Preliminary Investigation of Crushed Stone Aggregate Sources in

Larimer County, Colorado

and Adjacent Areas of Albany and Laramie Counties, Wyoming.

by

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ABSTRACT

Alluvial deposits, which have been Denver Metropolitan area's major source of aggregate are being rapidly depleted. New sites for aggregate production close to Denver have been difficult to develop due to problems caused by rapid expansion of the metropolitan area. Proposed close-in sites for aggregate extraction within the greater Denver Metropolitan area have been unable to obtain operating permits because of their incompatibility with local communities. Reserves located in currently permitted and operating Denver area mines will only last until the year 2004 (Nasser, 1986). The aggregate industry will have to move further from the metro area in the near future.

The eastern part of the Front Range in north-central Colorado and southeast Wyoming has good potential as a future source of crushed stone to supply the Denver Metropolitan area. An area in Larimer County, Colorado and Albany and Laramie Counties, Wyoming, was examined for its aggregate potential in this study. Resources of the Sherman and Silver Plume Granites in the area are unlimited.

Thirteen samples were collected from potential sites throughout the area for petrographic study. Five samples
were then selected for engineering tests. Five study sites, Calloway Hill, Granite, Harriman, Livermore, and Virginia Dale, were chosen for evaluation of future development. Petrographic results indicated that samples from the five sites have sound internal structure, and no deleterious constituents. L.A. Abrasion test results from exposed surface samples at these sites have an average of 34.61% weight loss with the lowest and highest values of 20.41% and 38.96-%, respectively. Specific gravity test results range from 2.57 to 2.68 while absorption test results range from 0.36 to 0.82. These results meet Federal Highway Administration standards for general pavement usage and would meet the Federal Aviation Administration standards for the new Denver airport once unexposed fresh rock, which could not be sampled in this reconnaissance, was developed. Resource volumes at each site were estimated, environmental factors were considered, and the cost of producing material per ton was calculated, incorporating initial cost of development, production cost and transportation cost. The average estimated cost per ton delivered to Denver is $7.50, which translates to approximately $8.60 per ton sale price. According to Denver price trends, this level of sale price may be reached
in 1999, which could make development of the proposed sites economically feasible.
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1.0 INTRODUCTION

Over the last 30 years, the Denver Metropolitan area has exploited alluvial aggregate resources along major drainages in the Denver region as its source of construction materials. As in many other rapidly growing areas, these high quality resources are being depleted. Furthermore, expansion of the Denver Metropolitan area has made many valuable resource lands inaccessible to extraction.

During the last ten years, potential close-in sites for aggregate extraction within the greater Denver Metropolitan area, such as North and South Table Mountain, Clear Creek Canyon, and Coal Creek Canyon, as well as many others, have been denied applications for permits based on their incompatibility with local communities. Increased noise, dust pollution and truck traffic are cited as unacceptable.

While present sources are being depleted and permits for new sites of aggregate productions are difficult to acquire within the vicinity of the Denver Metropolitan area and its suburbs, new projects requiring large amounts of good quality rocks are being developed. These projects include the new Denver Airport and the 470 Beltway system, which will intensify the need for new aggregate sources in the near future.
At an aggregate consumption rate of 8.5 tons per capita, reserves located in currently permitted and operating Denver area mines will last 15 years, or until the year 2004 (Nasser, 1986). New locations for aggregate sources to meet future needs are essential.

Because of the considerations previously mentioned, sources of good quality aggregate from areas previously considered remote from the Denver Metropolitan area, which do not have siting problems, may become economically attractive.

1.1 Objectives

This study assesses the possibilities of developing aggregate sources in the area of north-central Colorado in Larimer County and the adjacent area of southern Wyoming in Albany and Laramie Counties as a solution to the Denver area's future aggregate needs. This study has the following objectives:

1. To determine the quality of granite in the study area as an aggregate base, using Federal Aviation Administration (FAA) standards as criteria.

2. To evaluate the possibilities of developing the granite in the study area as a long-term source of
aggregate for the Denver area, incorporating environmental factors involved in utilization.

3. To make a preliminary economic assessment of cost factors and to assess the level to which the value of aggregate in the Denver market must rise before development of mines in the study area is financially reasonable.

1.2 Location and description of the study area

The study area covers an area of approximately 900 square miles in north-central Colorado in Larimer County and extends north into southern Wyoming in Albany and Laramie Counties. Fort Collins is located just south of the study area, while Laramie and Cheyenne are situated northwest and northeast of it, respectively. The city of Denver is approximately 80 miles south of the study area. The area is east of the Rocky Mountains, within the southern Laramie Range, comprised of a rolling upland at 6,000-8,000 feet. East of the study area are the high plains at 4800 feet.

The study area is traversed northwesterly, almost diagonally, by Highway 287. Interstates 25 and 80 traverse along the east and north boundaries of the area, respectively. Two railroads are within the area, the Colorado and Southern line paralleling Interstate 25 in the eastern part
of the area and the Union Pacific line extending into the area just east of Livermore, approximately 20 miles north-west of Fort Collins, in the southern part of the area. A map of the study area showing major geographic features is presented in Figure 1.
Figure 1. Location of the Study Area (Modified after U.S. Geological Survey, 1968).
1.3 Method of study

The first stage of this study was to gather geologic information on bedrock by reconnaissance and research on available documents and to delineate the suitable units of rock. Study sites were selected to collect representative samples as well as observe field evidence. Samples were crushed to fragments varying in size to simulate crushed stone product from a quarry. Three engineering tests were performed on the crushed samples to determine their basic quality. These are (1) resistance to degradation of large-size coarse aggregate by abrasion and impact in the Los Angeles machine (L.A. Abrasion test), ASTM Method C-535, (2) specific gravity of material test, ASTM Method C-127, and (3) absorption of coarse aggregate test, ASTM Method C-127.

Another set of samples were used in thin section study in order to determine mineral compositions, grain sizes, textures, and internal structures as well as detecting possible deleterious compositions. The results from initial investigations together with the engineering and petrographic test results were then evaluated and suitable sites were chosen for further economic assessment to determine if they can be developed into production. Preliminary investigations were made from present physiography of the chosen sites to
determine if any of them would be susceptible to environmental problems.

For each site resource volume was estimated over an appropriate area by summing volumes of simplified geometric shapes of topography and proposed pit shape. Cost estimations were then calculated based on estimated resource volume, and cost data obtained from developed quarries. Sales prices per ton were set from the estimated costs and compared with the Denver aggregate price in order to determine the possibility of economically productions.
2.0 GEOLOGY

The project area can be subdivided into two major parts, differentiated by topography: the Front Range-Southern Laramie Range on the west side and the High Plains, which covers the eastern part of the area. A simplified geologic map is presented in Figure 2. The Front Range is underlain by Precambrian (1700-1800 Ma) metasedimentary and layered meta-igneous crystalline rocks, which have been intruded by a series of massive Precambrian (1400 Ma) granite plutons and smaller Tertiary bodies of varying composition (Schwochow, 1974). Steeply eastward-dipping (30-60°) sandstones, shales and carbonates overlie Precambrian basement along a north-south trending foothill belt. East of the foothills is the High Plains region underlain by gently dipping late Tertiary formations of sand and gravel, sandstone, clay and siltstone.

2.1 Precambrian Basement

The crystalline core of the Front and Laramie Range is essentially Precambrian granite, schist and gneiss. The oldest rocks are the schist and gneiss of the Idaho Springs Formation, which are highly metamorphosed sedimentary and volcanic rock of early Precambrian age that may have had an
Figure 2. Simplified Geologic Map of the Study Area (Modified after Tweto, 1979; and Love and Christiansen, 1985).
Igneous Rock

Yg  Granitic rocks of 1400 Ma age group, includes the Sherman and Silver Plume

Xg  Granitic rocks of 1700 Ma age group

Metamorphic Rock

Xb  Biotite Gneiss, Schist, and Migmatite. Locally contains minor Hornblend Gneiss, Calc-silicate rock, Quartzite, and Marble. Derived principally from sedimentary rocks.

Xfh  Felsic and Hornblend Gneiss, either separate or interlayered. Include Metabasalt, Metatuff, and interbedded Metagraywacke; locally contains interlayered Biotite Gneiss. Derived principally from volcanic rocks.

Sedimentary Rock

PPif  Limestone and Calcareous Sandstone, Ingleside and Fountain Formation.

Twr,Tmu  Ashy Claystone and Sandstone, White River Formation and upper Miocene rocks.

Quaternary

Q  Gravel and Alluviums

Figure 2 (continued)
original thickness of approximately 20,000 feet (Lovering, 1950). The hornblende schist and gneiss of the Swandyke hornblende gneiss overlie the Idaho Springs formation and have an approximate thickness of 6,000 feet (Lovering, 1950). Gneissic granite, gneissic aplite and gneissic diorite are abundant in small masses within the metamorphic terrain and are believed to be similar to it in age.

This metamorphic terrain was intruded by an anorogenic granite intrusion of batholithic scale. The primary batholithic granite in the study area is the Sherman granite, which is a medium-to-coarse-grained equigranular to porphyritic rock that varies from granodiorite to quartz monzonite to granite (Peterman, 1968). Small batholiths and stocks of the Silver Plume granite are also present as biotite-muscovite quartz monzonite or granite containing distinct tabular microcline grains that have a subtrachytic alignment (Peterman, 1968). Although the Sherman granite is crosscut by the Silver Plume granite in some areas, the period of time separating these two was apparently too short to be resolved by present dating techniques. Peterman (1968) determined that the major period of emplacement for the Sherman and Silver Plume granites was from 1450 to 1390 Ma. These granite bodies are not foliated and have not been metamorphosed.
2.2 Sedimentary Rocks

Paleozoic and Mesozoic sedimentary rocks are exposed in the eastern portion of the study area. Cambrian, Ordovician, Devonian, Silurian and Mississippian rocks are absent in this area. Stratigraphic relationships are summarized in Figure 3.

