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GEOLOGY, GENESIS, AND MINING OF HIGH BRIGHTNESS, HIGH PURITY LIMESTONE DEPOSITS AT PLUESS-STAUFER (CALIFORNIA) INC. LUCERNE VALLEY CALIFORNIA OPERATION

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INTRODUCTION

Pluess-Staufer (California) Inc. Lucerne Valley California operation is one of the largest producers of high brightness high purity fine grind limestone products in western North America. The San Bernardino Mountains area of southern California contains the largest high brightness, high purity limestone mining operations and undeveloped reserves in western North America (Fig. 1, Brown 1987). Combined annual production of high brightness limestone products from several operations is approximately 1.5 million tons, with an estimated gross value of $75 million dollars per year (Fig. 2). An additional 5.0 million tons of cement grade limestone is mined by several large cement producers in the nearby Mojave area (Brown, in press).

The purpose of this paper is to summarize the geologic setting, genesis and mining of white, high purity crystalline limestone by Pluess-Staufer (California) Inc.

REGIONAL GEOLOGIC SETTING

A variety of rocks of Precambrian to recent age are exposed within the San Bernardino Mountains and they have close affinity to rocks exposed in the Mojave Desert area. Late Precambrian and Paleozoic metasedimentary rocks unconformably overlie earlier Precambrian basement. Three major facies, including cratonal, miogeoclinal, and deeper water marine strata, can be recognized (Fig. 3) within the region.

Paleozoic rocks exposed in the southeastern Mojave region are characterized by a thin, incomplete sequence of shallow marine cratonal strata. These sequences are very similar to the classical cratonal section exposed in the Grand Canyon area (Stone and others, 1983). Paleozoic sequences in the central and western Mojave region and San Bernardino Mountains contain elements of both cratonal and miogeoclinal affinity (Brown 1991) A major unconformity is present between Upper Cambrian and Devonian strata throughout the Mojave region. In the San Bernardino Mountains, Upper Precambrian and Lower Cambrian rocks are of miogeoclinal aspect, middle Cambrian strata are of cratonal aspect, and upper Paleozoic rocks are identical to inner miogeoclinal facies of the central and eastern Mojave region (Brown 1984, 1986)(Fig. 4, Table 1).

High brightness, high purity crystalline limestone deposits occur in upper Paleozoic miogeoclinal limestone formations in the San Bernardino Mountains (Table 2).

Several major tectonic events have been recognized in various parts the San Bernardino Mountains and Mojave Desert region (Brown 1981, 1982, 1984b, 1989, 1991). These include complex Mesozoic age multiphase folding and thrust faulting, contact and regional metamorphism, and intrusive events. Cenozoic activity includes high and low-angle faults, mild folding, and abundant volcanism. The major province boundaries (San Andreas and Garlock fault zones) were formed and many ranges in the Mojave area were uplifted and eroded during Cenozoic time. The San Bernardino Mountains however, have undergone very recent (Plio-Pleistocene age) uplift on a series of low angle thrust faults.

The San Bernardino Mountains and Mojave Desert area continue to be seismically active as evidenced by the large number of significant earthquakes in the area during 1992.

The complex geologic history of the San Bernardino Mountains has allowed the formation of several large high brightness, high purity limestone deposits which are currently being mined or will be mined in the future.

GENESIS OF WHITE HIGH CALCIUM LIMESTONE DEPOSITS IN THE SAN BERNARDINO MOUNTAINS

Carbonate rocks are found extensively on all continents, but high purity, high brightness (white) limestone deposits are relatively uncommon in nature because their formation is dependant on the superposition of several independent geologic processes, acting over a long period of time.

Among the processes are:

1) Deposition of originally pure limestone in high energy agitated, shallow marine environment.
2) Post depositional changes including metamorphism and/or magmatic processes to bleach and recrystallize the rock, and disperse any impurities which may have been present.
3) Structural controls including folding, faulting and orogenic processes to place the rocks in desirable structural settings.
4) Uplift and erosion.
5) Preservation thru geologic time.

Because all the geologic processes are required, deposits of high calcium white crystalline limestone are relatively uncommon in nature, and are vastly different from common limestone. Deposits of high purity, high brightness crystalline limestone suitable for high quality filler and extender applications are limited and only occur in restricted areas.

Within the southwestern United States, the largest productive, deposits of white, high purity limestone are present in the San Bernardino Mountains of southern California, and the area is by far the largest producing district in western North America.

In this section the various processes influencing the genesis of the deposits will be summarized.

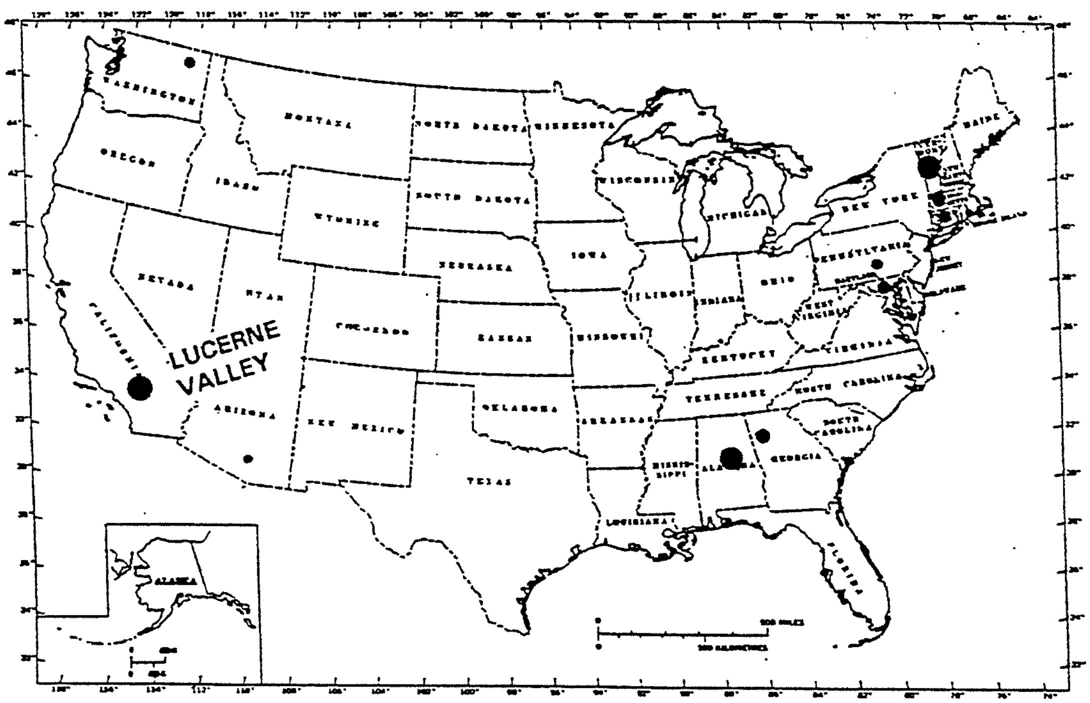


Figure 1.. Major white, high purity calcium carbonate producers in the United States

