Canyon. Angular talus debris and coarse crushed rock are used for riprap. Coarse sand and finer crushed rock are used for concrete aggregate, base course, and ballast (Van Horn, 1957; Hickey, 1950). A smaller quarry in similar rock types lies across the canyon on Colorow Hill, west of Lookout Mountain.

Two other rock quarries are situated in the highly fractured gneisses and schists in the Turkey Creek and Deer Creek canyons, southwest of Denver.

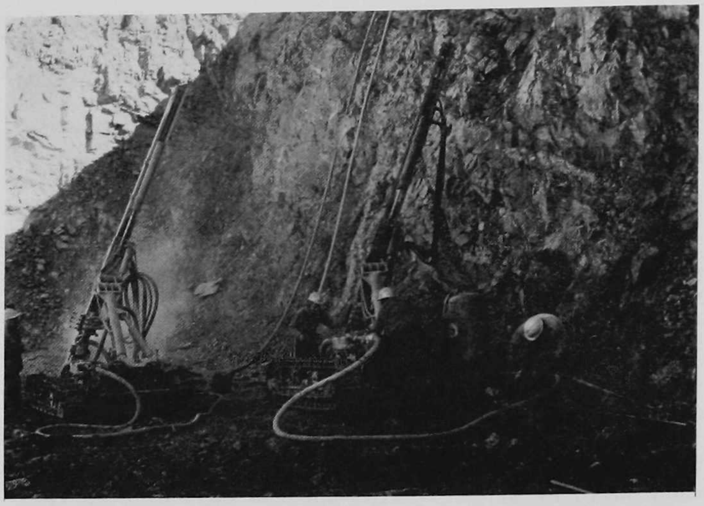

Figure 6. Air-track drilling in the Specification Aggregates Inc. Quarry, Jefferson County. Quarry aggregate is important to the Denver market. Photograph by A. L. Hornbaker, Colorado Geological Survey.

Granitic Rocks

Boulder Creek Batholith: The outcrop area of the Boulder Creek batholith is primarily in Boulder County. This rock is a medium- to fine-grained granodiorite and might be developed as a quarry aggregate in a few places. A few small outcrops of younger fine- to medium-grained Silver Plume granite in the same area might also be utilized as quarry aggregate.

Sherman Granite: The mountainous part of Larimer County lying north of the Cache la Poudre River and east of the Laramie River is the principal outcrop area of the Sherman Granite in Colorado. Weathering has produced a deep layer of grus (decomposed granite) over much of the Sherman Granite in this region. This grus, used as road-surfacing material on many local roads, is generally mined from the sides of road cuts near the site of intended use. Some grus pits were found in Larimer County, but road-surfacing aggregate appeared to be the principal use made of the material. Aggregate for paved county roads is obtained from stream deposits near Fort Collins; however, it is possible that grus may be just as satisfactory for asphalt aggregate.

Pikes Peak Batholith: The Pikes Peak Batholith of Jefferson, Douglas, and El Paso Counties is a complex coarse-grained granitic intrusive. Although most of the Pikes Peak Batholith is too coarse grained to make a quality crushed aggregate, Schmidt Construction Inc. is quarrying a biotite-poor, medium-grained phase of the granite in Turkey Creek Canyon 15 miles southwest of Colorado Springs. This aggregate meets Colorado Division of Highways specifications for concrete aggregate and is being shipped as far east as Limon.

Schmidt Quarry is the only major quarry in granite of the Rampart Range; however, exploration of the batholith may reveal other areas where the rock is also suitable for quarry aggregate.

Basaltic Flows and Intrusives

All the potential basaltic and andesitic quarry aggregate occurs in central Jefferson County and eastern Boulder County. North and South Table Mountains in Golden are ancient lava flows that cover an area of nearly 3½ sq mi. The two upper flows total about 150 ft in thickness and are composed of hard, dense, resistant shoshonite, a fine-grained potassium-rich basalt. These flows were quarried at 4 localities on South Table Mountain and at one on North Table Mountain. Van Horn (1957) states that the rock has been used for concrete aggregate, riprap, road metal, and building stone. Hard, durable monzonite in the so-called "Ralston Dike" north of Golden also was quarried for concrete aggregate, riprap, and road metal. Alteration and weathered zones, slope stability, esthetic and land-use problems will be serious limiting factors to the development of these quarry aggregates in Jefferson County.

The fine-grained, potential quarry aggregates in eastern Boulder County include the basaltic dike at Valmont Butte, east of Boulder, and the andesitic intrusive in the mountains southwest of Lyons. Rock from the quarry near Lyons is crushed and used for road material, concrete aggregate, septic-system rock, filter media, riprap, and decorative stone. The rock quarried at the west end of Valmont Dike around the turn of the century was used as building stone and in cobblestone pavement.

Quartzite

The Coal Creek quartzite in Jefferson County is an extremely hard and tenacious rock that, upon crushing, produces clean, angular fragments and very little dust. These qualities and the proximity to the Boulder-Denver market make this rock very attractive as quarry aggregate. Road access and environmental concerns may, however, severely limit the location of potential quarry sites.

Limestones and Dolomites

Some of the Paleozoic limestones and dolomites of the Front Range make excellent concrete aggregate. Outcrops of these rocks are found in Jefferson, Douglas, and El Paso Counties, but large quarries are developed in El Paso County only, near Colorado Springs. The Lennox-Breed and Queen's Canyon quarries are well-known quarries, but the Snyder Quarry is planned as an underground operation. Aggregate from these quarries is important to the Colorado Springs market and has been used in the construction of the NORAD complex and Air Force Academy. Plates 2 and 3 show the location of these rocks and the principal quarries.

Rhyolite

Rhyolite lava flows cap mesas through out much of eastern Douglas County. This rock was quarried near Castle Rock, and has had limited use as building stone, rubble masonry, riprap, and veneer in private homes and small public buildings (Lindvall, 1968). Testing might demonstrate this rock's suitability for crushed aggregate. Although this rock is now located far from principal urban growth centers, it is strategically located in a potential growth area between Denver and Colorado Springs.

Conglomerates

Conglomerates are cemented clastic rocks containing rounded rock fragments that correspond in size to gravel or pebbles. Four units in the study area might be classified as conglomerates. With the exception of the Green Mountain Conglomerate, conglomerates were omitted from the regional maps but appear on the 7½-min quadrangles in the atlas.

In the Colorado Springs-Castle Rock area, the Colorado Springs member of the Dawson Arkose is conglomeratic. This formation is mined in a few places where the material is poorly consolidated; however, in most places the rock would require blasting and crushing. Since no evidence was found that the formation has been crushed for aggregate anywhere along the Front Range, the unit is not shown on the maps that accompany this report.

The Castle Rock conglomerate, which crops out in the Castle Rock area, is similar to the Colorado Springs member of the Dawson Arkose in that it will require blasting and crushing before it can be utilized as aggregate.

The Green Mountain formation is a 650-ft-thick deposit of conglomerate, claystone, and sandstone on Green Mountain located in the Lakewood-Golden area of Jefferson County. The Green Mountain Conglomerate is shown on Plate 2 as an unevaluated upland deposit. A large part of the formation lies within a Lakewood city park, and there is no evidence the formation ever has been mined for aggregate. Mining the Green Mountain Conglomerate will require that certain engineering and environmental problems be overcome.

Several hills along Lone Tree Creek 5 miles south of Carr are capped by conglomerates of the White River Group. There is no evidence that these conglomerates ever have been mined for aggregate; however, the conglomerates might be utilized as riprap, but blasting would be required.

AGGREGATE RESOURCES OF THE FRONT RANGE COUNTIES

Adams

The valleys of Beebe Draw, Box Elder Creek, Kiowa Creek, and East and West Bijou Creeks, in eastern and central Adams County, contain thick deposits of gravel and sand that grade upward into fine-grained alluvium. Eolian sands, in places, partially bury the valleys. These valley deposits probably will not become significant because of the thick overburden and the importance of the area's farmlands and ground-water resources.

In southwestern Adams County, the flood-plain and terrace deposits along Sand Creek have yielded excellent sand, but the city of Aurora covers about half the resources there.

Appendix 2 summarizes the production of sand and gravel, and crushed rock in the Front Range counties for the years 1954-71. Adams has consistently been one of the leading gravel-producing counties in Colorado. Annual production exceeded 3,000,000 tons for several of the last 15 yr. Most of the material was mined from the Clear Creek valley between Sheridan Boulevard in Arvada and the South Platte River. The gravel supply in this area, however, is nearly exhausted.

The South Platte River in Adams County extends from 52d Avenue in Denver to Brighton. Whereas virtually all of the terrace and flood-plain deposits south of 72d Avenue have been lost, considerable mining has occurred at the Clear Creek confluence and on the edge of the Broadway terrace between 72d Avenue and 136th Avenue.

Despite the declining quality of the river gravels north of Denver, new mining operations north of 104th Avenue indicate that the flood-plain and lower terrace gravels will become increasingly important to the suburban growth demands in the Denver metropolitan area. The surplus sand and fines will become very significant if and when the problems of full-scale quarry-aggregate operations in Boulder and Jefferson Counties are solved.

Arapahoe

In eastern and central Arapahoe County, the valley-fill deposits in Box Elder, Kiowa, East Bijou, and West Bijou Creeks probably will not become significant resources for reasons stated above in the Adams County summary. The upland sands and gravels along Bijou and West Bijou Creeks are used as road dressing and base material. The valley fills of Sand Creek and Cherry Creek, in the western part of the county, contain thick, high-quality specialty sands.

In the southwestern corner of the county, the South Platte River extends from Littleton, near the Massey Draw confluence, to Yale Avenue, in Englewood. Much of the high-quality river gravel has been mined in Sheridan, at the Chatfield Golf Course, and on the terrace east of Columbine Hills. Most of the sites in Sheridan are in some phase of sanitary landfilling. In spite of the relatively heavy gravel mining in this area, a number of deposits have been lost to urbanization, notably those gravels lying beneath Wolhurst Country Club, Columbine Valley, Centennial Race Track, and several commercial districts in Littleton and Englewood. Due to pressures of suburban expansion, few gravel lands along the river yet remain available for mining. Serious attention must be given to these valuable tracts—the only remaining sources of coarse aggregate within the county.