The lower Pennsylvanian Fountain formation which lies directly on a deeply weathered erosional surface developed in underlying Precambrian rocks, consists of maroon-colored arkosic conglomerate in which pebbles are coarse, crudely sorted detritus derived from the underlying regolith. Thin beds of shale, micaceous shale, and siltstone are dispersed through the formation. The thickness of the Fountain Formation is approximately 1,000 feet (Hunter, 1955). This formation is overlain by the younger Pennsylvanian Ingleside formation, which in this area consists of red quartzose sandstone, sandy limestone, and massive, fossiliferous crystalline limestones that are light pink or gray. The Ingleside formation has a thickness of approximately 600 feet in this area (Hunter, 1955). Hunter (1955) also suggested that the uppermost part of the Ingleside is of
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<th>Era</th>
<th>Formation</th>
<th>Thickness</th>
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<tr>
<td></td>
<td>Oligocene</td>
<td>Twr White River</td>
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<td></td>
<td>Upper Cretaceous</td>
<td>Kl Laramie</td>
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<td></td>
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<td>Kfh Fox Hill</td>
<td>100 ft.</td>
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<td></td>
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<td>Kp Pierre</td>
<td>5,000-8,000 ft.</td>
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<td></td>
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<td>Kn Niobrara</td>
<td>300-500 ft.</td>
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<td></td>
<td></td>
<td>Kb Benton</td>
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<tr>
<td></td>
<td>Lower Cretaceous</td>
<td>Kd Dakota Group</td>
<td>200-400 ft.</td>
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<tr>
<td></td>
<td>Jurassic</td>
<td>Jm Morrison</td>
<td>300-400 ft.</td>
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<tr>
<td></td>
<td>Triassic</td>
<td>Je-Tj Jelm &amp; Entrada</td>
<td>400 ft.</td>
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<tr>
<td></td>
<td></td>
<td>Tc Chugwater</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Permian</td>
<td>Pfo Forelle</td>
<td>800 ft.</td>
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<tr>
<td></td>
<td></td>
<td>Psu Satanka upper</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Psl Satanka lower</td>
<td>180 ft.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Psi Ingleside</td>
<td>600 ft.</td>
</tr>
<tr>
<td></td>
<td>Pennsylvanian</td>
<td>Ppi Fountain</td>
<td>1,000 ft.</td>
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Figure 3. Stratigraphic Column for North-Central Colorado
Permian age. The red micaceous Permian lower Satanka shale conformably overlies the Ingleside formation and is approximately 180 feet thick (Lovering, 1950). The Lower Satanka shale in this area may consist of a thin sandy tongue which thickens rapidly toward the south and becomes Lyons formation (Hunter, 1955). The Permian upper Satanka formation overlies the lower Satanka shale. It is composed of a brick-red shale, discontinuous lenses of red siltstone, limy sandstone, and gypsum. The Forelle formation sandy limestone overlies the upper Satanka shale and is in turn overlain by the Triassic Chugwater formation, which consists of red shales, sandy shales, and thin-bedded siltstones. The combine thickness of the upper Satanka, Forelle and Chugwater interval are approximately 800 feet. The Jelm and Entrada formations overlie the Chugwater formation. The Jelm formation is considered to be of Late Triassic age and older than the Entrada, but because the unit is thin, this salmon-colored sandstone is included with the massive white fine-grained Jurassic Entrada sandstone (Hunter, 1955). Total thickness of the Jelm and Entrada formations is approximately 400 feet.

The Jurassic Morrison Formation is present in the area. The upper part of the formation comprises massive light-colored friable sandstones and calcareous sandstones inter-
beded with maroon and purplish variegated arenaceous shales. The lower part is comprised of green, gray and maroon thin-bedded shales, thick, gray to brown calcareous sandstone, and thin beds of pure freshwater limestones. The thickness of the Morrison Formation is approximately 300-400 feet (Hunter, 1955). The Morrison is overlain by the Cretaceous Dakota group, which in this area is comprised of a lowest unit, the Cloverly sandstone formation, a middle unit, the Skull Creek shale, and an upper sandstone unit, the Muddy. The thickness of the Dakota group is approximately 200-400 feet (Hunter, 1955). The upper Cretaceous Benton formation overlies the Dakota group conformably. This black fissile organic shale formation has a thickness of approximately 500 feet (Hunter, 1955). The Niobrara Formation which conformably overlies the Benton shale is approximately 300-500 feet thick (Lovering, 1950) and comprises of predominantly limy shale and interbedded limestone. It is overlain conformably by the Pierre shale which varies from 5,000 to 8,000 feet thick (Hunter, 1955). The Fox Hills sandstone overlies the Pierre shale conformably. The Fox Hills serves as a transitional zone between the marine Pierre shale and the brackish-water Laramie formation. The thickness of the Fox Hills is approximately 100 feet in this area (Hunter, 1955). The Laramie sandstone formation which overlies the Fox Hills and
contains interbedded fresh and brackish-water shales and sandstone. Its thickness is approximately 600 feet (Hunter, 1955). No Paleocene or Eocene units have been recognized in the area. The Pierre shale, Fox Hills sandstone and Laramie sandstone are covered by the White River formation northeast of the area.

The Oligocene White River formation primarily consists of color-banded fine silt. The lower part of the formation consists of red clays and silts containing sandy channel fills and blue clays derived from re-worked Pierre shale. Higher in the formation, massive sandstones appear intercalated with red silts, clay pebble conglomerates and chert lenses. The upper part of the White River is predominantly volcanic ash and pink to white in color. The thickness of the White River formation is approximately 200 feet (Hunter, 1955). No Miocene, Pliocene, nor Pleistocene deposits have been recognized in this area.

2.3 Structural and Geomorphic Sequence

The major structural features of the Southern Rocky Mountains are products of the Laramide orogeny. The Laramide orogeny began in early Cretaceous time and reached its peak in Paleocene time (68-45 Ma) (Thornbury, 1965).
The regional stress field which produced Laramide structures in this area was primarily generated by vertical uplift. Many of the faults in this region are curved, high-angled reverse faults which steepen downward (Matthews, 1976) and theoretical stress fields, calculated by Hafner (1951), show that reverse faults of this nature are the result of vertical uplift. The existence of reverse faults, which flatten with depth and are the result of horizontal compression has not been demonstrated in this region (Matthews, 1976).

During the Laramide orogeny, basement rocks deformed in a brittle manner while most sedimentary rocks were much more ductile. Therefore, the basement responded to Laramide stress by faulting while the sedimentary rocks responded by folding. The geometry and character of these structures has lead many geologists to interpret them as drape folds over differentially-uplifted basement fault blocks (Matthews, 1976).

A short distance south of the Colorado-Wyoming state boundary the Front Range separates into two ranges, the Laramie on the east and the Medicine Bow on the west. The study area is a part of the Laramie Range which is a broad asymmetrical anticlinal structure with the west limb steeper than the east.
Systems of faults are recognized throughout the western part of the area especially in the Precambrian lithologies of meta-sedimentary, meta-igneous and igneous rocks. Three major faults are present in the vicinity of the study sites. They are the north Livermore fault; south of Calloway Hill, Colorado, which strikes north-east, the North Fork fault; south of the town of Livermore, Colorado, which strikes north-south, and the Mill Creek fault; west of Virginia Dale, Colorado, which strikes north-west.

Following the Laramide uplift, the region was eroded to a gentle topography by middle Tertiary then subjected to additional uplift and erosion during late Tertiary time, which removed much of the Tertiary sediment cover. However, in the area west of Cheyenne, known as the Gangplank, Tertiary sediments escaped this later erosion and still extend across the Paleozoic and Mesozoic formations onto Precambrian rocks. The Gangplank merges on its western edge with an erosion surface cut on the top of the Laramie Range, which is called the Sherman peneplain because of its extensive development in the Sherman granite belt. This surface, remarkable for its lack of relief, correlates with the Eocene Rocky Mountain erosion surface of the Colorado Front Range. Highest elevations on the surface are approximately 8500 feet along the western margin. There is an eastward
slope of between 90 to 100 feet per mile, resulting to an eastern margin elevation of approximately 7300 feet. The peneplain surface is undulating and composed of weathered granite debris as thick as 40 to 50 feet (Moore, 1960). All the aggregate extraction sites proposed in this report lie on this surface. Thornbury (1965) suggested that Paleozoic and Mesozoic sediments were stripped from the Sherman granite as early as Oligocene. Moore (1960) recognized that a balance between erosion on the Sherman granite and deposition on the plains was attained at that time and continued into the Pleistocene.

Moore (1960) proposed that the geomorphic evolution of the east flank of the Laramie Range occurred in three stages of development. The first stage began with uplift and dissection of the range near the end of the Cretaceous (Laramide) and continued until the end of the Eocene. The second stage was characterized by deposition of Oligocene, Miocene, and Pleiocene sediments. Stage three was Pleistocene dissection of this Tertiary mantle, which continues to the present.

