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# MINERAL LAND CLASSIFICATION OF PORTLAND CEMENT CONCRETE AGGREGATE IN THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

1988

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

SPECIAL REPORT 160

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*ACTING STATE GEOLOGIST*

SPECIAL REPORT 160

# MINERAL LAND CLASSIFICATION OF PORTLAND CEMENT CONCRETE AGGREGATE IN THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

1988

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## FOREWORD

Special Report 160, "Mineral Land Classification of Portland Cement Concrete Aggregate in the Stockton-Lodi Production-Consumption Region," is part of the continuing analysis of aggregate resources in California to be developed by the California Department of Conservation, Division of Mines and Geology under authority of the Surface Mining and Reclamation Act of 1975 (SMARA). This classification is provided to the State Mining and Geology Board for transmittal to the local governments that regulate land use in this region, and for consideration of areas, if any, to be designated as regionally significant. SMARA was enacted by the State Legislature to assure mineral resource conservation and adequate mined land reclamation.

The State Mining and Geology Board adopted guidelines in June 1978 to be employed by the Division in its mineral resource classification. This report was prepared in conformance with those directives. The undertaking is of great importance in economic geology because it deals with very specific mineral conservation issues in areas of intensive competing land use.

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# PREFACE

Reserve tonnage data presented in this report was accurate as of January 1987. In May 1988, a preprint version of the report was circulated to lead agencies and made available to the public. Changes in reserves resulting from either the premature closure of mines active in 1986, or the permitting of new mines since that time, may have impacted forecasted depletion dates for the production-consumption region studied. However, the material presented and the fundamental conclusions of the report remain valid and useful.

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CONTENTS


Page

EXECUTIVE SUMMARY ..... xi

INTRODUCTION ..... 1
Overview of Classification ..... 2
Brief Overview of Designation ..... 4
Lead Agency Response to Classification ..... 4
Overview of Aggregate Uses ..... 4
Transportation Rates ..... 5

DETERMINATION OF THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION ..... 6

ESTABLISHMENT OF MINERAL RESOURCE ZONES ..... 9
Areas Classified MRZ-1 ..... 10
Areas Classified MRZ-2 ..... 10
Areas Classified MRZ-3 ..... 11
Areas Classified MRZ-4 ..... 11

EVALUATION OF PCC-GRADE AGGREGATE IN THE STOCKTON-LODI P-C REGION ..... 11
Concepts Used in Identifying Available Aggregate Resource Areas ..... 11
Sectors ..... 11
Resources within Parks ..... 14
Calculations of Available Resources ..... 14
Reserves and Resources ..... 14
Factors Considered in Calculations ..... 14
Resource Sector Descriptions ..... 14
Sectors A-1, A-2, A-3, A-4 — Corral Hollow Creek Alluvial Fan ..... 15
Sector A-1 ..... 15
Sector A-2 ..... 16
Sector A-3 ..... 16
Sector A-4 ..... 16
Sector B — Lone Tree Creek Alluvial Fan ..... 16
Sector C — Hospital Creek Alluvial Fan ..... 18
Sector D — Lathrop Deposit ..... 18

PCC-GRADE AGGREGATE DEPOSITS BELOW MINIMUM THRESHOLD VALUE ..... 19
Mokelumne River ..... 19
Calaveras River ..... 20

CLASSIFICATION OF ACTIVE MINES PRODUCING OTHER MINERAL COMMODITIES ..... 20

ESTIMATED 50-YEAR CONSUMPTION OF AGGREGATE ..... 21
Basis of 50-Year Forecast ..... 21
Correlations Between Aggregate Production and Consumption ..... 21
Projected Population and Per Capita Consumption through the Year 2036 ..... 22
Factors Affecting Per Capita Consumption Rates ..... 23
Comparison of the 50-Year Aggregate Demand with Current Reserves ..... 23

ALTERNATIVE SOURCES OF AGGREGATE ..... 25
Potential Sources of Aggregate within the Stockton-Lodi P-C Region ..... 25
Potential Sand Sources within the Stockton-Lodi P-C Region ..... 26
Potential Sources of Aggregate Outside the Stockton-Lodi P-C Region ..... 27

CONCLUSIONS ..... 27

ACKNOWLEDGMENTS ..... 27

REFERENCES ..... 28

APPENDIX ..... 29

## FIGURES


Page

Figure 1. General location of the Stockton-Lodi Production-Consumption Region ..... 1

Figure 2. The Stockton-Lodi Production-Consumption Region boundary ..... 2

Figure 3. Index map of U.S. Geological Survey 7.5-minute quadrangles covering the Stockton-Lodi P-C Region ..... 3

Figure 4. Minimum distance rates for trucking aggregate within the Stockton-Lodi P-C Region ..... 5

Figure 5. Location of aggregate extraction sites in relation to urbanized and urbanizing regions (modified OPR boundary) of the Stockton-Lodi P-C Region ..... 6

Figure 6. The two PCC-grade aggregate production districts that supply the Stockton-Lodi P-C Region, and the percentage of the P-C region's aggregate demand that each district supplies ..... 7

Figure 7. Location of P-C regions adjacent to the Stockton-Lodi P-C Region ..... 8

Figure 8. Stockton-Lodi PCC-grade aggregate marketing distribution pattern for 1986-1987 ..... 9

Figure 9. Index to geologic mapping used in the classification of the Stockton-Lodi P-C Region ..... 10

Figure 10. Generalized geologic map of the Stockton-Lodi area ..... 12

Figure 11. Aggregate consumption (3-year averages) for the Stockton-Lodi P-C Region, 1961-1985 ..... 22

Figure 12. Population for the Stockton-Lodi P-C Region, 1960-1986 ..... 24

Figure 13. Annual per capita consumption of aggregate in the Stockton-Lodi P-C Region, 1961-1985 ..... 24

Figure 14. Projected population of the Stockton-Lodi P-C Region for the years 1986-2036 ..... 26


## TABLES


Table 1. Minimum hourly rates for transport of aggregate in the Stockton-Lodi area ..... 5

Table 2. Lead agencies located within the Stockton-Lodi Production-Consumption Region ..... 7

Table 3. Aggregate resources in Sector A-1 ..... 16

Table 4. Aggregate resources in Sector A-2 ..... 17

Table 5. Aggregate resources in Sector A-3 ..... 17

Table 6. Aggregate resources in Sector A-4 ..... 17

Table 7. Aggregate resources in Sector B ..... 18

Table 8. Aggregate resources in Sector C ..... 18

Table 9. Total aggregate resources in Sectors A (A-1, A-2, A-3, A-4), B and C ..... 19

Table 10. Aggregate resources in Sector D (sand only) ..... 19

Table 11. Population, aggregate consumption (tons) and per capita consumption (tons) in the Stockton-Lodi P-C Region during the period 1960-1986 ..... 21

Table 12. Percentage of total aggregate consumption used for Portland cement concrete aggregate in the Stockton-Lodi P-C Region during the years of 1960-1986 ..... 23

Table 13. Projected aggregate consumption through the year 2036 for the Stockton-Lodi P-C Region ..... 25

## PLATES

### Mineral Land Classification Maps


Plate 1. Lodi North Quadrangle
Plate 2. Lockeford Quadrangle
Plate 3. Clements Quadrangle
Plate 4. Wallace Quadrangle
Plate 5. Lodi South Quadrangle
Plate 6. Waterloo Quadrangle
Plate 7. Linden Quadrangle
Plate 8. Valley Springs SW Quadrangle
Plate 9. Stockton West Quadrangle
Plate 10. Stockton East Quadrangle
Plate 11. Union Island Quadrangle
Plate 12. Lathrop Quadrangle
Plate 13. Manteca Quadrangle
Plate 14. Tracy Quadrangle
Plate 15. Vernalis Quadrangle
Plate 16. Lone Tree Creek Quadrangle
Plate 17. Solyo Quadrangle


### Aggregate Resource Sector Maps


Plate 18. Lathrop Quadrangle
Plate 19R. Tracy Quadrangle
Plate 20. Vernalis Quadrangle
Plate 21. Solyo Quadrangle


### General Maps and Cross Sections


Plate 22. Generalized geologic map of the Stockton-Lodi area
Plate 23. Generalized geologic column of the central San Joaquin Valley
Plate 24. Generalized geologic cross section of the Corral Hollow Creek alluvial fan in Tracy (A-A', B-B', C-C')
Plate 25. Generalized geologic cross section across the Mokelumne River near Clements (D-D')

# EXECUTIVE SUMMARY

The Stockton-Lodi Production-Consumption (P-C) Region, as defined in this report, covers 430 square miles and includes the large urbanizing portions of San Joaquin County. In any urban region, it is important that land-use decisions be made with full recognition of the local natural resources. Mineral resources, including construction aggregate, are limited within a given region. This is especially true when the resource in question is Portland cement concrete (PCC) aggregate, an indispensable, high-grade construction aggregate which is costly to transport. This report provides information concerning the location, tonnage, and quality of aggregate resources of the Stockton-Lodi P-C Region and the projected demand for aggregate for the next 50 years.

In past years, the Stockton-Lodi area has had adequate quantities of relatively low-cost aggregate materials locally available. However, the amount of this material is diminishing as active aggregate producers deplete their deposits and land containing suitable sand and gravel resources is pre-empted from mining by urban development.

The loss of regionally significant mineral deposits to land uses that preclude mining is one of the problems that the California Surface Mining and Reclamation Act of 1975 (SMARA) was framed to address. Based on guidelines adopted by the California State Mining and Geology Board (the Board), the California Department of Conservation's Division of Mines and Geology (DMG) has classified land for Portland cement concrete aggregate resources in the Stockton-Lodi P-C Region. This classification study will assist the Board if a subsequent process, called designation, is initiated. Designation is the formal recognition by the Board, of lands containing regionally significant PCC-grade aggregate resources that are needed to meet the region's future demand.

Both processes, classification and designation, require specific mandated actions by the lead agencies having jurisdiction over the resources identified in this report. These actions include:

1. Recognizing the mineral classification information, including the classification maps transmitted to the lead agency by the Board.

2. Emphasizing the conservation and development of identified mineral deposits.

DMG has classified the Stockton-Lodi P-C Region according to the presence or absence of significant sand, gravel, and stone deposits that are suitable as sources of Portland cement concrete aggregate. The land classification within the Stockton-Lodi P-C Region is presented in the form of Mineral Resource Zones (MRZ) on 17 U.S. Geological Survey topographic quadrangles that accompany this report (plates 1-17).

Mineral Resource Zones for PCC-grade aggregate were established on the basis of a sand, gravel, and crushed stone resource appraisal which included a study of pertinent geologic information, field investigations of mines and quarries, and analysis of well-logs and drilling records. Land is classified MRZ-2 if the area contained a minimum threshold value of $8.7 million ($5 million 1978 dollars) of suitable aggregate that can be extracted profitably by current mining technology, or mining technology which can reasonably be expected to exist in the foreseeable future.

Five areas within the Stockton-Lodi P-C Region are classified MRZ-2 for PCC-grade aggregate. Four of these MRZ-2 areas contain PCC-grade sand and gravel resources; three areas are located on alluvial fans south of Tracy along the east side of the Diablo Range, and one MRZ-2 area is located along the Mokelumne River immediately below Camanche Dam. The latter MRZ-2 area contains a dedicated park within its boundaries and is unlikely to be a candidate for mining in the foreseeable future. The remaining MRZ-2 area is classified for PCC-grade sand and is located along the San Joaquin River near Lathrop. Although the sand from this deposit is used primarily for specialty sand products, this material can substantially comply with the California Department of Transportation's (Caltrans) specifications for PCC-grade sand. This sand deposit is excluded in calculating the projected life expectancy of PCC aggregate in the Stockton-Lodi P-C Region because it is only useful if an equal amount of coarse material is made available. Cumulatively, these MRZ-2 areas cover 14 square miles (3 percent of the total classified area) — 12 square miles contain PCC-grade sand and gravel, and 2 square miles contain only PCC-grade sand.

The bulk of aggregate in the Stockton-Lodi P-C Region is obtained from the southern end of San Joaquin County in the Corral Hollow Creek production district. Four active aggregate pits supply the Stockton-Lodi P-C Region. Three of these active pits — Teichert Aggregates, Lone Star Industries, Inc., Granite Construction Co. — are in the Corral Hollow Creek production district and supply more than 80 percent of the P-C region's aggregate consumption. The fourth active PCC-grade aggregate pit, Claude C. Wood, in the Mokelumne River production district, supplies less than 20 percent of the P-C region's aggregate consumption.

The permitted aggregate properties in the Mokelumne River production district are classified MRZ-3 rather than MRZ-2, because their aggregate reserves are below the Board's minimum threshold value. Past mining has reduced the aggregate resources in these deposits to the point where they cannot be shown to meet the minimum threshold value of $8.7 million.

Active mines within the P-C region extracting mineral commodities other than PCC-grade aggregate and fill, are classified MRZ-2 if the deposit being mined contains at least the minimum threshold value for that commodity established by the Board. Four mining sites are noted as containing suitable aggregate for road base; only one mine site is classified MRZ-2 (road base). The three other mine sites are not zoned MRZ-2 (road base) because the quantity of material is below minimum threshold value. Except for these active mines, the Stockton-Lodi P-C Region is not classified for mineral commodities other than PCC-grade aggregate.

Large areas in the P-C region are classified MRZ-3 for PCC-grade aggregate resources. The significance of these resources cannot be evaluated from the available data. This includes material from the Laguna Formation which, with further beneficiation and testing, could prove to be an economic source of PCC-grade aggregate in the future.

In order to organize the volume calculations of the aggregate resources, the State Geologist has developed the concept of "sectors." Sectors identify portions of MRZ-2 areas that have not been urbanized. Sectors provide a means of calculating resource tonnages with some reliability by providing a geometrical configuration that is uniform in geologic continuity. The sector concept is used for the convenience of arraying resource information, and is intended to convey accurate information regarding the location and approximate tonnage of resources found in non-urbanized areas.

In the Stockton-Lodi P-C Region, four MRZ-2 areas are divided into seven sectors (one MRZ-2 area is not sectorized because it encompasses a dedicated park). These sectors are further subdivided into 84 subsectors. Together the 84 subsectors cover approximately nine square miles (2 percent of the total classified area) and contain a total of 599.2 million tons of PCC-grade sand and gravel and 90.2 million tons of PCC-grade sand. The sectors are described in this report and are shown on plates 18-21. Existing land uses within sectors are compatible with mining. The purpose of resource sectors is to inform lead agencies and others of aggregate resources that could be made available to mining by virtue of the current, undeveloped status of the land. The sectorization of any specific area is not an advocacy of mining in that area.

Throughout this report, the terms reserves and resources will be used. *Reserves* are aggregate materials that a mining company owns or controls, the mining of which is currently authorized by appropriate lead agencies through a valid mining permit. *Resources* are the total amount of available aggregate within an area, including reserves. The estimated PCC-grade sand and gravel resources within six of the sectors (A-1, A-2, A-3, A-4, B, and C) amount to 599.2 million tons. Of this total, 79.6 million tons are identified as reserves as of January 1987. The remaining sector (Sector D) contains an estimated 90.2 million tons of PCC-grade sand. The reserves in Sector D are proprietary and cannot be disclosed. Total reserves in the Stockton-Lodi P-C region cover less than two square miles, which is less than 1 percent of the total classified area.

The total projected aggregate consumption to the year 2036 is estimated to be 281 million tons, of which 113 million tons must be of PCC quality. The projected life expectancy of the reserves in the Stockton-Lodi P-C Region is estimated to be 16 years (depletion by the year 2004).

The projected aggregate consumption for the Stockton-Lodi P-C Region was obtained by determining an average annual per capita rate of aggregate consumption multiplied by the projected population for the next 50 years. The average annual per capita rate was derived by correlating aggregate production and population figures for the past 25 years (1960-1986). The derived per capita rate of 8.5 tons per year and the total population projected to 2036 were used to determine the P-C region consumption of 281 million tons. Should unforeseen events occur, such as massive urban renewal, disaster reconstruction, or major recession, the aggregate demand could change considerably.

In addition to those deposits classified MRZ-2, areas classified MRZ-3 within the Stockton-Lodi P-C Region contain possible alternative sources of aggregate. Included in this group are Holocene alluvial and Tertiary sedimentary deposits. Too little is known about the physical and chemical qualities of these possible sources to permit even crude resource estimates.

