SPECIAL REPORT 177

MINERAL LAND CLASSIFICATION OF THE LONG VALLEY POZZOLAN DEPOSITS, LASSEN COUNTY, CALIFORNIA

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MINERAL LAND CLASSIFICATION OF THE LONG VALLEY POZZOLAN DEPOSITS, LASSEN COUNTY, CALIFORNIA

By

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This report was completed before the name of the California Division of Mines and Geology was changed to the California Geological Survey. The report has retained the former name throughout to speed its publication and release.

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(in pocket)

EXECUTIVE SUMMARY

California's Surface Mining and Reclamation Act of 1975 (SMARA) requires the State Geologist to classify land based on the known or inferred mineral resource potential of that land. The primary goal of mineral land classification is to help ensure that the mineral resource potential of lands is recognized and considered in the land use planning process. This report explains the classification process, its application to the subject properties, and presents conclusions. This report is intended primarily for the use of Lassen County as lead agency under SMARA.

In response to a request by the Lassen County Planning Department, the State Geologist has conducted a Mineral Land Classification study of naturally occurring pozzolan in the Long Valley area of southeastern Lassen County. Lassen County requested classification of the pozzolan deposit based on its high visibility along the Highway 395 corridor and concerns about visual impacts associated with mining. This study identifies an area of about 8.6 square miles as containing significant natural pozzolan resources. The study also includes a general discussion of types, uses, quality, and economics for both natural and man-made pozzolans.

The Long Valley pozzolan deposit is a lacustrine diatomaceous and tuffaceous siltstone which is exposed in a north-south trend for a distance of nearly 10 miles. The deposit was mined intermittently between 1965 and the late 1980s and was a source of natural pozzolan when ground and calcined. Long Valley pozzolan was used as a portland cement concrete admixture in important structures such as Bullards Bar Dam in Yuba County and the Palo Verde Nuclear Generating Station near Phoenix, Arizona.

Pozzolan is defined as a siliceous or siliceous and aluminous material of natural or artificial origin that, in the presence of moisture, reacts with calcium hydroxide to form cementitious compounds. Upon hardening, cementitious compounds adhere to adjacent materials effectively binding them into a hard and durable mass. Pozzolans can be natural or artificial. <u>Natural pozzolans</u> occur as geologic materials including diatomaceous earth, diatomite, volcanic ash, opaline shale, pumicite, tuff, and certain clays such as kaolinite. Most naturally occurring pozzolans require further processing such as grinding or calcining to enhance their pozzolanic properties. Since the early twentieth century, natural pozzolans have been used in large-scale public works projects such as dams, bridges, canals and waterways, and highways. <u>Artificial pozzolans</u> are industrial byproducts that have found markets in the construction industry. The most common artificial pozzolan is fly ash, a waste residue from coal fired power generating plants. Other artificial pozzolans include silica flume, a byproduct of the production of silicon metal or ferrosilicon alloy, and blast furnace slag, the vitrified byproduct of iron ore smelting.

The primary use of both natural and artificial pozzolan today is as a portland cement concrete admixture. The addition of pozzolan to concrete controls the deleterious affects of Alkali Silica Reactivity (ASR), increases compressive strength and density, decreases permeability, lowers the heat

of hydration, increases resistance to sulfide attack, and reduces concrete cost. ASR results from the chemical reaction of unstable siliceous minerals in the concrete aggregate with excess calcium hydroxide liberated during the hydration of portland cement. ASR causes concrete to degrade via expansion, cracking, and spalling. Secondary uses of pozzolans include structural fills, flowable fills, waste stabilization, soil amendments, evaporation controls, and environmental absorbents.

Based upon the classification study of the Long Valley pozzolan deposit, the following conclusions were reached:

- The Long Valley pozzolan resources, when ground and calcined, meet specifications for a high-grade natural pozzolan admixture for portland cement concrete.

- An area of approximately 5 acres encompassing the former Lassenite Industries mine site is classified MRZ-2a as shown on Plate 2. MRZ-2a areas are underlain by mineral deposits for which geologic information indicates that significant measured or indicated resources are present. The estimated reserves are proprietary although they do meet the minimum threshold value for classification of 2.5 million 1998 dollars (2.7 million 2001 dollars) established by the State Mining and Geology Board (SMGB) for industrial minerals other than aggregate.

- Approximately 1.1 billion tons of pozzolan resources contained in an area of roughly 8.6 square miles has been classified MRZ-2b as shown on Plate 2. MRZ-2b areas are underlain by mineral deposits for which geologic information indicates that significant inferred resources are present. Resources were calculated to a maximum depth of 100 feet.

- The market for natural pozzolan has been in steady decline since the mid 1970s. This is primarily due to environmental regulations such as the Resource Conservation and Recovery Act (RCRA) which requires the Environmental Protection Agency (EPA) to designate and mandate the use of recycled materials such as fly ash or ground blast furnace slag in lieu of natural pozzolan as a concrete admixture. Exceptions to this requirement are allowed when designated materials don't meet design specifications, are cost prohibitive, or their procurement would result in unreasonable delays.

- Doubts surrounding the long-term effectiveness of fly ash in controlling ASR have renewed interest in natural pozzolans for concrete admixtures. Newly developing markets for natural pozzolan as a soil amendment, environmental absorbent, and cat litter have also helped stimulate interest in the resumption of mining of the Long Valley pozzolan deposits.

- To be competitive with fly ash, the market for the Long Valley pozzolan is expected to be confined to areas in reasonable proximity to the deposit. The most likely markets for the Long Valley deposit are in the Reno metropolitan area. Large-scale public works projects such as dams, highways, and canals may also provide a future market for the Long Valley Pozzolan deposits.

- For the foreseeable future, demand for portland cement concrete in the building and paving industries is expected to increase, as is the demand for pozzolan in general. However, market forces, environmental concerns, and regulatory pressures favor the continued dominance of fly ash in the majority of construction projects.

- Available information concerning known pozzolan deposits throughout the western states indicates few deposits are similar in quantity, quality, and utility as a portland cement concrete admixture to the Long Valley deposits. Several deposits which exhibited good pozzolanic properties consist of higher purity diatomite than the Long Valley deposits and are valued more for their physical attributes in the filtration, pharmaceutical, and consumer products industries rather than their pozzolanic properties. Accordingly, these materials command prices from $250 - $500 per ton effectively precluding their use as a competitive pozzolan in the marketplace.

INTRODUCTION

This study classifies areas of naturally occurring pozzolan resources in the Long Valley area about 50 miles southeast of Susanville along Highway 395, in southern Lassen County (Figure 1). The area includes potions of the Beckwourth Pass, Constantia, Evans Canyon, and Loyalton 7.5 minute quadrangles (Figure 2). The study was conducted by the State Geologist as specified by the California Surface Mining and Reclamation Act of 1975 (SMARA). SMARA requires the State Geologist to classify land based on the known or inferred mineral resource potential of that land. Classification is the process of identifying lands containing significant mineral deposits, based solely on geologic factors, and without regard to present land use or ownership. The primary goal of mineral land classification is to ensure that the mineral resource potential of lands is recognized and considered in the land use planning process.

Background

The decision to classify for natural occurring pozzolan in Long Valley was based in part on responses by the Lassen County Planning Department staff to constituent surveys conducted in 1993 and 1999 by the Division of Mines and Geology (DMG). The purpose of the survey was to establish priorities for Mineral Land Classification based on each county's needs for classification. Lassen County staff expressed a need for the Long Valley pozzolan deposit to be formally recognized through the process of classification. Lassen County premised their need for classification on the deposit's high visibility along the Highway 395 corridor. County staff expressed concerns about visual impacts associated with mining that may affect development of the deposit.

The only mineral commodity that DMG staff is proposing to classify in Lassen County is naturally occurring pozzolan. Pozzolan is a natural or artificially manufactured material that combines with alkaline and calcium hydroxides in cement paste to form stable insoluble compounds possessing cementitious properties. Pozzolans are not cementitious in themselves. They are routinely used as a partial replacement for portland cement in concrete to help control Alkali Silica Reactivity (ASR) in cured concrete. While there are no active pozzolan mining operations in Lassen County, commercial mining of the Long Valley deposits has occurred in the past and several operators have recently expressed interest in resuming mining of Long Valley pozzolan.