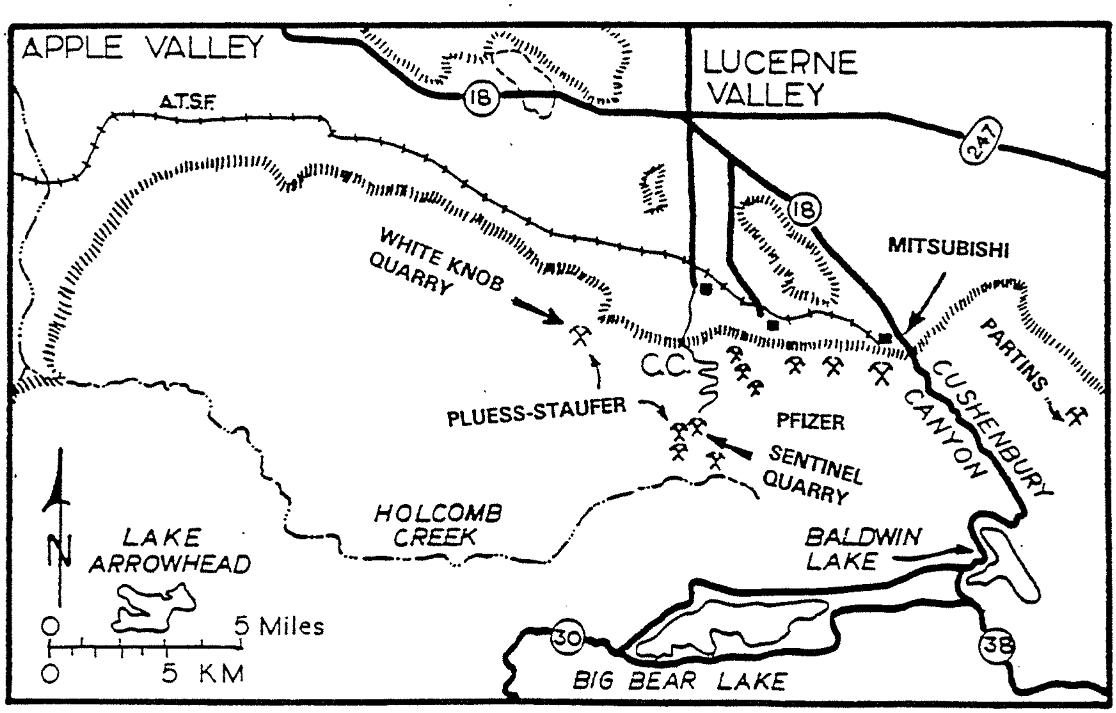


Figure 2. Index map of the northern San Bernardino Mountains and Lucerne Valley showing limestone producers and quarries discussed in text.

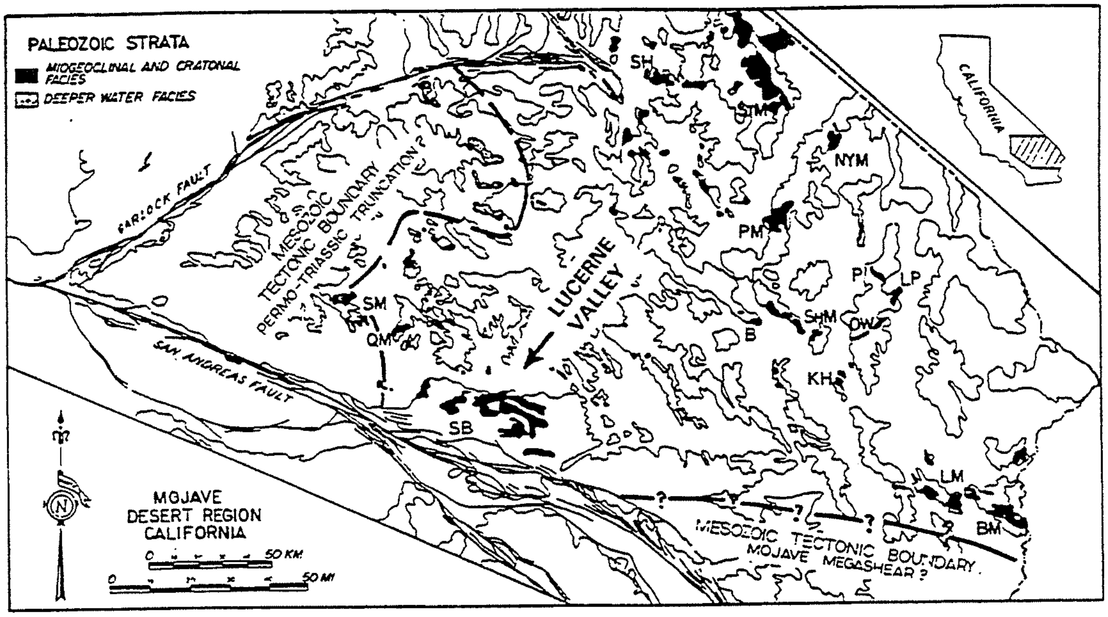


Figure 3. Mojave Desert area showing paleozoic rocks.

ENVIRONMENT OF DEPOSITION

Environment of deposition is important because it determines the size, shape, purity, and other economically significant characteristics of the carbonate rock deposit.

Limestones that form in high energy environments generally contain only minor non-carbonate impurities, and are the source of high purity limestone. Limestones which form in low energy environments contain mud, clay, silica, and other impurities. Turbulent or agitated water will winnow mud from the sediments. Calm water allows mud to settle to the bottom and remain there.