If additional aggregate is needed in the Stockton-Lodi region, the most readily available source would be from the producers in Jenny Lind that supply the foothill region, or producers along the Stanislaus River that serve Modesto. However, utilization of these deposits by Stockton-Lodi residents would cause supply problems in the marketing areas already served by these mines.

As with many forecasts of economic activity, the forecasts in this report should not be viewed as offering unqualified predictions of how the future will unfold. The forecasts of this report are based on assumptions of the accuracy of the basic data, and the continuation of development trends of the past three decades into the five decades ahead.

Assuming that consumption forecasts are accurate, the following conclusions were reached:

- The anticipated consumption of aggregate in the P-C region through the year 2036 is forecasted to be 281 million tons, of which 40 percent or 113 million tons, must be of PCC quality.
- About 80 million tons of permitted PCC-grade sand and gravel reserves exist in the P-C Region (this does not include the sand resources in the Lathrop deposit).
- Based on information obtained in January 1987, a total of 12 mines operated by nine different companies are permitted to produce aggregate in the Stockton-Lodi P-C Region. Eight mines contain PCC-grade aggregate: four are currently active, one produces PCC-grade sand only, two are new operations which have not produced aggregate yet, and one is temporarily out of production. Four mines contain road base aggregate: one is currently active and three are new operations which have not produced aggregate yet.
- Unless additional resources are permitted for mining, or alternative resources are utilized, total existing PCC aggregate reserves will be depleted by the year 2004, only 16 years from the publication of this report.
- In total, the 80 million tons of permitted PCC-grade aggregate reserves can only provide 28 percent of the anticipated consumption of all aggregate during the next 50 years.
- The expected longevity of the existing PCC-grade aggregate reserves is based upon the assumption that mining of these reserves will continue to be permitted until the reserves are depleted.
- Approximately 599 million tons of PCC-grade sand and gravel resources (including reserves) have been identified within the Stockton-Lodi P-C Region.
- All resources and reserves in the Stockton-Lodi P-C Region are contained in deposits of sand and gravel.

- In addition, approximately 90 million tons of PCC-grade sand resources (including reserves) have been identified within the P-C region. Deposits with only sand resources are not included in determining the life expectancy of PCC-grade aggregate in the Stockton-Lodi P-C Region because an equivalent tonnage of coarse aggregate is needed prior to their utilization in Portland cement concrete.

- The Stockton-Lodi P-C Region covers an area of 430 square miles, of which 14 square miles (3 percent of the P-C region) were classified MRZ-2. Only about nine square miles (2 percent of the P-C region) have been sectorized as having current land uses which do not preclude mining. Less than two square miles (less than 1 percent of the P-C region) of the sectorized areas are currently permitted for mining.

- The nine square miles of sectorized lands considered in this study to be available for meeting future aggregate needs, may be a larger area than local governments consider to be available for mining. Local governments may have already committed sectorized land to purposes other than aggregate mining which may account for this discrepancy. The significance of this difference of opinion regarding availability is that projected available resources (as defined by the Board) may be optimistic. The problem of meeting future aggregate needs could therefore be greater than described in this report. It is important that local governments promptly review these sectors which show areas as being available for future aggregate extraction. Local governments will then be able to verify, or amend as necessary, the conclusions reached in this report.

# MINERAL LAND CLASSIFICATION OF PORTLAND CEMENT CONCRETE AGGREGATE IN THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

## INTRODUCTION

This study provides information on the estimated availability of, and demand for, aggregate resources within the Stockton-Lodi Production-Consumption Region. The study area covers approximately 430 square miles and includes portions of San Joaquin County and northern Stanislaus County (Figures 1 and 2). In the Stockton-Lodi area, as in any rapidly urbanizing area, important land-use decisions should be made with full recognition of the region's natural resources. This is particularly important when the resource in question is high-grade construction aggregate used in Portland cement concrete. PCC-grade aggregate is an indispensable building material that is costly to transport. This classification report documents for the Stockton-Lodi area:

1. the location of aggregate resources
2. the quantity of PCC-grade aggregate within deposits which meet Caltrans specifications for use in Portland cement concrete
3. the demand for aggregate within the region for the next 50 years

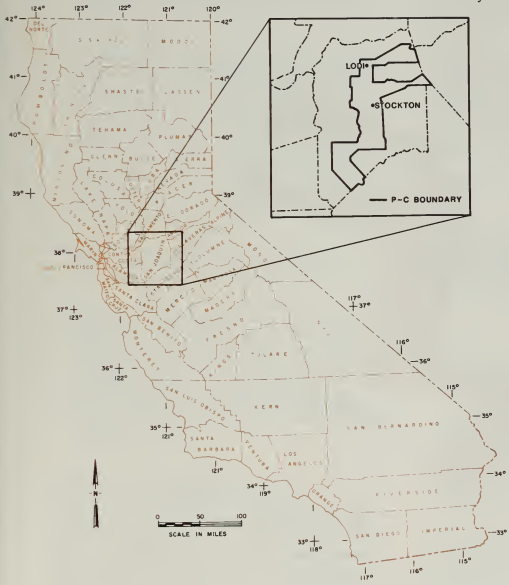


Figure 1. General location of the Stockton-Lodi Production-Consumption Region.

This study was conducted as specified by the Surface Mining and Reclamation Act (SMARA) of 1975. SMARA was passed by the California State Legislature in response to the loss of significant mineral resources due to urban expansion, the need for current information concerning the location and quantity of essential mineral products, and to ensure adequate mined land reclamation. To address mineral resource conservation, SMARA mandated a two-phased process called classification-designation. The objective of the classification-designation process is to ensure, through appropriate local lead agency policies and procedures, that raw material is available when needed and does not become inaccessible as a result of inadequate information during land-use decision-making actions.

SMARA mandates that guidelines for classification and designation be developed by the State Mining and Geology Board (the Board). The Board originally adopted a set of guidelines on June 30, 1978. Section I.1.a of the guidelines requires that the State Geologist classify specified areas into *Mineral Resource Zones* (MRZ). Classification is the process of identifying lands containing significant mineral deposits based solely on geologic factors, and without regard for present land use or ownership. The Board recognizes that construction materials (sand, gravel, and crushed stone) are produced regionally, are used in every urban area of the state, and require special classification data. Section I.3 of the guidelines requires that classification reports pertaining to deposits of construction aggregate materials include the following information: (1) the location and estimated total quantity of construction aggregate available for mining; (2) limits of the market (production-consumption) region which

these potential resources would supply; and (3) an estimate of the total quantity of aggregate material that will be needed to supply the consumption region for the next 50 years. This information will assist the Board in determining the statewide or regional significance of these types of deposits. A copy of the guidelines can be obtained in DMG Special Publication 51, "California Surface Mining and Reclamation Policies and Procedures" (1983). While this publication is currently out-of-print and is being revised, a xerox copy can be obtained free of charge from DMG.

## Overview of Classification

The DMG is responsible under SMARA for carrying out the classification phase of the classification-designation process. Classification entails seven distinct but interrelated steps. These seven steps are described below.

1. *Determination of Production-Consumption (P-C) Region Boundaries.* The boundaries of the P-C region (Figure 2) are drawn along the limits of the marketing area of the active aggregate operations supplying the urban center under study. The Stockton-Lodi area was chosen for study because the State Office of Planning and Research (OPR) determined it to be an expanding urban center. The marketing area of the production sites supplying the Stockton-Lodi area was determined by interviews with aggregate operators and analysis of transport rates set by the Public Utilities Commission (PUC).

2. *Establishment of Mineral Resource Zones.* All lands within the Stockton-Lodi P-C Region are assigned Mineral Resource Zone classifications (MRZ-1, MRZ-2, MRZ-3, or MRZ-4 which are defined on page 9) based upon the geologic appraisal of PCC-grade aggregate resource potential. This mineral land classification is presented on plates 1-17; Figure 3 is an index map showing the coverage of the plates in the P-C region. This appraisal includes study of pertinent geologic reports and maps, field investigation and sampling at outcrops and at active and inactive pits and quarries, and analysis of water well-logs and drilling records.

3. *Identification of Available Aggregate Resource Areas as Sectors.* Lands containing significant deposits of PCC-grade sand and gravel (areas classified MRZ-2 in step 2) are evaluated to determine whether or not current

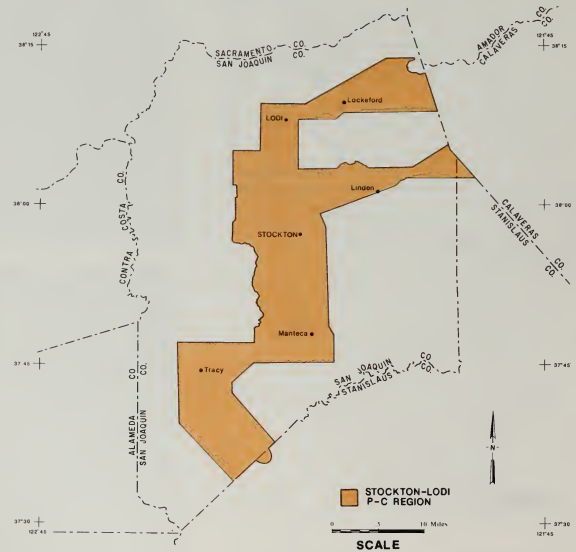


Figure 2. The Stockton-Lodi Production-Consumption Region boundary.

uses of these lands preclude possible future mining. Areas currently permitted for mining and areas found to have land uses compatible with possible future mining are considered available for mining. MRZ-2 areas which are not yet developed, but which have Specific Plans approved, were not considered available. Sectors which identify available land are delineated on plates 18-21 and described in detail in this report. Criteria for sectorization of MRZ-2 areas, established by the Board, are given in the Appendix.

4. *Calculation of Resource Tonnages within Sectors*. Investigation and analysis of on-site conditions, measurement of the areal extent of deposits, drill-hole information, waste-material percentages, and deposit densities are used to calculate total tonnages of PCC-grade aggregate *reserves* (deposits in land owned by an aggregate producer and permitted for mining by local government as of January 1987) and *resources* (all deposits of PCC quality, including the reserves) within each sector. Calculations reflect conditions of the deposits as of January 1987. Because annual aggregate production statistics for 1987 have not yet been released by the U.S. Bureau of Mines, resource depletion since January 1, 1987 has not been considered.

5. *Forecast of 50-Year Needs and the Life Expectancy of Current Reserves*. The total tonnage of aggregate needed to satisfy the demand in the Stockton-Lodi P-C Region over the next 50 years is based on a comparison of the projected population over that period with the average annual per-capita rate of total aggregate consumption from 1960-1986. Even though all identified reserves are of PCC quality, other aggregate commodities are routinely produced and marketed from them. The projected life expectancy of the reserves is based on the assumption that this practice will continue. Results of this forecast are used to determine the life expectancy of the P-C region's current reserves.

6. *Identification of Alternative Resources*. Alternative sources of aggregate to meet the forecasted 50-year demand are identified and briefly considered.

7. *Other Commodities*. Active mines, where commodities other than PCC-grade aggregate are produced, are located and classified MRZ-2 if they meet the minimum threshold value set by the State Mining and Geology Board. Resources at the site are not quantified beyond confirming this minimum value. This classification is site-specific where commercial mineral resource extraction occurs. It is not a classification of the entire P-C region for specific resources other than PCC-grade aggregate.

The Mineral Land Classification of the Stockton-Lodi Production-Consumption Region was initiated in 1985 by the State Geologist (due to other program obligations, the study was interrupted for a year). Included in the project area is most of San Joaquin County and a small portion of Stanislaus County. Portland cement concrete-grade aggregate resources of the area were selected for initial classification. Deposits suitable for PCC-grade aggregate were classified MRZ-2 and the volume of available material within them quantified. All other known mines

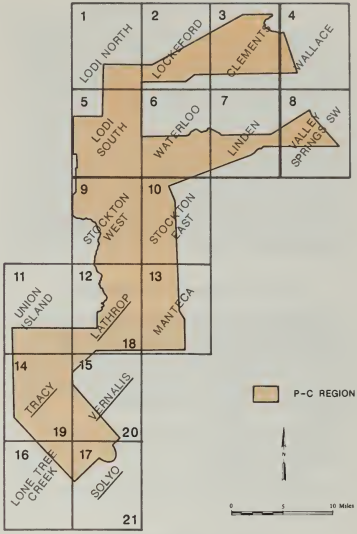


Figure 3. Index map of U.S. Geological Survey 7.5-minute quadrangles covering the Stockton-Lodi P-C Region. The Mineral Land Classification Maps (Plates 1-17) are indicated by numbers in the upper left-hand corner; the Aggregate Resource Sector Maps (Plates 18-21) are indicated by plate numbers in the lower right-hand corner and by underlined quadrangle name.

within the P-C region were classified MRZ-2 for their particular product but were not quantified beyond the establishment of a threshold value.

Each PCC-grade aggregate deposit was evaluated separately, and then considered as part of a single production-consumption region established on the basis of the existing aggregate marketing distribution pattern. The Stockton-Lodi marketing region is served by one major and one minor production district with overlapping marketing regions — Tracy (Corral Hollow Creek alluvial fan) deposit and Mokelumne River deposit, respectively.

Stockton-Lodi residents have been fortunate in having adequate quantities of low-cost, high-quality aggregate materials locally available. However, the amount of these materials available for future development is diminishing as active aggregate producers deplete their deposits and land containing suitable sand and gravel resources is utilized for urban development.

## Brief Overview of Designation

This report contains the classification phase of the two-step process mandated by SMARA. The designation phase follows receipt and approval of this classification report by the State Mining and Geology Board. Designation is the formal recognition by the Board of areas containing mineral deposits of regional or statewide significance that should be considered by lead agencies for protection from land uses incompatible with mineral extraction. Recognition is achieved by the adoption of regulations which designate certain deposits to be of prime importance in meeting the future needs of the region or the state. Designation is based upon this DMG report and consultation with lead agencies and other interested parties. Procedures for the designation of lands containing significant mineral deposits are specified in Section II.2 of the Board's Guidelines for Classification and Designation of Mineral Lands (California Division of Mines and Geology, 1983, p. 23).

## Lead Agency Response to Classification

The State Mining and Geology Board, upon receipt of the classification information from the State Geologist, transmits the classification report to the appropriate lead agencies and makes it available to other interested parties. Within 12 months of receipt of the classification report, each lead agency must develop and adopt mineral resource management policies to be incorporated in its general plan. These policies will:

1. Recognize the mineral classification information, including the classification maps transmitted to the lead agency by the Board.

2. Emphasize the conservation and development of identified mineral deposits.

## Overview of Aggregate Uses

Sand, gravel and crushed stone are "construction materials." These commodities, collectively referred to as "aggregate," provide bulk and strength to Portland cement concrete, asphaltic concrete, plaster and stucco. Aggregate is also used as road base, subbase, railroad ballast and fill. Aggregate normally provides from 80 to 100 percent of the material volume in the above uses.

Aggregate material is essential to the needs of a modern society. It is a resource of great importance to the economy of any metropolitan area.

During 1986, nearly 3 million tons of aggregate worth approximately $13 million were mined from the deposits which dupply the Stockton-Lodi P-C Region. Nearly 85 percent of this was consumed within the P-C boundaries. Approximately 40 percent of the aggregate produced from 1960 to 1986 was used as Portland cement concrete aggregate. This high quality material is used in concrete highways, dams, canals, airport runways, bridge abutments, foundations, buildings and general construction.

In this aggregate resource classification study, special emphasis is given to aggregate that meets the specifications used in making Portland cement concrete. The material specifications for PCC-grade aggregate are more restrictive than the specifications for aggregate used in other applications. Deposits that are acceptable for use as PCC-grade aggregate are the rarest and most valuable of aggregate resources. Aggregate produced from such deposits can be, and is commonly, used in other lower quality products. Because of this versatility, value, importance in construction and relative scarcity, PCC-grade aggregate deposits are of major concern when planning for the future availability of aggregate commodites.

In past years, the population in the Stockton-Lodi area has been served by high-quality, relatively low-cost aggregate deposits from the Tracy (Corral Hollow Creek alluvial fan) and the Mokelumne River areas. However, the high-quality deposits in these two production districts are rapidly being depleted by mining. In fact, the Mokelumne River production district can no longer be demonstrated to contain resources exceeding the minimum threshold value. Many of the potential sources are becoming inaccessible as urbanization encroaches on lands once used solely for mining and agriculture.