After initial investigation, it was determined that the mountainous part of the study area extending from north of the Cache la Poudre River between the Laramie River and the sedimentary cover of the high plains, which is primarily
underlain by the Sherman and Silver Plume granites was the best area for aggregate exploitation. This portion of the area is comprised of exposed Precambrian metasedimentary and layered meta-igneous crystalline rock (1700-1800 Ma) intruded by a series of Precambrian granites including the Sherman and Silver Plume (1400 Ma). The main phase of the Sherman granite in this area is a red to pink, coarse-grained, equigranular granite with secondary pinkish gray, porphyritic, biotite monzogranite phases. The Silver Plume granite is a fine-to medium-grained, equigranular to seriate, porphyritic biotite-muscovite granite (Eggler, D.H., and Braddock, W.A., 1988). These two types of granites with their massive, undifferentiated and extensive nature were determined to be the best materials for quarrying operations.
3.0 DESCRIPTION OF STUDY SITES

"Aggregate" refers to sand, gravel and crushed stone. While it is recognized that the quality of the gravel from each pit varies greatly, river rock is generally lower in specific gravity, less resistant to abrasion and lower in fractured faces than crushed stone. Since the sources of high quality materials are the focus of this study, sources of aggregate considered will be solely from crushed rock.

The main criteria necessary for a good quarry operation are size of rock deposit, accessibility, and possibility of development. A large number of specific sites could have been assessed for this study, but only five arbitrary sites were chosen, primarily because the sites provided access to relatively fresh rock in road cuts or stream canyons. The sites are meant to be representative of rock type and access factors and are not necessarily proposed as potential development locations. Sites selected were: (1) Calloway Hill, Colorado, (2) Livermore, Colorado, (3) Virginia Dale, Colorado, (4) Harriman, Wyoming, and (5) Granite, Wyoming. Locations for these sites are given in Figure 4 and specific detailed descriptions of each follow. Each site evaluates the effects of different variables of rock type, location,
1. Livermore  
2. Calloway Hill  
3. Virginia Dale  
4. Harriman  
5. Granite  

Figure 4 Location of the five study sites.
and accessibility that might be expected to influence the viability of quarries in this region.

3.1 Calloway Hill, Colorado

Calloway Hill is approximately 3 miles west of Highway 287 along Cherokee Park Road, Larimer County, Colorado. The distance from the site to the closest railroad, which is east of Livermore, is approximately 10 miles. The area is unpopulated with no buildings within a 5 miles radius.

3.1.1 Geology of the Site. The Calloway Hill site is comprised of Silver Plume granite throughout an area of at least three square miles. The Silver Plume granite in this area is a fine to medium-grained, equigranular porphyritic biotite granite with minor granitic gneiss xenoliths. The granitic gneiss is a gray, pink, or red, fine-to medium-grained, weakly foliated rock composed of quartz and plagioclase, with a lesser amount of microcline, and small amounts of biotite and hornblende. It crops out over an area of approximately one-half square mile.

On the south, the site is bounded by the North Livermore fault, which strikes north-east with a dip of 66 degrees and as a fracture zone approximately 200 feet wide. This reverse fault uplifted the granite to the north above and over the Fountain formation to the south. South of the site,
a branch of this fault cuts west as a shear zone in the granite.

Elevation at this site varies from approximately 6000 feet south of the fault to approximately 6600 feet north of it. The local relief is likely to due to differential erosion with the fault as locus of a fault line scarp which changes elevation from 6000 to 6600 feet in one-half mile. Petrographic study has shown quartz grains with strain shadows and bent albite twins in plagioclase in the granite which is likely the effect of distributed shear strain due to displacement on the fault. All the surface-exposed rocks at this site are weathered to the depth of at least 15-20 feet.

The reason that this site was chosen is because of the availability of good Silver Plume granite exposures along Calloway Canyon. The deposit is also extensive and has the potential to be developed since it is located in an area relatively free from potential environmental problems. The local relief might facilitate extraction and potentially be used to shield operations from view.

3.2 Granite, Wyoming

The sample site for this particular location is the Granite Canyon quarry, a currently operating quarry in the
town of Granite, Wyoming, just north of Interstate 80 and approximately 20 miles west of Cheyenne, Wyoming. The quarry is owned and operated by a joint venture between Meridian Aggregate Company and Peter Kiewit and Sons Company. The quarry was originally owned and operated by Morrison Gnudsen Company since 1944 and was taken over by the current owner in 1987. The quarry was temporarily closed down, and completely new machinery and equipment were installed in order to increase efficiency and production rate. The Granite Canyon Quarry was re-opened in 1989. Its current production rate is 1.4 million tons per year with maximum capacity to produce up to 4.0 million tons per year. The company has the right to mine in 2500 acres of land with 150 million tons of reserve. Railroad track was constructed from the Union Pacific main line into the quarry to transport the material. Although the material from this quarry is considered to be of exceptionally high quality with percentage loss in L.A. Abrasion test of 19%, the majority of the material is used as railroad ballast (Mr. Charles Rose, Granite Canyon Quarry Engineer, Personal communication).

3.2.1 Geology of the Site. The quarry is mined from the Sherman granite which, in this area, is a pinkish-gray, porphyritic biotite monzogranite. Petrographic study
shows that the rock at this particular site has a porphyritic texture with medium-grained phenocrysts embedded in a fine-grained groundmass. The bonding between the phenocrysts and their finer groundmass might result in a lower percentage of particle breakdown in L.A. Abrasion test.

This site has been chosen because the Granite Canyon quarry is the only large scale operation quarry in the study area. The information obtained from this quarry can also assist the evaluation of other sites.

3.3 Harriman, Wyoming

Harriman is situated approximately 15 miles south of Granite, Wyoming along an unnamed secondary hard surface road.

3.3.1 Geology of the Site. The Sherman granite at this site is red to pink, coarse grained equigranular granite composed of quartz, microcline, oligoclase and biotite. The topography is a truncated flat plain with small hills. The degree of weathering in this type of rock is higher than in other lithologies because of its larger-grained character. The exposure of the rock is extensive since the pluton covers an area of at least four square miles.

3.4 Livermore, Colorado
This study site is approximately one mile west of Highway 287 and one mile south of Livermore in Larimer County, Colorado. With the exception of the small town of Livermore north of the area and one cattle ranch and few houses off Highway 287 northeast of the area, the area is unpopulated. The Union Pacific railroad line is approximately seven miles from the site. The city of Fort Collins is approximately 20 miles south-southeast of the area.

3.4.1 Geology of the Site. The Sherman granite at this site forms a topography of small hills with average elevation of approximately 6300 feet and covers the area of at least three square miles. The Sherman granite is medium-grained, equigranular porphyritic biotite-hornblende granite which is intruded locally by smaller stocks of Silver Plume granite, which is a fine- to medium-grained, slightly porphyritic, biotite granite (Braddock, W.A., Wohlfold, D.D., and Conner, J.J., 1988). Small xenoliths of quartzofeldspathic mica schist and Quaternary surface deposits are present south of the site. A fault system with a general strike of north-northeast is present throughout the area. The largest is the North Fork fault, present just west of the site, with a displacement of approximately one-third of a mile. Depth of weathering at this site is at least 40 feet.
This site has been chosen because it is the first large deposit of Sherman granite along Highway 287 from Fort Collins. It is approximately 7 miles from the Union Pacific railroad which also is a relatively close distance. Rocks of this site were more visibly affected by weathering than those from other sites and gave an assessment of this factor in rock suitability.

3.5 Virginia Dale, Colorado

This study site is approximately one mile northwest of the town of Virginia Dale along Highway 287, Larimer County, Colorado. The majority of the area is unpopulated except for the small town of Virginia Dale southeast of the area. The closest railroad is the Union Pacific line which is approximately 30 miles to the southeast.

3.5.1 Geology of the Site. The Sherman granite forms small hills at an average elevation of 7000 feet on both sides of Highway 287. The granite deposit at this site is a part of the eastern inner and outer caprock phases of the Virginia Dale ring structure, whose center lies approximately two miles west of the site. The ring structure covers an area of approximately 50 square miles. The center of the structure is composed of Silver Plume granite surrounded by
three phases of the Sherman granite, the inner caprock, the outer caprock, and the main phase (Braddock and others, 198-9). The rock at this site is pinkish-gray, porphyritic biotite monzogranite. The deposit covers an area of at least four square miles on both sides of Highway 287. Immediately southeast of the site, xenoliths of quartzofeldspathic mica schist and feldspathized diorite are present along the contact between the outer cap rock and the main phase of the Sherman granite.

This site was chosen because it is comprised of Sherman granite and provided good exposures along roadcuts which were expected to contain fresh rocks.
4.0 ENGINEERING TESTING

Approximately 70 pounds of rock selected from the freshest exposures available were collected from each of the five sites. All the samples are weathered to a certain degree, but fresher rocks were uncollectible without drilling.

After a small portion of each sample was separated for microscopic study, the remaining material was crushed to fragments varying in size from 1/8" to 2" using a 2" opening jaw-crusher in the Colorado School of Mines Metallurgy Department. The samples were taken to Cooley Gravel Company's material laboratory at the company's Morrison plant where three tests were performed on the samples. They were the Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (LA Abrasion Test), Specific Gravity, and Absorption of Coarse Aggregate.

4.1 Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine (LA Abrasion Test), ASTM Method C-535

Materials in which individual grains are weak or are loosely cemented are not desirable as aggregate because these materials break down under pressure from use or during handling and mixing procedures. The breakdown of aggregate
causes a deviation from the devised gradation and may generate excess fine particles. Tests that measure the resistance of an aggregate to abrasion are conducted on a Los Angeles machine, and the test is commonly called the L.A. Abrasion Test or the Los Angles Rattler Test (ASTM Method C-131 or C-535) (ASTM, 1988).