Boulder

Boulder County ranks among the leading Front Range counties in the production and consumption of sand and gravel. The county may contain sufficient reserves to satisfy demands imposed by future growth, provided that urban expansion is directed away from the major areas of aggregate resources. The main sources of high-quality gravel within the county occur east of the mountain front in flood plains of the major streams, including Boulder, South Boulder, and St. Vrain Creeks. The flood plain gravels along Coal and Lefthand Creeks are of unknown quality and may contain some silt and clay. Numerous upland gravels located in the eastern portion of the county tend to be thinner, of more limited areal extent, and include more deleterious material than the flood plain deposits. These lower quality aggregates may be best used for road base, subbase, surfacing material, and fill. These uses would permit reserving the supplies of high-quality flood-plain gravel for concrete aggregate and asphalt mix.

The mountainous portion of the county tends to be deficient in sand and gravel, although several large deposits are located in the vicinity of Nederland. Utilization of this material could help reduce construction costs of future roads and mountain developments. An alternate and more costly source of aggregate would be the quarrying and crushing of granite bedrock.

Denver

The City and County of Denver now extend over many of the valuable sand and gravel deposits along the South Platte River, Sand Creek, Cherry Creek, and Bear Creek. Although production figures for the county are scanty, tonnages certainly have decreased in recent years mainly because of rapid urbanization. Whereas many deposits were lost to this urbanization, a number of depleted pits within the city were profitably reclaimed by sanitary landfilling and by subsequent development into industrial, commercial, residential, and recreational sites. Landfilling already has begun in the only active gravel pit within the city.

To meet the demands of the expanding metropolitan area, the possibilities are very real that aggregate will be brought in by unit train from areas as far away as Greeley. With the growing importance and potential of quarry aggregate west of Denver, caused, in part, by the diminishing supply of coarse gravel in neighboring counties, the sand and fine-aggregate deposits along Cherry Creek, Sand Creek, and the South Platte River will become more valuable.

Analyses of the Denver problem and recommendations for its solution have been outlined by the Colorado Sand and Gravel Producers Association (1957), the Inter-County Regional Planning Commission (1961), and the U. S. Bureau of Mines (Sheridan, 1967). Other growing areas along the Front Range should learn from this example of inadequate zoning and mismanagement of aggregate resources.

Douglas

Douglas County, although not subject to section 92-36-5, C. R. S. 1963, was included in this study because of its rapidly increasing population and its strategic location between Denver and Colorado Springs. Abundant resources of fine aggregate occur in the terraces along Plum and Cherry Creeks; gravel deposits in the county are limited to the area adjacent to the South Platte River. Future supplies of coarse aggregate might be obtained from limestone in the mountains near Westcreek and Larkspar (Plate 2). Rhyolite flows in the vicinity of Castle Rock have been mined for building stone. Further testing might establish the suitability of this rock for concrete aggregate.

El Paso

El Paso County produces and consumes large quantities of sand, gravel, and quarry aggregate. The principal deposits in the county producing high-quality aggregate are Castle Concrete's Queen's Canyon and Lennox-Breed quarries west of Colorado Springs, the Schmidt Construction Quarry 15 miles southwest of Colorado Springs, the gravel-capped upland mesas west of Fountain Creek, and the large sand deposits in the southeastern part of Colorado Springs. Most high-quality gravel deposits in the county have been covered by the urban sprawl of Colorado Springs or lie within the U. S. Air Force Academy or the Fort Carson Military Reservation. Upland gravel deposits apparently cannot supply the demand for aggregate in Colorado Springs; therefore, quarry aggregate supplies a large part of the market, and increasing amounts of gravel are trucked into Colorado Springs from the Arkansas Valley, 40 miles to the south (Fig. 7). A great deal of the sand mined in the southeastern part of Colorado Springs is mixed with quarry aggregate. Three tons of sand are required for each 2 tons of quarry aggregate. Other sands northeast of the Colorado Springs area are mined and mixed with gravels brought in from the Arkansas Valley.

Widespread deposits of low-quality sands in the eastern half of El Paso County provide a large part of the aggregate required for maintaining the state and county highway systems. The large number of sand pits in northeastern El Paso County (Plate 3) indicate how pits have been conveniently developed for road maintenance. These widespread deposits substantially reduce the cost of county road maintenance.

The Fountain Sand and Gravel Company deposits located north of Colorado Springs near the south entrance of the Air Force Academy are of growing national importance. Material from these unique coarse-grained quartz sand deposits is used for fracturing petroleum-bearing reservoirs to increase the flow or yield of oil and gas. It is the unusually large size of the individual spherical sand grains that make this deposit unique. Demand for this coarse-grained sand is growing rapidly throughout the United States and Canada.

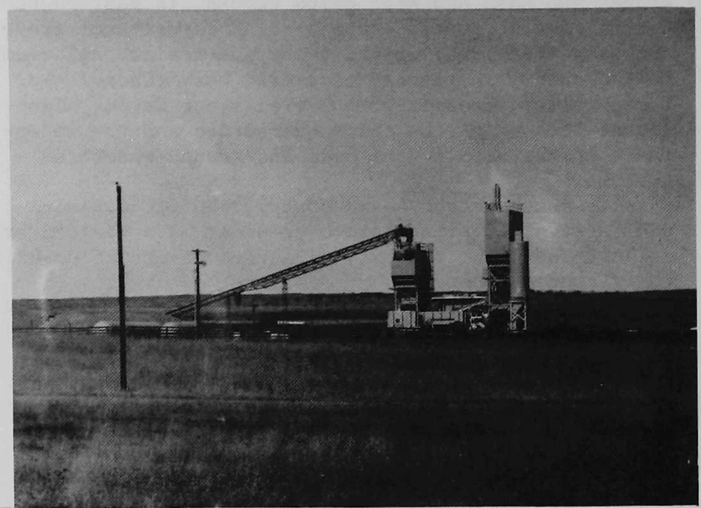

Figure 7. The Fountain Sand and Gravel Company plant northeast of Colorado Springs processes slag and gravels trucked from Pueblo 40 miles away. Photograph by P. C. Wicklein.

The most important aggregate deposits in El Paso County are located near Colorado Springs. Finding a solution to the problem of conservation of deposits near Colorado Springs that will satisfy the present landowners will not be easy. Planning will require a great deal of effort on the part of local government, with considerable input from the aggregate-producing industry and landowners.

Aggregate deposits in the eastern and northern parts of El Paso County are generally important only to the maintenance of the highway systems. Detailed plans involving the conservation of key deposits in this area should be developed in close cooperation with the county and state highway departments. Any El Paso County plan for the conservation of aggregate deposits should also consider Pueblo County, which provides aggregate to the Colorado Springs market. A more complete picture of aggregate resources of El Paso County may be obtained from the discussions on sand and gravel resources of the Arkansas River Basin and Pueblo County.

Jefferson

Annual sand and gravel production from Clear Creek and Bear Creek has exceeded 2,000,000 tons in recent years. Activity along Clear Creek is confined to the flood plain and terraces between Tabor Street and the Coors Brewery in Golden. More than 2,000 acres of flood-plain gravel land were lost due to the expansion of Arvada and Wheat Ridge. Two levels of terrace gravels on the north side of the valley have been worked extensively, west of Eldridge Street. Urbanization and heavy mining have left little land available for gravel extraction.

Factors such as percent fines, variable thickness and overburden, and oversize material probably have limited the mining activities along Bear Creek. Although a significant amount of land yet may be available, more drilling and test data are needed in order to determine the degree of upgrading required for the best utilization of these resources.

Very significant quantities of high-quality gravel and sand lie in the terraces and flood-plain of the South Platte River above the Chatfield Lake damsite. Possibilities exist that gravel mining may continue within the maximum flood-inundation limits after completion of the recreation area.

The Rocky Flats alluvial-fan and associated upland deposits represent a large untapped reserve of sound, durable gravel. Although the gravels contain significant clay, one commercial operation has begun on a Rocky Flats remnant along Barbara Gulch, near Colorado Highway 93.

Stone and crushed-rock production has increased in recent years because of the openings of the Morrison and Specification Aggregates, Inc., quarries in the Golden-Morrison area. North and South Table Mountains, Ralston Dike, and the Coal Creek quartzite are large deposits of potential, high-quality quarry aggregate that will become increasingly important in the Denver metropolitan area as coarse gravel resources diminish.

Jefferson County is in the fortunate position to encourage development of the Bear Creek, South Platte River, and Rocky Flats deposits to help offset the depletion of the Clear Creek gravels. At the same time, some of the economic, engineering, legal, and environmental problems associated with quarrying might be solved.

Larimer

Larimer County contains large reserves of high-quality gravel in the terraces and flood plain along the Cache la Poudre and Big Thompson Rivers between the foothills and the Larimer-Weld County line. These deposits have been extensively worked in the vicinity of Fort Collins and Loveland. Aggregate associated with Boxelder Creek, Little Thompson River, and the Laramie River are of limited value because they include large amounts of fines and weak rock or are buried beneath thick deposits of fine-grained alluvium. This material is suitable for road base, subbase, and for surfacing gravel roads.

In the mountain region, limited amounts of good quality stream gravels occur in the upper Cache la Poudre valley between Indian Meadows and Spencer Heights. Material high in fines and oversize clasts can be obtained from the alluvial fans and colluvial-slope deposits that are built over the stream terraces. Granite might be considered as a potential source of crushed aggregate for local use.

Pueblo

Pueblo County has sufficient reserves of high-quality sand and gravel for its own future needs and for export to Colorado Springs in El Paso County. Urban expansion over gravel deposits need not be the problem in Pueblo that it is in the Colorado Springs and Denver areas if proper action is taken. The principal sources of high-quality gravels in Pueblo County are the flood plain and stream terraces of the Arkansas River. Extraction of this sand and gravel along the Arkansas will always present a conflict with the use of the land for agriculture; however, potential conflicts with urban development can be avoided by directing urbanization away from the stream terraces and onto the unwatered uplands above the river. Utilization of the isolated undeveloped upland gravel deposits south of the Arkansas River should be undertaken early to avoid conflicts with urban growth.

Stream terraces along the lower St. Charles River probably will be important sources of sand and gravel for the future growth of Pueblo. Because these terrace deposits have not been developed as crop land, the only potential land-use conflict with sand and gravel extraction is future urbanization.