Rarely is in-place aggregate (raw material) physically or chemically suited for every type of aggregate use. Every potential deposit must be tested to determine how much material can meet specifications for a particular use, and what processing is required. Specifications for various uses of aggregate material have been established by several agencies, such as the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, and the California Department of Transportation (Caltrans), to ensure that aggregate is satisfactory for specific uses. These agencies, and other major consumers of aggregate, test aggregate for acceptance by standard test procedures defined by such organizations as the American Society for Testing Materials and the American Association of State Highway Officials.

Most aggregate specifications have been established to ensure the manufacture of strong, durable materials capable of withstanding the physical and chemical effects of weather and use. For example, specifications for Portland cement concrete and concrete products prohibit use of aggregate materials containing gypsum, pyrite, zeolites, opal, chalcedony, chert, siliceous shale, volcanic glass, and some high-silica volcanic rocks. Gypsum shortens the setting time of Portland cement, pyrite dissociates to yield sulfuric acid and an iron oxide stain, and other substances contain silica in a form that reacts with alkali substances in the cement, resulting in cracks and "pop-outs."

Specifications also call for precise particle-size distributions for the various uses of aggregate. Aggregate is commonly classified into two general sizes, coarse and fine. Coarse aggregate is rock retained on a 3/8″ or a #4 U.S. sieve. Fine aggregate passes a 3/8″ sieve and is retained on a #200 U.S. sieve (a sieve with 200 weaves per inch). For some uses, such as asphalt paving, particle shape is specified. The Standard Specifications (1988) issued by Caltrans requires that at least 25 percent by weight of coarse aggregate (1/4 inch to 3/4 inch diameter) used as Class 2 aggregate base material shall be crushed particles. Furthermore, aggregate material used with bituminous binder (asphalt) to form sealing coats on road surfaces shall consist of at least 90 percent by weight of crushed particles. Crushed stone is preferable to natural gravel in asphaltic concrete because asphalt adheres better to broken surfaces than to rounded surfaces, and the interlocking of angular particles strengthens the asphaltic concrete and road base.

The preferred use of one aggregate material over another in construction practices depends not only on specification stan-

dards, but also on economic considerations. Alluvial gravel is preferred to crushed stone for Portland cement concrete aggregate because the rounded particles of alluvial sand and gravel result in a mix that is easier to work than a mix composed of angular fragments. The workability of a mix consisting of Portland cement with crushed stone aggregate can be improved by adding more sand and water, but more cement must then be added to the mix to maintain concrete durability standards. At the present time, the additional cement amounts to about a quarter of a 94 pound sack per cubic yard of concrete at an additional cost of about $1.00 per yard of mix. Although more care is required in pouring and placing a mix containing crushed stone, Portland cement concrete made with this aggregate is as satisfactory as that made with alluvial sand and gravel of comparable rock quality.

In the Stockton-Lodi area, PCC-grade aggregate sells in bulk for about $5.00 per ton at the plant site (in January 1987). However, this selling price reflects only part of the cost to the consumer. Transportation cost is a significant part of the final delivery price. In areas lacking nearby aggregate sources, delivery charges alone may be greater than the sale price of the material at the plant site.

## Transportation Rates

Because it is a low-value, high bulk weight commodity, a major part of the cost of aggregate to the consumer is for transportation. In fact, transportation cost is the principal constraint defining the marketing area for a specific production district.

All aggregate marketed in the Stockton-Lodi P-C Region is transported by truck. Minimum rates for independent aggregate truckers are set by the California Public Utilities Commission. Rates for the San Joaquin Valley are published in "Minimum Rate Tarriff 7-A," sections 1 through 3 and supplement 27. Charges are calculated based on either an hourly rate (Table 1) or a distance rate (Figure 4). The minimum hourly rate or the minimum distance rate, whichever is larger, may be charged to the consumer. If the hourly rate is used, the carrier and debtor must enter into a written agreement prior to transport.

Figure 4 illustrates how the PUC rates increase with distance as specified in Minimum Rate Tarriff 7-A. For example, hauling aggregate from Tracy to downtown Stockton (approximately 25 miles) results in an additional cost of $3-4 per ton over the cost of the same material purchased F.O.B. mine site. To haul aggregate to Stockton from Sacramento or Livermore would increase its cost by approximately $4.50 and $5.50 per ton respectively, demonstrating the economic importance of maintaining an accessible local source.

*Table 1. Minimum hourly rates for transport of aggregate in the Stockton-Lodi area. From California Public Utilities Commission, 1987. Minimum Rate Tariff 7-A (Current rates as of May 1, 1987).*

| TYPICAL TONS PER LOAD | NO. OF AXLES PER UNIT OF EQUIPMENT | *HOURLY RATES ($) | $/HR/TON |
|---|---|---|---|
| 10 | 2 | $38.14 | $3.82 |
| 15 | 3 | 43.29 | 2.89 |
| 24 | 4 | 45.84 | 1.91 |
| 26 | 5+ | 49.38 | 1.90 |

*Rates are higher for work done on holidays and weekends

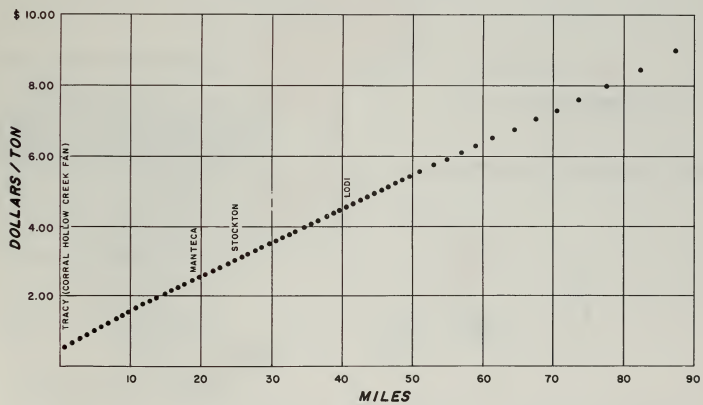


Figure 4. Minimum distance rates for trucking aggregate within the Stockton-Lodi P-C Region. Based on the PUC Minimum Rate Tariff 7A effective May 1, 1987 (includes surcharge as specified in Supplement 27). Rates are higher for holidays and weekends and if equipment other than "a tractor with bottom dump doubles in train" are required at the destination. Cities are located on the graph at distances from Corral Hollow Creek gravel pits in Tracy.

## DETERMINATION OF THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

The cities of Stockton and Lodi were targeted by the Office of Planning and Research as areas experiencing significant urban expansion, and were scheduled by the State Mining and Geology Board for a SMARA aggregate classification study to be performed by the Division of Mines and Geology. The boundaries of the study area (Production-Consumption region) must be delineated to include the urbanizing area targeted by OPR, and the aggregate production districts supplying the target area (Figure 5). Furthermore, it should include most of the population which consumes aggregate mined from the production district, even when this population is located outside the target areas. Except for aggregate that is exported to neighboring P-C regions, no more than 5 percent of the production districts' output should be consumed outside this region.

The boundary of the area targeted by the OPR was modified for this study because the current urban area and the General Plans of lead agencies exceeded the area the OPR projected for urbanizing by 1990. This modification was accomplished using general plan land-use maps obtained from San Joaquin County and observations of current land-use patterns in the field.

A study of sand and gravel production shows that most of the PCC-grade aggregate consumed in the Stockton-Lodi area is obtained from the southern end of San Joaquin County, just south of Tracy. The Stockton-Lodi marketing region is served by one major and one minor production district with overlapping marketing areas — Tracy (Corral Hollow Creek alluvial fan) deposit and Mokelumne River deposit, respectively. Three active aggregate pits on the Corral Hollow Creek alluvial fan and one active aggregate pit along the Mokelumne River supply the production-consumption region with PCC aggregate. More than 80 percent of the aggregate consumed in the Stockton-Lodi P-C Region comes from the Corral Hollow Creek production district and less than 20 percent is supplied by the Mokelumne River production district (Figure 6).

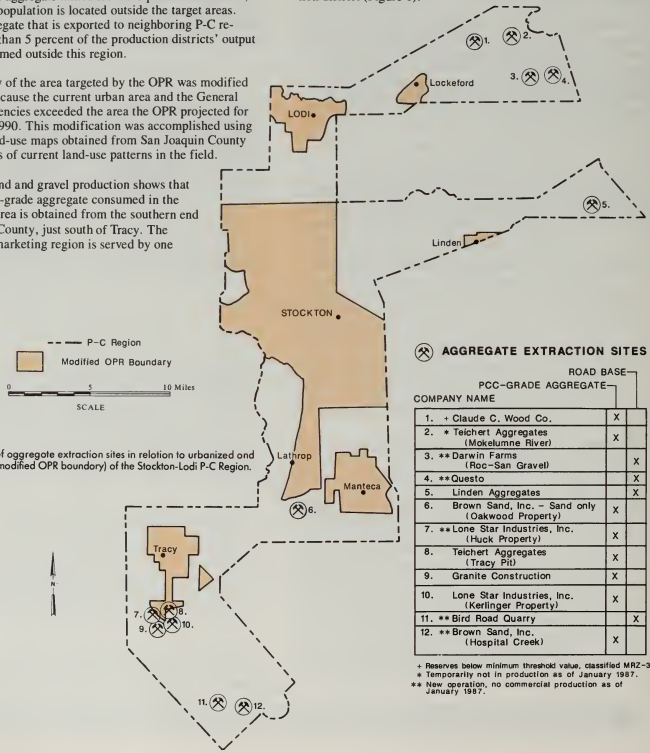


Figure 5. Location of aggregate extraction sites in relation to urbanized and urbanizing regions (modified OPR boundary) of the Stockton-Lodi P-C Region.

The production districts in the Stockton-Lodi P-C Region export 10-15 percent of their total aggregate production to adjacent P-C Regions (Figure 7). The Mokelumne River production district exports approximately 10 percent of its total production to the Foothill P-C Region (5 percent to Amador County and 5 percent to Calaveras County). The Corral Hollow Creek production district exports 15 percent of its aggregate production to the South San Francisco Bay P-C Region (10 percent to Alameda County and 5 percent to Contra Costa County) and 3 percent into the outlying areas of southern San Joaquin County (Figure 8). These exports have been subtracted from local aggregate consumption figures to determine the annual per capita use rate. Imports into the Stockton-Lodi P-C Region from other regions are insignificant, accounting for less than 5 percent of the total consumption.

The production-consumption region was delineated to encompass: 1) Stockton/Lodi/Manteca/Tracy metropolitan areas; 2) outlying towns like Lockeford and Linden and those areas between these towns and Stockton-Lodi which are anticipated to urbanize within the 50-year forecast period; 3) rural areas and towns like Waterloo and Clements not anticipated to become urban but which consume aggregate from the Stockton-Lodi production area; and 4) the production districts delineated in this study. The P-C region boundary, when not precisely following the modified OPR or production district boundary, was placed along the most suitable census tract boundary to allow use of existing census and other population data for forecasting. Lead agencies with jurisdiction within the P-C region are shown in Table 2.

*Table 2. Lead agencies (county and incorporated city governments) located within the Stocktan-Lodi Production-Consumption Regian. Agencies with sectors within their jurisdiction are underlined.*

| COUNTIES | CITIES |
|---|---|
| +* San Jaaquin | Lodi |
| + Stanislaus | Manteca |
| | Stacktan |
| | + Tracy |

+ Agencies that have land classified MRZ-2 within their jurisdiction.

*Agencies with active aggregate aperatians within their jurisdiction.

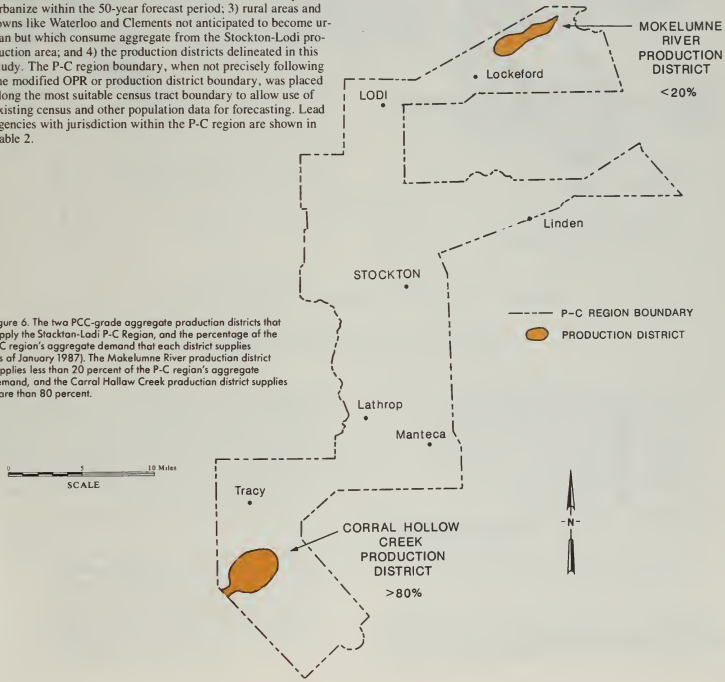


Figure 6. The twa PCC-grade aggregate pradaction districts that supply the Stacktan-Lodi P-C Regian, and the percentage af the P-C regian's aggregate demand that each district supplies (as af January 1987). The Makelumne River pradaction district supplies less than 20 percent of the P-C regian's aggregate demand, and the Carral Hallaw Creek pradaction district supplies mare than 80 percent.

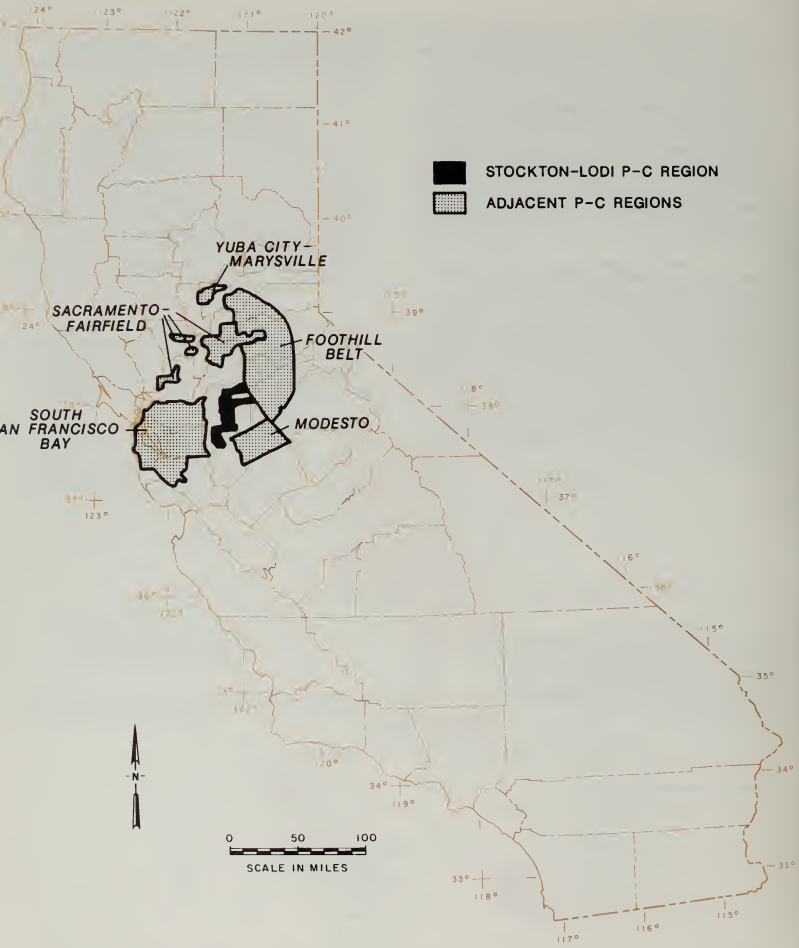


Figure 7. Location of P-C regions adjacent to the Stockton-Lodi P-C Region.