The particular test used for this study was performed in compliance with ASTM method C-131, Grading A (ASTM, 1988).

4.2 Specific Gravity of Material Test, ASTM Method C-127

Specific gravity of crushed stone is used to determine the solid volume occupied by the aggregate so that portland cement or bituminous concrete mixtures can be designed correctly. The specific gravity test was performed on all five sets of samples in compliance with ASTM method C-127 (ASTM, 1988).

4.3 Absorption of Coarse Aggregate Test, Method C-127

Absorption is a measure of the porosity and permeability of rock and is used to determine the proper amount of water to be added to portland cement concrete mixes. If the absorption of water by the stone is not taken into account, the resulting concrete mixes would be too dry. The ability of rock to absorb moisture is also an important consider-
ation in the manufacture of bituminous concrete mixes. All aggregate used in bituminous concrete must be dry, and water in the interior of more porous stone particles is difficult and expensive to remove (Schenck and Torries, 1983).

The absorption tests done for this study were performed in compliance with ASTM method C-127 (ASTM, 1988).

4.4 Discussion

The L.A. abrasion test result is among the most important criterion in determining the quality of material. The ASTM standard test procedure C-131 was performed in this study. This test method covers a procedure for testing sizes of coarse aggregate smaller than 1-1/2 in. (37.5 mm) for resistance to degradation using the Los Angeles testing machine. There are four sizes of material used in each test. The coarsest materials are those passing a 1-1/2" sieve and retained on a 1" sieve while the finest are those passing 1/2" sieve and retained on a 3/8" sieve. These materials are normally random samples from stockpiles in the quarry. Since the study samples were from outcrops, they had to be crushed to appropriate size. There are two factors that differentiate this test from the normal industrial L.A. abrasion tests. First, material crushed in a smaller jaw crusher, such as the one used in this test, tends to come
out of the crusher with a greater percentage of elongated and thin-chipped shapes, which break down more easily than normal, resulting in a higher percentage of loss. Secondly, the crushed materials tend to lack the finer particle size (1/2" - 3/8"). This finer range of particle had to be reduced to size from larger sizes using a hammer. The finer particles produced this way might be more fractured, which also leads to easier breakdown in the machine.

L.A. abrasion test results are often used as a standard to rate the quality needed for specific construction uses. As an example, for the new Denver airport construction project, the two types of runway surfaces to be constructed, rigid pavement and flexible pavement, are differentiated by the materials that are used for paving. The rigid pavement is paved with roller-compacted concrete, while the flexible pavement is a bituminous surface. Both are underlain by layers of base, subbase and subgrade. The base course is the principal structural component as the stresses at the top of the pavement are the highest. The major function of the base is to distribute wheel loads to the subbase and subgrade. The subbase, in turn, has the main function of distributing loads to the underlying foundation (Federal Aviation Administration, 1989).
Crushed stone can be used in construction of the surface course and base course of the flexible pavement and as aggregate in the cement mixture in the rigid pavement. The new Denver airport has specified a percentage wear of not more than 40% for the surface course and 50% for the base course in flexible pavement construction (Federal Aviation Administration, 1989). In rigid pavement, the crushed stone percentage wear shall not exceed 30%. (All the percentages are by weight, testing according to ASTM C-131)(Federal Aviation Administration, 1989).

The results of the L.A. abrasion tests performed on the five sample sites range from 20.41 to 38.96% (Table 4-1). The results higher than 30% loss could possibly be much lower and possibly lower than 30% loss if the method of sample collecting were sophisticated enough to obtain fresh, unweathered material. In other words, it is highly possible that once the weathered surficial materials are removed, better quality materials should be obtained from deeper levels. The sample from Granite, Wyoming, which yielded a percentage loss of 20.41%, which is highly acceptable, was collected from a fresh quarry front below the original land surface.
Table 1
Summary of Engineering Test Results

<table>
<thead>
<tr>
<th>Location of</th>
<th>(1) L.A. Abrasion (% loss)</th>
<th>(2) Specific Gravity</th>
<th>(3) Absorption</th>
<th>(4) Degree of Weathering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bulk</td>
<td>Apparent</td>
<td></td>
</tr>
<tr>
<td>Calloway Hill</td>
<td>37.64</td>
<td>2.60</td>
<td>2.63</td>
<td>0.45</td>
</tr>
<tr>
<td>Granite, WY</td>
<td>20.41</td>
<td>2.68</td>
<td>2.70</td>
<td>0.36</td>
</tr>
<tr>
<td>Harriman</td>
<td>38.96</td>
<td>2.62</td>
<td>2.68</td>
<td>0.81</td>
</tr>
<tr>
<td>Livermore</td>
<td>37.74</td>
<td>2.57</td>
<td>2.63</td>
<td>0.82</td>
</tr>
<tr>
<td>Virginia Dale</td>
<td>34.11</td>
<td>2.66</td>
<td>2.68</td>
<td>0.36</td>
</tr>
</tbody>
</table>


(2) Specific gravity of coarse aggregate test, ASTM Method C-127 (ASTM, 1988).


(4) Determined by petrographic analysis.
5.0 PETROGRAPHIC ANALYSIS

Microscopic examination is needed to make a proper assessment of potential problems in usage of crushed rocks. Important factors such as mineral composition, grain or crystal size, textural characteristics, and internal structure can be obtained from microscopic study and may be the basis for any further testing.

A total of 13 samples from six locations was collected for petrographic analysis. Five of these samples are from the sets of rocks used in the engineering tests.

Detailed petrographic information for each thin section studied is presented in Appendix A. The results are tabulated in Table 2 and Table 3.

5.1 Discussion

Although all of the samples are generally termed "granite," actual compositions range from granite to quartz syenite and quartz monzonite. Rock names were applied using Streckeisen's (Streckeisen, 1976) model classification of igneous rocks. The samples collected from Calloway Hill, Virginia Dale, and Granite, Wyoming are true granites while the Granite samples collected from Livermore, Stonewall Creek and Harriman, Wyoming, range from quartz monzonite to quartz syenite. All the samples are free of microcrystal
Table 2. Percentage of mineral constituents

<table>
<thead>
<tr>
<th>Mode</th>
<th>CH-1</th>
<th>CH-2</th>
<th>CH-3</th>
<th>CHLA</th>
<th>GCQ1</th>
<th>GMWA</th>
<th>H-1</th>
<th>HLA</th>
<th>L-1</th>
<th>LMLA</th>
<th>SC-1</th>
<th>SC-2</th>
<th>* VLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>k-feldspar</td>
<td>45</td>
<td>45</td>
<td>35-40</td>
<td>40</td>
<td>25/35</td>
<td>25/25</td>
<td>57</td>
<td>55</td>
<td>45</td>
<td>40</td>
<td>30-35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>30</td>
<td>35</td>
<td>30-35</td>
<td>35</td>
<td>5/10</td>
<td>5/10</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>35</td>
<td>40-45</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>Quartz</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>7/10</td>
<td>10/15</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20-25</td>
<td>35</td>
</tr>
<tr>
<td>Biotite</td>
<td>5</td>
<td>1</td>
<td>3-5</td>
<td>3</td>
<td>1/</td>
<td>1/</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2-3</td>
<td>5</td>
<td>trace</td>
<td>10</td>
</tr>
<tr>
<td>Amphibole</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>6/2</td>
<td>8/trace</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Muscovite</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>trace</td>
<td>trace</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>trace</td>
<td>--</td>
</tr>
</tbody>
</table>

* used in L.A. Abrasion Test
Table 3. Summary of samples characteristics

<table>
<thead>
<tr>
<th>Mode</th>
<th>CH-1</th>
<th>CH-2</th>
<th>CH-3</th>
<th>CHL A</th>
<th>GCO1</th>
<th>GML A</th>
<th>H-1</th>
<th>HLA</th>
<th>L-1</th>
<th>LML A</th>
<th>SC-1</th>
<th>SC-2</th>
<th>VLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain size</td>
<td>fine to medium</td>
<td>fine to medium</td>
<td>fine to medium</td>
<td>N/A</td>
<td>N/A</td>
<td>Coarse</td>
<td>Coarse</td>
<td>fine to medium</td>
<td>medium to coarse</td>
<td>medium to coarse</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>P</td>
<td>P</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>G</td>
</tr>
<tr>
<td>Degree of Alteration</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Low</td>
<td>Low</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
<td>Mod.</td>
</tr>
</tbody>
</table>

Texture: H - Hypidiomorphic, G - Granular, E - Equigranular
Mod. = Moderate
line or amorphous silicate minerals that might cause alkali-silica reaction when used in cement mix. No negative internal structures that might weaken the strength of rock were detected.

Grain size and texture are the rock properties that seem to control performance in L.A. abrasion tests. The petrographic analysis, together with the results of the L.A. abrasion tests in Chapter 4, suggest that the sample from Granite, Wyoming, with phenocrysts embedded in a finer groundmass, is the highest quality. The sample with the worst results was H-1, which is the equigranular, coarse-grained rock from Harriman, Wyoming.
6.0 ECONOMIC ASSESSMENT

6.1 Site Selection Criteria

From the five sampling sites, three were chosen for further study to determine whether they could be economically developed into production.

The sites were chosen according to the following factors:

1. **Quality of Rock**

The material at the sites is in the range of acceptable quality. The material at each site yields promising results in the L.A. Abrasion test (ASTM C-131) (ASTM, 1988), which should not exceed 40% weight loss along with acceptable results in specific gravity and absorption tests (ASTM C-127) (ASTM, 1988). Petrographic analysis of samples from the sites indicates they do not contain deleterious constituents, and their internal texture and structures show no sign of potential problems. Exposures of rock at each site show that the rock deposit is massive without extensive failure due to weathering and erosion.