Other commodities produced in Lassen County include sand and gravel, crushed rock, cinders, decomposed granite, and gold. Land use conflicts are not sufficient to warrant classification of these commodities at this time.

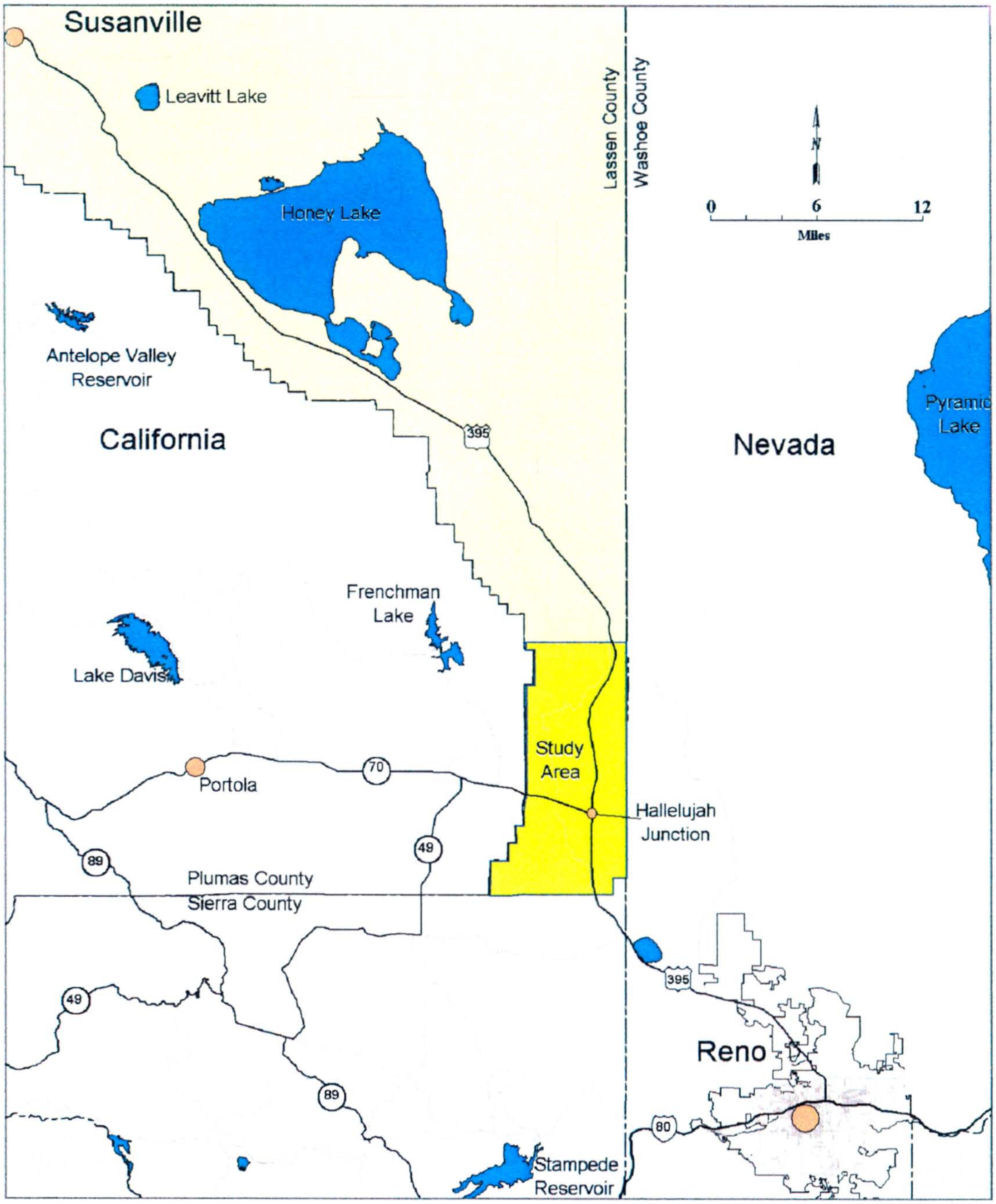

Figure 1. Location of the Long Valley pozzolan deposits, Lassen County, California

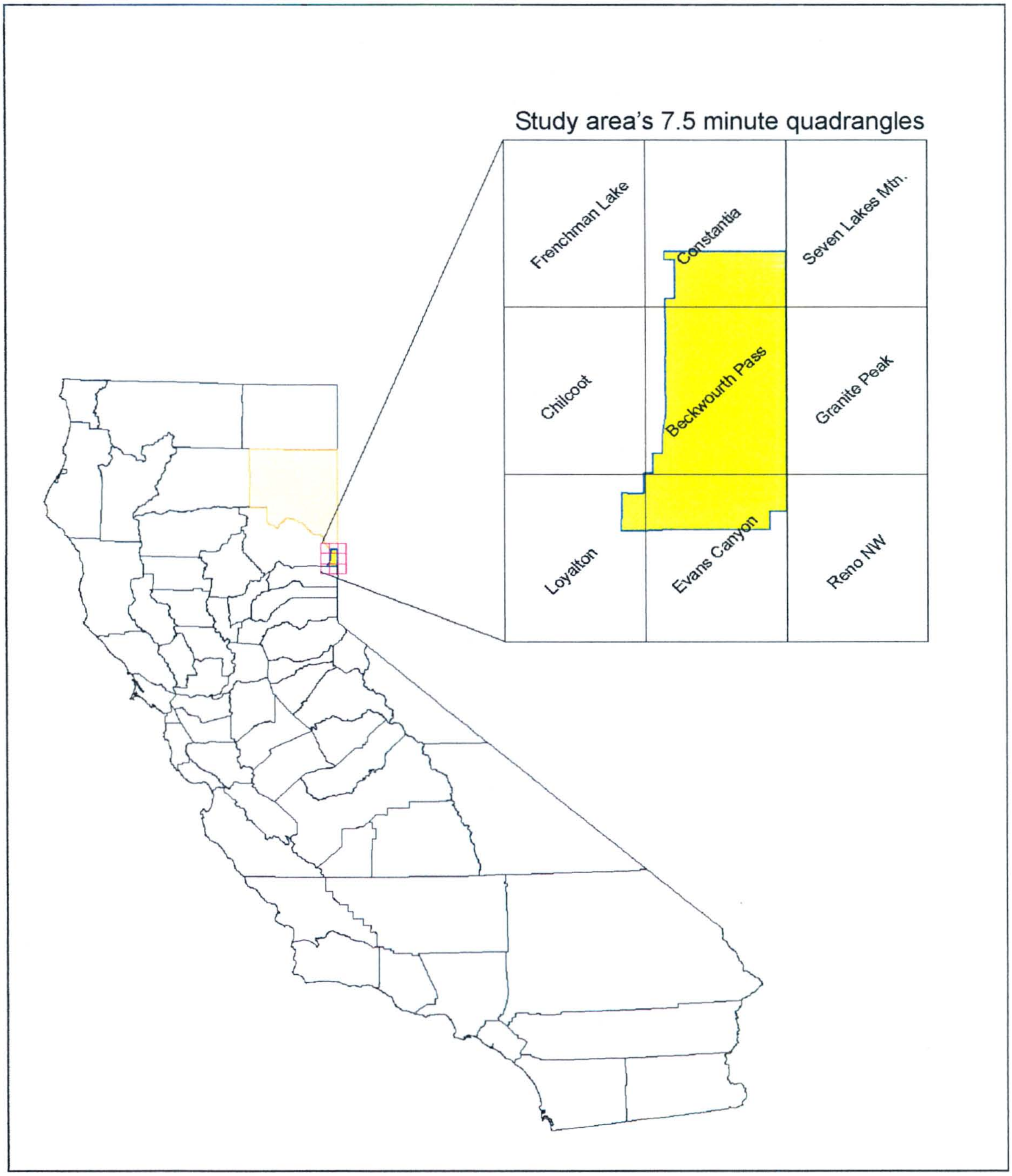

Figure 2. U.S.G.S. Quadrangles in the study area, Lassen County, California

The Surface Mining and Reclamation Act of 1975 (SMARA)

SMARA requires the State Geologist to classify land based on the presence, absence, or likely occurrence of significant mineral deposits in certain areas of the state subject to urban expansion or land uses incompatible with mining. The areas to be classified are set forth by the SMGB as shown on a priority list submitted by the State Geologist and approved by the SMGB, and by the SMGB's acceptance of petitions for classification of specific properties. The SMGB, upon receipt and acceptance of the classification information, transmits it to the appropriate lead agencies for incorporation into their general plans and for use in their land use planning process.