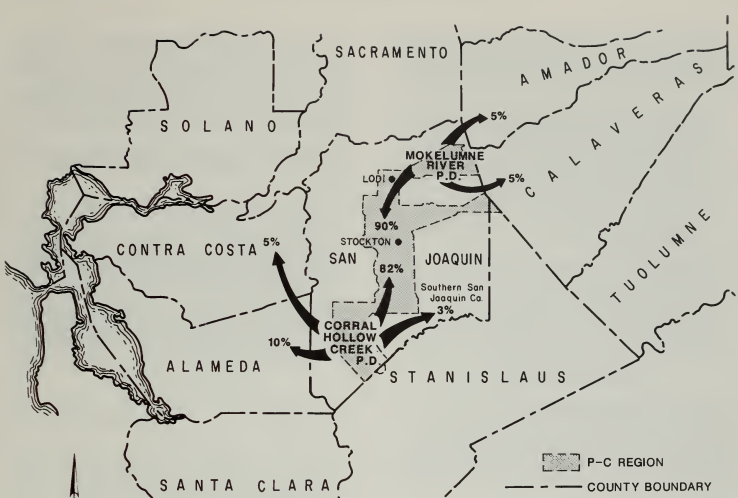


Figure 8. Stockton-Lodi PCC-grade aggregate marketing distribution pattern for 1986-1987.

## ESTABLISHMENT OF MINERAL RESOURCE ZONES

DMG has classified 430 square miles of land in the Stockton-Lodi P-C Region according to the presence or absence of significant PCC-grade aggregate deposits. The land classification is presented in the form of Mineral Resource Zones, or MRZ. Directions for the identification of Mineral Resource Zones are set forth in DMG's Special Publication 51 in the section entitled "Guidelines for Classification and Designation of Mineral Lands" (California Division of Mines and Geology, 1983).

The guidelines for establishing the Mineral Resource Zones are as follows:

*MRZ-1* Areas where adequate information indicates that no significant mineral deposits are present, or where it is judged that little likelihood exists for their presence. This zone shall be applied where well-developed lines of reasoning, based upon economic-geologic principles and adequate data, demonstrate that the likelihood for occurrence of significant mineral deposits is nil or slight.

*MRZ-2* Areas where adequate information indicates that significant mineral deposits are present, or where it is judged that a high likelihood for their presence exists. This zone shall be applied to known mineral deposits or where well-developed lines of reasoning, based upon economic-geologic principles and adequate data, demonstrate that the likelihood for occurrence of significant mineral deposits is high.

*MRZ-3* Areas containing mineral deposits, the significance of which cannot be evaluated from available data.

*MRZ-4* Areas where available information is inadequate for assignment to any other Mineral Resource Zone.

Mineral Resource Zones in the Stockton-Lodi P-C Region are presented on seventeen 1:48,000 reductions of U.S. Geological Survey 7.5-minute topographic quadrangles (plates 1-17). Figure 3 shows the quadrangle maps that cover the Stockton-Lodi area.

Mineral Resource Zones within the Stockton-Lodi P-C Region were established on the basis of an aggregate appraisal that included the following tasks for assessing the quantity, quality, and extent of the aggregate deposits:

1. Examination and compilation of relevant geologic maps, aerial photos, geologic literature, aggregate industry data (some of which is proprietary) and aggregate engineering test data. The geologic maps used in classification of the Stockton-Lodi P-C Region are indicated on Figure 9. Figure 10 and Plate 22 show the generalized geology of the Stockton-Lodi area.

2. Interviews with aggregate operators, company geologists, and consultants.

3. Compilation and analysis of subsurface water well-log data and drilling records.

4. Field investigation of active and depleted aggregate quarries.

## Areas Classified MRZ-1

Areas classified MRZ-1 were judged, on the basis of available data, to have little likelihood of containing significant deposits of PCC-grade aggregate. Deposits that have excessive amounts of clay, silt, organic matter, absorptive rock, alkali-reactive rock, platy rock, or soft rock are unsuitable as sources of PCC aggregate. Areas containing such deposits are classified as MRZ-1.

The areas in the Stockton-Lodi P-C Region that are classified MRZ-1 are underlain by material judged to contain too much clay, silt or other deleterious material for use as PCC-grade aggregate. These include basin deposits in the center of the San Joaquin Valley and sedimentary deposits contaminated by or derived from the Mehrten Formation in the foothills of the Sierra Nevada. The location of the basin deposits and the Mehrten Formation were determined from water well-logs and compilation of geologic mapping. Additionally, areas depleted of aggregate or buried by landfill material are also classified MRZ-1.

## Areas Classified MRZ-2

Five areas are classified MRZ-2 for PCC-grade aggregate (one MRZ-2 area contains PCC-grade sand only) in the Stockton-Lodi P-C Region. These are areas for which data indicate that there is a high likelihood that significant deposits of PCC-grade aggregate exist.

SMARA guidelines set forth two requirements to be used to determine if land should be classified MRZ-2:

1. The deposit must be composed of material that is suitable as a marketable commodity.

2. The deposit must meet threshold value. The projected value (gross selling price) of the deposit, based on the value of the first marketable product, must be at least $8.7 million (which equates with 5 million 1978 dollars).

Areas classified MRZ-2 for PCC-grade aggregate contain resources that are either proven PCC-grade or highly probable to be PCC-grade. Some of the aggregate in the MRZ-2 areas have not been identified as PCC-grade aggregate through formal engi-

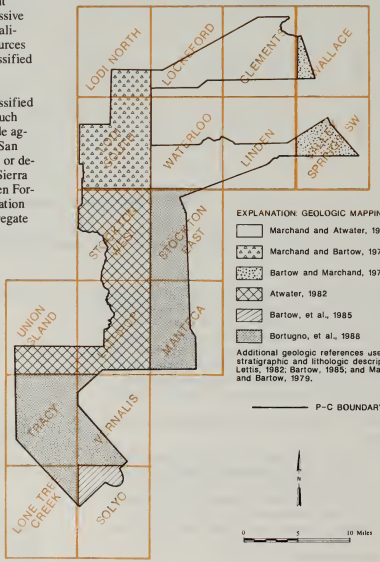


Figure 9. Index to geologic mapping used in classification of the Stockton-Lodi P-C Region.

neering tests. Aggregate deposits in untested, unproven areas identified as MRZ-2 are believed to contain PCC-grade aggregate for either of the following reasons:

- The aggregate in unproven areas is similar in age, lithology, and was deposited under similar geologic conditions to that in areas containing proven PCC-grade aggregate.
- The unproven deposit is a lateral extension of an alluvial formation from which PCC-grade aggregate has been produced.

Approximately 14.4 square miles have been classified MRZ-2 for PCC-grade aggregate in the Stockton-Lodi P-C Region. These MRZ-2 areas are underlain by Quaternary alluvial fan, floodplain and channel deposits — three alluvial fans south of Tracy, channel and floodplain deposits of the Mokelumne River, and Quaternary sand deposits of the San Joaquin River near Lathrop. The geographic extent of the MRZ-2 classifications for most of these areas was primarily based on well-log information. See the descriptions of each resource area for a more detailed discussion.

### Areas Classified MRZ-3

Areas classified MRZ-3 contain aggregate deposits, the significance of which cannot be evaluated from available data.

Sedimentary, metamorphic, and igneous rock types are often included in this category. Evidence obtained from geologic literature or petrologic field investigations that show a rock unit to contain abundant, hard, durable material without excessive amounts of deleterious materials is necessary for it to be considered a suitable candidate for an MRZ-3 classification. Additional information, such as engineering test data on the physical and chemical properties of the material in these areas could either upgrade the classification to MRZ-2 or downgrade the classification to MRZ-1.

In the San Joaquin Valley, older unconsolidated alluvial sediments are often classified MRZ-3. Though much of these sediments were deposited under similar conditions and derived from the same source rocks as those classified MRZ-2, they cannot be classified MRZ-2 because: 1) they are older and have undergone more weathering; 2) they have not been used to produce PCC-grade aggregate in the past; or, 3) the quality of the material cannot be determined to meet PCC-grade specifications. An exploration and testing program might locate areas of acceptable PCC-grade material within these areas.

Land on which mining once occurred, or where mining is near completion, may be classified MRZ-3 if the resources have not been depleted. This occurs when the remaining quantity of aggregate cannot be shown to meet the minimum threshold value stipulated in SMARA. In the Stockton-Lodi P-C Region, active PCC-grade aggregate extraction sites on the Mokelumne River have been zoned MRZ-3 rather than MRZ-2, because the reserves are below the minimum threshold value. If a mined area is depleted of resources it is classified MRZ-1.

### Areas Classified MRZ-4

Areas classified MRZ-4 are those areas for which available information is inadequate for assignment into any other MRZ categories.

In the Stockton-Lodi area, dredge tailing deposits (Plate 8) are classified MRZ-4 due to lack of information regarding the quality of the material.

## EVALUATION OF PCC-GRADE AGGREGATE IN THE STOCKTON-LODI P-C REGION

An assessment of aggregate resources in the Stockton-Lodi P-C Region is presented in this section of the report. The assessment was conducted on the basis of a quantitative evaluation of available and suitable aggregate resources classified MRZ-2.

### Concepts Used in Identifying Available Aggregate Resource Areas

The State Geologist is responsible for calculating aggregate resources for those areas classified MRZ-2. Recognizing that there are lands within MRZ-2 areas that have already been urbanized and therefore have a limited opportunity for mineral resource conservation and extraction, the State Geologist has limited the calculation of aggregate resource tonnages to areas classified MRZ-2 for PCC-grade aggregate that have not been urbanized.

For purposes of classification, incompatible uses are urbanized lands containing high-cost improvements, such as high-density residential developments, intensive industrial developments, commercial developments, and major public facilities (see Appendix, Interim Criteria for Sectorization of MRZ-2 Areas for Aggregate). In addition, lands for which the lead agency has issued an approved Specific Plan are treated as incompatible with mining. Compatible uses include nonurbanized land comprised of very low density residential land (approximately one unit or less per ten acres) that does not have high-cost improvements, agricultural land, silvicultural land, grazing land, and open space.

For this report, determination of non-urbanized land classified MRZ-2 was based upon conditions of the land at the time of the study (April 1987 through June 1987). The use of the land was determined by the authors after consultations with lead agencies, reference to aerial photographs and photo-revised topographic maps, and field reconnaissance.

#### *SECTORS*

Sectors are areas that have been classified MRZ-2 for PCC-grade aggregate by the State Geologist and are deemed to be available for mining based upon criteria for availability provided by the State Mining and Geology Board.

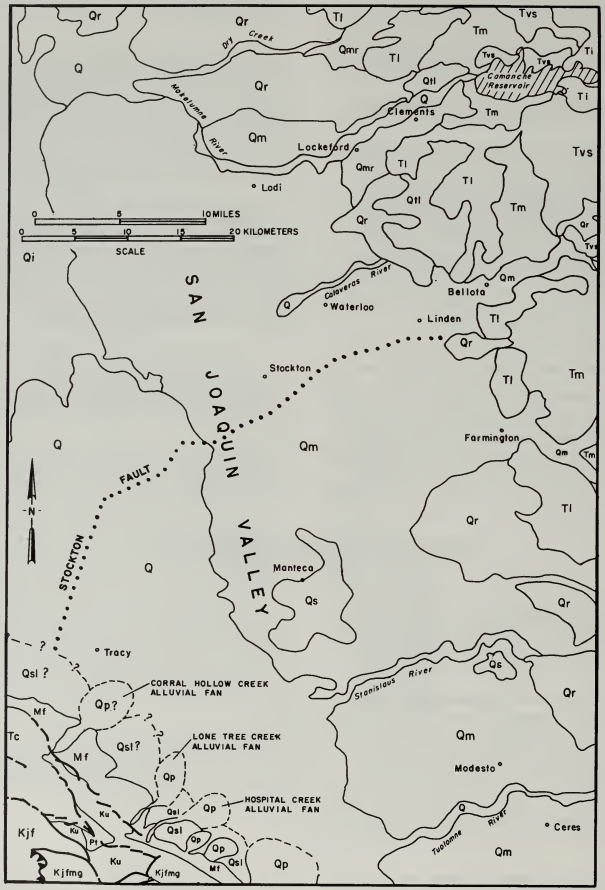


Figure 10. Generalized geologic map of the Stockton-Lodi area (see Plate 22).

## LEGEND FOR GENERALIZED GEOLOGIC MAP

| Epoch or Period | Western Margin | | San Joaquin Valley | | Eastern Margin | |
|---|---|---|---|---|---|---|
| *HOLOCENE* | Q | *Recent stream & basin deposits* | Q | *Recent stream & basin deposits* | Q | *Recent stream and basin deposits* |
| | Qp | *Patterson Alluvium* | Qi | *Intertidal deposits* | t | *Dredge tailings* |
| | | | Qs | *Windblown sand* | | |
| *PLEISTOCENE* | Qsl | *San Luis Ranch Alluvium & Los Banos Alluvium* | | | Qm | *Modesto Formation* |
| | | | | | Qr | *Riverbank Formation* |
| | | | | | Qmr | *Modesto & Riverbank Formations* |
| | | | | | Qtl | *Turlock Lake Formation* |
| *PLIOCENE* | Mf | *Carbona Formation & Oro Loma Formation* | | | Tl | *Laguna Formation* |
| *MIOCENE* | Tc | *San Pablo Group* | | | Tm | *Mehrten Formation* |
| | | | | | Tmv | *Mehrten Formation & Valley Springs Formation* |
| | | | | | Tvs | *Valley Springs Formation* |
| *EOCENE* | Es | *Kreyenhagen Formation, Domengine Sandstone, Megonos Formation* | | | Ti | *Ione Formation* |
| | Pt | *Tesla Formation* | | | | |
| *CRETACEOUS* | Ku | *Moreno Formation Panoche Formation* | | | Kc? | *Chico Formation?* |
| | Kjf | *Franciscan Complex* | | | Mz | *Mesozoic dioritic and granitic rocks* |
| *JURASSIC* | Kjfmg | *Franciscan metagraywacke and argillite* | | | | |

*(See Geologic Column, Plate 23, for age correlations & rock descriptions)*

A sector is an area in which the geometrical configuration of the deposit is sufficiently regular to permit reliable calculation of the tonnage of the mineral resource present. For example, sector boundaries would be established between that part of a natural deposit formed on a fan, and that part within the confines of an adjacent modern stream channel and its floodplain. Sectors are often divided into subsectors to exclude major pipelines, transmission lines, canals and roads. These sectors and subsectors have been employed to focus the attention of land-use planners and local governments on areas that remain accessible for mineral extraction. Mineral land classification, which is done without regard for current land use, by itself, does very little to put into perspective the resource base that is available to meet the future needs of a region. The State Geologist calculates the available resources of each sector, and identifies the amount of remaining resources that have been permitted for mining. A more specific term for these permitted resources is *reserves*. The resources present in non-sectorized MRZ-2 resource areas are not calculated because they are regarded as unavailable.

The calculated reserves and resources of all sectors in a region are compared with the State Geologist's forecast of the 50-year needs of that region. The comparison of regional needs with available reserves and resources provides the opportunity to focus attention on the mineral resource issues confronting the region; *viz.* the need to plan carefully for the use of any lands containing mineral resources, and the need to consider the permitting of additional mining operations in the region as currently mined deposits are depleted.

Each sector meets or exceeds the Board's threshold values for deposits of significant size, and each sector may be considered for designation as an area of regional or statewide significance by the State Mining and Geology Board pursuant to Section 2790 of SMARA. Areas that have not been sectorized by the State Geologist are not considered for designation by the Board.

Although the classification by the State Geologist and the designation by the Board are actions explicitly provided for by SMARA, and although the results of such actions yield reports that must be acted upon by affected local governments, the sectorization and sector maps do not of themselves carry with them specific obligations imposed on local governments by SMARA. The maps and resource base calculations, however, do contain the essential facts that are needed to focus the attention of planners on the mineral availability problems and the alternative solutions to meet the mineral resource needs of the region. Without the sector maps and the accompanying calculations, the primary objectives of SMARA could not be achieved.

The Board's criteria for sectorization focus on the apparent suitability of the land for mining and do not take into account conflicting commitments that may restrict the suitability of some sectors for mining. It is possible that the available resource base as calculated by the State Geologist may be overestimated and the problems confronting local government may be understated. Considering these possibilities, it becomes important for local governments to carefully review the sectors and estimated

resources to ensure that planning decisions are made using a correct perspective on available resources.