Limestone formed in strongly agitated environments are characterized as being medium to coarse grained. The predominant sand sized grains are crinoid columnals, and lesser fragments of brachiopods and ostracods. Crinoids need well aerated water of relatively high salinity. Sediments of this type accumulated in a shallow marine environment where vigorous winnowing currents were common.

A direct relationship exists between depositional environment and carbonate chemistry. Limestones which form in high energy environments contain more $CaCO_3$, and less MgO, Fe_2O_3, SiO_2, and Al_2O_3 impurities than muddy low energy limestones. In addition, a relationship exists between type of alochem present and chemical composition. Limestones containing abundant crinoidal debris generally have high $CaCO_3$ and low Al_2O_3 and MgO values.

Crinoidal limestones which form in high energy shallow environments are the most economically favorable type of carbonate rocks.

Within the San Bernardino Mountains, are high energy shallow marine environment. Formations which contain pure limestone include portions of the Bird Spring Formation (Pennsylvanian-Permian) Monte Cristo Limestone Bullion Member (Mississippian), and Sultan Limestone Crystal Pass Member (Devonian), (Brown 1991). Table 2 shows Paleozoic carbonate formations of economic interest as sources of high brightness high purity crystalline limestone in the San Bernardino Mountains.

METAMORPHISM

Metamorphism is of great importance in the formation of high purity, high brightness (white) limestone deposits. Metamorphism of limestones in proximity to igneous intrusions often results in bleaching of susceptible rock, and coarsening of grain size. Regional metamorphism caused by pressure and heat at depth also cause the limestone to recrystallize, resulting in coarsening of grain size, dispersion of impurities (if present), and bleaching or whitening of the rock.

Pure limestones formed in agitated water, when subjected to metamorphism may form very white, coarse grained, very pure calcite marble deposits of premium quality. Within the San Bernardino Mountains the Paleozoic rocks have been subjected to regional and or contact metamorphism (Brown 1987). Formations or Members which have been recrystallized and bleached to white calcite marble include Devonian Sultan Limestone, Crystal Pass Member, Mississippian Monte Cristo Limestone Bullion Member, and portions of the Bird Spring Formation of Pennsylvanian-Permian age.

Cretaceous Age regional metamorphism is variable but ranges from greenschist facies amphibolite and in some areas to granulite facies (Brown 1991).

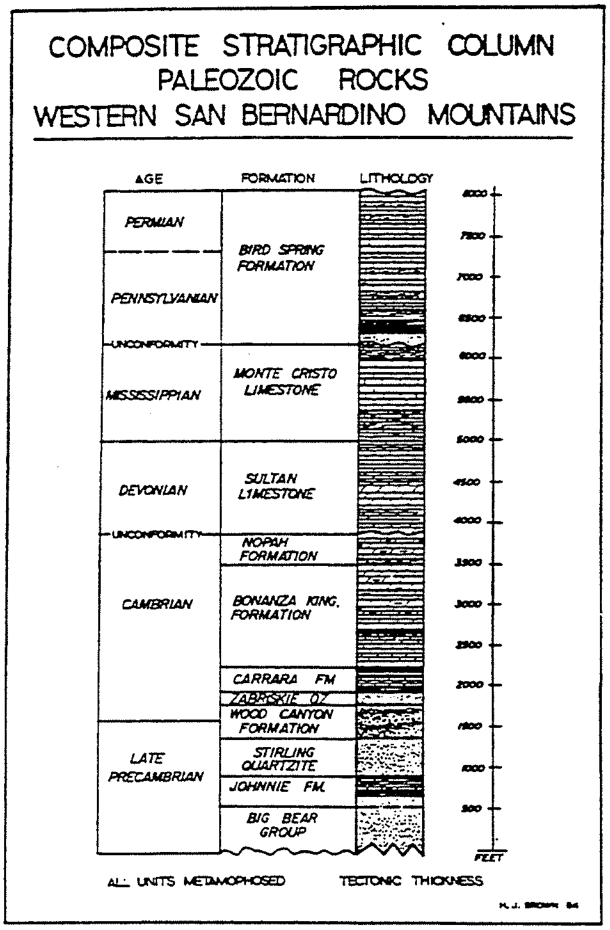


Figure 4. Composite stratigraphic column of Paleozoic rocks in the San Bernardino Mountains.

ranging from Permo-Triassic thru Late Cretaceous Age has resulted in contact metamorphism in many areas. Some limestone deposits have been affected by multiple metamorphic events and have been bleached and recrystallized to exceedingly coarse grained, very white calcite marble.

STRUCTURAL CONTROLS

Structural controls of carbonate deposits have an important influence on the formation of a deposit. Folding can strongly influence a deposit. Thickness may be increased in the core of folds, while the limbs may be significantly thinned. Faulting may also exercise strong influence on a deposit. Faults can truncate a deposit at shallow depth, or hide a vast deposit under shallow cover. Other faults may cause repetition or omittance of a deposit.

As noted previously, Paleozoic rocks in the San Bernardino Mountains have undergone a complex deformational history which includes multiphase folding and faulting (Fig. 5). Deposits therefore are often complexly folded and faulted.

UPLIFT, EROSION, AND PRESERVATION THRU GEOLOGIC TIME

Uplift and erosion has strong influence upon the preservation and mining of a deposit. Prolonged erosion may completely remove a deposit, while more recent uplift and erosion may remove the overburden.

Paleozoic rocks in the Mojave area originally covered the region. Uplift during Tertiary time, and erosion have largely removed most of the Paleozoic rocks in the Mojave, leaving islands (remnants) of Paleozoic rocks in a sea of granite and alluvium.

The San Bernardino Mountains however were not uplifted until more recent (Plio-Pleistocene) time (May and Repenning 1982), thus the root pendants are more extensive, and large deposits of white, crystalline limestone are present.

USES AND SPECIFICATIONS OF HIGH BRIGHTNESS, HIGH PURITY LIMESTONE

High purity white crystalline limestones have a large number of uses and are classified as white fillers and extenders with value added characteristics. The products are finely ground, high brightness, high purity limestone, and are the whitest, purest, and most valuable per ton of all limestone products.

Desirable characteristics are high brightness (white color), low tint, uniform fine particle size, freedom from grit, and chemical purity. Color and purity are of utmost importance in virtually all applications. Limestone suitable for white fillers and extenders is limited to a minimum of 98% $CaCO_3$, and a maximum of 2% combined $MgCO_3$, SiO_2, and all other impurities combined. Brightness requirements range from low 90's to greater than 95. Tint values are generally below 2.0.