The primary goal of mineral land classification is to ensure that the mineral resource potential of lands is recognized and considered before land use decisions that could preclude mining are made. The availability of mineral resources is vital to our society. Yet, for most mineral commodities, economic deposits are rare, isolated occurrences. In addition, access to land for purposes of mineral exploration and mine development has become increasingly difficult because California is faced with growing land use competition. As a consequence, local planning agencies are confronted with increasingly difficult land use decisions. If the minerals industry is to continue supplying raw materials for California, it is essential that areas containing significant mineral resources be identified so that this information can be incorporated into land use planning decisions.

MINERAL LAND CLASSIFICATION

As set forth in Section 2761(b) of SMARA, the State Geologist shall classify land solely on the basis of geologic factors and without regard to existing land use. Areas subject to mineral land classification studies are divided by the State Geologist into various Mineral Resource Zone (MRZ) categories that reflect varying degrees of mineral resource potential. The MRZ criteria and nomenclature adopted by the SMGB (DMG, 2000) are described below.

Mineral Resource Zone (MRZ) Categories

MRZ-1: Areas where available geologic information indicates that little likelihood exists for the presence of significant mineral resources.

MRZ-2a: Areas underlain by mineral deposits where geologic data indicate that significant measured or indicated resources are present. As shown on the California Mineral Land Classification System Diagram (Figure 3), MRZ-2 is divided into MRZ-2a and MRZ-2b on the basis of degree of knowledge and economic factors. Areas classified MRZ-2a contain discovered mineral deposits that are either measured or indicated reserves as determined by such evidence as drilling records, sample analysis, surface exposure, and mine information. Land included in MRZ-2a is of prime importance because it contains known economic mineral deposits.

MRZ-2b: Areas underlain by mineral deposits where geologic information indicates that significant inferred resources are present. Areas classified MRZ-2b contain discovered mineral deposits that are significant inferred resources as determined by their lateral extension from proven deposits or their similarity to proven deposits. Further exploration could result in upgrading areas classified MRZ-2b to MRZ-2a.

MRZ-3a: Areas containing known mineral occurrences of undetermined mineral resource significance. Further exploration within these areas could result in the reclassification of specific localities into MRZ-2a or MRZ-2b categories. As shown on the California Mineral Land Classification System Diagram, MRZ-3 is divided into MRZ-3a and MRZ-3b on the basis of knowledge of economic characteristics of the resources.

MRZ-3b: Areas containing inferred mineral occurrences of undetermined mineral resource significance. Land classified MRZ-3b represents areas in geologic settings that appear to be favorable environments for the occurrence of specific mineral deposits. Further exploration could result in the reclassification of all or part of these areas into the MRZ-2a or MRZ-2b categories.

MRZ-4: Areas of no known mineral occurrences where geologic information does not rule out either the presence or absence of significant mineral resources.

The distinction between the MRZ-1 and the MRZ-4 categories is important for land use considerations. It must be emphasized that MRZ-4 classification does not imply that there is little likelihood for the presence of mineral resources, but rather that there is a lack of knowledge regarding mineral occurrence. Further exploration could result in the reclassification of land in MRZ-4 areas to MRZ-3 or MRZ-2.

Mineral Resource-Reserve Classification Nomenclature

The following definitions are important when studying the different resource categories used in the California Mineral Land Classification System Diagram (Figure 3). Particular attention should be given to the distinction between a mineral deposit and a resource and to how a mineral deposit may relate to resources.

MINERAL DEPOSIT: A naturally occurring concentration of minerals in amounts or arrangements that under certain conditions may constitute a mineral resource. The concentration may be of value for its chemical or physical characteristic or for both of these properties.

MINERAL OCCURRENCE: Any ore or economic mineral in any concentration found in bedrock or as float, especially a valuable mineral in sufficient concentration to suggest further exploration.

ECONOMIC: This term implies that profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

MINERAL RESOURCE: A concentration of naturally occurring solid, liquid, or gaseous material in or on the earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible. The terms resource and mineral resource are synonymous in this report.

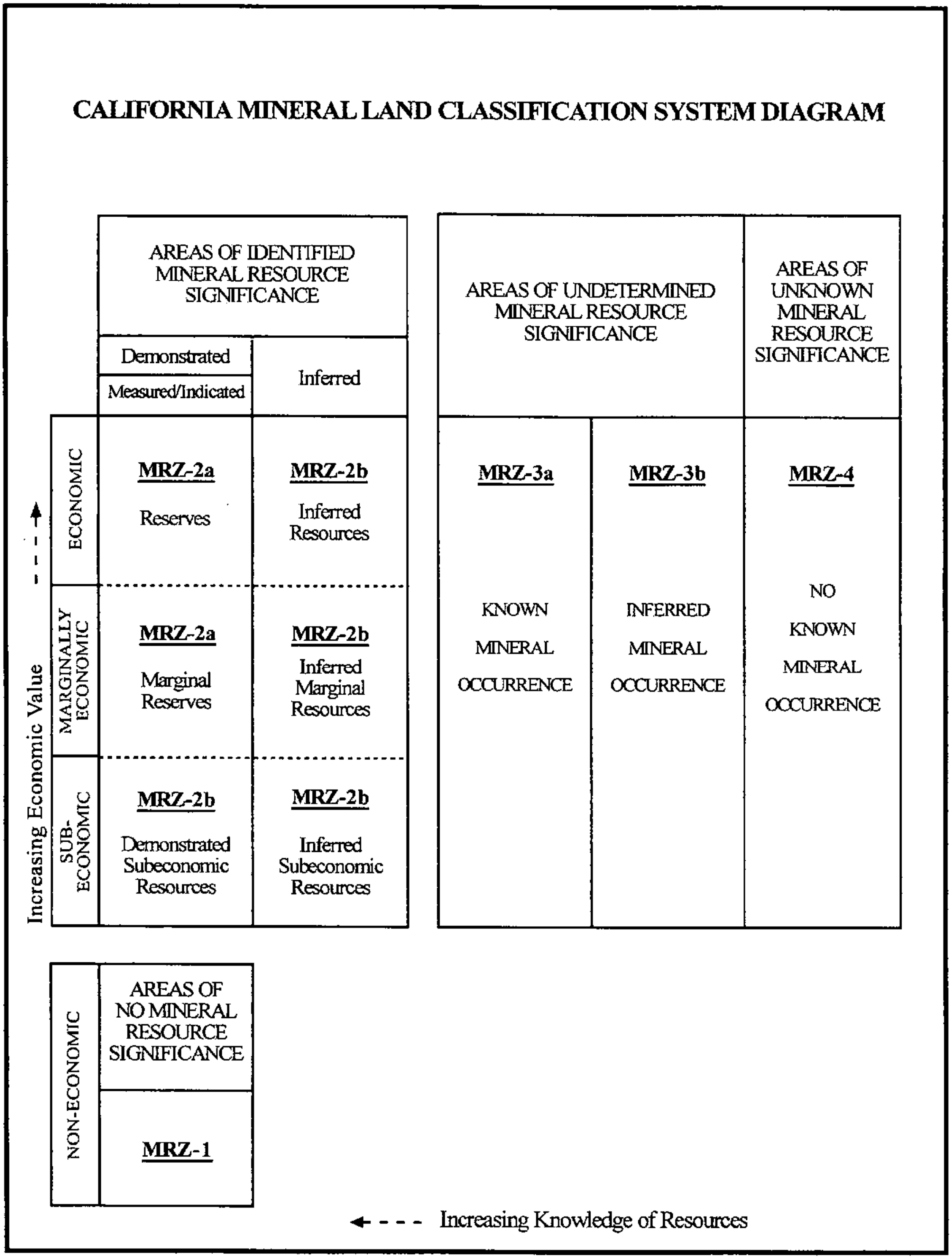

Figure 3. Relationship of MRZ categories to the resource/reserve classification system. Adapted from the U.S. Bureau of Mines/U.S. Geological Survey (1980)

RESERVES: The part of the resource base that could be economically extracted or produced at the time of determination. In this report, the term **reserves** has been further restricted to include only those deposits for which a valid mining permit has been granted by the appropriate lead agency.