### *RESOURCES WITHIN PARKS*

Dedicated parklands are recognized as having a special status when encompassed within an MRZ-2 area because mining is usually a specifically forbidden land use within park boundaries. The resources are not sectorized within parks because the Board has recognized that land in dedicated parks is not generally available for mining.

One park is included within an MRZ-2 area in the Stockton-Lodi P-C Region. Van Assen Park is encompassed in an MRZ-2 area along the Mokelumne River just below Camanche Dam (Plate 3). The only area available for mining is the stream channel adjacent to the park. Well-logs, located at the base of Camanche Dam in the river channel (Kleinfelder, 1981), show the depth of aggregate to be 6 feet. The calculated resource within this narrow portion of the river, excluding the parklands, is only 1.4 million tons. At $5.00-6.00 per ton, this area contains less than the minimum threshold value, and hence has not been sectorized.

## Calculations of Available Resources

### *RESERVES AND RESOURCES*

In this report, *reserves* are estimates of tonnages of aggregate that have been determined to be acceptable for commercial use, that exist within properties owned or leased by aggregate producing companies, and for which permits have been granted to allow mining and processing of the material. *Resources* include reserves as well as all potentially usable aggregate materials that may be mined in the future, but for which no permit allowing mining has been granted.

### *FACTORS CONSIDERED IN CALCULATIONS*

The resource estimates given here are limited to those PCC-grade aggregate resources present in resource sectors, which are, as explained in the previous section, the nonurbanized portions of the areas classified MRZ-2. The resource sectors defined in this study are shown on the sector maps (Plates 18-21) that accompany this report. Deposits where mineral resources other than PCC-grade aggregate are currently mined have also been classified, but are not quantified beyond the establishment that they exceed threshold value. These deposits have not been sectorized since their regional significance has not been confirmed.

Each sector is identified by a capital letter and represents a resource area or a portion of a resource area which appears to have both a fairly consistent geometrical configuration and identical geologic parameters. The sectors are subdivided into numbered subsectors to exclude the location of existing freeways, major roads, canals, bridges, dams, major powerlines and pipelines. These criteria allow for the calculation of realistic resource tonnages.

The following factors were used to determine the areal extent and tonnage of PCC-grade aggregate resources within the sectors:

1. Sector resource tonnage estimates were based on measurements taken from base maps that have a scale of 1:24,000 or maps obtained from aggregate companies with varying larger scales.

2. Even in proven PCC-grade aggregate deposits, a small percentage of the aggregate cannot be used in concrete and is referred to in this study as "waste." Waste includes pit-run and production waste, both of which may be utilized in non-PCC uses, primarily fill. Known waste percentages were extrapolated to deposits in untested sector areas from proven, nearby PCC-grade deposits.

3. Thickness of PCC-grade deposits were determined through analysis of water well-log data, examination of active aggregate pits and natural outcrops, and other information provided by persons who have knowledge concerning aggregate deposits in this region.

4. A standard setback of 100 feet from utility and rail lines, and urban developments was used in determining the areal limits of sectors that border areas not available for mining.

5. Side slopes were calculated to have a 1:1 gradient.

6. An in-place material density of .055 tons per cubic foot was assumed in calculating alluvial resources. This value is an average density for alluvial deposits; no direct density measurements were made during this study.

7. Overburden, if present, was subtracted from the thickness of the deposit.

## Resource Sector Descriptions

Seven resource sectors have been identified in the Stockton-Lodi P-C Region. The total area of the resource sectors in the P-C region is approximately 9.2 square miles, of which 1.3 square miles are currently permitted for mining PCC-grade sand and gravel (not including Mokelumne River reserves which are zoned MRZ-3) and approximately 0.3 square miles for PCC-grade sand. The aggregate resources in these sectors consist of Quaternary alluvial channel, floodplain, and fan deposits. The estimated total PCC-grade aggregate resources in Sectors A-1, A-2, A-3, A-4, B, and C is 599.2 million tons. Sector D contains 90.2 million tons of PCC-grade sand resources. As of January 1987, 79.6 million tons of PCC aggregate resources were permitted for mining in Sectors A-1, A-2, A-3, A-4, B and C, and qualify as reserves. Sector D, which is composed entirely of sand suitable for use in Portland cement concrete, is only useful if an equal tonnage of coarse material is made available. Therefore, Sector D is excluded in calculating the projected life expectancy of PCC-grade aggregate in the Stockton-Lodi P-C Region. Because Sector D is controlled by a single company (Brown Sand, Inc.), the tonnage of reserves is proprietary.

Resource and reserve volumes for Sectors A, B and C are shown on tables 3-9. Parameters used in calculating these figures include: slope of 1 to 1, in-place density of .055 tons per cubic foot, waste varies between subsectors (15-50 percent), 100 foot setbacks from roads, powerlines, houses, and 300 foot setbacks from the center of the California Aqueduct and Delta-

Mendota Canal. Table 9 shows the total quantity of reserves and resources used in calculating the life expectancy of PCC-grade aggregate in the Stockton-Lodi P-C Region.

One MRZ-2 area immediately downstream of the Camanche Dam on the Mokelumne River, has not been included as a resource sector (Plate 3). A major portion of this zone encompasses Van Assen Park. Dedicated parklands are not sectorized; therefore this material is considered unavailable for mining (see Resources within Parks).

Resource sectors A-1, A-2, A-3, A-4 (collectively called Sector A), B and C are located on the eastern flanks of the Diablo Range just south of Tracy. Streams flowing northeastward have developed a succession of lobate-shaped alluvial fans at the base of the mountains. These fans are composed of San Luis Ranch alluvium and Los Banos alluvium (Bartow, et. al., 1985) which contain reworked sediments derived from older alluvial fan deposits. These units are approximately the same age as the late Pleistocene Modesto and Riverbank Formations located across the valley on the eastern flank of the Sierra Nevada Mountains (Plate 23). A thin veneer of Holocene Patterson alluvium overlies these fans (Figure 10 and Plate 22). Resource Sectors A, B and C are identified, respectively, as the Corral Hollow Creek, Lone Tree Creek and Hospital Creek alluvial fans on Resource Sector Maps (Plates 19, 20 and 21) and Mineral Land Classification Maps (Plates 14, 15 and 17).

All three fans are very similar in age, lithology and source area. The coarse clasts are largely composed of metagraywacke, chert, and quartz. Smaller amounts of quartzite, schist, sandstone, basalt and andesite are present. Most of the cobbles are subrounded to subangular, consistent with the relatively close source area. The maximum clast diameter is 10 inches, with 40 percent estimated to be +1 inch. The fans contain an abnormally high amount of clay and silt for PCC-grade deposits. Aggregate producers in these alluvial fans process material containing 10 to 50 percent clay, usually dependent upon depth. The upper 30 to 60 feet of the Corral Hollow Creek alluvial fan deposit (Sector A) usually contains significantly less clay than deeper sections. The sand fractions consists mostly of quartz and rock fragments.

Sand and gravel is currently being mined from Sectors A and C. Just south of Tracy on the Corral Hollow Creek alluvial fan (Sector A), three aggregate companies — Lone Star Industries, Teichert Aggregates, and Granite Construction — are producing PCC-grade aggregate from three pits. Aggregate has been extracted from this fan since 1906 (Clark, 1955). Hospital Creek alluvial fan (Sector C) is approximately 12 miles south of Tracy. Sector C was mined in the early 1970's, probably for the construction of Interstate Highway 5 or the California Aqueduct, but no information on the actual product or destination is available. Brown Sand, Inc. has recently started mining sand and gravel from this sector for use as PCC-grade aggregate. To our knowledge, no mining has occurred on the Lone Tree Creek alluvial fan (Sector B), which is located between Sector A & C.

### *SECTORS A-1, A-2, A-3, A-4 — CORRAL HOLLOW CREEK ALLUVIAL FAN*

Sector A (Corral Hollow Creek alluvial fan deposit) contains the most valuable deposit of PCC-grade aggregate in the Stockton-Lodi P-C Region. Sectors A-1, A-2, A-3, and A-4 contain a total of 497 million tons of PCC-grade aggregate resources. Eighty-three percent of the available resources in the P-C region are contained in this one deposit.

Sector A has three active sand and gravel operations, Teichert Aggregates, Lone Star Industries, and Granite Construction Co. The aggregate in this deposit extends to a depth of at least 200 feet (cross-sections A-A′, B-B′, and C-C′, Plate 24), but mining is usually permitted only to the water table which occurs approximately 95 to 120 feet below the surface. Mining is feasible 40 to 50 feet below the water table without the use of a dredge. Only Lone Star Industries is currently permitted to mine 40 to 50 feet below the water table. Both Teichert Aggregates and Granite Construction Co. are restricted by permit to mine only to the depth of the water table. Another limiting factor is the existence of a 20 to 30 foot-thick clay layer between 70 to 120 feet (average 90 to 100) below the surface. Since all three operators extract from the same deposit, the high clay content (15 to 50 percent) is a factor that impacts all competitors equally, resulting in aggregate prices that are competitive.

Many portions of Sector A are now unavailable for mining due to rapid urbanization of the City of Tracy. The land zoned MRZ-2 which contains Sector A encompasses 8.0 square miles. Only half of the MRZ-2 area (4.5 square miles) contains available PCC-grade aggregate, of which 1.3 square miles are currently permitted for mining. Therefore, approximately 3.2 square miles of available aggregate are not permitted for mining and could be lost to urbanization as the City of Tracy grows.

Within this MRZ-2 area are small islands of land classified MRZ-1 and MRZ-3. The areas classified MRZ-1 contain lands previously mined and backfilled with silt and clay. Toward the center of the MRZ-2 area, two portions are classified MRZ-3. These lands have been previously mined to a depth of 30 to 60 feet, but are not backfilled. These lands could contain potential sources of minable aggregate, but it is unknown whether it would be economically feasible to extract from them. At this depth, a thick clay lens commonly occurs and could be the reason that mining originally ceased. At the southeast corner of the MRZ-2 area, land is classified MRZ-3 because it contains aggregate with such high clay content that it may not be economic to mine.

The Corral Hollow Creek alluvial fan is divided into four sectors: A-1, A-2, A-3, A-4. These sectors represent areas with differing percentages of PCC-grade material. The percentages range from 85-50 percent PCC-grade aggregate. Sector A-1 contains the highest percentage of PCC-grade material and Sector A-4 contains the lowest percentage. The non-PCC-grade percentage reflects the clay content in each sector.

#### *SECTOR A-1*

Sector A-1, which has been divided into 17 subsectors, is located at the southwest corner of the Corral Hollow Creek alluvial fan just northeast of Highway 580. This sector contains the highest percentage of PCC-grade aggregate (85 percent) in this production district. Granite Construction Co. and Lone Star Industries, Inc. hold mining permits in this sector. Major urban development surrounds these aggregate mines — two canals (the California Aqueduct, and the Delta-Mendota Canal), one airport (Tracy Municipal Airport), and a water treatment plant.

Generally, alluvial fans are composed of finer sediment towards the distal ends of the fan apron and coarser material near

the apex. The general composition of Sector A-1 is 55 percent gravel, 30 percent sand, 15 percent silt/clay, which is consistent with its location at the apex of the fan where coarse material has been deposited by Corral Hollow Creek. The other sectors (A-2, A-3, A-4) contain higher percentages of clay because Corral Hollow Creek has carried finer sediment to their locations in the distal portions of the fan. Due to the erratic nature of alluvial fan sedimentation, clay lenses occur throughout the Corral Hollow Creek deposit and certain areas of Sector A-1 can contain clay in amounts as high as 50 percent.

Currently, Granite Construction is the only operator producing aggregate in Sector A-1. Lone Star Industries, Inc. has obtained a mining permit in this sector, but is not in production yet. Mining in this sector averages 70 to 120 feet below the surface, depending on whether or not isolated clay lenses are encountered at the mine site.

### *SECTOR A-2*

Sector A-2, which has been divided into 26 subsectors, contains approximately 68 percent PCC-grade aggregate and 32 percent clay and silt. Lone Star Industries, Inc. is producing PCC-grade aggregate from portions of this sector. Most of the available aggregate resources in Sector A that are not currently permitted for mining are contained within Sector A-2. Large portions of land in the north-central portion of Sector A-2 are not sectorized because of inclusion in the City of Tracy's specific plan.

Lone Star Industries, Inc. has been mining in this sector since 1947. Due to previous mining, large portions of Lone Star's holdings are depleted and are classified MRZ-1. The clay content in these gravel pits varies from 15 to 50 percent. The high clay percentages occur below the 20-foot-thick clay lens. The average clay content is approximately 32 percent, with 34 percent sand and 34 percent gravel. Lone Star Industries, Inc. is permitted to mine 40 to 50 feet below the water table. The water table occurs approximately 97 feet below the surface. Lone Star Industries, Inc. was not permitted to mine their property in Subsectors A-2v and A-2w because of the proximity to the Delta-Mendota Canal. As a compromise, Lone Star Industries, Inc. was allowed by San Joaquin County to mine below the water table in their existing pits.

Teichert Aggregates has holdings in Sector A-2 which they are not presently mining.

### *SECTOR A-3*

Sector A-3 contains three subsectors, each composed of 60 percent PCC-grade aggregate. All three subsectors are permitted by Teichert Aggregates, which has been mining in the Corral Hollow Creek deposit since 1955. Teichert Aggregates' reserves contain 40 percent clay, 30 percent gravel and 30 percent sand. Teichert Aggregates, Inc. is permitted to mine to the water table, which is approximately 90 to 100 feet below the surface in this sector.

### *SECTOR A-4*

Sector A-4, which is divided into two subsectors, contains land with 50 percent PCC-grade aggregate. Both subsectors, which have not been previously mined, are permitted by Lone Star Industries, Inc. The material in Lone Star's property has a high clay content of 50 percent. The property immediately to the east of this sector is zoned MRZ-3 because of high percentages of clay.

### *SECTOR B — LONE TREE CREEK ALLUVIAL FAN*

Sector B (Lone Tree Creek alluvial fan) covers 2.5 square miles. Sector B has never been mined, and was classified on the basis of Caltrans test data, water well-log data and geologic similarity with the Hospital Creek alluvial fan which contains proven deposits of PCC-grade aggregate. Geologic mapping by Lettis (1976) delineated the general shape of the fan and water well-logs provided depth control. An average depth of 25 feet was used in our calculations. The waste factor of 10 percent, used for resource calculations, was extrapolated from Sector C.