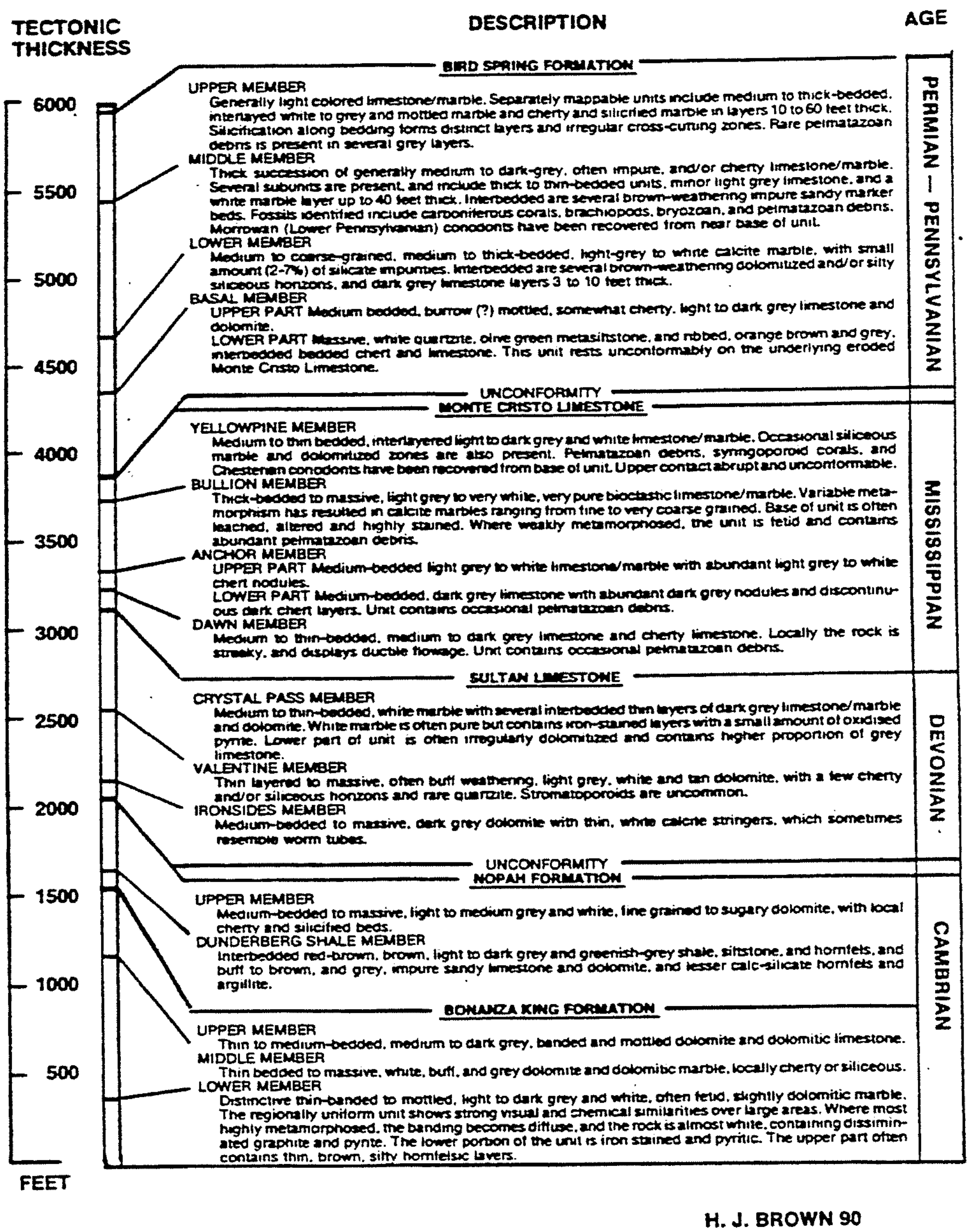
The greatest uses of fillers and extenders are paint, rubber products, putty, pottery, paper, a variety of plastics, food, flooring, PVC pipe, white ink, tooth paste, wire coating, glue, caulking compounds, resins, and polyesters. Uses in the housing industry include ceiling and wall textures, dry wall mud, joint compounds, stucco, and fiberglass roofing shingles.

As can be seen, for most uses, white fillers and extenders requires not only the most pure limestone, but also the whitest color of all limestones. The restricted nature of the deposits and the fact that products are shipped as far as 2000 miles from the source, indicates a large demand by our society for these valuable products.

HIGH BRIGHTNESS LIMESTONE MINING OPERATIONS SAN BERNARDINO MOUNTAINS

Several large, open pit, white, crystalline limestone/calcite marble quarries and undeveloped deposits are present in the San Bernardino Mountains (Fig. 2). Combined annual production is approximately 1.5 million tons with an estimated gross value of $75

Table 1. Description of Paleozoic carbonate rocks.



million dollars per year. Pluess-Staufer (California), Inc., Specialty Minerals Inc. (formerly Pfizer Inc.), and Partins Limestone (Riverside Cement) are the major producers of white crystalline limestone products (Figure 2).

An estimated 5.0 million tons of cement grade limestone is also mined by several large cement producers from the San Bernardino Mountains and nearby Mojave Desert area.

PLUESS-STAUFER (CALIFORNIA), INC. MINING OPERATIONS

Pluess-Staufer (California), Inc. mines and processes high quality white limestone from extensive deposits in the San Bernardino Mountains, and is the second largest producer of high quality limestone fillers and extenders in the western United States. Currently active mines are located along the north range front, and along the range crest, and the processing plant is located in Lucerne Valley, at the base of the mountains (Fig. 2).

Pluess-Staufer produces a full range of coarse, fine, and ultra fine grind, high brightness, high purity calcium carbonate products. Plant facilities offer both bulk and bagged materials in truck or rail quantities.