That part of the Arkansas River above Pueblo owned by the U.S. Government is lost as a source of gravels. However, several other terrace and flood-plain deposits on the upper Arkansas are important for the future growth of the area.

Upland deposits near Turkey Creek and between U.S. Highway 50 and the Arkansas River in northwestern Pueblo County are important now and will become increasingly important in the future as nearby land is developed. Upland deposits in southwestern Pueblo County are necessary for maintaining the local road system and supplying the Rye-Colorado City growth area. Deposits along the upper St. Charles River near Beulah provide aggregate for maintaining local roads.

Sparsely settled southeastern Pueblo County relies upon the stream terraces and upland deposits of the Huerfano and Arkansas Rivers for all of its sand and gravel needs. Sedimentary rocks are crushed locally for road aggregate. Unpopulated northeastern Pueblo County is covered by large areas of upland and wind-deposited sands. These deposits more than maintain the present road system. Most of this part of Pueblo County is owned by the State of Colorado, and aggregate reserves here should satisfy at least the short-term needs of the area.

Weld

Weld County, which comprises about one-fourth of the study area, contains extensive reserves of sand and gravel. Annual production of aggregate over the past 10 yrs has ranged between 250,000 and 2,400,000 tons. Deposits of high-quality aggregate occur in the western one-third of the county. These deposits include pebbly sands in the flood plain and terraces along the South Platte River below Brighton and gravels along Lone Tree Creek and the lower reaches of Boulder Creek, St. Vrain Creek, Big Thompson River, and the Cache la Poudre River. These reserves are adequate to meet the needs of the area. Some of these raw materials could be shipped by unit train to aggregate-deficient areas such as metropolitan Denver.

Vast dune fields in the southeastern part of the county partially bury segments of Beebe Draw, Crow Creek, Box Elder Creek, Lost Creek, and Kiowa Creek. These valley deposits are not considered to be of substantial economic significance because of the thick overburden, adequate supply of coarse sand near large urban markets, and value of present farmland and ground-water resources.

The upland and alluvial-fan deposits along the northern boundary of the county might be best utilized for local road construction and maintenance.

THE ROLE OF HB 1529 IN LAND-USE PLANNING AND THE AGGREGATE INDUSTRY IN COLORADO

Sand and gravel rank first in value and amount among the nonmetalic, non-fuel mineral commodities produced in this country. These raw materials are basic to the construction of our homes, schools, hospitals, churches, shopping centers, streets and highways, airfields, and bridges. In addition, they play important roles in the areas of sewage treatment, water filtration, agriculture, landscaping, transportation, manufacturing, recreation, and petroleum production. We consumers cannot take for granted that our supplies of these resources are inexhaustible. It must be realized that sand and gravel are the result of geologic processes, that their distribution is limited, that they can be mined only where they occur naturally, that they are essential to all kinds of construction, and that proper steps must be taken to ensure that adequate supplies are kept available to meet present and future demands. The assurance that future generations will have optimum aggregate resources will necessarily entail certain problems.

All the conflicts of priority that arise among the sand and gravel industry, government, and the citizenry will never be completely solved. As in other areas, such problems that exist along the Colorado Front Range stem from several causes:

1) Urban and suburban expansion is motivated most strongly by short-term profit, with little regard to the presence of sand and gravel deposits or of potential geologic hazards.
2) Flood plains and low terrace lands appeal to many home buyers and developers; but often such lands also represent prime sources of high-quality sand and gravel, as well as areas of flood hazards.
3) Areas of extensive aggregate extraction that once were beyond most growth areas are now surrounded by new developments, forcing gravel trucks to operate through residential zones and already congested commercial districts (Fig. 8).

Figure 8. Spreading urbanization eventually conflicts with once isolated sand and gravel operations. View to west up the Clear Creek valley toward Golden and the Front Range. Photograph by M. E. Gardner, U. S. Geological Survey.

4) Urbanization, as it covers valuable aggregate deposits, forces extractors to mine farther away from principal markets. The increased haulage costs are paid for by the consumer.
5) As urbanization and mining proceed away from metropolitan areas, the agricultural sector becomes involved in land-use conflicts (Fig. 9). Flood-plain and terrace lands in many places provide rich soil and irrigation water for farming.

Figure 9. Existing land-use conflicts between farm land, gravel deposits, and industrialization in the flood plain of the Cache la Poudre River. View to the northwest across the Cache la Poudre River flood plain toward the Kodak plant, Weld County. Photograph by W. P. Rogers, Colorado Geological Survey.

6) In past years, sand and gravel companies have not been required to rehabilitate the land they have mined.
7) In the search for new aggregate sources, extractors have encountered strong resistance from environmental groups concerned with the effects of mining, truck traffic, proximity to residential areas, blasting, rehabilitation of mined areas, and potential damage to existing ecosystems.

Although the problems and considerations are complexly interrelated, solutions may come about sooner through public awareness of the importance of sand and gravel, through adequate legislation and planning funds, and through the cooperative efforts of various technical, social, industrial, and governmental groups. More emphasis should be placed on the fact that mined lands have important economic potential for everyone. For example, the concept of multiple or sequential land use has long been realized in many parts of the country. Some aggregate lands can be mined, landfilled, and developed for residential, industrial, and agricultural use (Fig. 10). Other mined lands can be converted directly into attractive recreational sites (Fig. 11). The overall result of sequential use of lands underlain by aggregate deposits is an increased value to the community that may be spread over many decades.

Figure 10. Hutchinson Building Corporation sand and gravel operation on the future site of their Green Mountain subdivision. Sequential utilization of land conserves resources and maximizes profits. Gravel-capped Mount Carbon and Bear Creek valley are in the middle ground. View is to the south from Alameda Parkway near Green Mountain, Jefferson County. Photograph by P. C. Wicklein.

Figure 11. Western Paving Construction Company's Gordon Lake property at 64th Avenue and Pecos Street, Adams County. The lake is on the site of an abandoned sand and gravel pit in Clear Creek valley. Photograph by M. E. Gardner, U. S. Geological Survey.

With the passage of House Bill 1529 and of the Open Mining Land Reclamation Act of 1973 (Appendix 3), Colorado has taken a positive step toward mineral-aggregate conservation and land use. These laws will effectively complement such recent legislation as the 1972 Senate Bill 35 and the 1974 land-use act, House Bill 1041. Utilizing the basic mapping herein provided, the particular governing agencies are directed by HB 1529 to prepare master plans that will preserve valuable aggregate deposits by zoning for mineral extraction or by prohibiting zoning changes that would hinder extraction. In order to properly plan for resource utilization, a time frame for planning should be established. It has been suggested by advisory committee members that the next 20 yrs may be a logical unit of time upon which to base plans. In addition, estimates of the quantities of minable gravels and estimates of annual consumption for the planning period should be made in conjuction with gravel producers, contractors, and public works organizations.

The input of various disciplines is essential to the success of each master plan. The continuing efforts of geologists, hydrologists, engineers, geophysicists, geographers, agriculturalists, environmentalists, economists, and gravel producers, as well as that of various governmental and civic groups, can be of immeasurable value during the development, implementation, and revision of each plan. Liaison among neighboring counties, including those not under HB 1529 jurisdiction, is vital in resolving problems of regional or mutual concern. Successful mineral-aggregate conservation and land-use planning depend upon teamwork and the cooperation of all Colorado citizens.

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APPENDIX 1

Table of grain-size terminology

Wentworth

Component		mm	in.	U. S. sieve series
Gravel	Boulder			
		256	10	
	Cobble			
		64	2 1/2	2 1/2-in.
	Pebble			
		4	5/32	#5
Sand	Granule			
		2	5/64	#10
	Very Coarse			
		1	0.0394	#18
	Coarse			
		1/2	0.0197	#35
	Medium			
		1/4	0.0098	#60
	Fine			
		1/8	0.0049	#120
	Very Fine			
		1/16	0.0025	#230
Silt				
		1/256	0.00015	#400
Clay				

Unified Soil Classification

U. S. sieve series	mm	in.	Component	
				Cobbles
3-in.	76.1	3		
			Coarse	Gravel
3/4-in.	19.0	3/4		
			Fine	Gravel
#4	4.76	0.187		
			Coarse	Sand
#10	2.00	5/64		
			Medium	Sand
#40	0.42	0.0165		
			Fine	Sand
#200	0.074	0.0029		
				Fines (silt & clay)

Modified Unified Soil Classification

U. S. sieve series	mm	in.	Component		
				Boulders	Gravel
	256	10			
				Cobbles	Gravel
3-in.	76.1	3			
			Coarse	Pebbles	Gravel
3/4-in.	19.0	3/4			
			Fine	Pebbles	Gravel
#4	4.76	0.187			
			Coarse	Sand	
#10	2.00	5/64			
			Medium	Sand	
#40	0.42	0.0165			
			Fine	Sand	
#200	0.074	0.0029			
				Fines (silt & clay)	

The grain size terms used in this report are adapted from two other common systems. The first system is the Wentworth scale, which is based on a modified geometric progression. The gravel cutoff is placed at 2 mm (5/64-in.; #10 screen) and that for sand is placed at 1/16 mm (0.0025 in.; #230 screen). This is the standard scale used in most geologic descriptions. The second scale is the Unified Soil Classification, an engineering scale with the gravel cutoff at 4.76 mm (0.187 in.; #4 screen) and the sand cutoff at 0.074 mm (#200). This report uses the Unified Soil Classification modified by the addition of the Wentworth gravel terms. For visual classification (as in the map explanation) the 1/4-in. size may be used as equivalent to the #4 sieve size (Asphalt Institute, 1969, p. 69-86).