*Table 3. Aggregate resources in Sector A-1.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICKNESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| A-1a | 4 | | 135 | 85 | | 1,000,000 |
| A-1b | 3 | | 135 | 85 | | 800,000 |
| A-1c | 3 | 3 | [50] | 85 | * | * |
| A-1d | 9 | 9 | [60] | 85 | * | * |
| A-1e | 24 | | 135 | 85 | | 4,500,000 |
| A-1f | 16 | | 135 | 85 | | 2,500,000 |
| A-1g | 37 | | 135 | 85 | | 7,300,000 |
| A-1h | 144 | 144 | [125] | 85 | * | * |
| A-1i | 46 | | 105 | 85 | | 8,100,000 |
| A-1j | 28 | 28 | 135[30] | 85 | * | * |
| A-1k | 68 | 68 | 105[60] | 85 | * | * |
| A-1l | 16 | | 135 | 85 | | 2,100,000 |
| A-1m | 37 | | 135 | 85 | | 7,800,000 |
| A-1n | 22 | 22 | 132[87] | 85 | * | * |
| A-1o | 42 | 42 | 134[60] | 85 | * | * |
| A-1p | 53 | 53 | 132[87] | 85 | * | * |
| A-1q | 28 | | 135 | 85 | | 5,700,000 |
| SUBTOTALS | 580 | 369 | | | * | 97,600,000 |

*Proprietary data

*Table 4. Aggregate resources in Sector A-2.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICK-NESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| A-2a | 43 | | 135 | 68 | | 7,300,000 |
| A-2b | 211 | | 135 | 68 | | 41,900,000 |
| A-2c | 396 | | 135 | 68 | | 80,100,000 |
| A-2d | 27 | | 135 | 68 | | 4,500,000 |
| A-2e | 165 | | 135 | 68 | | * |
| A-2f | 17 | | 135 | 68 | | 2,300,000 |
| A-2g | 41 | | 135 | 68 | | 7,300,000 |
| A-2h | 71 | | 135 | 68 | | 12,900,000 |
| A-2i | 152 | | 135 | 68 | | 29,300,000 |
| A-2j | 38 | 38 | 132[95] | 68 | * | * |
| A-2k | 94 | | 135 | 68 | | 17,600,000 |
| A-2l | 23 | | 135 | 68 | | 3,700,000 |
| A-2m | 16 | | 135 | 68 | | 1,800,000 |
| A-2n | 323 | | 135 | 68 | | 65,600,000 |
| A-2o | 111 | | 135 | 68 | | 21,400,000 |
| A-2p | 33 | 33 | 105[65] | 68 | * | * |
| A-2q | 73 | 73 | 135[95] | 68 | * | * |
| A-2r | 10 | | 135 | 68 | | 1,400,000 |
| A-2s | 51 | | 95 | 68 | | 700,000 |
| A-2t | 39 | 39 | [45] | 68 | * | * |
| A-2u | 43 | 43 | [45] | 68 | * | * |
| A-2v | 19 | | 135 | 68 | | * |
| A-2w | 65 | | 135 | 68 | | * |
| A-2x | 30 | | 135 | 68 | | 4,600,000 |
| A-2y | 37 | 37 | 132[87] | 68 | * | * |
| A-2z | 16 | | 135 | 68 | | 2,100,000 |
| SUBTOTALS | 2,144 | 263 | | | * | 384,600,000 |

*Proprietary data

*Table 5. Aggregate resources in Sector A-3.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICK-NESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| A-3a | 31 | 31 | 135[95] | 60 | * | * |
| A-3b | 33 | 33 | 88[48] | 60 | * | * |
| A-3c | 76 | 76 | [40] | 60 | * | * |
| SUBTOTALS | 140 | 140 | | | * | * |

*Proprietary data

*Table 6. Aggregate resources in Sector A-4.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICK-NESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| A-4a | 16 | 16 | [90] | 50 | * | * |
| A-4b | 39 | 39 | [60] | 50 | * | * |
| SUBTOTALS | 55 | 55 | | | * | * |

*Proprietary data

*Table 7. Aggregate resources in Sector B.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICKNESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| B-1 | 17 | | 12 | 90 | | 400,000 |
| B-2 | 24 | | 25 | 90 | | 1,200,000 |
| B-3 | 17 | | 25 | 90 | | 900,000 |
| B-4 | 256 | | 25 | 90 | | 13,600,000 |
| B-5 | 19 | | 25 | 90 | | 900,000 |
| B-6 | 85 | | 25 | 90 | | 4,500,000 |
| B-7 | 374 | | 25 | 90 | | 19,900,000 |
| B-8 | 57 | | 25 | 90 | | 2,900,000 |
| B-9 | 12 | | 25 | 90 | | 600,000 |
| B-10 | 11 | | 25 | 90 | | 500,000 |
| B-11 | 27 | | 25 | 90 | | 1,400,000 |
| B-12 | 47 | | 25 | 90 | | 2,400,000 |
| B-13 | 87 | | 25 | 90 | | 4,600,000 |
| B-14 | 204 | | 25 | 90 | | 10,700,000 |
| SUBTOTALS | 1,237 | | | | | 64,600,000 |

*SECTOR C — HOSPITAL CREEK ALLUVIAL FAN*

Sector C (Hospital Creek alluvial fan) covers 1.7 square miles. Brown Sand, Inc. recently opened operations to mine PCC-grade aggregate in Sector C and began producing in mid-1987. The classification of this deposit was based on the presence of an active mining operation, Caltrans data, water well-logs and geologic similarity with known deposits. A portion of the fan as outlined by Lettis (1976) was classified MRZ-3 due to the presence of a well-log showing a high clay content. Additional drilling and testing would be required to confirm or deny the existence of detrimental amounts of clay in this portion of the fan. Well-logs, current mining, and previous investigations by Goldman (1964) establish the depth of material in this fan to range between 12 to 25 feet. Brown Sand, Inc. plans to retain +30 mesh material from this sector and mix sand from their Lathrop pit to produce PCC-grade aggregate. This eliminates much of the processing costs involved in producing PCC-grade aggregate from a single, clay-rich, deposit.

*SECTOR D — LATHROP DEPOSIT*

Sector D is a 2.0 square mile, fluvial sand deposit of Recent age located south of Lathrop and west of Manteca. The deposit has been classified MRZ-2 (Plate 18) for PCC-grade sand. Brown Sand, Inc. is presently mining on 160 acres of this deposit, primarily for specialty sand products. The company also incorporates some of this sand with coarse aggregate material extracted from their Hospital Creek deposit (Sector C) to make PCC-grade aggregate. This deposit was classified MRZ-2 for PCC-grade sand on the basis of aggregate quality test data, the quantity of available material, and the current mining activity. The extent of the deposit was determined on the basis of water well-logs and company information. Areas surrounding this deposit were zoned MRZ-3 due to insufficient information regarding quality of the sand.

Although the sand from this deposit is used primarily for specialty sand products, this material can meet the Caltrans specifications for PCC-grade sand. Four aggregate tests — sand equivalency, injurious organics, durability, and sodium sulfate soundness tests — were performed on samples from this deposit by Kleinfelder, an engineering consulting firm. Screen grading test reports and Kleinfelder's test results were evaluated by Caltrans Materials Testing Laboratory, Pavement Branch. Based on this information, Caltrans concurred that ". . . this material substantially complies with Caltrans' specifications [for PCC-grade sand]," and also recommended a sand mortar strength test

*Table 8. Aggregate resources in Sector C.*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICK-NESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| C-1 | 29 | | 12 | 90 | | 700,000 |
| C-2 | 107 | | 12 | 90 | | 2,700,000 |
| C-3 | 12 | 12 | [35] | 90 | * | * |
| C-4 | 26 | 26 | [15] | 90 | * | * |
| C-5 | 2 | | 25 | 90 | | 100,000 |
| C-6 | 151 | | 22 | 90 | | 7,000,000 |
| C-7 | 142 | | 22 | 90 | | 6,500,000 |
| C-8 | 20 | | 22 | 90 | | 800,000 |
| C-9 | 390 | | 22 | 90 | | 18,300,000 |
| SUBTOTALS | 879 | 38 | | | * | 37,700,000 |

*Proprietary data

*Table 9. Total aggregate resources for Sectors A-1, A-2, A-3, A-4, B, and C.*

| SECTOR | TOTAL ACRES | ACRES PERMITTED | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|
| A | 2,919 | 827 | * | 496,900,000 |
| B | 1,237 | | | 64,600,000 |
| C | 879 | 38 | * | 37,700,000 |
| SUBTOTALS | 5,035 | 865 | 79,600,000 | 599,200,000 |

*Proprietary data

*Table 10. Aggregate resources in Sector D (Sand Only).*

| SUB-SECTOR | TOTAL ACRES | ACRES PERMITTED | THICKNESS (feet) [reserve] | PERCENT PCC GRADE | RESERVES (tons) | RESOURCES (tons) |
|---|---|---|---|---|---|---|
| D-1 | 5 | | 80 | 60 | | 500,000 |
| D-2 | 86 | | 80 | 60 | | 9,000,000 |
| D-3 | 23 | | 80 | 60 | | 2,700,000 |
| D-4 | 130 | | 80 | 60 | | 13,800,000 |
| D-5 | 6 | | 80 | 60 | | 600,000 |
| D-6 | 39 | | 80 | 60 | | 3,700,000 |
| D-7 | 153 | | 80 | 60 | | 16,100,000 |
| D-8 | 31 | | 80 | 60 | | 3,500,000 |
| D-9 | 280 | 70 | [80] | 60 | * | * |
| D-10 | 9 | 9 | [80] | 60 | * | * |
| D-11 | 63 | 63 | [80] | 60 | * | * |
| D-12 | 19 | 19 | [80] | 60 | * | * |
| D-13 | 40 | | 80 | 60 | | 3,900,000 |
| SUBTOTALS | 884 | 161 | | | * | 90,200,000 |

*Proprietary data

(California Test 515) be performed. Since the material performed very well on the aggregate tests, especially in durability, the DMG concluded that this deposit could be zoned MRZ-2 without requiring a mortar strength test.

The Lathrop deposit occurs within the floodplain of the San Joaquin River, but has a nominal silt content compared with the contemporary river channel. The sand is composed of fine- to coarse-grained angular quartz, with varying amounts of feldspar, heavy minerals and rock fragments. The sand is derived from rocks found in the Sierra Nevada Mountains. The deposit shape, size and stratigraphic position suggests that this material was deposited during the flooding of the San Joaquin River during the last glacial melting in the Sierra Nevada Mountains.

Brown Sand, Inc. has been mining this deposit, which was discovered while grading land for farming, since 1969. Active site reclamation is worth noting. Oakwood Lake Resort, a family recreation area, has been constructed on previously mined sections of the deposit. As mining progresses, expansion of recreational facilities will follow. A 30-foot-deep lake, the focal point of the recreation area, is the end result of mining activity and the naturally high water table. Forty-foot-deep sand resources occur below the lake bottom; extraction of this sand would require dredging.

The following parameters were used in calculating the PCC-grade sand resources in Sector D (Table 4). The density of the material is .055 tons per cubic foot and the average resource depth is 80 feet. The deposit thins to the east, but continues laterally to the west under the river. Setbacks are required to be 100 feet by permit, but are 300 feet in practice. For our calculations, a 100-foot setback was used.

## PCC-GRADE AGGREGATE DEPOSITS BELOW MINIMUM THRESHOLD VALUE

### Mokelumne River

Even though there is active PCC-grade aggregate mining on the Mokelumne River (Plate 3), most of the river area has been zoned MRZ-3. Due to past mining activity, the Mokelumne River production district cannot be shown to meet the minimum threshold value of 5 million 1978 dollars as required by SMARA for MRZ-2 classification. Aggregate mining along the Mokelumne River is documented as early as 1931 (Clark, 1955). The construction of Camanche Dam in 1963 eliminated replenishment of aggregate below the dam. The reservoir also eliminated extraction of major deposits of PCC-grade aggregate that exist immediately upstream of the dam. Currently, only one operator, Claude C. Wood, is producing PCC-grade aggregate from

this area, but the quantity of aggregate reserves at this mine site are less than the minimum threshold value. This is not to be misconstrued to say that the reserves of active aggregate producers on the Mokelumne River are not important to the Stockton-Lodi residents. Discontinued production from these deposits would significantly affect the regional supply and the demand on other aggregate producers in the P-C region.

Channel and floodplain deposits and dredge tailings have been mined from the Mokelumne River. The shallow channel and floodplain deposits are 6 to 14 feet thick. The floodplain deposits are overlain by 6 to 12 feet of overburden. Mining is limited to the water table, which averages 20 feet below the surface. A sandstone layer occurs at the same depth as the water table and marks the economic limit to mining (cross-section D-D′, Plate 25). Most of the coarse dredge tailing material has already been mined and only sand and silt remain.

The lithologic composition of the Mokelumne River deposits is markedly different than the material in the alluvial fans of Sectors A, B and C, reflecting different source areas. Up to 60 percent of the gravel in the Mokelumne River consists of quartzitic metasediments and greenstone. The remainder consists of varying amounts of vein quartz, silicic plutonic rocks, Tertiary volcanic rocks, and schist. The sand is composed of quartz, feldspar and rock fragments.

As previously stated, none of the areas under permit for mining along the Mokelumne River were zoned MRZ-2 because aggregate reserves are below the minimum threshold value required by SMARA. Currently, Claude C. Wood, Inc. is the only active PCC-grade aggregate producer in this area. Teichert Aggregates retains two permitted areas along the Mokelumne River. Teichert Aggregates' reserves were also determined to be below minimum threshold value. The major source of PCC-grade aggregate, mined in the past by Teichert Aggregates were dredge tailings. The coarse material has been mined-out leaving mostly sand and silt. A portion on the south side of the river that Teichert Aggregates plans to mine contains virgin floodplain alluvium. The quantity of aggregate resources in this portion is also too low to meet minimum threshold value. Therefore, all the reserves on the Mokelumne River below Camanche Dam have been zoned MRZ-3.

### Calaveras River

Construction aggregate from Calaveras River deposits has been used in the Stockton-Lodi area, but the aggregate resources along the river were determined to be below the minimum threshold value as required by the SMGB. Areas previously mined by Stockton Sand and Gravel are depleted (per Bill Tickler, personal communication) and are zoned MRZ-1. The floodplain areas zoned MRZ-3 (Plate 7) contain gravel, but it is unknown whether there is sufficient quantity or quality for economic exploitation. PCC-grade deposits are present upstream to Jenny Lind, but these materials are consumed in the foothill region and are thus not included as part of the Stockton-Lodi P-C Region. Downstream, available water well-logs indicate that gravel is not present in economic concentrations.

Vein quartz and quartzitic metasedimentary rocks comprise up to 50 percent of the coarse material present. The remainder consists mostly of greenstone, with minor Tertiary volcanic rocks and basic igneous rocks. Only a trace of granitic rocks is present. The maximum clast size is 10 inches, with 25 percent larger than 3/4 of an inch. Sand comprises 40 to 55 percent of the deposit and there is approximately 5 percent waste.

Historical information is sketchy, but it is known that the area was mined in the late 1950's by Calaveras Rock Company and was continually permitted and probably mined until the late 1970's by Stockton Sand and Gravel. A sand and gravel operation at Bellota in 1924 was reported by Laizure (1925). Teichert Aggregates is currently producing PCC-grade aggregate upstream near Jenny Lind, but this plant serves the foothills, as the distance to the Stockton-Lodi area is too great.

## CLASSIFICATION OF ACTIVE MINES PRODUCING OTHER MINERAL COMMODITIES

The entire P-C region has been classified for PCC-grade aggregate. Additionally, during this study, sites of active production of other commodities were encountered. It was decided that deposits which contain active mining operations, regardless of the type of mineral commodity produced, would also be classified MRZ-2. The reserves and resources at these sites have not been quantified beyond ensuring that they exceed the minimum threshold value established by the State Mining and Geology Board for each particular commodity. It is important to note that the classification of individual mine sites is not to be construed as a classification of the entire region for these commodities, but is solely a classification of individual sites where commercial extraction of a mineral resource occurs. Because no attempt was made to determine the regional significance of these individual operations, they have not been sectorized as candidates for designation by the SMGB.

In the Stockton-Lodi P-C Region, there are four sites where commodities other than PCC-grade aggregate are mined. Only one of the four sites is zoned MRZ-2. Approximately four miles east of Bellota, Linden Sand and Gravel excavates Tertiary Laguna Formation conglomerate for roadbase with gold as a by-product. Two proposed operations, Questo Ranch and Darwin Farms (Roc-San Gravel), two miles southwest of Wallace, also plan to extract Laguna Formation conglomerate for use as roadbase and recover gold as a by-product. Eight miles south of Tracy, Billy Kitchen (Bird Road Quarry) is opening operations to produce roadbase from Quaternary terrace gravels adjacent to Lone Tree Creek. Darwin Farms (Roc-San Gravel) and Questo Ranch are not currently operating, but have active permits and are in the process of assembling and testing their respective processing plants. Darwin Farms is the only mine site that contains enough reserves to meet the minimum threshold value, and is classified MRZ-2 for roadbase.

# ESTIMATED 50-YEAR CONSUMPTION OF AGGREGATE

## Basis of 50-Year Forecast

The State Mining and Geology Board, as specified in its "Guidelines for Classification and Designation of Mineral Land" (Part II of California Division of Mines and Geology Special Publication 51), requires that mineral land classification reports for regions containing construction materials classified MRZ-2 include "An estimate of the total quantity of each such construction material that will be needed to supply the requirements of both the county and the marketing region in which it occurs for the next 50 years. The marketing region is defined as the area within which such material is usually mined and marketed. The amount of each construction material mineral resource needed for the next 50 years shall be projected using past consumption rates adjusted for anticipated changes in market conditions and mining technology." In the "Guidelines," the Board also specifies that these estimates be reviewed periodically (every 10 years or less).

Fifty-year forecasts of PCC-grade aggregate needs in the Stockton-Lodi P-C Region were made on the basis of reported aggregate production during the years 1960-1986 (excluding exports). Excluding aggregate that is exported to neighboring P-C regions, the P-C region boundary is defined to ensure that no more than 5 percent of PCC-grade aggregate produced in the Stockton-Lodi area is consumed outside the study area and that imports of PCC-aggregate from outside the study area are insignificant (less than 5 percent).