Pluess-Staufer (California), Inc. took over operations during the late 1970's and began an intensive, and ongoing, plant rebuilding and expansion program, as well as intensive and continuing geologic exploration and

Cenozoic	Q	Quaternary alluvium
	QL	Quaternary lake deposits
	QLS	Quaternary landslide deposits
	Qo	Plio-Pleistocene older alluvium
	Pow	Pliocene Old Woman Sandstone
		UNCONFORMITY
Mesozoic	Mqm	Cretaceous quartz monzonite
	Mhd	Jurassic hornblende diorite
	Mlp	Jurassic quartz latite porphyry complex
	Mm	Permo-Triassic monzonite and granite cataclasite
Paleozoic	Pzu	Upper Paleozoic rocks; Pennsylvanian-Permian Bird Spring Formation, Mississippian Monte Cristo Limestone, Devonian Sultan Limestone Crystal Pass Member.
	Є	Cambrian and Devonian carbonate rocks; Cambrian Bonanza King Formation, Cambrian Nopah Formation, Devonian Sultan Limestone Lower Members.
Precambrian	PєC	Late Precambrian-Cambrian strata; Late Precambrian Big Bear Group, Late Precambrian Johnnie Formation, Stirling Quartzite, Late Precambrian-Cambrian Wood Canyon Formation, Cambrian Zabriskie Quartzite, Cambrian Carrara Formation.
		UNCONFORMITY
	PЄg	Older Precambrian basement gneiss.

GENERALIZED GEOLOGIC MAP
OF THE
NORTHWESTERN SAN BERNARDINO MOUNTAINS
SAN BERNARDINO COUNTY, CALIFORNIA

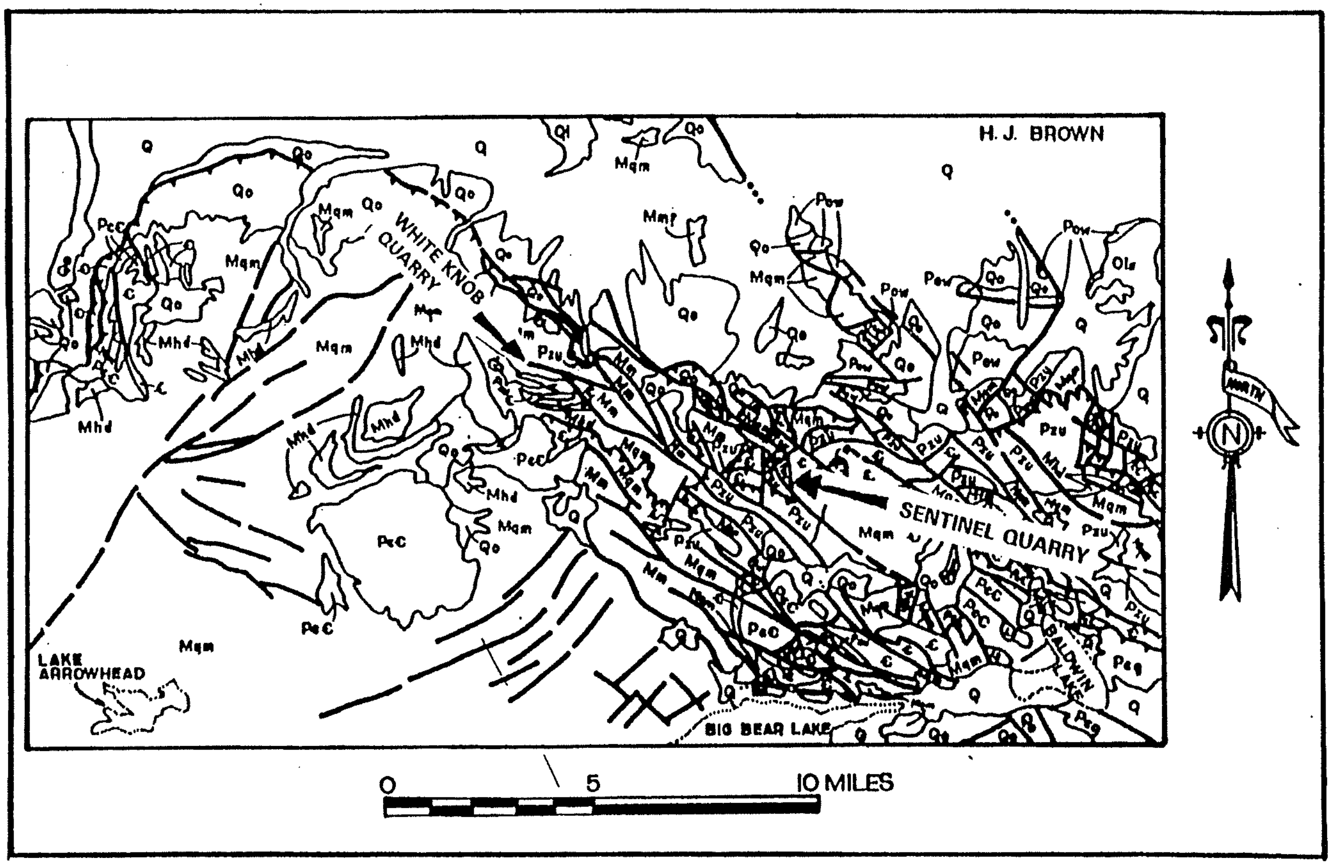


Figure 5. Generalized geologic map of the northwestern San Bernardino Mountains.

Table 2. Paleozoic formations of economic interest as potential sources of high brightness, high purity crystalline limestone in the San Bernardino Mountains.

AGE	THICKNESS (FEET)	FORMATION/MEMBER, DESCRIPTION
PENNSYLVANIAN	UP TO 350 FEET	BIRD SPRING FORMATION, (UNNAMED MEMBER) Medium to coarse grained white calcite marble. Contains 2-7% silicate impurities, and occasional thin interbeds of grey and brown silty limestone and dolomite.
MISSISSIPPIAN	UP TO 400 FEET	MONTE CRISTO LIMESTONE, BULLION MEMBER Thick bedded to massive, light grey to very white, very pure, crystalline limestone and coarse grained calcite marble. Contains crinoid debris when weakly metamorphosed. Occasional iron oxide stain on fracture surfaces.
DEVONIAN	UP TO 350 FEET	SULTAN LIMESTONE, CRYSTAL PASS MEMBER Medium to thin bedded, medium grained, pure, white calcite marble. Contains several interbeds of grey limestone, and or dolomite. Common iron oxide stain on bedding and fracture surfaces.

quarry development programs. Successful exploration and core drilling have discovered several new deposits, and proven sizable reserves at existing mines. Existing proven minable and permitted reserves are adequate for over 25 years. Currently the bulk of the ore comes from two quarries, the Sentinel Quarry and the White Knob Quarry.