IDENTIFIED MINERAL RESOURCES: Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified mineral resources include economic, marginally economic, and subeconomic components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into demonstrated and inferred.

DEMONSTRATED: A term for the sum of **measured** plus **indicated.**

MEASURED: Quantity is computed from dimensions revealed in outcrops, trench workings, or drill holes; grade and/or quality are computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, depth, and mineral content of the resource are well established.

INDICATED: Quantity and grade and/or quality are computed from information similar to that used for measured resources, but the sites for inspection, sampling, and measurement are farther apart or otherwise less adequately spaced. The degree of assurance, although lower than that for measured resources, is high enough to assume continuity between points of observation.

INFERRED: Estimates are based on an assumed continuity beyond measured and/or indicated resources for which there is geologic evidence. **Inferred resources** may or may not be supported by samples or measurements.

MARGINAL RESERVES: The part of the demonstrated reserve base that, at the time of determination, borders on being economically producible. The essential characteristic of this term is economic uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors.

MARGINAL RESOURCES: The part of the inferred resource base that, at the time of determination, would be economically producible, given postulated changes in economic or technologic factors.

SUBECONOMIC RESOURCES: The part of identified resources that does not meet the economic criteria of marginal reserves and marginal resources.

Classification Criteria

To be considered significant for the purpose of mineral land classification, a mineral deposit, or a group of mineral deposits that can be mined as a unit, must meet marketability and threshold value criteria adopted by the SMGB (SP 51, Division of Mines & Geology, January 2000). The criteria vary for different minerals depending on (1) whether they are strategic or non-strategic minerals, (2) their uniqueness or rarity, and (3) their commodity-type category (metallic minerals or industrial minerals). For example, to be considered significant, the threshold value of the first marketable product for a metallic ore deposit (such as a gold deposit) is $1,250,000 (1998-dollars), $2,500,00 (1998-dollars) for an industrial mineral deposit (such as a diatomite or clay deposit), and $12,500,000 (1998-dollars) for a construction aggregate deposit (such as a sand and gravel or crushed stone deposit). To adjust for inflation since 1998, each of these values is multiplied by 1.091, a factor based on the U.S. consumer price index (CA Department of Finance website) to calculate the threshold value in 2001 dollars. These results are:

Metallic Deposits	$ 1,363,750
Industrial Minerals	$ 2,727,500
Construction Aggregate	$13,637,500

Pozzolan is an industrial mineral subject to the threshold value of $ 2,727,500. The significance of the Long Valley pozzolan resources was determined by evaluating the quality of the deposit and its suitability as a marketable commodity, and by calculating the available volume and value of resources contained within the study area. The data necessary to evaluate this deposit were compiled from geologic literature, proprietary company files, and limited field study by the DMG staff of the Department of Conservation.

Mineral Resources Zone Notation

Mineral Resource Zones (MRZs) are delineated on Plate 2. Zone assignments are denoted by a MRZ category adapted from the California Mineral Land Classification System Diagram (Figure 3). The symbols and colors on the plate depict the MRZ category for each classified area.

OVERVIEW OF POZZOLANIC MATERIALS

"Pozzolan" refers to a material that exhibits specific physical properties and chemical reactivities. The term pozzolan does not infer a material of specific geologic origin or composition. Conventional pozzolans may be natural mineral materials or artificially made materials. The American Society for Testing and Materials (ASTM) Standard C 618-98 defines a pozzolan as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."

Materials having pozzolanic properties differ markedly from one another in their origin and mineralogical constitution. While the chemical composition must meet minimum requirements, chemical composition, in itself, is not a reliable indicator of pozzolanic reactivity. To be pozzolanic, the material must also exhibit an inherent chemical instability due to an amorphous (non-crystalline) structure or an alteration of the crystal structure. Quartz, for instance, is not pozzolanic, yet it has nearly the same chemical composition as amorphous opal which is highly reactive.

Pozzolans find their largest market as a mineral admixture in the blending of portland cement concrete. In this capacity, pozzolan is used as a substitute, by weight, for part of the cement in a concrete mix. Substitution proportions vary between 15% and 45% depending on the desired attributes of the concrete. Typically, a 15% to 25% replacement is customary. The addition of a pozzolan lends numerous desirable attributes to portland cement concrete including reduced deterioration resulting from ASR, increased density and compressive strength, reduced permeability to deleterious and aggressive fluids, reduced heat of hydration, and significantly reduced concrete cost.

Pozzolanic materials also find secondary uses in applications such as stabilized road base, structural fills, concrete grouts, flowable fills, soil amendments, and environmental absorbents. Generally, most of these applications employ artificial pozzolans.

History of Pozzolans

The Romans are attributed with first exploiting the benefits of pozzolans in cement over 2,000 years ago. Roman structures built using this technique survive today due to the enhanced durability that pozzolan imparted to the concrete. The best Roman cement was made with a glassy siliceous volcanic ash mined near the Italian maritime town of Pozzouli near Naples; hence the name *pozzuolana*. Roman pozzuolana cement was a mixture of lime, pozzuolana ash, various aggregates, and water and was used to build such famous structures as the Appian Way, the Roman baths, the Pont du Gard aqueduct in France, and the Coliseum and Pantheon in Rome which survive to this day.

The Romans also recognized pozzuolana cement's ability to harden under water. Chemical reactions between the ash and the lime in the cement result in insoluble compounds that allowed the cement to not only harden underwater, but resist the degenerative effects of long term immersion in seawater. This principle is the basis for today's hydraulic cements which are capable of setting both underwater and in air.

Over time, the term pozzuolana was shortened to pozzolan and has come to mean any material that exhibits the requisite physical and chemical attributes.

Pozzolan Types and Classes

The American Society for Testing and Materials (ASTM) established classes for pozzolans under Standard Specification C 618-98:

Class N pozzolan

Class N pozzolans include raw or calcined natural pozzolans such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or uncalcined; and various materials requiring calcination to induce satisfactory properties, such as some clays and shales.

Class F pozzolan

Class F pozzolan consists of fly ash normally produced from burning powdered anthracite or bituminous coal. This class of fly ash has pozzolanic properties.

Class C pozzolan

Class C pozzolan consists of fly ash normally produced from ignition of lignite or subbituminous coal. Class C fly ash, in addition to having pozzolanic properties, also has some cementitious properties. Some class C fly ashes may contain lime contents higher than 10%.

Natural Pozzolans

Pozzolans occur naturally as diatomaceous earth, diatomite, volcanic ash, opaline shale, pumicite, tuff, and certain clays such as kaolinite. However, many of these require further processing to enhance their pozzolanic properties. Whereas some volcanic ashes, diatomites, pumicites, and tuffs may require only drying and finish grinding, others, including most diatomaceous earths, shales, and clays require calcining to develop optimum reactivity. In the United States, most natural pozzolans are found in the arid western states of Nevada, Arizona, and California.

Calcining involves heating a substance to its temperature of disassociation in order to induce chemical instability. The process is often used to liberate a mineral's water of crystallization such as when opaline silica is heated and its bound water molecules are liberated. Calcining is also used to collapse a mineral's crystalline structure such as when clays are calcined.

Since the early twentieth century, natural pozzolan amended concretes have been used in large scale public works projects including massive gravity dams, bridges, canals, and waterways. The primary benefits are increased compressive strength, decreased permeability, lowered heat of hydration, increased resistance to sulfate attack, and ASR control.

Examples of structures using natural pozzolans are the Bonneville Dam in which a natural pozzolan portland cement admixture was used and the Los Angeles aqueduct which employed a rhyolitic pumicite pozzolan cement mix.

The most common natural pozzolans are the volcanic glasses, opal or opaline rocks, clays and calcined shale:

Volcanic glasses

The volcanic glasses are composed of amorphous silica and alumina glasses that comprise many volcanic ashes and rocks such as pumice, pumicite, and tuff. Volcanic glasses may be partially hydrated.