## Correlations Between Aggregate Production and Consumption

Past studies of aggregate marketing regions in California have shown that there is a strong correlation between the amount of aggregate produced and the population in a given aggregate production-consumption region (Anderson, and others, 1979). On this basis, aggregate production and population figures in the Stockton-Lodi P-C Region were correlated for the years 1960-1986 (Table 11). Correlations between the annual aggregate production records and the population statistics were used to obtain historic annual per capita consumption rates of aggregate in the study area. This historical aggregate production data in the study area was obtained from mining records of the U.S. De-

*Table 11. Population, aggregate consumption (tons) and per capita consumption (tons) in the Stockton-Lodi P-C Region during the period 1960-1986. (All figures have been rounded to nearest 1,000)*

| YEAR | POPULATION | AGGREGATE CONSUMPTION | 3-YEAR AVERAGE OF CONSUMPTION | ANNUAL PER CAPTIA CONSUMPTION |
|---|---|---|---|---|
| 1960 | 237,000 | 1,700,000 | | |
| 1961 | 241,000 | 2,343,000 | 2,013,000 | 8.4 |
| 1962 | 245,000 | 1,996,000 | 2,278,000 | 9.3 |
| 1963 | 249,000 | 2,496,000 | 2,409,000 | 9.7 |
| 1964 | 253,000 | 2,734,000 | 2,794,000 | 11.0 |
| 1965 | 257,000 | 3,153,000 | 3,036,000 | 11.8 |
| 1966 | 261,000 | 3,222,000 | 3,039,000 | 11.6 |
| 1967 | 265,000 | 2,742,000 | 2,820,000 | 10.6 |
| 1968 | 269,000 | 2,496,000 | 2,612,000 | 9.7 |
| 1969 | 273,000 | 2,597,000 | 2,546,000 | 9.3 |
| 1970 | 277,000 | 2,544,000 | 2,733,000 | 9.9 |
| 1971 | 282,000 | 3,057,000 | 2,562,000 | 9.1 |
| 1972 | 287,000 | 2,085,000 | 2,307,000 | 8.0 |
| 1973 | 293,000 | 1,780,000 | 2,092,000 | 7.1 |
| 1974 | 298,000 | 2,411,000 | 1,901,000 | 6.4 |
| 1975 | 303,000 | 1,513,000 | 2,100,000 | 6.9 |
| 1976 | 309,000 | 2,375,000 | 2,229,000 | 7.2 |
| 1977 | 314,000 | 2,800,000 | 2,693,000 | 8.6 |
| 1978 | 319,000 | 2,905,000 | 2,892,000 | 9.1 |
| 1979 | 325,000 | 2,972,000 | 2,871,000 | 8.8 |
| 1980 | 330,000 | 2,737,000 | 2,645,000 | 8.0 |
| 1981 | 342,000 | 2,227,000 | 2,227,000 | 6.5 |
| 1982 | 354,000 | 1,717,000 | 2,061,000 | 5.8 |
| 1983 | 366,000 | 2,238,000 | 2,139,000 | 5.8 |
| 1984 | 378,000 | 2,463,000 | 2,509,000 | 6.6 |
| 1985 | 390,000 | 2,825,000 | 2,654,000 | 6.8 |
| *1986 | 402,000 | *2,675,000 | | |

Average annual per capita consumption for 1960-1985 is 8.5 tons.

Calculations may not replicate exactly due to rounding.

*Preliminary estimate collected from aggregate producers. Statistics from U.S. Bureau of Mines not available at the time of study.

partment of the Interior, Bureau of Mines (1960 to 1982, and 1984) and the aggregate companies (1983, 1985, 1986). The Bureau of Mines records are compiled from responses to voluntary questionnaires that are sent annually to all known mining operators. Each producer is requested to divulge the production from each of his producing properties for the preceding year. It is important to note that the degree of accuracy of these statistics depends entirely on the producer's response. Although compliance is usually good, the DMG staff did not seek to verify production data or obtain production data from companies that did not respond to the U.S. Bureau of Mines inquiry. Historical population data for the Stockton-Lodi area were taken from census data obtained from the California State Department of Finance (California Department of Finance, 1986).

The average per capita consumption rate in the Stockton-Lodi P-C Region is 8.5 tons of aggregate per year over the period from 1960 to 1986 (Table 11). Due to the erratic variations in aggregate production from year to year, three-year moving averages of the annual aggregate production (Figures 11 and 12) were used in conjunction with population statistics (for purposes of curve smoothing) to compute the per capita consumption rates for the P-C region (Figure 13). The moderately high consumption rates in the Stockton-Lodi area are characteristic of aggregate marketing regions in which the overall population density is relatively low and the rate of urban development is high. A moderately high consumption rate probably will be maintained in the Stockton-Lodi P-C Region until the onset of urban maturity, then it will decrease and eventually drop to a general maintenance level. Urban maturity is the point in the development of an area at which construction materials are used primarily to maintain what has already been developed, rather than to provide for further development.

## Projected Population and Per Capita Consumption Through the Year 2036

A simple analysis of the historical aggregate production and population statistics was conducted to forecast basic trends in the per capita consumption rate of aggregate within the Stockton-Lodi area through the year 2036. The total aggregate needs of the study area through the year 2036 were calculated on the basis of two factors: (1) the past average annual per capita consumption rate of 8.5 tons (the average per capita consumption rate for the years 1960-1986) and (2) the projected population of the region for future years through the year 2036. The total PCC aggregate demand through the year 2036 is based on historic PCC aggregate consumption. The average percentage of total aggregate consumption used as PCC aggregate was calculated from 1960-1986. For the Stockton-Lodi P-C Region, the PCC aggregate percentage is 40 percent of the total aggregate consumption (Table 12).

Population projections for the years 1980 to 2020 (Figure 14) were obtained from the California Department of Finance (1986). This data was extrapolated by DMG for the study area on a straight line basis through the year 2036 to provide the 50-year population projection as specified under the SMARA guidelines. The results of these calculations (Table 13) reveal that an estimated 281 million tons of aggregate will be needed to satisfy the projected future demand for this construction material in the Stockton-Lodi P-C Region through the year 2036. Of this total, 40 percent, or 113 million tons must be PCC-grade aggregate.

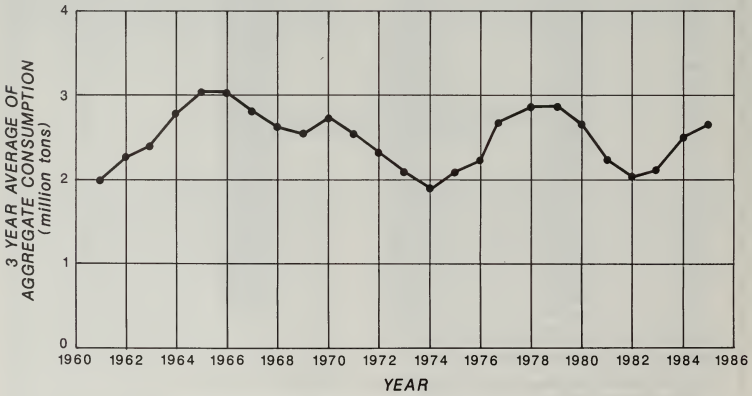


Figure 11. Aggregate consumption (3-year averages) for the Stockton-Lodi P-C Region, 1961-1985.

*Table 12. Percentage of total aggregate consumption used for Portland cement concrete (PCC) aggregate in the Stockton-Lodi P-C Region during the years 1960-1986.*

| YEAR | TOTAL AGGREGATE CONSUMED (tons) | PCC AGGREGATE CONSUMED (tons) | PERCENT OF TOTAL AGGREGATE CONSUMPTION USED AS PCC AGGREGATE |
|---|---|---|---|
| 1960 | 1,700,000 | 673,000 | 40 |
| 1961 | 2,343,000 | 896,000 | 38 |
| 1962 | 1,996,000 | 1,114,000 | 56 |
| 1963 | 2,496,000 | 1,096,000 | 44 |
| 1964 | 2,734,000 | 1,481,000 | 54 |
| 1965 | 3,153,000 | 1,768,000 | 56 |
| 1966 | 3,222,000 | 1,919,000 | 60 |
| 1967 | 2,742,000 | 1,498,000 | 55 |
| 1968 | 2,496,000 | 1,328,000 | 53 |
| 1969 | 2,597,000 | 1,506,000 | 58 |
| 1970 | 2,544,000 | 733,000 | 37 |
| 1971 | 3,057,000 | 831,000 | 27 |
| 1972 | 2,085,000 | 555,000 | 27 |
| 1973 | 1,780,000 | 601,000 | 34 |
| 1974 | 2,411,000 | 477,000 | 20 |
| 1975 | 1,513,000 | 454,000 | 30 |
| 1976 | 2,375,000 | 974,000 | 41 |
| 1977 | 2,800,000 | 896,000 | 32 |
| 1978 | 2,905,000 | 1,162,000 | 40 |
| 1979 | 2,972,000 | 862,000 | 29 |
| 1980 | 2,737,000 | 821,000 | 30 |
| 1981 | 2,227,000 | 779,000 | 35 |
| 1982 | 1,717,000 | 618,000 | 36 |
| 1983 | 2,175,000 | 761,000 | 35 |
| 1984 | 2,463,000 | 933,000 | 34 |
| 1985 | 2,825,000 | 1,095,000 | 35 |
| 1986 | *2,675,000 | 1,033,000 | 33 |
| TOTALS | 66,740,000 | 26,864,000 | |

Average percentage of total aggregate consumption used as PCC-aggregate = 40 percent.

Percentage calculations may not replicate precisely due to rounding.

*Preliminary estimate collected from aggregate producers. Statistics from U.S. Bureau of Mines not available at the time of study.

## Factors Affecting Per Capita Consumption Rates

The wide variations from year to year in the per capita consumption rate (Figure 11) (6.1 to 11.8 tons per person per year) probably reflect changes in urban growth rates with time, and the construction of major facilities (for example, freeways, dams, canals). In part, these variations also result from incompleteness and inaccuracies in the production records supplied to the U.S. Bureau of Mines. Certainly the economic climate is a powerful variable that influences the annual per capita consumption rates for aggregate. Very high interest rates, for example, such as existed in California from 1980 to 1982, tend to lower the amount of new construction in an area and consequently lower the demand for aggregate. The oil crisis in 1973 and 1974 caused a low demand for aggregate, probably because of the high cost of transportation. High consumption of aggregate in the mid-1960's occurred due to construction of major highways (Interstate 5) in California. Since San Joaquin County is currently experiencing a growth boom, the average per capita consumption rate could conceivably rise, further increasing the demand for aggregate.

At some point in the future, the average annual per capita consumption rate of 8.5 tons for the Stockton-Lodi P-C Region will probably decrease with the onset of urban maturity and then stabilize at a lower rate. However, should unforeseen events occur, such as massive urban renewal, rapid urban expansion, disaster reconstruction, or a major recession, the per capita consumption rate could change radically.

## Comparison of the 50-Year Aggregate Demand with Current Reserves

The total PCC-grade aggregate reserves for the Stockton-Lodi P-C Region were estimated to be 79.6 million tons (this figure does not reflect reserve depletion by any producer since January, 1987). At the average rate for past aggregate consumption in the region (8.5 tons per person annually), these reserves are theoretically sufficient to last 16 years, until 2004.

According to the U.S. Bureau of Mines aggregate production statistics and information from aggregate operators in the P-C region for the years 1960 to 1986, 40 percent of the total aggregate consumed in the region was used for PCC. This equates to 113 million tons of PCC-grade aggregate that will be required within the next 50 years (40 percent of the total 50-year demand). If the 79.6 million tons of reserves were used exclusively for PCC, the supply would theoretically last 35 years (2023). In reality, much of the PCC-grade aggregate reserves will be used for other products, and depletion date of 2004 is more likely.

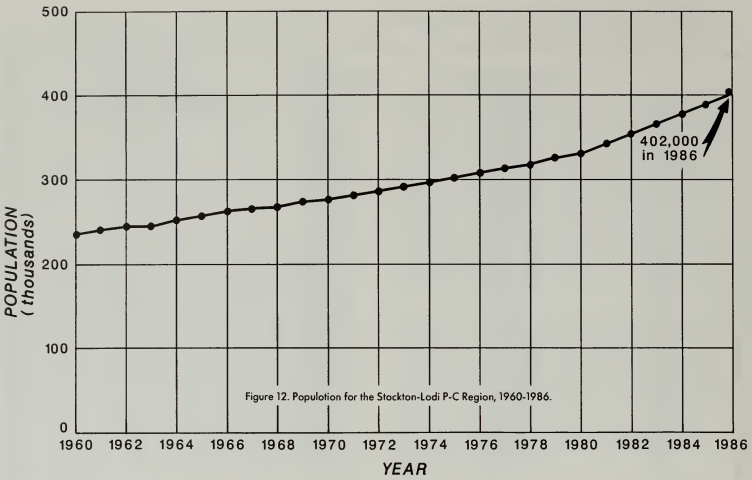


Figure 12. Population for the Stockton-Lodi P-C Region, 1960-1986.

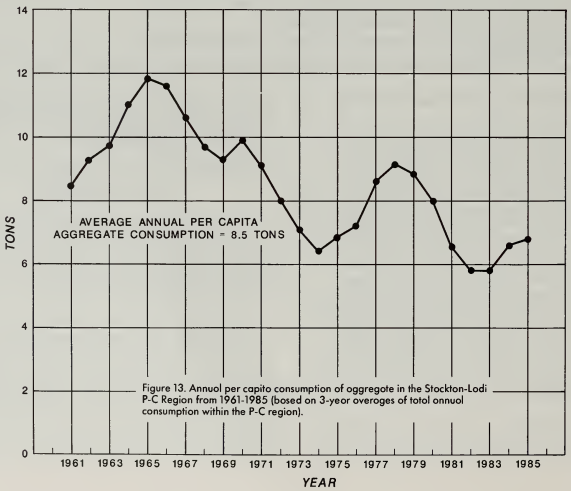


Figure 13. Annual per capita consumption of aggregate in the Stockton-Lodi P-C Region from 1961-1985 (based on 3-year averages of total annual consumption within the P-C region).

*Table 13. Projected aggregate consumption through the year 2036 for the Stockton-Lodi P-C Region. Five-year per capita consumption = 42.5 tons/person/ (one year per capita consumption = 8.5 tons/person)*

| YEARS | PROJECTED AVERAGE YEARLY POPULATION* | AGGREGATE CONSUMPTION ALL AGGREGATE (million tons) | AGGREGATE CONSUMPTION PCC-AGGREGATE (million tons)** |
|---|---|---|---|
| 1987-1991 | 442,000 | 18.8 | 7.5 |
| 1992-1996 | 498,000 | 21.2 | 8.5 |
| 1997-2001 | 545,000 | 23.2 | 9.3 |
| 2002-2006 | 590,000 | 25.1 | 10.0 |
| 2007-2011 | 638,000 | 27.1 | 10.8 |
| 2012-2016 | 688,000 | 29.2 | 11.7 |
| 2017-2021 | 735,000 | 31.2 | 12.5 |
| 2022-2026 | 782,000 | 33.2 | 13.3 |
| 2027-2031 | 828,000 | 35.2 | 14.1 |
| 2032-2036 | 874,000 | 37.1 | 14.9 |
| TOTALS | | 281.4 | 112.5 |

*Population projections for the years 1987-2020 were obtained from the California Department of Finance (1986). Population data for 2020-2036 were linearly projected by DMG.

**This figure is based on the fact that 40 percent of the aggregate consumed from 1960 to 1986 was PCC quality (Table 12).

## ALTERNATIVE SOURCES OF AGGREGATE

Although most of the area in the Stockton-Lodi P-C Region has been classified MRZ-1, there is a significant amount of land classified MRZ-3. Insignificant portions of the P-C region have been classified MRZ-4. Portions of these areas most likely to contain sand and gravel suitable for use as PCC-grade aggregate are discussed in the following paragraphs.