APPENDIX 2

Production of sand and gravel, stone and crushed rock[1] in the Front Range counties.
(thousand short tons)

Year	Adams		Arapahoe		Boulder		Denver	Douglas		El Paso		Jefferson		Larimer		Pueblo		Weld	
	s/g	s/cr	s/g	s/cr	s/g	s/cr	s/g	s/g	s/cr[2]	s/g	s/cr	s/g	s/cr	s/g	s/cr	s/g	s/cr	s/g	s/cr
1954	1400	-	564	-	-	-	-	145	-	674	-	658	-	349	-	940[4]	-	-	-
1955	W	-	763	-	-	-	-	60	-	518	-	660	-	333	-	986[4]	-	-	-
1956	2358	-	1430	-	505	-	-	312	-	994	-	987	-	493	-	986[4]	-	-	-
1957	2345	-	1640	-	399	-	340	67	-	1317	-	2037	-	291	-	992[4]	-	-	-
1958	1648	-	1693	-	619	-	-	136	-	1826	574.6	1534	-	749	-	2454	-	-	-
1959	3229	W	1521	0.25	839	4.79	-	321	2.15	1315	W	1458	3.11	476	827.78	1133	1.13	1243	4.28
1960	3344	22.54	1288	-	527	4.32	-	288	3.24	1377	W	2044	4.67	833	791.66	1042	12.49	1102	4
1961	3330	7.92	1683	4.05	535	8.48	-	562	0.70	1113	W	1985	12.19	457	866.31	571	0.04	1101	13.25
1962	3644	3.29	1482	6.52	591	8.77	-	553	1.09	917	W	2422	30.42	468	887.53	722	-	818	4.72
1963	3178	0.56	1093	0.22	692	37.34	W	526	59.79	1291	W	1988	21.15	1337	864.90	1257	11.34	800	58
1964	-	2.77	1383	40.87	1025	31.20	W	507	6.9	1547	508.4	1995	27.14	730	804.17	912	0.72	2400	7.85
1965	2797	1.55	1227	9.97	1169	131.21	-	635	24.39	1171	523.3	2251	13.36	1432	668.64	1210	1.57	403	0.89
1966	2717	2.21	1024	14.37	1387	44.94	-	608	86.07	1409	450.5	2199	25.47	973	671.62	2008	11.95	873	10.78
1967	3057	2.98	1011	23.42	1789	45.04	-	754	17.93	1023	W	1620	56.27	1099	727.48	1033	W	525	52.27
1968	3401	0.50	1212	2.30	1244	97.22	-	435	W	1550	W	2407	23.55	1098	496.97	1032	W	699	2.91
1969	2582	1.72[3]	858	0.96	1770	11.85	-	407	10.62	1285	W	2191	88.66	678	520.62	943	-	545	-
1970	2794	W	1562	-	1596	228[5]	W	611	15[6]	1453	-	2228	W	676	W	1299	-	668	-
1971	3047	-	1386	-	3051	W	129	1312	W	3010	-	2117	W	1130	560	1093	3[3]	250	3[3]

[1]Stone sold or used by producers
[2]Silica rock
[3]Granite
[4]Sand, gravel, clay
[5]Sandstone, limestone, granite
[6]Dolomite, quartz, traprock, other
W = information withheld
\- = no data listed

Sources of information: U. S. Bureau of Mines Minerals Yearbooks, 1959-1971. Colorado Division of Mines Annual Reports, 1954-1958.

COLORADO

OPEN MINING LAND RECLAMATION ACT

The following statutes concern the reclamation of land affected by the mining of natural mineral deposits of limestone used for construction purposes, coal, sand, gravel and quarry aggregate, by removing the overburden lying above such deposits and mining directly from the deposits thereby exposed and reclamation to take place during the after such activities. The act and the provisions thereof are effective on and after July 1, 1973. They are printed for information and compliance.

92-13-1. Short title. – This article shall be known and may be cited as the "Colorado Open Mining Land Reclamation Act of 1973".

92-13-2. Declaration of policy. – It is hereby declared to be the policy of this state to provide, during the mining process and after mining operations have been completed, for the reclamation of land subjected to surface disturbance by open mining and thereby conserve natural resources, aid in the protection of wildlife and aquatic resources, and establish recreational, home, and industrial sites, to protect and perpetuate the taxable value of property, and to protect and promote the health, safety, and general welfare of the people of this state.

92-13-3. Definitions. – (1) As used in this article, unless the context otherwise requires:

(2) "Overburden" means all of the earth and other materials which lie above natural mineral deposits of limestone used for construction purposes, coal, sand, gravel, and quarry aggregate, and also means such earth and other materials disturbed from their natural state in the process of open mining.

(3) "Open mining" means the mining of natural mineral deposits of limestone used for construction purposes, coal, sand, gravel, and quarry aggregate, by removing the overburden lying above such deposits and mining directly from the deposits thereby exposed. The term includes, but is not limited to, such practices as open cut mining, open pit mining, strip mining, quarrying, and dredging.

(4) "Operator" means any person, firm, or corporation engaged in and controlling an open mining operation.

(5) "Affected land" means the area of land from which overburden shall have been removed, or upon which overburden has been deposited, or both, on or after July 1, 1969.

(6) "Refuse" means all waste material directly connected with the cleaning and preparation of substances mined by open mining.

(7) "Ridge" means a lengthened elevation of overburden created in the open mining process.

(8) "Peak" means a projecting point of overburden created in the open mining process.

(9) "Department" means the department of natural resources or such department, commission, or agency as may lawfully succeed to the powers and duties of such department.

(10) "Executive director" means the executive director of the department of natural resources, or such officer as may lawfully succeed to the powers and duties of such executive director.

(11) "Board" means the land reclamation board established by section 92-13-14.

(12) "Reclamation" means the employment during and after an open mining operation of procedures reasonably designed to minimize as much as practicable the disruption from the open mining operation and to provide for the rehabilitation of any such surface resources adversely affected by such open mining operations through the rehabilitation of plant cover, soil stability, water resources, and other measures appropriate to the subsequent beneficial use of such mined and reclaimed lands.

92-13-4. Necessity of permit – application to existing permits. – (1) It shall be unlawful, after July 1, 1973, for any operator to engage in new open mining without first obtaining from the department a permit so to do, in such form as provided in this article. Permits granted prior to July 1, 1973, shall be subject to the provisions of this article. No other governmental office of the state or any political subdivision of the state shall have the authority to grant the issuance of a permit. However, the department shall not grant a permit in violation of city, town, county, or city and county zoning or subdivision regulations.

(2) An operator shall be deemed to be engaged in new open mining when he removes or deposits any amount of overburden or refuse on or after July 1, 1973.

92-13-5. Application for permit – bond – fee. (1) Any operator desiring to engage in new open mining shall make written application to the board for a permit. The permit, if approved, shall authorize the operator to engage in open mining upon the area of land described in his application until June thirtieth of the fifth year following approval of the permit.

(2) (a) An operator desiring a permit shall file an application which shall state:

(b) The legal description and area of land to be affected by the operation;

(c) The owner or owners of the surface of the area of land to be affected;

(d) The owner or owners of the substance to be mined;

(e) The source of the applicant's legal right to enter and open mine on the land affected by the permit;

(f) The address of the general office and the local address or addresses of the applicant;

(g) Whether the applicant or any affiliated person holds or has held any other permits under this article, and an identification of such permits;

(h) The detailed description of the method of operation to be employed;

(i) The size of the area or areas to be worked at any one time; and

(j) The timetable giving the periods of time which will be required for the various stages of the operation.

(3) (a) The application for a permit shall be accompanied by two copies of an accurate map of the area affected. The map shall:

(b) Be made by a qualified person, registered land surveyor, or professional engineer;

(c) Identify the area which corresponds with the application;

(d) Show adjacent deep mining and adjacent surface owners;

(e) Be made to a scale of not less than one hundred feet to the inch and not to exceed six hundred sixty feet to the inch;

(f) Show the name and location of all creeks, roads, buildings, oil and gas wells and lines, and power and communication lines on the area of affected land and within two hundred feet of all boundaries of such area;

(g) Show the total area to be involved in the operation including the area to be mined and the area of land affected;

(h) Show the topography of the area with contour lines of sufficient detail to portray the direction and rate of slope of the land in question;

(i) Indicate the general type, thickness and distribution of soil over the area in question.

(j) Show the type, character, and density of present vegetation covering the area in question;

(k) Show the depth and thickness of the coal, sand, gravel, quarry aggregate, or limestone used for construction purposes, to be mined and the thickness and type of the overburden to be removed; and

(l) Show the expected physical appearance of the area to be mined and the area of land affected, correlated to the timetable required by paragraph (j) of subsection (2) of this section.

(4) A basic fee of fifty dollars plus fifteen dollars for each acre or fraction thereof of the area of land to be affected by the operation shall be paid before the issuance of the permit and shall accompany the application. The application shall also be accompanied by a bond meeting the requirements of section 92-13-8.

(5) (a) Upon receipt of an application, fee, and bond or security as required by this article, the board shall review the application and accompanying maps and issue a permit if:

(b) The method of operation, physical appearance, and timetable are reasonable in view of the public interest in physically attractive surroundings and completion of the operation as soon as practicable;

(c) The operator makes a satisfactory showing to the board that his operation will not adversely affect the stability of any man-made structure on the area of the affected land and within two hundred feet of all boundaries of such area;

(d) In the case of an application for a permit to extract sand, gravel, and quarry aggregate, the extractor shall complete such extraction and begin reclamation within five years after the initial permit is issued. All reclamation is to be completed within three years after the date the operator advises the board that reclamation has commenced as provided in section 92-13-6 (1) (a) (i).

(6) An operator may within the term of a permit apply to the board for a permit renewal or for an amendment to the permit increasing or decreasing the acreage to be affected. There shall be filed with any application for amendment a map and form with the same content as required for an original application, and the application shall be accompanied by a basic fee of ten dollars plus a fee of fifteen dollars for each acre or fraction thereof by which the original area is to be increased and a supplemental bond for such additional acreage. If the area of the original application is reduced, the amount of the bond shall proportionately be reduced. Renewal applications shall contain the information required in the original application if different from that in the original application or renewal. The renewal permit shall show the area mined or disturbed and the area reclaimed since the original permit or the last renewal. Applications for renewal or amendment of a permit shall be reviewed by the board in the same manner as provided in subsection (5) of this section with regard to applications for new permits.