The pozzolanic reactivity of volcanic glasses results from the unorderly atomic arrangement and subsequent instability of the silica in the amorphous state as compared to the high stability of crystalline silica. Instability in volcanic glasses is enhanced by the increased surface area within the glasses resulting from small ducts and voids generated by rapid cooling and release of gases dissolved in the liquid magma.

Opaline materials

Materials consisting of or containing opaline silica may also display pozzolanic reactivity. Opal is an amorphous hydrous silica containing up to 10% water ($SiO_2 \times nH_2O$). Like volcanic glasses, the unorderly atomic structure of opal makes it reactive with lime. Opal's reactivity is enhanced by common inclusions of submicroscopic crystals of cristobalite (a high temperature polymorph of quartz stable only at temperatures above 2,680°F). Opaline rocks employed as pozzolans include tuffs, opaline shales, diatomites, and diatomaceous earths.

Clay minerals and calcined shales

Clays comprise a series of hydrated aluminum silicates with variable replacement of the alumina by oxides of iron, magnesium, sodium, and calcium. Most clays contain 10-15% hydrate water. The primary pozzolanic clays are the kaolinite, montmorillonite, and illite groups. In order to instill the necessary reactivity, kaolins require calcination at temperatures between 1,000 and 1,800°F to collapse the internal crystal lattice and weaken or destroy the bonds between the silica and alumina. Metakaolin, a calcined partially dehydrated kaolin clay, is considered one of the premier pozzolans. Montmorillonite clays such as bentonite also require calcination to collapse the crystal structure and maximize pozzolanic activity. Illite clays, while similar to the montmorillonite clays, are rarely used as a pozzolan since its pozzolanic reactivity is only slightly improved by calcining.

Ground calcined shales have also been effectively used as pozzolan. Their pozzolanic properties stem from their component clay minerals. The Golden Gate Bridge and Flaming Gorge Dam are structures which incorporated calcined shale as a concrete admixture.

Artificial Pozzolans

All artificial pozzolans are industrial waste stream byproducts that have found markets in the construction industry as a portland cement concrete admixture, stabilized road base, structural fill, flowable fill, or in waste stabilization.

While many natural pozzolans, including the Long Valley pozzolan, are recognized as superior to most artificial pozzolans, government policy has encouraged widespread usage of artificial pozzolans.

The Resource Conservation and Recovery Act of 1976 (RCRA) requires that procuring agencies that spend more than $10,000 a year on a material must use materials composed of the highest practicable percentage of recovered materials. Procuring agencies are any federal, state, and local agencies, and their contractors, that use appropriated federal funds. The purpose of this provision is to reduce the solid waste stream, and to conserve both natural mineral and energy resources. Under RCRA, the Environmental Protection Agency (EPA) was charged with designating suitable recovered materials for specific applications and to prepare a Comprehensive Procurement Guideline (CPG). Through the CPG, the EPA designates items that must contain recycled content and specifies the recovered material content which must be used.

In respect to portland cement concrete, the CPG designates fly ash or ground blast furnace slag as suitable replacements for natural pozzolan. Exceptions to the CPG requirements are allowed when the price of a designated item is cost prohibitive, there is inadequate competition (few sources of supply), the material does not meet the procuring agency's performance specifications, or unreasonable delays would result from procuring the designated item.

The artificial pozzolan market is dominated by fly ash, silica fume, and ground blast furnace slag. Testing is ongoing as new waste materials are shown to have pozzolanic properties such as rice hull ash. The primary artificial pozzolans are:

Fly ash

Fly ash is the most common artificial pozzolan. It is produced as a finely divided waste residue from powdered coal combustion fired power generating plants. Hence, fly ash is also referred to as a coal combustion product (CCP).

Pulverized coal is blown into a combustion chamber and ignited to heat the boiler tubes. Most of the carbon is burned and the volatile components are vaporized. The inorganic non-combustible impurities either remain in the chamber or are carried away in the flue gas stream. The heavier debris settles to the bottom of the chamber as bottom ash and boiler slag. The finer material, fused into tiny spherical glass particles, remains in the flue gas stream and is carried up the flue to be captured by electrostatic precipitators or scrubbing systems.

Of the various CCPs, fly ash exhibits the widest range of applications. It is also the only one recognized as a commercial pozzolan and is the major component of all CCPs produced (59%). In 1999, almost 63 million tons of fly ash were produced. Of that, 24 million tons were used in applications or stored for use and 39 million tons were disposed of. Cement and concrete production tops the list of applications at 48% of the fly ash used (Kalyoncu, 1999).

In northern California, fly ash is widely available at approximately $45/ton FOB terminal.

Silica fume

Silica fume is a byproduct of the reduction of high purity quartz with coal in an electric arc furnace during the production of silicon metal or ferrosilicon alloy. Typically an extremely fine spherical material (up to 100 times smaller than cement particles), it exhibits an extremely high surface area and extraordinary pozzolanic reactivity. Because of its fineness, large surface area, high silica content, and absence of alkali, it is the most reactive pozzolan and is employed in specialized concretes to attain compressive strength upwards of 15,000 psi. However, its limited availability and high cost ($300 - $400/ton) have limited its use to specialty applications.

Blast furnace slag

The vitrified byproduct of the iron ore smelting process, blast furnace slag contains silica, alumina, lime, and other minerals in proportions such that it is pozzolanic when very finely ground. Consistency of quality blast furnace slag is a problem and testing implies that it may be inferior to the other available pozzolans. While slag is uncommon in the western states, small volumes are being imported from the Asia.

Rice hull ash

The controlled combustion of rice hulls can produce amorphous silica particles that are microporous, thus enhancing an already high surface area. A relative newcomer in the pozzolan market, tests have shown that properly prepared rice hull ash can be comparable to silica fume and produce a very strong impermeable concrete (Mehta, 1998). Rice hull ash has not caught on commercially, but the enormous volume of rice produced in northern California each year, coupled with a trend towards fueling cogeneration plants with waste rice hulls, bodes well for its future use.

Pozzolan Use in Portland Cement Concrete

The primary uses of natural and artificial pozzolans stem from the pozzolanic reaction and the advantageous characteristics they impart as an admixture to portland cement concrete. Probably the most important quality gained by the addition of pozzolan to portland cement concrete is control of ASR. Other desirable qualities include increased compressive strength and density, reduced permeability and porosity, reduced heat of hydration, reduced bleeding and aggregate settling, improved workability, and reduced concrete cost.

Reduced Alkali-Silica Reactivity (ASR)

ASR is a chemical phenomenon that has an extremely deleterious effect on concrete. It is caused by an excess of calcium hydroxide, $Ca(OH_2)$, in cured concrete. When portland cement hydrates, its primary components (calcium silicate, aluminates, and aluminoferrites) react with water to form the cementitious compounds responsible for nearly all of concrete's strength, and free calcium hydroxide. Approximately 20% of the weight of the cement in each cubic yard of concrete is converted to calcium hydroxide which contributes nothing to the strength of concrete. Calcium hydroxide is also soluble in water and is easily leached from concrete leaving it porous, permeable, and susceptible to degradation by aggressive sulfate and chloride solutions such as certain groundwaters and seawater.

Over time, calcium hydroxide reacts with any amorphous opaline silica or microcystalline silica in or on the concrete aggregate particles. The silica diffuses out of the aggregate combining with the calcium hydroxide to form a viscous silicate gel which, upon exposure to moisture, is highly expansive. This expansion degrades concrete by causing severe cracking and spalling. As long as calcium hydroxide is available to fuel this reaction, expansion continues over time and pressures in the gel may exceed the tensile strength of the concrete and fracture the surface.

Aggregate constituents that are particularly susceptible to ASR are microcrystalline silica and amorphous silica such as opal. Opal is also a frequent secondary mineral filling or coating on aggregate particles. Only minor amounts of reactive aggregate particles are sufficient to cause serious ASR damage. Cores from Parker Dam showed serious degradation due to reactive rhyolite and andesite particles composing only 2% of the total aggregate material.