2. **Size of Deposit**

The deposit of rock at each site is large enough for long-term production of at least 20 years, a necessity for economically feasibility. The lithologies at each site
are not only extensive but also constant in composition without inclusions of undesired material both underground and on the surface.

3. Other Factors

The selected sites must reasonably comply with regulated environmental restrictions such as visual impact, air quality, noise pollution, blasting, etc.

The cost estimations in this study are order-of-magnitude estimates that are normally done in the early stages of planning and evaluation of a project. The degree of variation for this type of estimation can be as much as ±30%, because fixed capital investment must be estimated with minimal knowledge of the local site, based on previous cost data obtained from developed quarries.

6.2 Description of fixed-cost items

6.2.1 Permitting Cost This cost includes all expenses incurred in the process of acquiring a permit to open quarry operation, including all legal fees. Normally, other detailed permits designed to limit water and air pollution are required before the operating permit is granted. Mine plans and land reclamation plans are necessary submissions included with a mine permit application. Blasting and highway use permits, along with licenses for engineers, blasters, and
weigh scales, are other necessary documents before operations can be started.

Surface mining regulations require the posting of substantial financial assets as a bond that land reclamation will be done. The bond will be for a special tract of land and can amount to as much as $5000 per acre, which will be in the form of collateral such as US treasury bills or surety bond (Schenck, and Torries, 1983). The bond must exist before mining can start.

An estimate of $500,000 for permitting costs was obtained from personal communications with major quarry rock producers in the Denver area based on their recent experience.

6.2.2 Land Acquisition Cost The amount of $500 per acre is the maximum cost of undeveloped open-land in north-central Colorado and southern Wyoming, based on personal communications with producers.

6.2.3 Start-up Cost and Equipment Start-up costs include the cost of stripping, general layout of the plant site and plant set up. Equipment costs, incorporated the cost of all machinery; front-end loaders, jaw crushers, cone crushers, screens etc. A total amount of $15,000,000 is based on major producers' previous cost through personal communication.
6.2.4 Trestle  Although transportation by rail is cheaper than by truck, there is a difficulty in unloading material from railroad cars. An effective way to unload the material is by using a structure called a trestle. A trestle can be described as a structure resembling an open bottom railroad bridge on which all the rail cars can stop and unload the material through their belly openings to the area below at one time. Material is then removed to the plant or to appropriate stockpiles. The information on the cost of building a trestle for 25-30 rail cars was provided by a quarry operating company in Denver, through personal communication.

6.2.5 Railroad spur  Since all the proposed sites are relatively remote from markets, the most economical means of transporting material to the market would be by rail. A railroad spur must be constructed from the main railroad line to a loading site in a quarry. A cost of approximately $100 per running foot for such construction was obtained from a quarry operating company in Denver through personal communication.

6.2.6 Production Cost  Production cost can be broken down into stripping, drilling, blasting, loading, hauling, processing, stockpiling, maintenance, dust control, labor, and marketing. There are also fixed costs such as depreci-
tion and office overhead. A cost of $3.15 per ton was obtained from a Denver quarry operator (personal communication) based on a production rate of 1.25 million tons per year.

6.2.7 Rail Transportation Cost A cost of $3.95 per ton for transportation to Denver was obtained from the Union Pacific Company, Omaha, Nebraska, through Mr. Ray Gardner, on the basis of running 25 one-hundred-ton cars at a time, using private equipment.

The fixed costs used for calculations in this study are summarized in Table 4.
Table 4

Fixed Cost

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Permitting Cost</td>
<td>$500,000</td>
</tr>
<tr>
<td>2</td>
<td>Land acquisition</td>
<td>$500/acre</td>
</tr>
<tr>
<td>3</td>
<td>Start-up Cost and Equipment</td>
<td>$15,000,000</td>
</tr>
<tr>
<td>4</td>
<td>Trestle</td>
<td>$750,000</td>
</tr>
<tr>
<td>5</td>
<td>Railroad spur</td>
<td>$100/ft.</td>
</tr>
<tr>
<td>6</td>
<td>Production cost (at 1.25 mt/yr)</td>
<td>$3.15/ton</td>
</tr>
<tr>
<td>7</td>
<td>Rail transportation</td>
<td>$3.95/ton</td>
</tr>
</tbody>
</table>

*Information in 1, 2, 3, 4, and 6 was obtained from major producers in the Denver metropolitan area and its suburbs by direct inquiry.

**5 and 7 obtained from Union Pacific Company, Omaha, Nebraska through Mr. Ray Gardner, on the basis of using private equipment and transporting 25 cars with capacity of 100 tons/car at a time.
6.3 Resource and Cost Estimations

Detailed calculations for each site are given below. For each site resource volume was calculated over an appropriate area by summing of geometric simplifications of topography and pit shape. This calculation is for resource volume in place and actual minable reserves would be somewhat smaller. Total start-up costs for each site are tabulated and then used to calculate per ton costs, which are also tabulated.

6.3.1 Calloway Hill

The potential site consists of an east-west trending flat-topped hill approximately two miles in length and 1.75 miles in width (Figure 5). The operating plan for this site is to mine from the southern side of the hill and continue northward. Resource volume above ground and below-ground are calculated in Figures 6 and 7 to be approximately 980,000,000 yd$^3$ and 1,500,000,000 yd$^3$, respectively, for a total resource volume at this site of approximately 2,480,000,000 yd$^3$ or 4,900 million tons. Cost calculations are summarized in tables 5 and 6. Detailed calculations are in Appendix B.
Figure 5  Geologic map of Calloway Hill site (After Braddock and Connor, 1988)
Igneous Rock

- Ysp Silver Plume Granite
- Yxp Pegmatite
- Yd Mafic dikes

Metamorphic Rock

- Xgg Granitic Gneiss

Quaternary

- Qal, Qng Alluvium Deposits

Figure 5 (continued).
Figure 6 Mine layout for Calloway Hill site (Modified after USGS, 1960).
Cost Estimation

Table 5
Initial Cost of Development at Calloway Hill

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land, 2560 acres, $500/acre</td>
<td>$1,280,000</td>
</tr>
<tr>
<td>Permitting Cost</td>
<td>$500,000</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>$15,000,000</td>
</tr>
<tr>
<td>Trestle</td>
<td>$750,000</td>
</tr>
<tr>
<td>Railroad Spur, 10 miles, $100/foot</td>
<td>$5,280,000</td>
</tr>
<tr>
<td>Total</td>
<td>$22,810,000</td>
</tr>
</tbody>
</table>

Table 6
Estimated Cost/Ton for Calloway Hill Site

<table>
<thead>
<tr>
<th>Production Period at 1.25 million tons/yr.</th>
<th>Total material produced (tons)</th>
<th>Production &amp; Transportation Cost ($)</th>
<th>Total Cost (Amount in last column plus initial cost ($)</th>
<th>Cost/Ton ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 years</td>
<td>25,000,000</td>
<td>177,500,000</td>
<td>200,310,000</td>
<td>8.01</td>
</tr>
<tr>
<td>50 years</td>
<td>62,500,000</td>
<td>443,750,000</td>
<td>466,560,000</td>
<td>7.46</td>
</tr>
<tr>
<td>100 years</td>
<td>125,000,000</td>
<td>887,500,000</td>
<td>910,310,000</td>
<td>7.28</td>
</tr>
</tbody>
</table>
Deposit Above Ground

South distant (mile) North

Volume (1) = \( \frac{1}{2} \times (0.25 \times 1760) \times \left( \frac{200}{3} \right) \times 3520 \)
= 50,629,333 yd\(^3\)

Volume (2) = \( (0.5 \times 1760) \times \left( \frac{200}{3} \right) \times 3520 \)
= 206,506,666 yd\(^3\)

Volume (3) = \( \frac{1}{2} \times (0.5 \times 1760) \times \left( \frac{200}{3} \right) \times 3520 \)
= 103,253,333 yd\(^3\)

Volume (4) = \( (0.75 \times 1760) \times \left( \frac{400}{3} \right) \times 3520 \)
= 619,520,000

Total volume above ground = 979,909,332 yd\(^3\)

Figure 7 Calculation of resources volume above ground at Calloway Hill Site.
Deposit underground

<table>
<thead>
<tr>
<th>South distance (mile)</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.50</td>
</tr>
<tr>
<td></td>
<td>250</td>
</tr>
</tbody>
</table>

\[(1.5 \times 1760 \times 3) - 250\]'

\[
Volume (1) = \frac{1}{2} \left( \frac{250}{3} \right) \times \left( \frac{500}{3} \right) \times 3520 = 24,444,444 \text{ yd}^3
\]

\[
Volume (2) = \left( \frac{7670}{3} \right) \times \left( \frac{500}{3} \right) \times 3520 = 1,499,911,112 \text{ yd}^3
\]

Total volume underground = 1,524,355,556 \text{ yd}^3

Figure 8 Calculation of resources volume below ground at Calloway Hill site.
6.3.2 Livermore

The potential deposit at Livermore is located along the northeast trending Eagles Nest mountain (Figure 8). This mountain has an approximate length and width of 1.5 and 1 mile, respectively. The average elevation through the trend is 6,381 feet. Resource volume above ground and underground are calculated in Figure 9 at approximately 177,000,000 yd$^3$ and 446,000,000 yd$^3$, with the total of approximately 623,000,000 yd$^3$ (1,200 million tons). Cost calculations are summarized in Tables 7 and 8. Detailed calculations are in Appendix B.
Figure 9  Geologic map of Livermore site (After Braddock, and others, 1988).
Igneous Rock