SENTINEL QUARRY

Sentinel Quarry is located at the north range crest at an elevation of about 7600 feet, and is reached by the Crystal Creek Haul Road (Fig. 2). Topography in the quarry area is rugged and steep. Location is shown on Figure. Rocks in the quarry area include metamorphosed Paleozoic sedimentary rocks and Mesozoic intrusive rocks.

PALEOZOIC ROCKS

Paleozoic rocks exposed in the quarry area include Cambrian Nopah formation, Mississippian Monte Cristo limestone, Bullion Member, and Pennsylvanian Bird Spring Formation. Cambrian Nopah Formation is exposed along the west side of the quarry and is in reverse fault contact with upper Paleozoic rocks. The moderate to steeply dipping Nopah Formation is composed of white to grey Dolomite marble of variable purity. For mining purposes all Dolomite is waste rock.

Mississippian Monte Cristo Limestone Bullion member is exposed in the quarry area and forms the orebody. The gently dipping Bullion member is up to 350 feet thick and is composed of exceedingly pure, variably light grey to white calcium carbonate marble. Originally fossil rich bioclastic limestone, variable metamorphism has bleached the rock into light grey to white fine grained calcite marble, of very high purity, typically > 99.5%

The orebody is up to 350 feet thick, 2500 feet long and up to 500 feet wide on the P.S.C. claims.

Pennsylvanian Bird Spring Formation exposed in the southern portion of the quarry area, is in thrust fault contact with the Mississippian Monte Cristo limestone and forms the hanging wall (overburden) above the orebody. Bird Spring Formation in the quarry area is dark grey to black impure limestone and dips gently toward the south.

MESOZOIC ROCKS

Mesozoic rocks in the quarry area include an altered porphyry dike which has intruded into the west dipping reverse fault which has juxtaposed Cambrian Dolomite against upper Paleozoic rocks. The dike is generally less than 8 feet thick dips steeply to the west and is highly altered to clay minerals.

METAMORPHISM

Paleozoic rocks in the area have been regionally metamorphosed to greenschist grade. Conodont color index measurements indicate metamorphic temperatures of over 430 degrees C. Metamorphism of the Bullion member of the monte Cristo limestone has formed variable white to light grey, fine grained, very pure Calcite Marble which forms the ore body.

STRUCTURE

Rocks in the quarry area have been both folded and faulted. Folds seen during mining are F2 folds and are upright open undulations in the shallow dipping upper Paleozoic rocks.

Faults are common in the quarry and have faults are present in the north part of the quarry. The faults progressively down drop the footwall to the south, and are generally marked by iron oxide stain zones. A major north trending west dipping reverse fault has juxtaposed Cambrian Dolomite against upper Paleozoic limestones and forms the west boundary of the ore. Several other smaller north trending faults of smaller magnitude are also present.

The Bird Spring Formation has been juxtaposed over the Monte Cristo Limestone on a south dipping thrust fault. Several hundred feet of Bird Spring Formation have been removed along the fault. Other minor low angle shears are also present in the area. Most of the faults are of Cenozoic Age and may be related to the uplift of the range.

FORMATION OF LIMESTONE ORE DEPOSIT

As noted, the ore deposit is formed from depositionally pure limestone of the Bullion Member of the Monte Cristo limestone of Mississippian Age. Greenschist grade metamorphism has bleached the rock white, resulting in Calcium Carbonate of exceptionally uniform and high purity, and moderate to high brightness.

The orebody on the P.S.C. claims is triangular in plain view, 2500 feet long, up to 500 feet wide and up to 350 feet thick. Drill proven, recoverable reserves are adequate for 30 years mining at present and projected future mining rate.

MINING OPERATION SENTINEL QUARRY

Mining of the Sentinel deposit began by La Habra Products during the early 1970's, and has been more or less continuous since then. Core drilling by P.S.C. since 1978 has proven recoverable reserves sufficient for 30 years. Core drilling will continue into the future. Reserves have been maintained at 30 years despite quadrupling of the production rate during the last decade.

The Sentinel Quarry is a multi bench open pit mine. Two or three working levels are operated at any one time to supply the quota of ore needed to meet production demands. The multiworking level concept allows for greater selectivity and blending of rock qualities to meet stringent quality standards of customers, and allow maximum utilization of the resource.

Currently four grades of ore are selectively mined from Sentinel Quarry. The ore is drilled and blasted, loaded with a 13 yd^3 front end loader into 85 ton haul trucks and hauled to the crusher, 1/4 mile south of the pit. At the crusher, the rock is reduced in size to -7", screened and separated into the various quality grades. Crushed ore is then loaded into 85 ton haul trucks and transported 8 miles on the Crystal Creek Haul Road to the existing processing plant in Lucerne Valley.

The Sentinel deposit is mined in 20 foot cuts with a safety bench every 40 feet. Bench height has been determined as a result of detailed studies of the geologic consultations with various experts including government and private sector. Face angle averages 70 degrees. Bench width is 20 feet, but is greater if wall height is over 40 feet. Generally, bench width is 1/2 wall height. Pit ramps are 30 to 50 feet wide and grade is 10 to 15 % depending on conditions. The operating plan is designed with overall pit slopes of about 45 to 48 degrees (about 1:1 overall slope). The highest level of the pit is 7600 feet. Mining will ultimately reach the 7170 foot elevation, and the quarry will have up to 11 benches.

Five mining phases have been previously approved (USFS 11-1-88). Currently Phase 2 is being completed and Phase 3 began in 1993. Mining presently occurs on the 7430, 7450, 7520 and 7540 foot levels. During the next five years (Phase 3) the pit will be deepened to the 7400 foot level. Phase 4 and 5 (1998-2022) will progressively develop (push back) toward the southern mining limit and eastward to the property line. During Phase 4 and 5 the pit will be deepened to the 7170 level. Currently the pit is triangular in plan view, and is about 1500 feet long, 500 feet wide and 160 feet deep. The final pit will be about 2300 feet long, 800 feet wide, and up to 400 feet deep.