The addition of a pozzolan admixture to the concrete mix has proven to be the most effective method of controlling or eliminating the ASR reaction. The high surface area of finely divided pozzolan and the amorphous and unstable nature of the contained silica cause it to be extremely reactive. The pozzolan combines readily with the excess calcium hydroxide in the cement paste causing the majority of the surplus calcium hydroxide to react during the curing process. Little calcium hydroxide remains after curing to fuel deleterious reactions with the aggregate particles.

The amount of substitution of a pozzolan for portland cement is dependent on the desired finished concrete specifications as well as the specific chemical composition and physical characteristics of the pozzolan and the cement. Generally, an optimal substitution of pozzolan for cement ranges between 15% and 25% by weight.

The California Department of Transportation (Caltrans) has recognized the importance of pozzolan in controlling ASR-related deterioration to the state highway infrastructure. A "Special Provision Mandate" currently requires a 25% replacement by weight of cement in all concretes used in state highway contracts (Pyle–personal communication).

Increased compressive strength and density

Since addition of pozzolan to a concrete mix contributes insoluble cementitious compounds at the expense of non-cementitious calcium hydroxide, it improves the ultimate compressive strength. The amount of portland cement required for a given strength is reduced. In engineered high strength applications, the addition of pozzolans can achieve compressive strengths in concrete not attainable with cement alone.

Reduced permeability and porosity

The replacement of soluble calcium hydroxide with cementitious and insoluble compounds minimizes leaching resulting in lesser permeability and porosity in the cured concrete. This equates to extended life and durability in aggressive fluid environments.

Reduced heat of hydration

The substitution of pozzolan for cement in a concrete mix reduces the amount of cement to be hydrated with a subsequent reduction in the heat of hydration. This provides a measure of temperature control which in large structures can be so excessive as to crack the concrete.

Reduced bleeding and aggregate settling

In fresh concrete, bleed channels are blocked with cementitious compounds resulting in lessened surface bleeding. These compounds also lend support to the heavier aggregate particles.

Improved workability (fly ash and silica fume)

The spherical nature of fly ash and silica fume particles improve concrete workability by reducing particulate friction (the "ball bearing effect"). This also results in a lessened water demand.

Reduced cost

Since portland cement may cost double that of some pozzolans, the substitution of pozzolan for cement results in substantial savings. In the case of fly ash, which currently sells for approximately half the cost ($45/ton) of an equivalent weight of portland cement ($90/ton), the savings in a large scale construction project can be substantial.

Other Pozzolan Uses

Natural pozzolanic materials have found limited use in other applications. Many of these applications do not take advantage of the pozzolanic properties of the materials, instead relying on the physical characteristics such as the high surface area and capillary action of the materials. Examples of these applications include specialty filtration products, absorbents, and soil amendments to control evaporation.

GEOLOGY OF THE LONG VALLEY POZZOLAN DEPOSITS

Structural Geology

Long Valley is one of several Miocene-Pliocene age sedimentary basins in northeastern California and northwestern Nevada. The area is marked by the complex structural styles of the Sierra Nevada–Basin and Range transition zone. Among the leading structural styles are northerly trending normal faulting characteristic of the eastern Sierra Nevada and north-northeast trending extensional normal faulting characteristic of the Basin and Range. The generalized geology of Long Valley is shown on Plate 1.

Long Valley takes the form of an extensional, westerly dipping half graben. It is bounded on the west by Late Cretaceous intrusive granodiorites of the Sierran Batholith, exposed in the Diamond Mountains, and to the east by Cretaceous granodiorite of the Petersen Range. The valley terminates against the Verdi Range to the south and ends in a gap between the Diamond and Seven Lakes Mountains to the north.

On the east flank of Long Valley, basinal sediments of the Hallelujah Formation rest unconformably on basement granodiorite or volcanic beds of the Hartford Hills Rhyolite. On the west, the valley is bounded by high angle easterly dipping normal faults of the Diamond Mountains Fault Zone.

Faulting, rotation and uplift have exposed the Hallelujah Formation throughout the valley. Beds generally exhibit westerly dips ranging from 20–35 degrees. Lesser dips appear to be associated with drag along down-dropped fault blocks.

Stratigraphy

The Hartford Hill Rhyolite unconformably overlies the Sierran basement complex and is exposed in outcrops to the east on the flanks of the Peterson Mountains. This unit is a sequence of interbedded ash flow tuffs and interbedded sandstones ranging in thickness up to 1,000 feet. The Hartford Hill Rhyolite is overlain by the late Pliocene-Miocene Hallelujah Formation except in areas where the rhyolite has been removed by erosion, in which case the Hallelujah beds rest directly on the basement.

Hallelujah Formation exposures are locally obscured by a veneer of Quaternary colluvium and alluvium associated with Long Valley Creek.

Hallelujah Formation

Van Couvering (1962) named the Hallelujah Formation for the Tertiary sedimentary rocks exposed in the vicinity of Hallelujah Junction. This formation is host to the Long Valley pozzolan deposits which are classified in this report. The formation varies in thickness from an average of approximately 3,300 feet in the north to about 8,000 feet in the vicinity of Hallelujah Junction. Farther south, the Hallelujah beds thin. However, limited field mapping and Quaternary cover obscures much of the upper Hallelujah Formation and precludes accurate thickness determinations in the southern valley.

The formation is not well exposed throughout the valley. Low relief, weathering, and Quaternary cover obscure outcrops. However, railroad cuts, highway cuts, prospect pits and trenches, along with former mine workings provide sufficient information to characterize the formation.

The Hallelujah Formation can be divided into three primary members based on lithology and depositional environment. The upper and lower members record marginal lacustrine and high energy terrestrial environments with interbedded fluvial, deltaic, and lacustrine sediments. The middle member is dominated by more homogeneous and massive open water diatomaceous lacustrine sediments.

Lower Hallelujah Member (Thl)

The lower member consists of a sequence of white to brown, immature, poorly sorted lenticular arkosic sandstones and siltstones ranging from 1,000–2,000 feet thick. Beds are frequently marked by trough cross-bedding with organic material or pebbles on the bedding faces and fluvial cut and fill features. In places, the lower member is punctuated with beds of granitic boulder conglomerate containing boulders up to 50 feet across and attributed to sporadic mass wasting processes such as debris flows and landslides.

Petrography of the lower member indicates local sources. Where it rests on the Hartford Hills Rhyolite it is primarily composed of volcanic material including pumice and ash. Where it rests on the crystalline basement, it is composed largely of granitic materials including quartz and feldspar.

The lower member is capped by a rather persistent boulder conglomerate that marks the top of the lower to middle Hallelujah member transition zone where it is present. When absent, the top of the lower member is generally defined at the contact between sandstone of the lower unit and the white siltstone of the middle unit.

Middle Hallelujah Member (Thm)

The middle member contains the pozzolanic materials that have been classified for this report. Variously termed Lassenite, Cherokee Lassenite, and pozzolanite by previous authors, the bulk of the unit consists of massive and homogeneous white to tan lacustrine diatomaceous and tuffaceous siltstone and shale, rich in vitric tuff shards and hydrated rhyolitic glass ash. Bedding is indistinct, dipping to the west at 20-35 degrees on average. Sedimentary structures are essentially absent. The siltstone matrix locally contains 75% ash sized pumice fragments that are partially hydrated to opaline silica. Locally, diatom frustules are abundant and may comprise up to 60% of the rock. A few percent potassium feldspar, cristobalite, and sparse clays are also present. Total amorphous silica material is often in excess of 80% (Goodman, 1974).

The middle unit is poorly indurated and weathers easily making the west dipping beds rarely observable in much of its outcrop area. It is best seen in prospect pits, mine pits, stream banks, and road and rail cuts. At the surface, the light colored, diatomaceous and ashy soil help make the unit mappable.

In the north part of Long Valley, the middle unit is interspersed with discontinuous boulder conglomerates much like the conglomerates in the lower member.

The profusion of diatoms (single celled aquatic algae that secrete opaline siliceous frustules or cell walls) and copious ash fall material indicates the middle member was dominated by a relatively calm, shallow, and well circulated lake environment.

The middle member reaches a maximum thickness of about 3,300 feet five miles north of Hallelujah Junction. Low rates of lakebed sedimentation suggests a persistent lake environment, possibly coupled with concurrent downwarping to allow the development of such thicknesses. The unit progressively thins to about 650 feet two miles southeast of Hallelujah Junction. Delineation of the middle unit farther south was not possible due to a lack of exposures and insufficient field investigations. However, the consistent thinning trend from north to south and the inferred depositional model suggests that the unit may thin to extinction near the Sierra County or Nevada state line.