Ysp Silver Plume Granite

Ysh Sherman Granite

Metamorphic Rock

Xqs Quartzofeldspathic mica schist

Sedimentary Rock

Pi Sandstone, Ingleside Formation

PPf Arkosic conglomerate, Fountain Formation

Figure 9 (continued)
Figure 10  Mine layout for Livermore site (Modified after USGS, 1960).
Deposit above ground

\[ \text{Volume} = \frac{1}{2} \times (0.6 \times 1760) \times \left(\frac{381}{3}\right) \times (1.5 \times 1760) \]
\[ = 177,027,840 \text{ yd}^3 \]

Deposit underground

\[ \text{Volume (1)} = \frac{1}{2} \times \left(\frac{250}{3}\right) \times \left(\frac{500}{3}\right) \times (1.5 \times 1760) \]
\[ = 18,333,333 \text{ yd}^3 \]

\[ \text{Volume (2)} = \frac{[(0.6 \times 1760 \times 3) - 250]}{3} \times \frac{500}{3} \times (1.5 \times 1760) \]
\[ = 427,973,333 \text{ yd}^3 \]

Total volume underground = 446,306,666 yd³

Figure 11 Calculation of resource volume at Livermore site.
Cost Estimation

### Table 7
Initial Cost of Development at Livermore

<table>
<thead>
<tr>
<th>Description</th>
<th>amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land, 2240 acres, $500/acre</td>
<td>$1,120,000</td>
</tr>
<tr>
<td>Permitting Cost</td>
<td>$500,000</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>$15,000,000</td>
</tr>
<tr>
<td>Trestle</td>
<td>$750,000</td>
</tr>
<tr>
<td>Railroad Spur, 7.5 miles, $100/foot</td>
<td>$3,960,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$21,330,000</strong></td>
</tr>
</tbody>
</table>

### Table 8
Estimated Cost/Ton for Livermore Site

<table>
<thead>
<tr>
<th>Production Period at 1.25 million tons/yr.</th>
<th>Total material produced (tons)</th>
<th>Production &amp; Transportation Cost ($)</th>
<th>Total Cost (Amount in last column plus initial cost ($))</th>
<th>Cost/Ton ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 years</td>
<td>25,000,000</td>
<td>177,500,000</td>
<td>198,830,000</td>
<td>7.95</td>
</tr>
<tr>
<td>50 years</td>
<td>62,500,000</td>
<td>443,750,000</td>
<td>465,080,000</td>
<td>7.44</td>
</tr>
<tr>
<td>100 years</td>
<td>125,000,000</td>
<td>887,500,000</td>
<td>908,830,000</td>
<td>7.27</td>
</tr>
</tbody>
</table>
6.3.3 Virginia Dale

The Sherman Granite at this site is present on both sides of Highway 287. The granite deposit forms small hills with an average relief of approximately 100 ft (Figure 10). Due to the local low relief topography and depth of weathering, material above ground at Virginia Dale was neglected. Resource volume below ground at this site were calculated for two areas, one northeast and one southwest of Highway 287. The two deposits were calculated to contain approximately 504,000,000 yd$^3$ and 1,967,000,000 yd$^3$, respectively (Figures 11 and 12). Total resource volume at this site is approximately 2,471,000,000 yd$^3$ or 5,000 million tons. Cost calculations are summarized in Tables 9 and 10. Detailed calculations are in Appendix B.
Figure 12 Geologic map of Virginia Dale site (After Braddock, and others, 1989)
Igneous Rock

Ysp Silver Plume Granite

Ysi Sherman Granite, Inner Cap Rock phase

Yso Sherman Granite, Outer Cap Rock phase

Ysh Sherman Granite, Main phase

Ydi, Ydif, Ydf Diorite, Feldspathized diorite

Yal Alaskite

Metamorphic Rock

Xam Hornblend gneiss and amphibolite

Xbgg Biotite granitic gneiss

Xqs Quartzofelspathic mica schist

Xlg Gneissic pegmatite

Figure 12 (continued)
Figure 13  Mine layout for Virginia Dale site (Modified after USGS, 1960).
Deposit underground

(1) Deposit northeast of Highway 287 (1 square mile)

Volume (1) = \( \frac{1}{2} \left( \frac{250}{3} \right) \times \left( \frac{500}{3} \right) \times 1760 = 12,222,222 \text{ yd}^3 \)

Volume (2) = \( \left\{ \frac{(1760 \times 3) - 250}{3} \right\} \times \frac{500}{3} \times 1760 = 491,822,222 \text{ yd}^3 \)

Total deposit northeast of Highway 287 =

12,222,222 + 491,822,222 = 504,044,444 \text{ yd}^3

Figure 14  Calculation of resource volume at northeast Virginia Dale site.
(2) Deposit southwest of Highway 287 (4 square miles)
- Separate into 4 pits, 1 mile$^2$ each with 2 sides bench cut.

\[ Volume (1) + (2) = 2 \left( \frac{1}{2} \times \frac{250}{3} \times \frac{500}{3} \times 1760 \right) = 24,444,444 \text{ yd}^3 \]

\[ Volume (3) = \left[ \frac{(1760 \times 4) - (500)}{3} \right] \times \frac{500}{3} \times 1760 = 467,377,777 \text{ yd}^3 \]

*Total deposit of Virginia Dale = 2,471,333,328 yd$^3$*
Cost Estimation

Table 9
Initial Cost of Development at Virginia Dale

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land, 4480 acres, $500/acre</td>
<td>$2,240,000</td>
</tr>
<tr>
<td>Permitting Cost</td>
<td>$500,000</td>
</tr>
<tr>
<td>Start-up Cost</td>
<td>$15,000,000</td>
</tr>
<tr>
<td>Trestle</td>
<td>$750,000</td>
</tr>
<tr>
<td>Railroad Spur, 20 miles, $100/foot</td>
<td>$10,560,000</td>
</tr>
<tr>
<td>Total</td>
<td>$29,050,000</td>
</tr>
</tbody>
</table>

Table 10
Estimated Cost/Ton for Virginia Dale Site

<table>
<thead>
<tr>
<th>Production Period at 1.25 million tons/yr.</th>
<th>Total material produced (tons)</th>
<th>Production &amp; Transportation Cost ($)</th>
<th>Total Cost (Amount in last column plus initial cost ($)</th>
<th>Cost/Ton ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 years</td>
<td>25,000,000</td>
<td>177,500,000</td>
<td>206,550,000</td>
<td>8.26</td>
</tr>
<tr>
<td>50 years</td>
<td>62,500,000</td>
<td>443,750,000</td>
<td>443,750,000</td>
<td>7.56</td>
</tr>
<tr>
<td>100 years</td>
<td>125,000,000</td>
<td>887,500,000</td>
<td>887,500,000</td>
<td>7.33</td>
</tr>
</tbody>
</table>
7.0 ENVIRONMENTAL ASSESSMENT

Aggregate mining has always been an environmentally sensitive issue. Although aggregate demand increases each year, new sources of aggregate are becoming more difficult to develop due to environmental concerns. The key problem stems from the nature of this industry. In order to keep aggregate prices competitive, the source should be as close as possible to the market to minimize transportation cost. Unfortunately the market of this industry is almost always in populated areas where the construction rate is high. Environmental problems concerning aggregate mining develop from the fact that the operations are too close to populated areas. Citizens living near proposed quarries are effective at blocking licensing on the basis of potential dust, noise, and traffic problems. Since many compromise attempts such as the aggregate resources mining roundtable in Jefferson County, could not develop an immediately answer to the dilemma, the only possible solution may be to site aggregate operations away from populated areas, where no local residents are present to be affected.

According to Mr. Henry Baker, Director of Planning for Larimer County, Colorado, the county, at present, does not have general regulations concerning quarrying operations.
Each evaluation of quarry operation permit application is done on a case by case basis.

Most of the area studied in this report is rural, sparsely populated cattle-ranching country. It is open, undeveloped land with the exception of some farm lands and small gravel operations. No large towns or cities are within a 15-mile radius of any of the suggested quarry sites.

The visual impact factor has been considered at all potential sites. Buffer zones, in the form of natural hills or mountains, are present in order to minimize the overall visibility of the mining areas from existing and possible residential areas.

Concerns for air quality and noise pollution problems are not likely at any of the potential sites since they are situated in remote, unpopulated areas. Water quality should not be affected from the operations due to the fact that they are mined from quarry rock and not from stream channel gravel.

None of the sites is likely to have any value in the sense of archeological, paleontological or historical attributes, but the prospective quarry operator would need to check public records for designated or known sites and most likely would need to conduct ground surveys of the property.
for undiscovered sites. Since the material will be transported solely by rail, there should be no truck traffic problems.
8.0 GENERAL DISCUSSION AND CONCLUSION

The demand for aggregate to supply the Denver metropolitan area will undeniably increase with population growth. The alluvial aggregate supplies located close to the Denver metro area, which have been a prime source for the last 30 years, have been nearly depleted. Environmental problems and public concern make new permits for aggregate operations close to the Denver metro area almost impossible to obtain. Undoubtedly, the aggregate industries will have to move farther from the metro area in the near future. At the present aggregate consumption rate, reserves located in currently permitted and operating mines will last 15 years (Nasser, 1987). It is also unlikely that problems with environmental protection and public concerns are going to be settled to a level that will allow new large, long-term aggregate mining operation to be developed near the Denver area.