The following major equipment is currently used in mining of the Sentinel Quarry:

A. Two 85 ton haul trucks
B. Two 50 ton haul trucks
C. One 12.5 yd3 loader
D. One D-9 dozer
E. One 16-G motorgrader
F. One 7000 gallon water truck
G. One Track Drill

QUALITY CONTROL

Prior to mining, the deposit was extensively core drilled to determine continuity and ore grade distribution. Quarry blasts are generally small (< 10,000 yd^3) to allow maximum selectivity. Blast hole cuttings are examined prior to blasting to verify ore grade. After blasting, quarry run rock is sampled as necessary to insure uniform quality within each specific ore grade. At the crusher is a small lab facility with a small jaw crusher, pulverizer and analytical equipment to determine brightness and tint. Turnaround on samples is less than 8 minutes from collection to results. The crusher operator and all mobile equipment operators communicate via two way radio. The crusher has a radial stacker to facilitate separating various grades of ore.

ON SITE ORE PROCESSING

Ore from the Sentinel Quarry is hauled to the primary crusher for size reduction, screening, and sorting of ore grades. After these operations have been completed, the ore is transported to the processing plant in Lucerne Valley.

The primary crushing area is located 1/4 mile south of the Sentinel quarry. The crusher area accommodates the primary crusher and its support facilities. Commercial high voltage powerlines and

The existing crushing system (Figure 4) consists of a dry screening and crushing operation utilizing a small quantity of water for a foam dust control system. Haul trucks dump quarry run ore into the system's feed hopper. A vibrating feeder moves the ore over the primary screen. The current screen arrangement separates the -3/16" ore from the load. This -3/16" material is removed from the system and stored separately. The +3/16" material is transferred over the primary screen and into the primary crusher. The 42" x 48" jaw crusher reduces the quarry run ore to a -7" size which is then transported via belt conveyors to the secondary screen. This screen is used to remove any remaining -3/16" ore. All the +3/16" ore is transferred over the screen and onto the radial stacker. Future sales and market conditions, however, may impact the choice of screen sizes. Stockpiles of ore, separated as to grade, are made by the radial stacker. Each of the four stockpiles are capable of holding approximately 3,000 tons of ore. From these stockpiles, haul trucks are loaded and transport the ore to the processing plant. Crushing and screening capacity of the system is approximately 400 tons per hour.

Dust control for the system is accomplished by means of a foam dust suppression system. The base suppressant is mixed with a small amount of water (approx. 15-20 gal/hr) and is pumped through hoses to nozzles at selected transfer points. Selection of spraying points is made to insure the even and complete application of the suppressant to the ore.

The entire system is controlled by means of a central Motor Control Center (MCC) located in a 40' van trailer. This MCC controls the starting and stopping of all the motors in the system. Timers and relays in the MCC control the order in which the motors start and stop.

Crushed ore is hauled on 85 ton trucks to the plant in Lucerne Valley for processing via the 8 mile Crystal Creek haul road. At the Plant the crushed ore is processed into a variety of ground limestone products. Figure 6 summarizes the processing.

WHITE KNOB QUARRY

The White Knob Quarry is located 6.5 miles to the west of the Pluess-Staufer plant in Lucerne Valley (Fig. 2). The deposit is located at elevations ranging from 5200 feet to 6300 feet. The deposit forms exceedingly rugged, rocky outcrops along the range front. Access to the deposit is via a 6 mile haul road from the plant.

Rocks in the White Knob Quarry area include highly metamorphosed Paleozoic sedimentary rocks, several varieties of Mesozoic age intrusive rocks, and alluvial deposits of Cenozoic age.

PALEOZOIC ROCKS

Paleozoic strata exposed in the quarry area form highly deformed roof pendants. The strata are highly metamorphosed and are often inverted. The rocks can be and correlated with strata of the Cordilleran miogeocline. Brown (1984) recognized the following formations in the quarry area; Late Precambrian Stirling Quartzite, Wood Canyon Formation, Cambrian Zabriskie Quartzite, Carrara Formation, Bonanza King Formation, Nopah Formation, Devonian Sultan Limestone, Mississippian Monte Cristo Limestone, and Pennsylvanian Bird Spring Formation. The Limestone deposit is formed in the Bullion Member of the Monte Cristo Limestone.

MESOZOIC ROCKS

Several varieties of Mesozoic age intrusive rocks are present in the mine area, and include Permo-Triassic syn-tectonic monzonites, Jurassic gabbro/diorite, and Cretaceous quartz monzonite batholithic rocks. Several east west trending steeply dipping felsite dikes are also present.

STRUCTURE

Structurally the area is exceedingly complex. Brown (1984) recognized two folding and associated thrusting events of Mesozoic age. The first event formed recumbent fold nappes and thrusts. The second event formed WNW trending isoclinal, overturned inverted folds on the previously inverted limb of the F_1 folds. The exceedingly ductile deformation resulted in the formation of ductile thrusts and bedding plane faults, as well as thinning and thickening of stratigraphic units. The White Knob deposit is formed in the core of a steeply dipping east plunging overturned isoclinal F_2 synform.

Several generations of Late Cenozoic faulting have also occurred. Several young low and high angle faults are present in the foothills and range front area, and offset Late Cenozoic alluvial units.

METAMORPHISM

During Mesozoic time the area was affected by both regional and contact metamorphism. Regional metamorphism in the White Knob area reached granulite facies, and anatectic melting appears to have occurred in some places. Various intrusive rocks have also contact metamorphosed the sedimentary rocks. The repeated and high grade metamorphism has formed exceedingly white, coarse grained marbles.

FORMATION OF THE WHITE KNOB LIMESTONE DEPOSIT

The White Knob limestone deposit is formed from Mississippian Monte Cristo Limestone Bullion Member. This depositionally pure limestone was deposited in a shallow marine environment. Later high grade metamorphism recrystallized and bleached the rock forming extremely coarse grained, pure, white calcite marble of very high quality. Calcite rhombs are commonly over 1" across. Favorable structural setting, and erosion have removed hanging wall rocks and left the deposit in its present form, which is highly favorable

WHITE KNOB QUARRY OPERATION

Mining of the White Knob deposit began in 1988, and has been continuous since then. Prior to mining core drilling proved recoverable reserves adequate for 30 years.

The White Knob Quarry is a multibench sidehill quarry which will eventually evolve into an open pit mine. Several working levels are operated at any one time to meet production demands, and allow greater selectivity and blending of various rock qualities, and allow maximum utilization of the resource.