Upper Hallelujah Member (Thu)

The upper member resembles the lower unit and consists of locally derived immature white, light gray to tan, fine to very coarse grained arkosic sandstones and siltstone interbeds with local beds of pebble and boulder conglomerate. Beds are laterally discontinuous. Sedimentary structures, indicative of intermittent high energy fluvial and deltaic sedimentation, include trough cross bedding, scour features, soft sediment deformation, and graded bedding,. The member attains a maximum thickness of approximately 3,300 feet in the vicinity of Hallelujah Junction.

The contact between the middle and upper unit is characterized by a 30 to 160 foot gradational contact of interbedded and intercalated upper member fluvial clastics and middle member diatomaceous siltstone, shale, and ash units.

EVALUATION OF THE LONG VALLEY POZZOLAN RESOURCES

Mining History

Long Valley pozzolan has been commercially mined and marketed at various times since Lassenite Industries first opened a mine and processing mill near the north end of the valley in 1965.

Interest in the pozzolan deposits was inspired by the need for a natural pozzolan concrete admixture for the construction of the Bullards Bar Dam on the North Yuba River in Yuba County, California. Lassenite Industries purchased a used cement mill with two calcining kilns and relocated it to a site adjacent to the Western Pacific (now Union Pacific) railroad line (SW/4 Sec. 2-T23N-R17E). The "Lassenite Pit" itself was located three quarters of a mile southeast of the mill and due west of Highway 395 (SW/4 NE/4 Sec. 11-T23N-R17E). Material was trucked from the pit to the mill where it was processed and prepared for rail shipment. The mine and mill were operational in late 1965.

Lassenite Industries actively operated the mine and mill from 1965 until 1972. While actual production records are no longer available for this period, it's estimated that approximately 100,000 tons were mined, processed, and delivered to the U.S Corp of Engineers for use in Bullards Bar Dam (Gaus, personal communication).

In 1972, Cherokee Industries took over operatorship of the mine and mill. No records of production are available for the period in which Cherokee Industries owned the properties.

In 1976, the mine and mill was again operated by Lassenite Industries until the late 1980s when it was closed. While no specific records are available, during this period, bulk rail shipments of finished pozzolan were shipped for several projects including construction of the Palo Verde Nuclear Generating Station near Phoenix, Arizona. Other projects employing pozzolan from this site during this period were the East Bay Municipal Utility District wastewater treatment plant, the Moscone Center in San Francisco, the Sacramento wastewater treatment plant, the Tehama-Colusa Canal, and the Pacheco Pass Tunnel (Gaus, personal communication).

Since then, no significant mining has taken place. Unconfirmed reports of limited and sporadic withdrawals of raw pozzolan from the pit area for soil amendment, water conservation, and absorbent applications have been reported. Over the years, the mill has been neglected and vandalized and allowed to fall into disrepair. However, the facility is currently being refurbished by Western Pozzolan Corporation in anticipation of renewed pozzolan mining in the near future.

Previous Studies

Several limited investigations have previously been conducted in order to evaluate both the quality and quantity of the Long Valley pozzolan deposits.

In anticipation of the Bullards Bar project, bulk samples from the proposed Lassenite Industries Pit in section 11 were analyzed by the Engineering Materials Lab at UC Berkely in April 1965 for chemical, physical, and portland cement mortar bar analysis. After calcining at 1,850 °F, tests indicated the pozzolan met the specifications for a portland cement concrete admixture set by the ASTM, U.S. Corp of Engineers, U.S. Bureau of Reclamation, and the California Department of Water Resources.

In the summer of 1965, Goodman conducted a limited assessment of lands in the pit area as well as sections 13 and 23-T23N-R17E. Eight surface samples were collected from the Middle Hallelujah pozzolan, two of which were collected adjacent to Highway 395 in section 11 from an outcrop and the pit site. Goodman described the material as diatomaceous shale and determined that the material was a satisfactory pozzolan for concrete if calcined. He also concluded the quality would improve with depth and that the deposits were laterally extensive.

In November 1965, Weiler sampled the Middle Hallelujah member at a location near the mine pit in section 11 for inclusion in his 1969 report on the pozzolanic resources of California and Nevada. This material proved to be a good pozzolan when calcined. Weiler estimated the thickness of the material was approximately 300 feet and that there was over 1 million tons available in the mine area alone. Weiler noted that crushing, screening, calcining, and fine grinding would be required to activate the material. He pointed out that in the uncalcined state there was little value as a pozzolan.

A second sample collected by Weiler from a bed in an exploratory shaft northeast of the mill (NE/4 NW/4 Sec. 2 T23N R17E) yielded high quality pozzolan in the uncalcined state. He concluded that this deposit (also known as the Red Rock Pumicite) was uneconomic due to the need for underground mining techniques (Goodman later concluded the bed was also of limited extent). Lithologic dissimilarities and its stratigraphic position, however, suggest this occurrence is not within the main Middle Hallelujah member pozzolan deposit, but more likely an isolated bed within the lower portion of the Upper Hallelujah member.

In June 1966, the California Department of Water Resources reported the results of concrete tests performed on samples of the Middle Hallelujah pozzolan. One sample was a finished pozzolan from the mill, collected in January, 1966 which proved to be a satisfactory pozzolan admixture for concrete.

In the spring of 1974, Goodman conducted a more extensive investigation of the Long Valley Pozzolan deposits on behalf of Cherokee Industries. The investigation included 16 reflection seismic lines, over 2,000 feet of bulldozer cuts, three boreholes, and extensive sampling within the middle member pozzolan. Sampling was conducted by spot sampling of outcrops, test excavations, and auger drill. Maximum depth of boreholes was 70 feet and indicated pozzolanic material to total depth in all holes. Samples were collected from throughout the Middle Hallelujah outcrop from as far south as section 1-T22N-R17E (near Hallelujah Junction) to as far north as exposures in sections 1 and 2-T23N-R17E (specific sample location maps are no longer available). All samples were subjected to x-ray diffraction for reconnaissance determination of amorphous silica material. Selected samples were thin sectioned and submitted for physical and chemical laboratory analysis.

X-ray data indicated that the pozzolanic material was consistently composed of greater than 80% amorphous silica. The remaining crystalline material (≤ 20%) consisted primarily of quartz, potassium feldspar, and cristobalite. Quartz, while generally less than 5%, ranged locally up to 10%. Potassium feldspar was the dominant crystalline material averaging 5% to 10%. Cristobalite was consistently > 5%. Trace amounts of vermiculite and montmorillonite were identified in some samples.

Two finished pozzolans were prepared. After calcining for 2 hours at 1,600°F, they were analyzed for full chemical, physical, and portland cement mortar bar properties. Four other samples were analyzed for specific surface, specific gravity, and portland cement mortar cube analysis. These results again indicated that the Long Valley pozzolan was an effective concrete admixture meeting all applicable requirements.

Five seismic refraction lines were run in, the mine area and eleven elsewhere in Long Valley to ascertain information about the deposit's depth, bedding, and continuity. Maximum depths reached by geophysics were about the same as by drill holes (slightly deeper than 70 feet) and suggested pozzolanic material to those depths.

Pozzolan Resources

Goodman conservatively estimated that close to 50 million cubic yards (67 million tons) of commercial grade pozzolan existed in the Lassenite Pit area alone (Secs. 11 and 14-T23N-R17E). His calculations limited resources to a depth of 60 feet. Goodman also recognized the thickness of the pozzolan unit far exceeded 60 feet and that its exposure could be traced 6 to 7 miles farther south. He concluded that there may be billions of tons of commercial grade pozzolan in Long Valley.

Composite geologic mapping compiled for this classification report indicates the Middle Hallelujah pozzolan member is exposed throughout more than 5,510 acres in Long Valley. It extends for almost 10 miles in a north-south trend from its most northerly exposures in section 6-23N-R18E to the exposures two miles southeast of Hallelujah Junction in section 24-22N-R17E. For nearly 3 miles south of the mine site in section 11, its surface exposure averages 8,000 feet wide and its thickness over 3,000 feet . It then narrows to approximately 2,000 feet near its southern exposures where it is 650 feet thick. Topographic relief along its outcrop exceeds 800 feet and ranges from an elevation of less than 4,600 feet to the north along Long Valley Creek to over 5,400 feet northeast of Hallelujah Junction (Sec. 36-T23N-R17E).