The eastern part of the Front Range in north-central Colorado and southeast Wyoming has good potential as a future source of crushed stone to supply the Denver metro area. The area is considered almost ideal for crushed stone production because of an unlimited supply of Sherman and Silver Plume granites. The quality of these granites is
considered to be good once fresh rock below the weathered surface is reached. L.A. abrasion test results from exposed surface samples have an average of 34.61% weight loss. Sample from Granite Canyon Quarry in Granite, Wyoming, an aplite porphyry hornblend granite, has the least loss (20.41%). It is also the freshest sample available since it was collected from an active quarry face. The highest loss (38.965) is from Harriman, Wyoming, a coarse-grained quartz syenite. Specific gravity test results range from 2.57 to 2.68, while absorption test results range from 0.36 to 0.82 with an average of 0.56. From petrographic study, the internal structures of these rocks are sound, and no deleterious constituents have been detected. The L.A. abrasion value for coarse aggregate, as set by the Federal Aviation Administration for the new Denver airport, is 30% weight loss (Federal Aviation Administration, 1989). This standard should easily be met once fresher rock samples can be collected for testing.

The Federal Highway Administration requires a percentage wear of not more than 50% in aggregate for subbase, base or surface courses; cold asphaltic concrete pavements and road-mixed asphaltic concrete pavements. The percentage wear is specified at not more than 40% for aggregate use in hot asphaltic concrete pavements (Federal Highway Administra-
tion, 1985). The quality of materials from the three selected sites is good enough to serve the purpose of general concrete construction since ASTM requires the percentage wear for coarse aggregate use for concrete of not more than 50% (ASTM, 1988).

From the point of environmental and public concerns, all the suggested sites of future mining are located in rural, unpopulated, undeveloped open area where the environmental concerns raised for mines in the Denver area are unlikely to be as critical in siting decisions. However, strict regulations should still be closely followed and considered in any planning.

Although the study area is well served by three major railroad lines, the major cost in production is still transportation, since the distance to the major market, the Denver metro area, is approximately 80 to 100 miles. This factor pushes the average estimated cost of the material to approximately $7.50 per ton. With a profit margin of 15%, the sales price should be approximately $8.60 per ton. Denver crushed stone prices should be around $8.50 per ton before these supplies would be competitive. According to Engineering News-Record, the average price per ton for 1-1/2- and 3/4-inch crushed stone in Denver has risen from approximately $7.13 per ton in 1980 to $7.65 per ton in
1987. At this rate of increase, a price of $8.50 per ton would be reached in 1999.
RECOMMENDATIONS

The results of this investigation are preliminary. Limited by equipments and time. Further studies, suggested below, are recommended as the next steps, at specific sites to be developed.

(1) Samples should be collected by drilling in order to reach fresh unweathered rock to gain more information on rock quality which could have been obscured in this test by use of surface samples.

(2) Additional engineering tests, which require additional equipment, time, and funding should be performed. The Magnesium Sulphate Test is highly recommended to determine the material's ability to resist weathering agents, particularly water freezing and thawing.

(3) Resources volume must also be more accurately calculated. Sites must be surveyed to obtain a topographic map as detailed as a four foot contour interval and specific boundaries must be set.

(5) More specific informations on environmental assessment should also be obtained for chosen sites.
REFERENCES CITED

Manual Book of ASTM Standards, Section 4, Volume 4.02 Concrete and Aggregates, ASTM, pp. 62-68, 73-75


Epis, R.C., and Chapin, C.E., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the southern Rocky Mountains: Geological Society of America Memoir 144, pp. 45-74


Fenneman, N.M., 1931, Physiography of Western United States, Mcgraw-Hill, Inc., New York


Appendix A

Detailed petrographic descriptions were prepared for thirteen thin-sections. Constraints are listed below.

- All samples were studied using a student model polarizing microscope.
- All thin-sections were stained to distinguish K-feldspar from plagioclase.
- Mode percentages are visually estimated.
- Degree of alteration is determined from condition of mineral grains, especially those sensitive to weathering such as plagioclase and biotite.
Sample: CH-1

Location: Calloway Hill

Texture: Holocrystalline, hypidiomorphic-granular (fine-medium grained)

Mode:
- Orthoclase -- 45%, subhedral, grain size approx. 2.0 mm, surrounded by slightly smaller quartz grains
- Plagioclase -- 30%, subhedral, grain size approx. 20 mm, slightly altered to clay
- Quartz -- 20%, anhedral, grain size approx. 0.5 mm. Biotite is fresh, though it is locally associated with fine secondary muscovite.
- Magnetite -- 1%, subhedral, grain size approx. 0.3-0.5 mm.

Degree of Alteration: Moderate

Rock name: Biotite granite
Sample: CH-2  
Location: Calloway Hill  
Texture: Holocrystalline, allotriomorphic-granular, fine to medium grained (1-4 mm)  

Mode  
- Orthoclase -- 45%, subhedral, grain size approx. 2 mm, invert to microcline  
- Plagioclase -- 35%, subhedral, grain size approx. 2 mm, slightly altered to clay and sericite, albite twins may be bent due to shearing  
- Quartz -- 20%, anhedral, grain size approx. 1.0 mm. Quartz has shown shadows.  
- Biotite -- 1%, subhedral, grain size approx. 0.5 mm, fresh, intergrowth with muscovite.  
- Muscovite -- trace, mostly secondary muscovite  

Degree of alteration -- Moderate  

Rock name: Biotite granite
Sample: CH-3
Location: Calloway Hill
Texture: Holocrystalline, hypidiomorphic-granular, fine to medium grained

Mode:
- Orthoclase -- 35-40%, subhedral, grain size approx. 0.5-0.2 mm, associate with quartz
- Plagioclase -- 30-35%, anhedral to subhedral, grain size 1.0-2.0 mm, sericitation
- Quartz -- 20%, anhedral, grain size approx. 0.5-1.0 mm, sign of strain.
- Biotite -- 3-5%, subhedral, grain size approx. 0.5 mm
- Muscovite -- trace, subhedral, grain size approx. 0.5 mm

Degree of alteration -- Moderate

Rock name: Biotite granite
Sample: CHLA

Location: Calloway Hill

Texture: Holocrystalline, hypidiomorphic-equigranular, fine to medium grained

Mode:

- K-feldspar -- 40%, anhedral, grain size 0.5-1.0 mm

- Plagioclase -- 35%, anhedral, grain size 0.5-1.0 mm. Moderately altered into sericite and clay, some grain intergrowth with quartz

- Quartz -- 20%, anhedral, grain size 1.0-1.5 mm, quartz grains extinction show sign of strain-ropy extinction

- Biotite -- 3%, anhedral to subhedral grains, grain size 0.5-1.0 mm, biotite is relatively fresh, locally altered into chlorite.

- Muscovite -- approx. 1%, anhedral, grain size 0.5 mm.

Degree of alteration: Moderate

Rock name: Biotite granite
Sample: GCQ-1
Location: Granite Canyon Quarry
Texture and Description: Holocrystalline, porphyritic-aphanitic with grain size varying from 1-3 mm. Anhedral quartz, subhedral feldspar (often glomeroporphyritic k-feldspar and plagioclase aggregates), and anhedral sieved biotite-hornblende aggregate with single hornblende crystals as phenocrysts.

Matrix is anhedral, grain size ranges from 0.05-0.5 mm, mostly consisting of quartz and feldspar with smaller percentage of hornblende and magnetite.

Mode: Aplitic texture

Phenocrysts - 40%, consisting of:
- k-feldspar -- 25%
- quartz -- 7%
- hornblende -- 6%
- plagioclase -- 5%
- biotite -- 1%

Groundmass -- 60%, consisting of:
- k-feldspar -- 35%
- quartz -- 10%
- plagioclase -- 10%
- hornblende -- 2%
- magnetite -- 1%

Degree of Alteration -- Low

Rock name: Aplite porphyry hornblende granite
Sample: GWLA

Location: Granite, Wyoming

Texture and Description: Holocrystalline, porphyritic-aphanitic
Grain size varying from 0.5-2.0 mm, anhedral to subhedral quartz; subhedral plagioclase; anhedral k-feldspar, amphibole and biotite.

Mode:
Phenocryst -- 50%
  k-feldspar -- 25%
  quartz -- 10%
  amphibole -- 8%
  plagioclase -- 5%
  biotite -- 1%

Groundmass -- 50%
  k-feldspar -- 25%
  quartz -- 15%
  plagioclase -- 10%
  amphibole -- trace

Degree of alteration -- Low

Rock name: Aplite porphyry hornblende granite
Sample: H-1

Location: Harriman

Texture: Holocrystalline, hypidiomorphic-equigranular

Mode:
- Alkali feldspar -- 57%, subhedral, grain size 5.0-15.0 mm, approx. 40-50% of alkali feldspar has been transformed to platy exsolved plagioclase upon cooling.
  - Plagioclase -- 20%, anhedral, grain size 1.0-4.0 mm, intergrowth with k-feldspar and quartz
  - Quartz -- 20%, anhedral, grain size 0.5-1.0 mm, quartz shows undulatory extinction which is the sign of deformation zone.
  - Biotite and its altered form -- 3%, grain size 0.3-0.2 mm, biotite grains are rare, some appeared as 1.0-2.0 mm grains. Most are altered to iron oxide, epidote and feldspar.