92-13-6. Duties of Operator. – (1) (a) Every operator to whom a permit is issued pursuant to the provisions of this article may engage in open mining upon the lands described in the permit, upon the performance of and subject to the following requirements with respect to such lands:

(b) On or before July 1 of each year the operator shall submit a reclamation plan and map showing the affected area and other pertinent details, such as roads and access to the area, and reclamation accomplished. All maps shall show quarter section, section, township, and county lines within the scope of the map, access to the area from the nearest public road, a meridian, a title containing the name of the operator and his address, the scale of the map, the name of the person or engineer who prepared the map, the date, and the township, range, and county. The reclamation plan prepared by the operator shall be based upon provisions for, or satisfactory explanation of, all general requirements for the type of reclamation chosen. The details of the plan shall be appropriate to the type of reclamation designated by the operator and based upon the advice of technically trained personnel experienced in that type of reclamation on open mined lands and upon scientific knowledge from research in reclaiming and utilizing open mined lands.

(c) Grading shall be carried on by striking off ridges to a width of not less than fifteen feet at the top and peaks to a width of not less than fifteen feet at the top. In all cases, an even or gently undulating skyline will be a major objective.

(d) Earth dams shall be constructed in final cuts of all operations, where practical, if necessary to impound water, if the formation of such impoundments will not interfere with mining operations or damage adjoining property.

(e) Acid forming material in the exposed face of a mineral seam that has been mined shall be covered with earth or spoil material to a depth which will protect the drainage system from pollution, unless covered with water to a depth of not less than four feet.

(f) All refuse shall be disposed of in a manner that will control stream pollution, unsightliness, or deleterious effects from such refuse, and water from the mining operation shall be diverted in a manner designed to control siltation, erosion, or other damage to streams and natural watercourses.

(g) On all affected land, the operator, subject to the approval of the board, shall determine which parts of the affected land shall be reclaimed for forest, range, crop, horticultural homesite, recreational, industrial, or other uses, including food, shelter, and ground cover for wildlife. Prior to approving any new reclamation plan or approving a change in any existing reclamation plan as provided in this section, the board shall confer with the local board of county commissioners and the board of supervisors of the soil conservation district if the open mining operation is within the boundaries of a soil conservation district. Reclamation shall be required on all the affected land.

(h) If the operator's choice of reclamation is forest planting, he may, with the approval of the department, select the type of trees to be planted. Tree planting shall be carried out based on a spacing of approximately ten feet by ten feet, and approximately four hundred thirty-five trees per acre. Planting methods and care of stock shall be governed by good planting practices. If the operator is unable to acquire sufficient planting stock of desired tree species from the state or elsewhere, at a reasonable cost, he may defer planting until planting stock is available to plant such land as originally planned, or he may select an alternate method of reclamation.

(i) The operator shall construct fire lanes or access roads when necessary through the area to be planted. These lanes or roads shall be available for use by the planting crews, and shall serve as a means of access for supervision and inspection of the planting work.

(j) On lands owned by the operator, the operator may permit the public to use the same for recreational purposes in accordance with the limited landowner liability law contained in article 4 of chapter 62, C.R.S. 1963, except in areas where such use is found by the operator to be hazardous or objectionable.

(k) If the operator's choice of reclamation is for range, he shall strike off all the peaks and ridges to a width of not less than fifteen feet, in accordance with the other requirements of this article, prior to the time of seeding. To the greatest extent possible, the affected land shall be restored to slopes commensurate with the proposed land use and shall not be too steep to be traversed by livestock, subject to the approval of the board. The legume seed shall be properly inoculated in all cases. The area may be seeded either by hand, power, or the aerial method. The species of grasses and legumes and the rates of seeding to be used per acre shall be determined primarily by recommendations from the agricultural experiment stations established pursuant to article 13 of chapter 124, C.R.S. 1963, and experienced reclamation personnel of the operator, after considering other research or successful experience with range seeding. No grazing shall be permitted on reclaimed land until the planting is firmly established. The board in consultation with the landowner and the local soil conservation district, if any, shall determine when grazing may start.

(l) If the operator's choice of reclamation is for agricultural or horticultural crops which normally require the use of farm equipment, the operator shall grade off peaks and ridges and fill valleys, except the highwall of the final cut, so that the area can be traversed with farm machinery. Preparation for seeding or planting, fertilization, and seeding or planting rates shall be governed by general agricultural and horticultural practices, except where research or experience in such operations differs with such practices.

(m) If the operator's choice of reclamation is for the development of the affected area for homesite, recreational, industrial, or other uses, including food, shelter, and ground cover for wildlife, the basic minimum requirements necessary for such reclamation shall be agreed upon by the operator and the board.

(n) (i) All reclamation provided for in this section shall be carried to completion by the operator with all reasonable diligence and shall be completed prior to the expiration of three years after the date on which the operator advises the board that reclamation work has commenced, except that:

(ii) No planting of any kind shall be required to be made on any affected land being used or proposed to be used by the operator for the deposit or disposal of refuse until after the cessation of operations productive of such refuse, or proposed for future mining, or within depressed haulage roads or final cuts while such roads or final cuts are being used or made, or any area where permanent pools or lakes have been formed;

(iii) No planting of any kind shall be required on any affected land, so long as the chemical and physical characteristics of the surface and immediately underlying material of such affected land are toxic, deficient in plant nutrients, or composed of sand, gravel, shale, or stone to such an extent as to seriously inhibit plant growth and such condition cannot feasibly be remedied by chemical treatment, fertilization, replacement of overburden, or like measures. Where natural weathering and leaching of any of such affected land, over a period of ten years after the end of the year in which open mining was completed thereon, fails to remove the toxic and physical characteristics inhibitory to plant growth, or if, at any time within such ten-year period, the board determines any of such affected land is and during the remainder of said ten-year period will be unplantable, the operator's obligations under the provisions of this article with respect to such affected land may, with the approval of the board, be discharged by reclamation of an equal number of acres of land previously mined and owned by the operator not otherwise subject to reclamation under this article. With the approval of the board, the operator may substitute, for all or any part of the affected land to be reclaimed, an equal number of acres of land previously mined and not reclaimed. If any area is so substituted, the operator shall submit a map of the substituted area, which map shall conform to all of the requirements with respect to other maps required by this article. Upon completion of reclamation of the substituted land, the operator shall be relieved of all obligations under this article with respect to the land for which substitution has been permitted.

92-13-7. Entry upon lands for inspection. – The board, bureau of mines of the state of Colorado, the chief inspector of coal mines, or their authorized representatives may enter upon the lands of the operator at all reasonable times for the purpose of inspection to determine whether the provisions of this article have been complied with.

92-13-8. Bond of operator – amount – sufficiency of surety – violations-compliance. (1) Any bond required under this article to be filed by the operator shall be in such form as the board prescribes, payable to the state of Colorado, conditioned that the operator shall faithfully perform all requirements of this article and comply with all rules and regulations made in accordance with the provisions of this article. Such bond shall be signed by the operator as principal and by a good and sufficient corporate surety authorized to do business in this state. The penalty of such bond shall be in such amount as the board deems necessary to insure the performance of the duties of the operator under this article with respect to the affected land. If a county or municipality requires, in the opinion of the board, an adequate reclamation plan and a bond sufficient to carry out that plan, evidence of such plan and bond shall be acceptable to the board. In lieu of such bond, the operator may deposit cash and government securities with the board in an amount equal to that of the required bond on conditions as prescribed in this subsection (1). In the discretion of the board, surety bond requirements may also be fulfilled by using existing reclaimed areas if owned by the operator in excess of cumulative permit or mined acres that have been reclaimed under the provisions of this article and approved by the board. The penalty of the bond or amount of cash and securities shall be increased or reduced from time to time, as provided in this article. Such bond or security shall remain in effect until the mined acreages have been reclaimed, approved, and released by the board.

(2) A bond filed as above prescribed shall not be cancelled by the surety without giving at least sixty days' notice to the board prior to the anniversary date of its intent to limit exposure to existing circumstances as of the next anniversary date. In such event the operator shall provide substitute surety covering operations or post cash bond in lieu thereof.

(3) If the license to do business in this state of any surety upon a bond filed with the board pursuant to this article shall be suspended or revoked, the operator, within sixty days after receiving notice thereof from the board, shall substitute for such surety a good and sufficient corporate surety licensed to do business in the state. Upon failure of the operator to make substitution of surety, the board shall have the right to suspend the permit of the operator to conduct operations upon the land described in such permit until such substitution has been made.

(4) The board shall have the power to reclaim, in accordance with the provisions of this article, any affected land with respect to which a bond has been forfeited.

(5) Whenever an operator shall have completed all requirements under the provisions of this article as to any affected land, he shall notify the board. If the board shall release the operator from further obligations regarding such affected land, the penalty of the bond shall be reduced proportionately.

92-13-9. Violations – administrative procedures – appeals from orders of the board. – (1) Whenever the board determines that an operator has not complied with the provisions of this article, the board shall, by private conference, conciliation, and persuasion, endeavor to remedy such violation. In case of the failure of such conference, conciliation, and persuasion to remedy any alleged violation, the board may cause to have issued and served upon the operator alleged to be committing such violation a written notice which shall specify the provision of this article which such operator allegedly is violating, and a statement of the manner in and the extent to which said operator is alleged to be violating this article, and shall require the operator so complained against to answer the charges of such formal complaint at a hearing before the board at a time not less than thirty days after the date of the notice. The board shall issue subpoenas at the request of the charged operator, requiring the attendance of witnesses and the production of such papers and documents as are relevant to such hearing. At such hearing, the charged operator may appear in person or by counsel, testimony shall be taken under oath and recorded stenographically, and the charged operator may cross-examine witnesses. A copy of the record of such hearing shall be furnished to the charged operator upon payment of the cost thereof. The board shall enter such order as it deems appropriate to effectuate the purposes of this article and shall forthwith mail a copy thereof to the charged operator or the operator's attorney of record. If such order of the board is not complied with in the required time, the board may then commence proceedings under section 92-13-13.

(2) An operator subjected to any order of the executive director or the board, including an order of refusal to issue or amend a permit, as the case may be, may institute proceedings to have such order reviewed in a court of competent jurisdiction in accordance with the provisions of section 3-16-5, C.R.S. 1963. The filing of such court proceedings shall stay the enforcement of such order.

92-13-10. Fees and forfeitures – deposit. – All fees and forfeitures collected under the provisions of this article shall be deposited in the general fund.