Currently four grades of ore are selectively mined at White Knob. The White Knob Quarry produces much of the highest grades of ore, and has a very high proportion of high grade ore. Ore is drilled and blasted, loaded with a 13 yd^3 front end loader into 50 ton trucks and hauled to the crusher located at the quarry site. At the crusher the rock is crushed to -7" and separated into the various quality grades. Crushed ore is then loaded into 85 ton haul trucks for the 6.5 mile haul to the processing plant in Lucerne Valley.

The White Knob deposit is mined in 50 foot cuts, with 25 foot wide benches. Bench height and width is determined as a result of detailed studies of numerous factors including topography, geology, equipment selection, safety and economics. Due to the extremely steep topography and steeply dipping nature of the limestone deposit, the various levels are accessed by a series of switchback roads which have been constructed in the granitic rocks in the hanging wall. Currently 9 benches have been developed over a 400 foot interval, ranging from 5500 feet to 5900 feet. As the 9 existing levels are pushed back, access ramps are being constructed to the top of White Knob at an elevation of 6300 feet. Once the top of the knob is reached, the deposit will be mined from the top down. The deposit is exposed over a vertical interval exceeding 1000 feet, and ultimately over 20 benches will be developed. Ultimately the ridge will be mined away, and in the later mining phases a pit will evolve. Currently mine life is in excess of 30 years, and thus White Knob is in a very youthful stage, with a long life ahead.

The following major equipment is used in mining at the White Knob Quarry

A. Two 50 ton haul trucks
B. Two 85 ton haul trucks
C. One 13 yd^3 loader
D. One D-9 Dozer
E. One 235 (equivalent) excavator
F. One 16-G motorgrader
G. One 7000 gallon water truck
H. Two track drills

Some of the equipment used at White Knob is shared with Sentinel Quarry.

QUALITY CONTROL

Quality control at the White Knob Quarry is similar to that at Sentinel Quarry (previously discussed) and includes pre mining core drilling, sampling of blast hole drill cuttings, and sampling and analysis of crusher run material as necessary during crushing to insure uniformity of quality grades. A grinder and analytical equipment are located at the quarry to perform analysis on site with minimal turn around time. Two way radios are used for communication among operators.

ON SITE ORE PROCESSING

Ore from the White Knob Quarry is hauled to the primary crusher for size reduction, screening and sorting of ore grades. After crushing and sorting, the ore is transported to the processing plant in Lucerne Valley.

The primary crusher is located at White Knob, at the 5500 level. Haul trucks dump quarry run ore into the feed hopper at an elevation of 5540 feet. A vibrating feeder moves the ore over a grizzly and the primary screen. The screen separates -1/8" material from the load. The -1/8" material is removed from the system and stored separately for blending. The +1/8" and -4" material is transferred under the crusher, while the +4" material goes through the 44" x 52" Nordberg Jaw Crusher, which reduces the material to -7". The crushed rock is then transported by conveyor to the radial stacker. The crushed ore is stockpiled on the 5450 elevation. Stockpile capacity is approximately 10,000 tons. From the stockpiles, 85 ton haul trucks are loaded and transport the ore 6.5 miles to the plant for further processing. Capacity of the system is approximately 400 tons per hour.

Dust control at the White Knob crusher is a similar water/foam system as utilized at the Sentinel crusher previously discussed. The entire crusher system is controlled by a central Motor Control Center (MCC) located in a 40' trailer. The system at White Knob is similar to the system at Sentinel.

PROCESSING AT THE PLANT IN LUCERNE VALLEY

Crushed ore is processed at the plant in Lucerne Valley at the base of the mountains (Fig. 6). At the plant, crushed ore is placed on the reclaim system or stockpiles by various quality grades. Rock enters the mill from the reclaim system by a series of underground feeders and conveyors, and flows through secondary and tertiary crushing prior to roller mill grinding, air classification, and or ball mill grinding. The computer controlled grinding systems, and quality control, allow very precise grinding of the material to very narrow product specifications, or to any specification a customer desires.

Pluess-Staufer (California) Inc. produces a full range of coarse, fine, and ultra fine grind, high brightness, high purity calcium carbonate products. Plant facilities offer both bulk and bagged materials in rail or truck quantities. The operation is and will continue to be one of the largest producers of high quality ground calcium carbonate products in western North America.

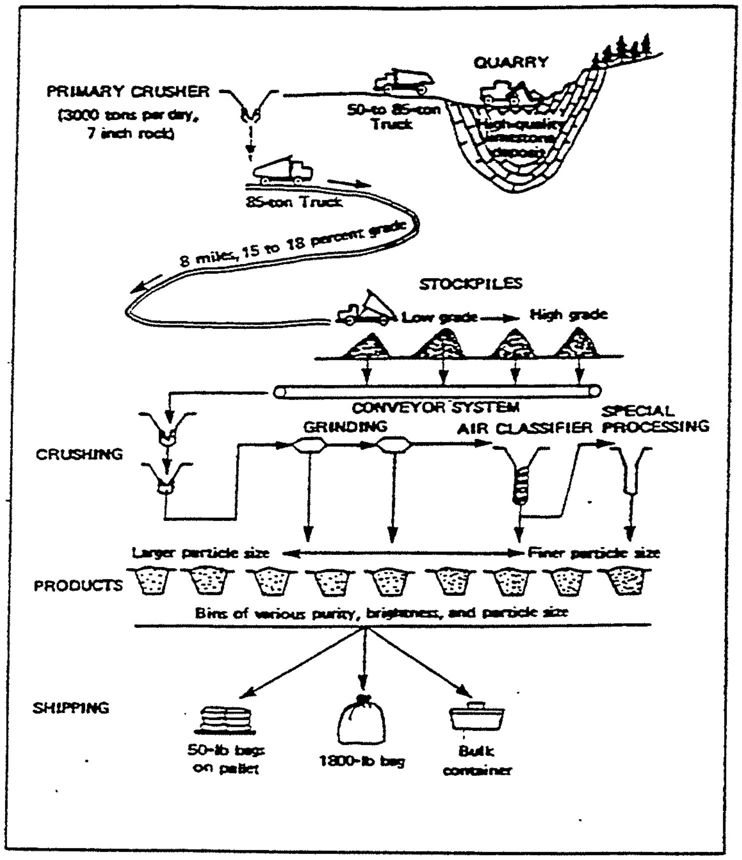


Figure 6. Simplified flow diagram showing sequence from quarry to end product for ground limestone at Pluess-Staufer (California) Inc. Lucerne Valley California operation.

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