Degree of alteration: Moderate-High

Rock name: Quartz syenite
Sample: HLA
Location: Harriman
Texture: Holocrystalline, hypidiomorphic-equigranular (medium to coarse grained)

Mode:
- Alkali feldspar -- 55%, subhedral, grain size, 4.0-15.0 mm
- Plagioclase -- 25%, anhedral, grain size, 1.0-5.0 mm
- Quartz -- 20%, anhedral, grain size, 0.5-1.5 mm, quartz shows sign of strain. Undulatory extinction within grain.
- Biotite -- 5%, anhedral, grain size, 0.5-2.0 mm. Almost entirely altered into iron oxide and feldspar.

Special note: Alkali feldspar has been largely transformed into plagioclase.

Degree of alteration: Moderate-High

Rock name: Quartz syenite
Sample: L-1
Location: Livermore
Texture: Holocrystalline, hypidiomorphic-equigranular, fine-grained (0.5-2.0 mm)
Mode:
- K-feldspar -- 45%, subhedral, grain size 0.5-2.0 mm
- Plagioclase -- 35%, anhedral, grain size 0.5-2.0 mm, slightly altered to clay
- Quartz -- 20%, anhedral, grain size 0.5-1.0 mm. Quartz is strained and recrystallized to subgrains.
- Biotite -- 2%, anhedral, grain size, 1.0 mm. Biotite is completely altered to clay and Fe-oxide, also intergrowths with some muscovite.
- Opaque -- < 1%

Degree of alteration--Moderate

Rock name 1) Quartz monzonite or 2) Quartz syenite
Sample   LMLA

Location   Livermore

Texture   Holocrystalline, hypidiomorphic-equigranular, fine-to-medium grained

Mode
- K-feldspar -- 40%, anhedral, grain size 0.5-3.0 mm
- Plagioclase -- 35%, anhedral, grain size 0.5-3.0 mm. Plagioclase grains are moderately altered into sericite.
- Quartz -- 20%, anhedral, grain size 0.1-0.3 mm. Quartz in this sample has shown recrystallization.
- Biotite -- 2-3%, anhedral, mostly altered into chlorite and iron oxide.
- Amphibole -- 1%
- Muscovite -- trace

Degree of alteration--Moderate

Rock name Quartz Syenite
Sample: SC-1
Location: Stonewall Creek
Texture: Holocrystalline, hypidiomorphic-equigranular, medium-grained

Mode:
- Plagioclase -- 40-45%, subhedral, grain size 1.0-1.5 mm
- K-feldspar -- 30-35%, subhedral, grain size average 3.0 mm
- Quartz -- 20%, anhedral, grain size 1.0-1.5 mm
- Biotite -- 5%, anhedral, grain size approx. 0.5 mm. Mostly altered into chlorite and clay.

Degree of alteration: Moderate

Rock name: Quartz monzonite
Sample  SC-2
Location  Stonewall Creek
Texture  Holocrystalline, medium-to-coarse grained
Mode
- Plagioclase  --  45%, subhedral, grain size 1.0-3.0 mm
- K-feldspar  --  35%, subhedral, grain size 2.0-8.0 mm. Larger feldspar grains are intergrown (graphically) with quartz, 5% shows unmixing to plagioclase.
- Quartz  --  20-25%, anhedral. Some minor nucleation of very fine unstrained quartz grains has occurred. Quartz has deformed slightly to an incipient mylonitic fabric.
- Biotite  --  trace, altered to chlorite

Degree of alteration--Moderate

Rock name  Quartz monzonite
Sample

VLA

Location

Virginia Dale

Texture

Holocrystalline, hypidiomorphic-granular, medium- to-coarse grained

Mode

- K-feldspar -- 35%, subhedral, grainsize 0.5-1.5 mm wide and up to 6.0 mm long. Some path has inclusion of smaller plagioclase within grain.

- Quartz -- 35%, anhedral to subhedral, grain sizes varied from 0.5-5.0 mm

- Plagioclase -- 20%, anhedral to subhedral, grain size 0.5-3.0 mm. Most of the grains show sericitation.

- Biotite -- 10%, anhedral to subhedral, grain size 0.5-1.0 mm

- Muscovite -- trace, grain size 0.2-1.0 mm

Degree of alteration--Low-Moderate

Rock name Biotite granite
APPENDIX B  Detailed Cost Calculation

Detailed Cost Estimation for Calloway Hill

- Cost of land (plus buffer zone) 4 square miles
  = 4 x 640 acres = 2,560 acre
  = 2,560 acres x $500/acre
  = $1,280,000 --- 1*

- Permitting + start-up + trestle
  = $500,000 + $15,000,000 + $750,000
  = $16,250,000 --- 2*

- Railroad spur cost, distance 10.0 mile
  = 10.0 x 1760 x 3 ft. x $100/ft.
  = $5,280,000 --- 3*

- Production cost + transportation cost/ton
  = $3.15 + $3.95 = $7.10/ton

*** 20 years production at 1,250,000 ton/yr.

Material produced = 1,250,000 x 20
  = 25,000,000 ton

Production + transportation cost = 25,000,000 x 7.1 = $177,500,000

Total cost = $177,500,000 + 1 + 2 + 3
  = $200,310,000
Cost/ton = \frac{200,310,000}{25,000,000} = $8.01/ton***

*** 50 years production at 1,250,000 ton/yr

Material produced = 1,250,000 \times 50

= 62,500,000 ton

Production + transportation cost = 62,500,000 \times 7.1 = $443,750,000

Total cost = $443,750,000 + 1 + 2 + 3

= $466,560,000

Cost/ton = \frac{466,560,000}{62,500,000} = $7.46/ton***

*** 100 years production at 1,250,000 ton/yr

Material produced = 1,250,000 \times 100

= 125,000,000 ton

Production + transportation cost = 125,000,000 \times 7.1 = $887,500,000

Total cost = $887,500,000 + 1 + 2 + 3

= $910,310,000

Cost/ton = \frac{910,310,000}{125,000,000} = $7.28/ton***
Detailed Cost Estimation for Livermore

- Cost of land (plus buffer zone) 3.5 square miles
  
  \[\text{Cost} = 3.5 \times 640 \text{ acres} = 2,240 \text{ acres}\]
  
  \[\text{Cost} = 2,240 \text{ acres} \times \$500/\text{acre}\]
  
  \[\text{Cost} = \$1,120,000 \quad \text{--- 1}\]

- Permitting + start-up + trestle
  
  \[\text{Cost} = \$16,250,000 \quad \text{--- 2}\]

- Railroad spur cost, distance 7.5 mile
  
  \[\text{Cost} = 7.5 \times 1,760 \times 3 \times \$100/\text{ft.}\]
  
  \[\text{Cost} = \$3,960,000 \quad \text{--- 3}\]

- Production + transportation cost/ton
  
  \[\text{Cost} = \$7.10/\text{ton}\]

*** 20 years production at 1,250,000 ton/yr.

Material produced = 25,000,000 ton

Production + transportation cost = 25,000,000

\[x 7.1 = \$177,500,000\]

Total cost = \$177,500,000 + 1 + 2 + 3

\[= \$198,830,000\]

\[\frac{\text{Cost/ton}}{\text{ton}} = \frac{198,830,000}{25,000,000} = \$7.95/\text{ton}***\]

*** 50 years production at 1,250,000 ton/yr.

Material produced = 62,500,000 ton

Production + transportation cost = 62,500,000
\[ x \times 7.1 = \$443,750,000 \]

Total cost = \$443,750,000 + 1 + 2 + 3

\[ = \$465,080,000 \]

\[ \text{Cost/ton} = \frac{465,080,000}{62,500,000} = \$7.44/\text{ton} \]

*** 100 years production at 1,250,000 ton/yr.***

Material produced = 125,000,000 ton

Production + transportation cost = 125,000,000

\[ x \times 7.1 = \$887,500,000 \]

Total cost = \$887,500,000 + 1 + 2 + 3

\[ = \$908,830,000 \]

\[ \text{Cost/ton} = \frac{908,830,000}{125,000,000} = \$7.27/\text{ton} \]
Detailed Cost Estimation for Virginia Dale

- Cost of land (plus buffer zone) 7 square miles
  = 7 x 640 acres = 4,480 acres
  = 4,480 acres x $500/acre
  = $2,240,000 --- 1***

- Permitting + start-up + trestle
  = $16,250,000 --- 2

- Railroad spur cost, distance 20 miles
  = 20 x 1,760 x 3 ft x $100/ft.
  = $10,560,000 --- 3***

- Production + transportation cost/ton
  = $7.10/ton

*** 20 years production at 1,250,000 ton/yr.

Material produced = 25,000,000 ton
Production + transportation cost = 25,000,000
x 7.1 = $177,500,000

Total cost = $177,500,000 + 1 + 2 + 3
= $206,550,000

\[\text{Cost/ton}=\frac{206,550,000}{25,000,000}=$8.26/ton***

*** 50 years production at 1,250,000 ton/yr.

Material produced = 62,500,000 ton
Production + transportation cost = 62,500,000
\[ x \times 7.1 = \$443,750,000 \]

Total cost = $443,750,000 + 1 + 2 + 3

= $472,800,000

\[
\text{Cost/ton} = \frac{472,800,000}{62,500,000} = \$7.56/\text{ton}^{**}
\]

** 100 years production at 1,250,000 ton/yr.

Material produced = 125,000,000 ton

Production + transportation cost = 125,000,000

\[ x \times 7.1 = \$887,500,000 \]

Total cost = $887,500,000 + 1 + 2 + 3

= $916,550,000

\[
\text{Cost/ton} = \frac{916,550,000}{125,000,000} = \$7.33/\text{ton}^{**}
\]