92-13-11. Administration. – In addition to the duties and powers of the department prescribed by the provisions of article 16 of chapter 3, C.R.S. 1963, as amended, it shall have full power and authority to carry out and administer the provisions of this article.

92-13-12. Rules and regulations. – The board may adopt and promulgate reasonable rules and regulations respecting the administration of this article and in conformity therewith.

92-13-13. Bond forfeiture proceedings – prerequisites – penalties. – (1) Subject to the provisions of section 92-13-9, the attorney general, upon request of the board, shall institute proceedings to have the bond of the operator forfeited for violation by the operator of an order entered pursuant to section 92-13-9. Before making such request of the attorney general, the board shall notify the operator in writing of the alleged violation of or noncompliance with such order and shall afford the operator the right to appear before the board at a hearing to be held not less than thirty days after the receipt of such notice by the operator. At the hearing the operator may present for the consideration of the board statements, documents, and other information with respect to the alleged violation. After the conclusion of the hearings, the board shall either withdraw the notice of violation or shall request the attorney general to institute proceedings to have the bond of the operator forfeited as to the land involved.

(2) Any person required by this article to have a permit who engages in new open mining without previously securing a permit to do so as prescribed by this article, is guilty of a misdemeanor, and upon conviction thereof shall be fined not less than fifty dollars nor more than one thousand dollars. Each day of operation without the permit required by this article shall be deemed a separate violation.

92-13-14. Land reclamation board – created. – (1) There is hereby created as a part of the division of mines in the department of natural resources the land reclamation board.

(2) The board shall consist of five members: The executive director of the department of natural resources, who shall be chairman; the deputy commissioner of mines; the chief inspector of coal mines; the state geologist; and a member of the state soil conservation board designated by such board. The members of the board shall receive no additional compensation for their services on the board but shall be reimbursed for necessary expenses incurred in the performance of their duties on the board.

(3) The board shall exercise its powers and perform its duties and functions specified in this article under the department of natural resources as if the same were transferred to the department by a type 1 transfer as such transfer is defined in the "Administrative Organization Act of 1968", being article 28 of chapter 3, C.R.S. 1963.

92-13-15. Duties of the board. – (1) (a) The board shall:

(b) Meet at least once each month;

(c) Carry on a continuing review of the problems of open mining and land reclamation in the state of Colorado;

(d) Develop and promulgate standards for land reclamation plans and substitution of affected lands as provided in section 92-13-6;

(e) Administer the land reclamation fund and determine the order of priority of reclamation of previously open mined lands as funds are available.

(2) It shall be the duty of the department of agriculture, department of higher education, state soil conservation board, Colorado geological survey, division of game, fish, and parks, the university of Colorado, Colorado state university, Colorado school of mines and the state forester to furnish the board and its designees, as far as practical, whatever data and technical assistance the board may request and deem necessary for the performance of total reclamation and enforcement duties.

92-13-16. Powers of board. – The board may: Initiate and encourage studies and programs through the department and in other agencies and institutions of state government relating to the development of less destructive methods of open mining; better methods of land reclamation; more effective reclaimed land use; and coordination of the provisions of this article with the programs of other state agencies dealing with environmental, recreational, rehabilitation, and related concerns.

92-13-17. Operators – succession. – (1) (a) Where one operator succeeds another at any uncompleted operation, the board may release the first operator from all liability as to that particular reclamation operation and may release his bond as to such operation if:

(b) Both operators have been issued a permit with respect to the operation;

(c) Both operators are in full compliance with the requirements of this article as to all of their operations within this state; and

(d) The successor operator assumes as part of his obligation under this article all liability for the reclamation of the land affected by the operation and his obligation is covered by an appropriate bond as to such affected land.

92-13-18. Permit refused defaulting operator. – No permit for new open mining shall be granted to any operator who is currently found to be in violation of the provisions of this article with respect to any operation in this state.

92-36-1. Legislative declaration. – (1) (a) The general assembly hereby declares that:

(b) The state's commercial mineral deposits are essential to the state's economy.

(c) The populous counties of the state face a critical shortage of such deposits.

(d) Such deposits should be extracted according to a rational plan, calculated to avoid waste of such deposits and cause the least practical disruption of the ecology and quality of life of the citizens of the populous counties of the state.

(2) The general assembly further declares that, for the reasons stated in subsection (1) of this section, the regulation of commercial mineral deposits, the preservation of access to and extraction of such deposits, and the development of a rational plan for extraction of such deposits are matters of concern in the populous counties of the state. It is the intention of the general assembly that the provisions of this article have full force and effect throughout such populous counties, including, but not limited to, the city and county of Denver and any other home rule city or town within each such populous county but shall have no application outside such populous counties.

92-36-2. Definitions. – (1) As used in this article, unless the context otherwise requires:

(2) "Commercial mineral deposit" means a natural mineral deposit of limestone used for construction purposes, coal, sand, gravel, and quarry aggregate, for which extraction by an extractor 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.

(3) "Extractor" means any individual, partnership, association, or corporation which extracts commercial mineral deposits for use in the business of selling such deposits or for use in another business owned by the extractor or any department or division of federal, state, county, or municipal government which extracts such deposits.

(4) "Populous county or populous counties of the state" means any county or city and county having a population of sixty-five thousand inhabitants or more according to the latest federal decennial census.

92-36-3. Geological survey to make study. – After July 1, 1973, the Colorado geological survey shall contract for a study of the commercial mineral deposits in the populous counties of the state in order to identify and locate such deposits. Such study shall be of sand, gravel, and quarry aggregate, and shall be completed on or before July 1, 1974, and shall include a map or maps of the state showing such commercial mineral deposits, copies of which may be generally circulated. Any commercial mineral deposits discovered subsequent to July 1, 1974, may be, upon discovery, included in such study.

92-36-4. Master plan for extraction. – (1) (a) The county planning commission for unincorporated areas and for cities and towns having no planning commission or the planning commission for each city and county, city, or town, within each populous county of the state, shall, with the aid of the map or maps from the study conducted pursuant to section 92-36-3, conduct a study of the commercial mineral deposits located within its jurisdiction and develop a master plan for the extraction of such deposits, which plan shall consist of text and maps. In developing the master plan, the planning commission shall consider, among others, the following factors:

(b) Any system adopted by the Colorado geological survey grading commercial mineral deposits according to such factors as magnitude of the deposit and time of availability for and feasibility of extraction of a deposit;

(c) The potential for effective multiple-sequential use which would result in the optimum benefit to the landowner, neighboring residents, and the community as a whole;

(d) The development or preservation of land to enhance development of physically attractive surroundings compatible with the surrounding area;

(e) The quality of life of the residents in and around areas which contain commercial mineral deposits.

(f) Other master plans of the county, city and county, city, or town;

(g) Maximization of extraction of commercial mineral deposits; and

(h) The ability to reclaim an area pursuant to the provisions of article 13 of this chapter.

(2) A planning commission shall cooperate with the planning commissions of contiguous areas and the land reclamation board created by section 92-13-14 in conducting the study and developing the master plan for extraction.

(3) (a) A county planning commission shall certify its master plan for extraction to the board of county commissioners or the governing body of the city or town where the county planning commission is acting in lieu of a city or town planning commission. A planning commission in any city and county, city, or town shall certify its master plan for extraction to the governing body of such city and county, city, or town.

(b) After receiving the certification of such master plan and before adoption of such plan, the board of county commissioners or governing body of a city and county, city, or town shall hold a public hearing thereon, and at least thirty days' notice of the time and place of such hearing shall be given by one publication in a newspaper of general circulation in the county, city and county, city, or town. Such notice shall state the place at which the text and maps so certified may be examined.

(4) The board of county commissioners or governing body of a city and county, city, or town may, after such public hearing, adopt the plan, revise the plan with the advice of the planning commission and adopt it, or return the plan to the planning commission for further study and rehearing before adoption, but, in any case, a master plan for extraction of commercial mineral deposits shall be adopted for the unincorporated territory and any city and county, city, or town in each populous county of the state on or before July 1, 1975.

92-36-5. Preservation of commercial mineral deposits for extraction. – (1) After July 1, 1973, no board of county commissioners, governing body of any city and county, city, or town, 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 by an extractor.

(2) After adoption of a master plan for extraction for an area under its jurisdiction, no board of county commissioners, governing body of any city and county, city, or town, 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 containing a commercial mineral deposit in a manner which would interfere with the present or future extraction of such deposit by an extractor.

(3) (a) Nothing in this section shall be construed to prohibit a board of county commissioners, a governing body of any city and county, city, or town, or any other governmental authority which has control over zoning from zoning or rezoning land to permit a certain use, if:

(b) Said use does not permit erection of permanent structures upon, or otherwise permanently preclude the extraction of commercial mineral deposits by an extractor from, land subject to said use.

(4) Nothing in this section shall be construed to prohibit a board of county commissioners, a governing body of any city and county, city, or town, or other governmental authority which has control over zoning from zoning for agricultural use, only, land not otherwise zoned on July 1, 1973.

(5) Nothing in this section shall be construed to prohibit a use of zoned land permissible under the zoning governing such land on July 1, 1973.

The following extracts of various portions of the Colorado statutes are quoted to provide additional amplification or qualifying information regarding mined land reclamation activities and related responsibilities. They are added in the order of their appearance in the statutes.

3-28-24. Department of natural resources – creation. – (3) (f) (v) The land reclamation board, created by article 13 of chapter 92, C.R.S. 1963, and its powers, duties, and functions are transferred by a *type 1* transfer to the department of natural resources as a part of the division of mines.

64-1-3. Objectives of the survey – duties of the director. – (3) The state geologist shall conduct a study and prepare a map or maps as provided in section 92-36-3, C.R.S. 1963.

(4) The state geologist shall, upon receiving a preliminary plan pursuant to section 106-2-37 (1) (j), C.R.S. 1963, or a major activity notice pursuant to section 139-59-25, C.R.S. 1963, review such plan or notice to determine whether the development or activity which is the subject of such plan or notice will interfere with the extraction of commercial mineral deposits as defined in section 92-36-2, C.R.S. 1963. If the state geologist determines that a potential for such interference exists, he shall, within twenty-four days after mailing such plan or notice, notify the appropriate board of county commissioners or governing body of a municipality of the existence of such potential interference.