For the foreseeable future, commercial pozzolan mining will be accomplished using conventional surface equipment such as scrapers, bulldozers, and loaders. Hence, mining depth will likely be limited by depth to the water table rather than the total thickness of the pozzolan resources.

Goodman identified groundwater in two of the three borings as 27.5 feet and 36.2 feet below ground level at locations with surface elevations of 4,690 feet and 4,710 feet respectively. These borings were placed at the lower elevations of pozzolan exposure in the vicinity of Long Valley Creek and during spring recharge, a period of high water table. A third boring, placed at a surface elevation of

4,750 feet, did not reach the water table at a total depth of 70 feet. As would be expected, this limited data indicates an inclined potentiometric surface discharging into Long Valley Creek. While it is difficult to extrapolate from so little data, it is assumed that minable pozzolan resources in exposures at or below a surface elevation of 4,750 feet would be less than 70 feet thick and thin considerably with declining elevation and proximity to Long Valley Creek. Conversely, the water table would be expected to rise with increasing surface relief and distance from Long Valley Creek, albeit at a lesser rate than the surface relief itself. Hence, pozzolan resources above the water table would be expected to easily exceed 70 feet at surface elevations above 4,750 feet and conservatively achieve thicknesses well in excess of 100 feet towards the higher surface elevations which exceed 5,200 feet in the southeast part of the study area.

For this report, minable pozzolan resources above the water table are assumed to average 50 feet thick for exposures below the 4,760 foot contour and average 100 feet thick throughout exposures above this contour. This conservative approach yields pozzolan resources of 1.1 billion tons. Applying a price competitive with the most popular current pozzolan (fly ash) of approximately $45/ ton equates to $50 billion, well in excess of the of $2.7 million (2001 dollars) classification threshold established by the SMGB.

Barring these constraints and recognizing that the Middle Hallelujah pozzolan unit ranges from 650 feet to 3,300 feet thick, the deposit probably contains gross pozzolan resources of many billions of tons; the limiting factor being increased production costs associated with deeper mining.

Area classified MRZ-2a

An area of approximately 4.9 acres comprising portions of the former Lassenite Pit is classified MRZ-2a (Plate 2). This area includes parts of Iron Cloud Mining Claims 11 and 12, for which Valtec Capital (later transferred to Western Pozzolan Corporation) filed a notice to mine with the Bureau of Land Management (BLM) in 1994 (BLM mine case file # N36-95-003N). Currently, Western Pozzolan is upgrading and refurbishing the former Lassenite Industries mill to process material from this property.

Under SMARA, information filed with the Department of Conservation regarding Western Pozzolan's reserves is proprietary. Independent assessments by DMG staff, however, indicates that the reserves are sufficient to exceed the threshold value of $2.7 million (2001 dollars).

Areas classified MRZ-2b

Plate 2 also shows the lands classified as MRZ-2b. Sufficient mapping and testing throughout the outcrop of the Middle Hallelujah member pozzolan unit indicate that the unit as a whole exhibits qualities sufficient to comprise inferred pozzolan resources. Areas requiring removal of overburden including Upper Hallelujah deposits, Quaternary cover, or boulder conglomerates are excluded from this classification. The area classified is 5,510 acres with resources exceeding 1.1 billion tons.

Economic Considerations

Many varieties of natural pozzolans are found in California and have been used in structures such as dams, aqueducts, canals, reservoirs, and sewage treatment plants. Since the 1960s, however, the market for natural pozzolans has been impacted by the increasing availability fly ash at competitive prices. The onset of RCRA requirements in 1976 to use recycled products further stimulated the use of fly ash and contributed to the reduction in the use of natural pozzolans.

An extensive infrastructure has also evolved to supply the construction industry with fly ash. Fly ash is routinely shipped 500 to 1,000 miles from power plants in the west and midwest to California markets where storage terminals and distribution facilities have been established in most high growth urban areas. Fly ash is often marketed by the major portland cement distributors themselves.

As a result, all natural pozzolan producers that were active in California and neighboring states during the 1960s and 1970s have ceased producing natural pozzolan for cement admixtures. However, recent concerns about the long term suitability of fly ash, particularly in regards to controlling ASR, have rekindled interest in natural pozzolan as a cement admixture. Additionally, newer markets for natural pozzolan as a soil amendment and environmental absorbent have helped renewed interest in mining the Long Valley deposits.

Since Long Valley pozzolan occurs in surface deposits that are easily ripped and crushed, mining costs can be kept to a minimum. Bulk transport costs could also be minimized by utilizing the existing Union Pacific Railroad spur adjacent to the existing mill building. However, producing a finished natural pozzolan requires crushing, drying, blending, and sizing; all of which add to the final cost. Historical testing and application has shown the Long Valley pozzolan also requires calcining. Calcining is energy intensive and, in the current environment of escalating energy costs, must be incorporated in any commercial evaluation.

For the foreseeable future, demand for portland cement concrete in the building and paving industries is expected to increase as is the demand for pozzolan in California. However, market forces, environmental concerns, and regulatory pressures favor the continued dominance of fly ash in the majority of construction projects. Whereas the EPA's CPG allows for exemptions when the price of a designated item is cost prohibitive or does not meet required performance specifications, opportunities still exist for the commercial exploitation of natural pozzolan, including Long Valley pozzolan. Since the largest markets for pozzolan concretes tend to be the urban areas, processing, transport, and distribution costs will hinder widespread utilization of these natural resources.

Natural pozzolan use is expected to be confined to projects in reasonable proximity to the deposits to be competitive with fly ash. With respect to Long Valley pozzolans, demand is expected to be limited to projects in the greater Reno metropolitan area and to large scale projects in northern California. Long Valley is suitably located to provide pozzolan for proposed large scale flood control projects such as the Auburn Dam, or for proposed CalFed water supply projects such as the Shasta Dam expansion and the Sites Reservoir.

Alternative Resources

A survey of pozzolanic materials in the western states, published by the U.S. Bureau of Mines in 1969, suggests that few deposits are similar in quantity, quality, and utility as a portland cement concrete admixture to the Long Valley deposits.

Analytical data generated from reconnaissance samples collected from twelve deposits within California, Nevada, and Oregon indicated materials potentially comparable to Long Valley pozzolan in respect to enhancing concrete compressive strength and in controlling ASR. Petrographically, these materials included volcanic tuff, perlite, pumice, tuffaceous shale, calcined shale, and high purity diatomite as opposed to the diatomaceous shale of the Long Valley deposits. In lieu of publishing actual analytical data, the results were assigned to one of four analytical categories making direct comparisons to the Long Valley pozzolan impossible. Further, whereas Long Valley pozzolan has a demonstrated record of excellent performance as a concrete admixture, little to no information is available regarding actual performance of these other materials in similar applications.

Several of the surveyed deposits consist of high purity diatomite as compared to the Long Valley deposits which are best described as diatomaceous shale. These high purity diatomites are valued more for their physical attributes rather than their pozzolanic properties and are especially suited for specialty filtration products as well as fillers and abrasives in pharmaceutical and consumer goods applications. These materials command prices from \$250 - \$500 per ton effectively precluding their use as a competitive pozzolan in the marketplace.

CONCLUSIONS

In accordance with the mandates of the SMARA, the staff of DMG, under the direction of the State Geologist, has evaluated the pozzolan deposits in Long Valley, Lassen County. While no specific sampling and testing was performed for this report, the previous mining history and application of the pozzolan, as well as the results of previous investigations involving physical, chemical, and mortar bar analyses consistently demonstrated that significant high quality pozzolan resources are present within the middle member of the Hallelujah Formation throughout most of Long Valley. Pozzolan resources in excess of 1.1 billion tons meet the suitability and threshold criteria established by the SMGB for inclusion into the MRZ-2b category for industrial minerals (Plate 2). Permitted reserves classified as MRZ-2a exist in the area of the former Lassenite Pit are and are currently scheduled to be mined in the near future.

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