106-2-5. Adoption of master plan – contents. – (3) The master plan of a county or region, with the accompanying maps, plans, charts, and descriptive and explanatory matter, shall show the county or regional planning commission's recommendations for the development of the territory covered by the plan and may include: the general location, character, and extent of streets or roads, viaducts, bridges, parkways, playgrounds, forests, reservations, parks, airports, and other public ways, grounds, places, and spaces; the general location and extent of public utilities and terminals, whether publicly or privately owned, for water, light, power, sanitation, transportation, communication, heat, and other purposes; the acceptance, widening, removal, extension, relocation, narrowing, vacation, abandonment, or change of use of any of the foregoing public ways, grounds, places, spaces, buildings, properties, utilities, or terminals; the general character, location, and extent of community centers, townsites, housing developments, whether public or private, and urban conservation or redevelopment areas; the general location and extent of forests, agricultural areas, flood control areas, and open development areas for purposes of conservation, flood and water supply, sanitary and drainage facilities, flood control, or the protection of urban development; and a land classification and utilization program. The master plan of a county or region shall also include a master plan for the extraction of commercial mineral deposits pursuant to section 92-36-4, C.R.S. 1963.

106-2-12. Regulation of size and use – districts. – (1) Except as otherwise provided in section 92-36-5, C.R.S. 1963, when the county planning commission of any county makes, adopts, and certifies to the board of county commissioners plans for zoning the unincorporated territory within any county, or any part thereof, including both the full text of a zoning resolution and the maps, after public hearing thereon, the board of county commissioners, by resolution, may regulate, in any portions of such county which lie outside of cities and towns, the location, height, bulk and size of buildings and other structures, the percentage of lot which may be occupied, the size of yards, courts, and other open spaces, the uses of buildings and structures for trade, industry, residence, recreation, public activities, or other purposes, and the uses of land for trade, industry, residence, recreation, or other purposes and for flood control. In order to accomplish such regulation, the board of county commissioners may divide the territory of the county which lies outside of cities and towns into districts or zones of such number, shape, or area as it may determine, and within such districts, or any of them, may regulate the erection, construction, reconstruction, alteration, and uses of buildings and structures and the uses of land, and may require and provide for the issuance of building permits as a condition precedent to the right to erect, construct, reconstruct, or alter any building or structure within any district covered by such zoning resolution.

139-59-25. Major activity notice. – Whenever a subdivision or commercial or industrial activity is proposed which will cover five or more acres of land, the governing body of the municipality in which the activity is proposed shall send notice to the Colorado land use commission, the state geologist, and the board of county commissioners of the county or counties in which the improvement is located of the proposal prior to approval of any zoning change, subdivision, or building permit application associated with such a proposed activity. Such notice shall be in a standard form, shall be promulgated as a rule and regulation prescribed by the land use commission, and shall contain such information as the land use commission shall prescribe.

139-60-1. Grant of power. – (1) Except as otherwise provided in section 92-36-5, C.R.S. 1963, for the purpose of promoting health, safety, morals, or the general welfare of the community, the legislative body of each city and incorporated town is empowered to regulate and restrict the height, number of stories, and size of buildings and other structures, the percentage of lot that may be occupied, the size of yards, courts, and other open spaces, the density of population, and the location and use of buildings, structures, and land for trade, industry, residence, or other purposes. Such regulations may provide that a board of adjustment may determine and vary their application in harmony with their general purpose and intent and in accordance with general or specific rules therein contained. Subject to the provisions of subsection (2) of this section, and to the end that adequate safety may be secured, said legislative body shall also have power to establish, regulate, restrict, and limit such uses on or along any storm or floodwater runoff channel or basin, as such storm or floodwater runoff channel or basin has been designated and approved by the Colorado water conservation board, in order to lessen or avoid the hazards to persons and damage to property resulting from the accumulation of storm or floodwaters. Any ordinance enacted under authority of this article shall exempt from the operation thereof any building or structure as to which satisfactory proof shall be presented to the board of adjustment provided for in this article that the present or proposed situation of such building or structure is reasonably necessary for the convenience or welfare of the public.

DEPARTMENT OF NATURAL RESOURCES
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

EXPLANATION

LANDFORM UNITS

F, V — Flood-plain (F) and Valley-fill (V) deposits: Water-deposited gravel, sand, silt, and clay along present stream courses.

T — Stream-terrace deposits: Older stream deposits now preserved as benches flanking present stream courses. Smaller and less distinct terraces are included with valley-fill deposits.

U, A — Upland deposits (U): Mesa or bench-like erosional remnants of ancient stream deposits isolated above present stream courses. Alluvial-fan deposits (A): Gently sloping, fan-shaped deposits of gravel, sand, silt, and clay produced by a stream that issued or issues from a narrow valley or point source onto an open plain or valley. Includes erosional remnants of fan deposits.

E — Wind-deposited (eolian) sand dunes.

RESOURCE CLASSIFICATION

Coarse Aggregates

1 Gravel: relatively clean and sound.

2 Gravel: significant silt, clay, incompetent rock and/or calcium carbonate (caliche).

Fine Aggregates

3 Sands: includes sands ranging from coarse gravelly stream sands to fine-grained wind-deposited dune sands.

Unevaluated Aggregates

4 Coarse and fine aggregate resources that were not evaluated because of inadequate exposures, lack of drill-hole data, location, access, poor potential, areal extent, or a prior land use that excludes the possibility of recovering aggregate.

MAP SYMBOLS

U2 — Landform unit; Resource classification

This example symbol indicates a low-quality upland gravel deposit. The gravel contains significant amounts of silt, clay, incompetent rock, and calcium carbonate (caliche).

Location of active or inactive gravel and sand pits.

Carbonates; Volcanics and Intrusives; Quartzite — Potential quarry aggregate resource area. Only the areas of most suitable rock for quarry aggregate are shown. Although some operating stone quarries lie within these potential resource areas, some quarries have been located in less suitable rock for environmental and economic reasons.

Active and inactive stone quarries.

Approximate boundaries of buried stream valleys.

Scale 1:250,000

5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers
5 0 5 10 15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

Base Map by the Army Map Service and U. S. Geological Survey

SAND, GRAVEL, AND QUARRY AGGREGATE RESOURCES OF THE COLORADO FRONT RANGE COUNTIES

BY
S.D. Schwochow, R.R. Shroba and P.C. Wicklein

1974
Graphics by Robert H. Gast

SELECTED REFERENCES

Colton, R. B., and Fitch, H. R., 1974, Map showing potential sources of gravel and crushed-rock aggregate in the Boulder-Fort Collins-Greeley area, Front Range Urban Corridor, Colorado: U. S. Geol. Survey Misc. Geol. Inv. Map I-855-D.
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Varnes, H. D., and Larrabee, D. M., 1946, Preliminary map showing sand and gravel deposits of Colorado: U. S. Geol. Survey Missouri Basin Studies No. 2.

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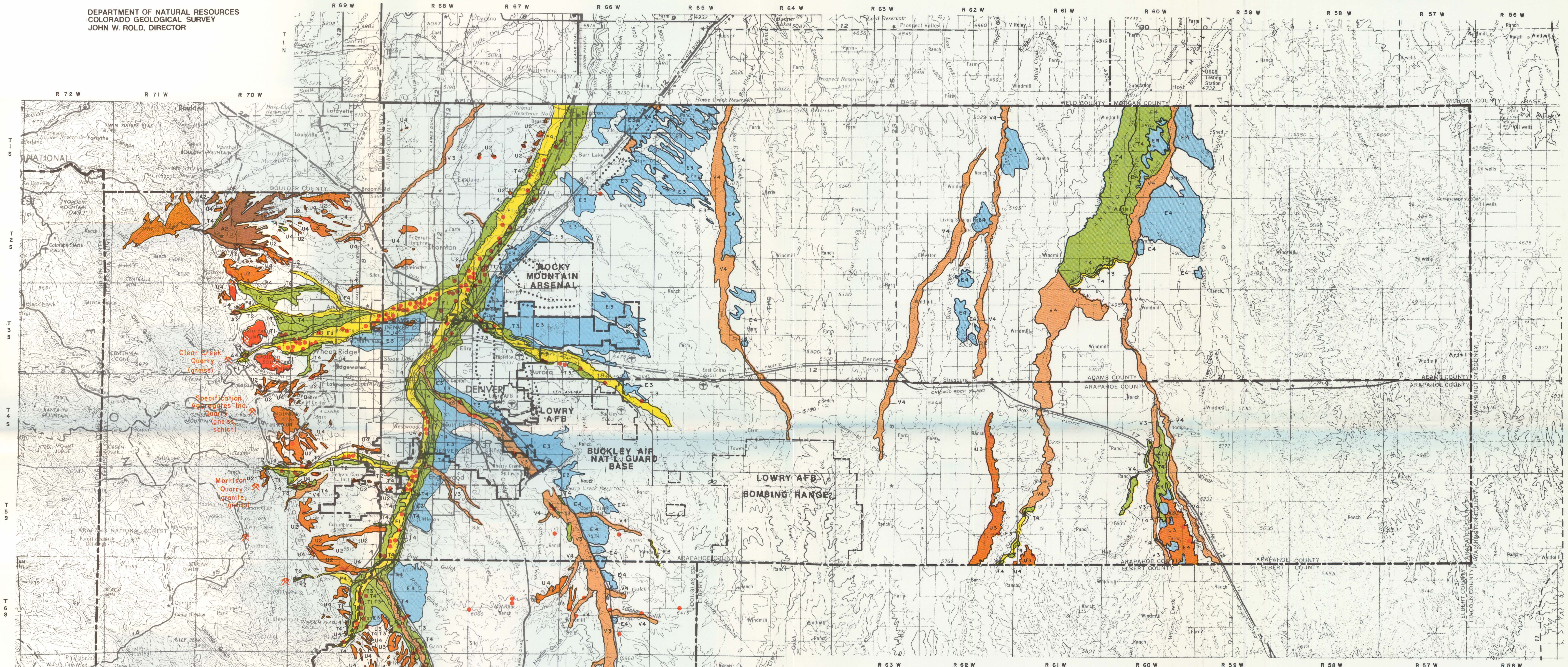

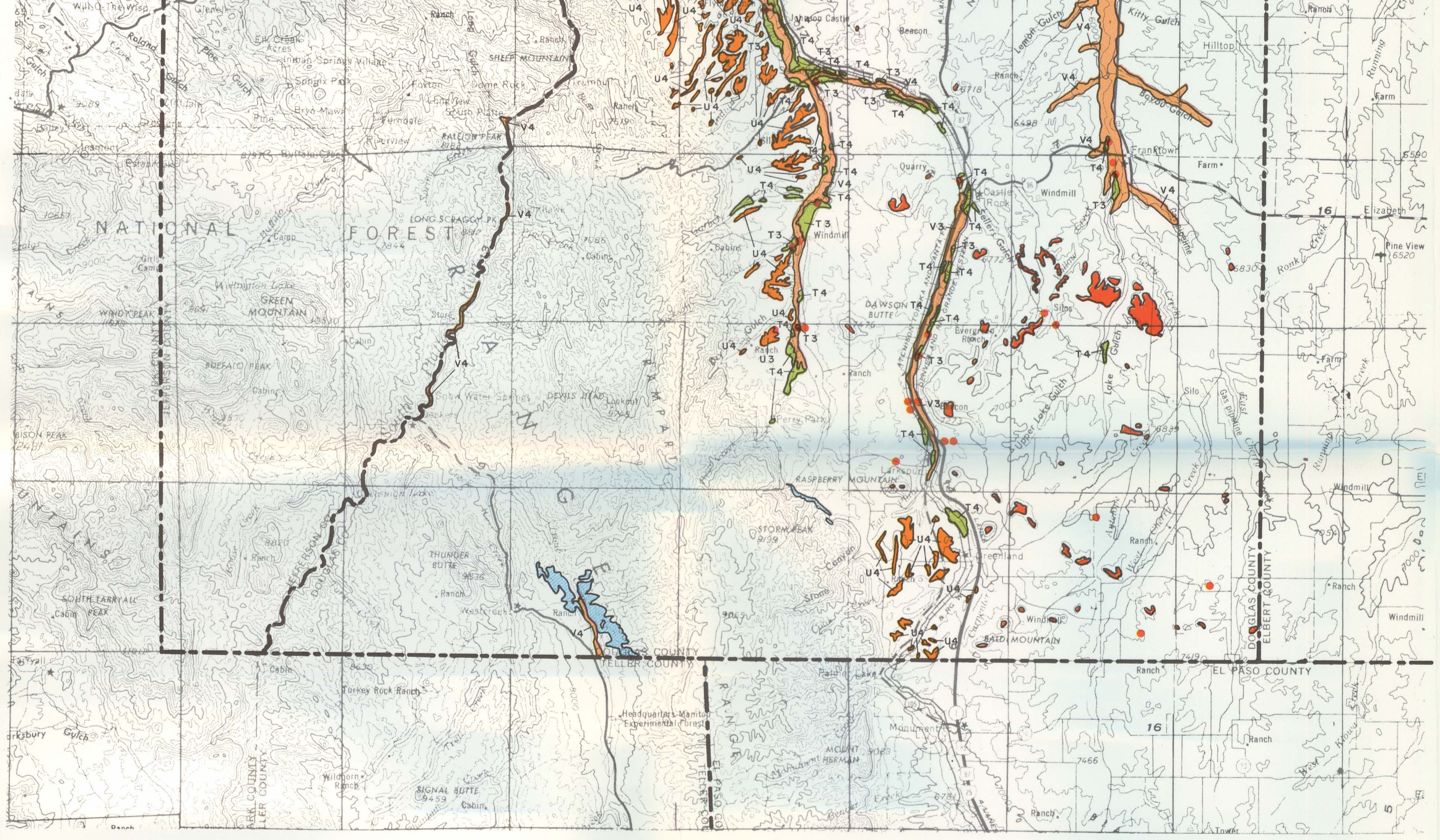

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__________ 1974b, Map showing potential sources of gravel and crushed-rock aggregate in the Greater Denver area, Front Range Urban Corridor, Colorado: U. S. Geol. Survey Misc. Geol. Survey Misc. Inv. Map I-856-A.

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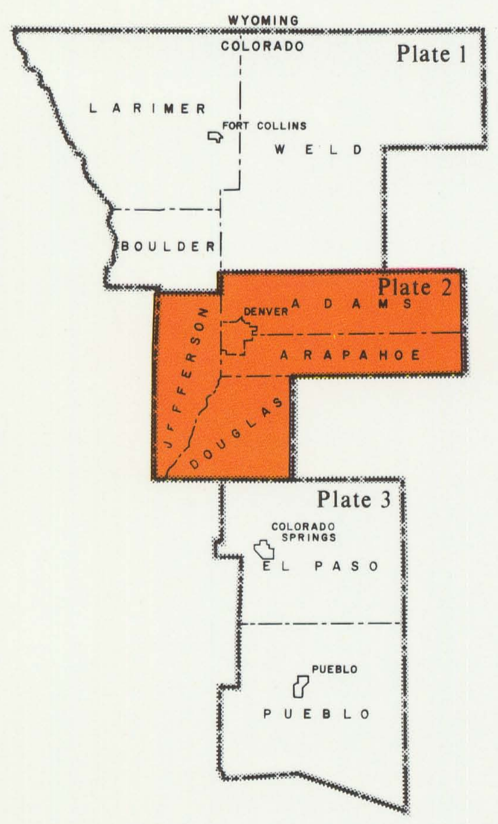

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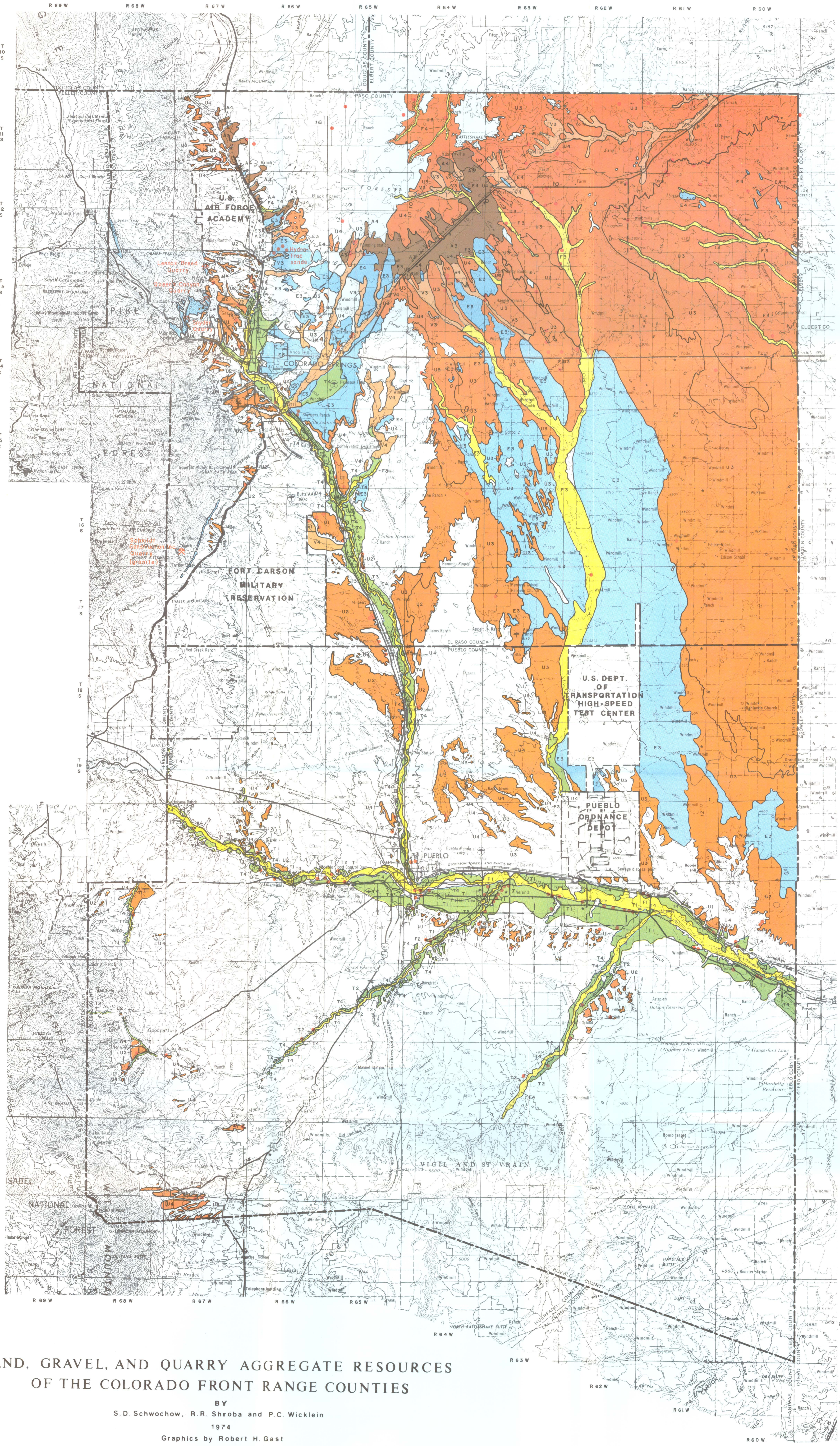
COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR

SPECIAL PUBLICATION 5-A

Plate 3



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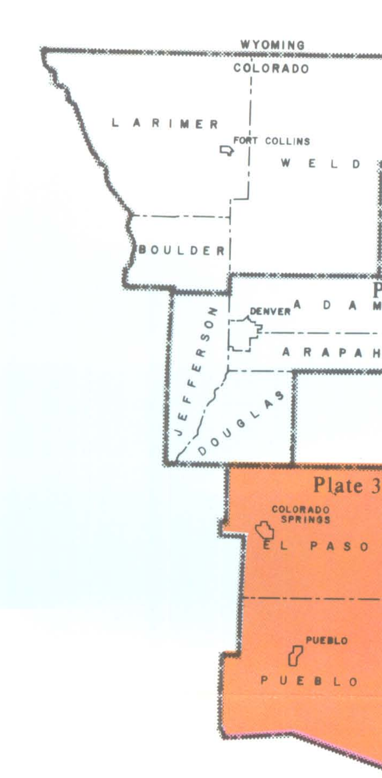

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