### Potential Sources of Aggregate within the Stockton-Lodi P-C Region

The Laguna Formation is exposed along the foothills of the Sierra Nevada. In the Stockton-Lodi area near Belotta and Clements, this unit is mined for aggregate base material by Darwin Farms (Roc-San Gravel) and Linden Sand and Gravel. Aggregate test results indicate that processed Laguna Formation conglomerate could meet PCC-grade standards if further beneficiation proves to be economical. The Laguna Formation is a Tertiary, sedimentary, glacial outwash deposit derived from source rocks in the Sierra Nevada. The Laguna Formation is composed of arkosic alluvium, gravel, sand and silt with pebbles of quartz and metamorphic fragments.

Aggregate tests are inconclusive as to whether PCC-grade aggregate could be produced economically from the Laguna Formation. Aggregate tests from Darwin Farms (Roc-San Gravel) were evaluated by Caltrans Materials Testing Laboratory, Pavement Branch. The Caltrans evaluation was inconclusive as to the suitability of this material for PCC grade aggregate. According to Caltrans, the sand equivalency (S.E.) test performed on Darwin Farms aggregate shows ". . . a high content of detrimental fine dust or clay-like materials in the fine aggregate." This material could be washed through a sand classifier until a satisfactory S.E. value is obtained, but it is uncertain whether beneficiation of this aggregate could be economical. Darwin Farms has never sold the aggregate and presently does not have a processing plant. However, aggregate from the deposit has been used in concrete farm structures on Darwin Farms property. Although this could indicate high quality, a compressive strength test has not been performed. In this test, a cylinder of concrete is made with the material and subjected to compressive stresses. This is usually the final determination of suitability for PCC use for structures that have to adhere to stringent safety standards. Because the compressive strength test has not been performed, and the results of other tests were borderline, it is still uncertain whether Laguna Formation material can be economically processed for PCC-grade aggregate. More complete testing and processing is needed to determine suitability for use as PCC-grade aggregate. Linden Sand and Gravel's material was tested for PCC-grade specifications and the results were marginal (per Bill Tickler of Linden Sand and Gravel). In conclusion, proper beneficiation of aggregate from the Laguna Formation could qualify this aggregate for PCC-grade, but it cannot be determined that the material would be economical to process.

If PCC-grade aggregate can be produced from the Laguna Formation, the market area would not extend very far south. The high processing costs would limit the market area to the Stockton area for Linden Aggregates, and to Lodi for Darwin Farms. If PCC-grade aggregate cannot be produced, the active operations producing road base and other products will still relieve pressure on other higher quality deposits, perhaps extending the life of these deposits. Exploration and testing on a site by site basis would be needed to determine the suitability of the material for PCC use.

South of Tracy along the terrace of Lone Tree Creek, Gary Kitchen operates a base rock pit. This material is derived from the Quaternary Los Banos alluvium (Bartow, and others, 1985). Although the material has not been tested for use as PCC-grade aggregate, the material is hard and durable and makes excellent road base. Potential problems include significant amounts of clay and absorptive clasts. These problems could be alleviated by processing, but more extensive testing and exploration would be required to verify the quality of the deposit.

Fringes of MRZ-3 exist along the fans zoned MRZ-2 formed by Corral Hollow, Lone Tree and Hospital Creeks. These areas contain potential PCC-grade aggregate, but could have deleterious factors such as high clay content or unsound clasts. Drilling and testing would be required to delineate areas of usable material.

The floodplains of the Mokelumne and Calaveras Rivers are zoned MRZ-3 because of questions regarding quantity of the contained aggregate. These areas contain PCC-grade aggregate, but the deposits could have detrimental factors such as excessive overburden and high clay content. Further exploration on a site by site basis would be required to thoroughly evaluate these floodplains.

Interfan deposits along the western edge of the P-C region, extending south from Tracy to the Stanislaus County line, are equivalent or slightly younger than the San Luis Ranch alluvium. Most of this material has never been tested, but it is assumed that large amounts of coarse material exist within these deposits. Possible detrimental factors include high clay content, possible discontinuity of coarse material and shallow depth. Extensive testing and drilling would be required to evaluate this area.

## Potential Sand Sources Within the Stockton-Lodi P-C Region

Sector D, located near Manteca, contains clean quartz sand with little waste. This material is suitable for use in PCC-grade aggregate if adequate coarse material is available. Because Portland cement concrete requires a 50-50 mix of coarse and fine aggregate, an equivalent-sized supply of coarse aggregate will be needed to fully utilize the sand from this sector.

In addition to Sector D, there are other areas of potential sand resources in the Stockton-Lodi P-C Region. MRZ-3 areas adjacent to Sector D, in and near Manteca, are potential sources of high quality sand. It cannot be confirmed that

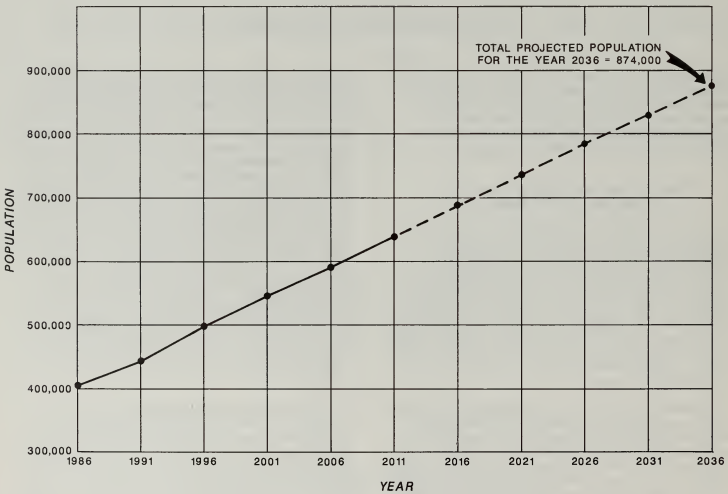


Figure 14. Projected population of the Stockton-Lodi P-C Region for the years 1986-2036 (50 years from date of study). The solid line represents the California Department of Finance projection (1986); the dashed line represents the extended projection by the Division of Mines and Geology.

these areas contain the same high quality sand present in Sector D. If testing demonstrates high quality, large amounts of sand resources could become available. A smaller area zoned MRZ-3 north of Lodi contains significant sand with some gravel of unknown quality. Drilling and testing would be required to determine the quality of this material.

As previously stated, if these sand resources are to be an important contribution to PCC production, they must be mixed with suitable coarse aggregate. Brown Sand, Inc. is currently mixing sand from the Lathrop deposit with coarse aggregate mined from the Hospital Creek alluvial fan deposit to produce PCC-grade aggregate, although on a limited scale. Other areas which might eventually contribute coarse aggregate for blending include alluvial fans north of Solyo and Laguna Formation coarse aggregate (if quality standards can be met). Transportation costs are an important factor, but this type of operation could become an alternative to the more expensive option of importing from a great distance.

### Potential Sources of Aggregate Outside the Stockton-Lodi P-C Region

The Stockton-Lodi P-C Region is adjacent to the Sacramento-Fairfield P-C Region on the north and the South San Francisco Bay P-C Region on the west. Aggregate is exported from Stockton-Lodi to the cities of Livermore, Brentwood, Pittsburgh and Antioch, so it is unlikely that the South San Francisco Bay P-C Region could contribute aggregate to Stockton-Lodi. Also, Sacramento faces shortages of aggregate in the very near future and is also an unlikely contributor of aggregate (Dupras, 1985). Future resources may be developed from hard rock deposits located near Ione, and from sand and gravel deposits near Jenny Lind. In addition, there are extensive deposits along the Stanislaus River that serve Modesto. In order for these deposits to compete, shortages of aggregate must be severe enough, or demand so high, that the prices paid offset the increased transportation and/or processing costs.

Speculative hard rock or alluvial deposits might be found in the hillsides between Tracy and Livermore or in the foothills of the Sierra Nevada. If it becomes necessary to locate deposits in these areas to supply aggregate, other alternatives exist, such as rail or barge transportation of PCC-grade aggregate from the Yuba River dredge fields in Marysville, which has an overabundance of high quality aggregate. It is important to note that high-quality materials will almost always be available to the consumer, but at a price that reflects the distance from the market and the quality of the source material.

## CONCLUSIONS

Within the Stockton-Lodi Production-Consumption Region, seven resource sectors were identified as containing significant resources of PCC-grade aggregate. These areas were determined to contain approximately 599.2 million tons of PCC-grade aggregate resources and 79.6 million tons of reserves. One of these resource areas is identified as a significant deposit of PCC-grade sand, containing 90.2 million tons of sand resources (reserves are proprietary).

Based upon available production data and population projections, the Stockton-Lodi P-C Region will need 281 million tons of aggregate during the next 50 years. Of this projected demand, approximately 40 percent (113 million tons) must be suitable for Portland cement concrete. The 80 million tons of aggregate reserves calculated to exist within the P-C region represent 28 percent of the projected demand for all aggregate over the next 50 years. Unless new resources are permitted for mining, or alternative resources are utilized, existing reserves will be depleted by the year 2004. If a major earthquake, or similar unforeseen catastrophic event, strikes the P-C region and necessitates reconstruction, the existing reserves would be depleted more rapidly.

## ACKNOWLEDGMENTS

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# APPENDIX

## Interim Criteria for Sectorization of MRZ-2 Areas for Aggregate

The purpose of sectorizing MRZ-2 areas is to provide a semi-quantified estimate of construction aggregate resources which are likely to be available to satisfy society's needs during the next 50 years. This estimate, when compared to DMG projected needs for the next half century, provides the context for communities to plan for future resource availability in their land-use policies. The determination of sectors is intended for the use of the State Mining and Geology Board (the Board) in identifying areas which are candidates for designation under SMARA. The development of sectors provides a perception of future mineral resource availability in the face of future needs and also portrays where these available minerals are generally located. This information is distributed by the Board to all affected lead agencies to provide them with the data necessary to plan for future resource availability in their land-use policies.

All areas within MRZ-2 classifications are sectorized if they have current land uses which are similar to those in areas which have undergone mineral extraction in the past. Areas within MRZ-2 classifications which have generally not been available for surface mining in the past for specified social or economic reasons are not sectorized. Since such areas are unlikely to be used for surface mining during the foreseeable future, their inclusion in estimates of future resource availability would be misleading.

The estimation of future mineral resource availability in sectors is not a precise analysis, but rather is the best general estimate which can be made with the data presently available. Areas within and without sectors, can be used for mining or other land uses at the discretion of the local governments charged with responsibility for making land-use decisions. Establishment of sectors in no way infringes on this authority. Rather, it provides a perception of future mineral resource availabilities in the face of future needs and also portrays where these available minerals are generally located.

The following criteria are used by DMG in identifying mineral resource areas which are available for future use. These criteria, in conjunction with the geologic and geometric characteristics of specific mineral deposits are used in sectorizing MRZ-2 areas. Use of these criteria assure that sectors contain geologically homogeneous mineral deposits which, based upon current land use, will be available for future use.

The following specific land uses are considered to be generally incompatible with mining and have been excluded from sectored lands. Mineral resource areas containing land uses not specifically listed will be considered for sectorization. The criteria are to be applied only to lands classified as MRZ-2.

There are two general categories of exclusion: I) Economic Exclusion, and II) Social Exclusion.

I) *Economic Exclusion*

Specific excluded land uses are:
1) Residential areas,
2) Commercial areas with land improvements (buildings),
3) Industrial areas (buildings and adjacent needed storage and parking facilities), and
4) Major public or private engineering projects, including:
   a) canals
   b) freeways
   c) bridges
   d) airports and associated developments such as parking lots
   e) dams
   f) railroads
   g) major pipelines
   h) major power transmission lines

II) *Social Exclusion*

Specific excluded land uses are:
1) Cemeteries,
2) Geologic Scientific Zones,
3) Public parks, developed historical sites and structures, and public recreation areas of all types,
4) Public or private schools, institutions, hospitals, and prisons, including adjacent grounds and related structures, and
5) Military bases and reservations.

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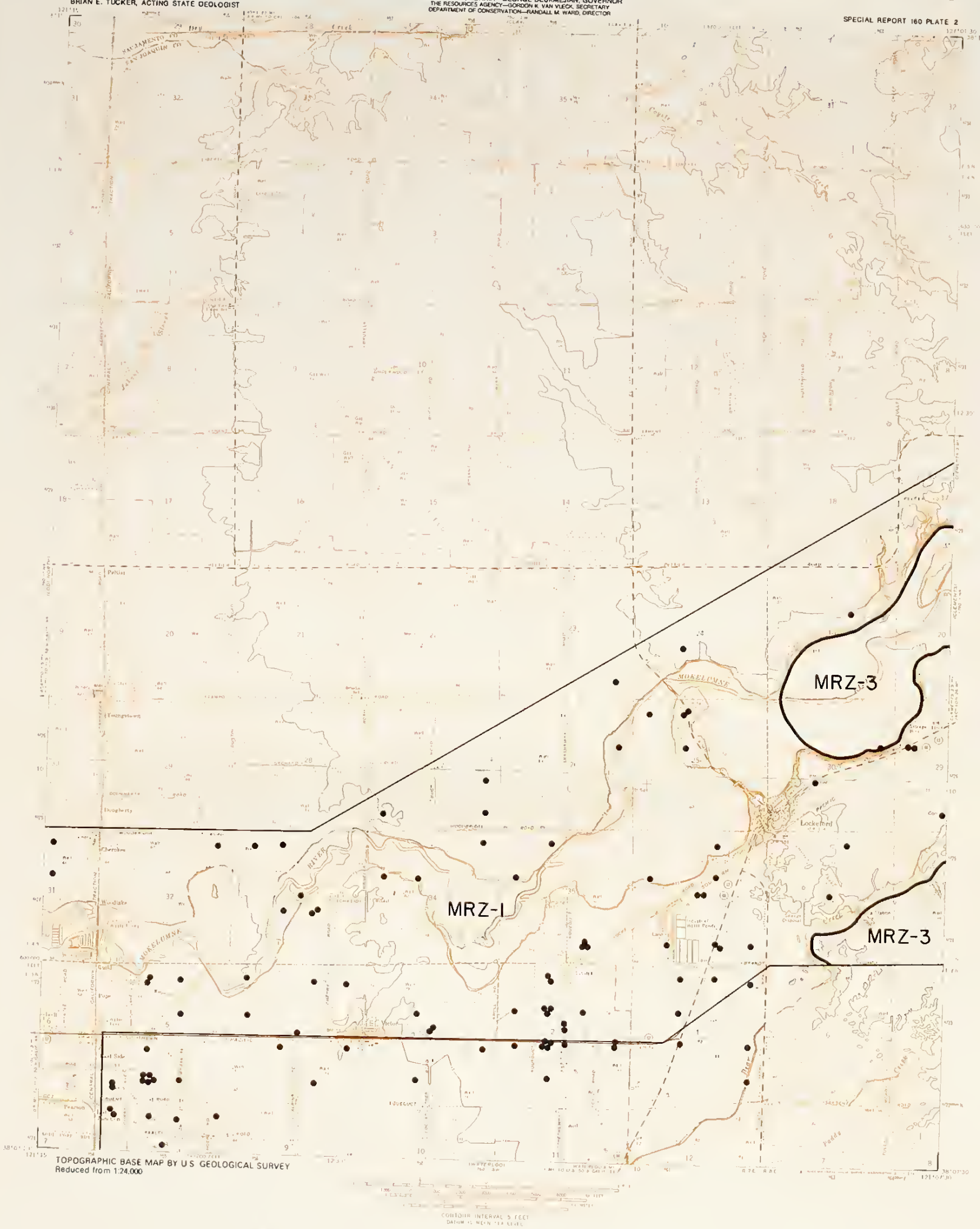


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## EXPLANATION

● DRILL HOLE

PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
Boundaries established from data supplied by the Office of Planning and Research with modifications developed from information supplied by local government and other sources.

MRZ-2

MINERAL RESOURCE ZONE BOUNDARIES
All Mineral Resource Zones are for Portland Cement Concrete Grade Aggregate unless otherwise indicated by Commodity name enclosed in parentheses

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- MRZ-3 Areas containing mineral deposits the significance of which cannot be evaluated from available data
- MRZ-4 Areas where available information is inadequate for assignment to any other MRZ zone

See text for additional explanation of MRZ Symbols.

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LOCKEFORD, CALIF

# MINERAL LAND CLASSIFICATION MAP
## AGGREGATE RESOURCES ONLY
## Stockton–Lodi P–C Region

By
Laurel S. Jensen and Michael A. Silva

1988

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LODI NORTH QUADRANGLE

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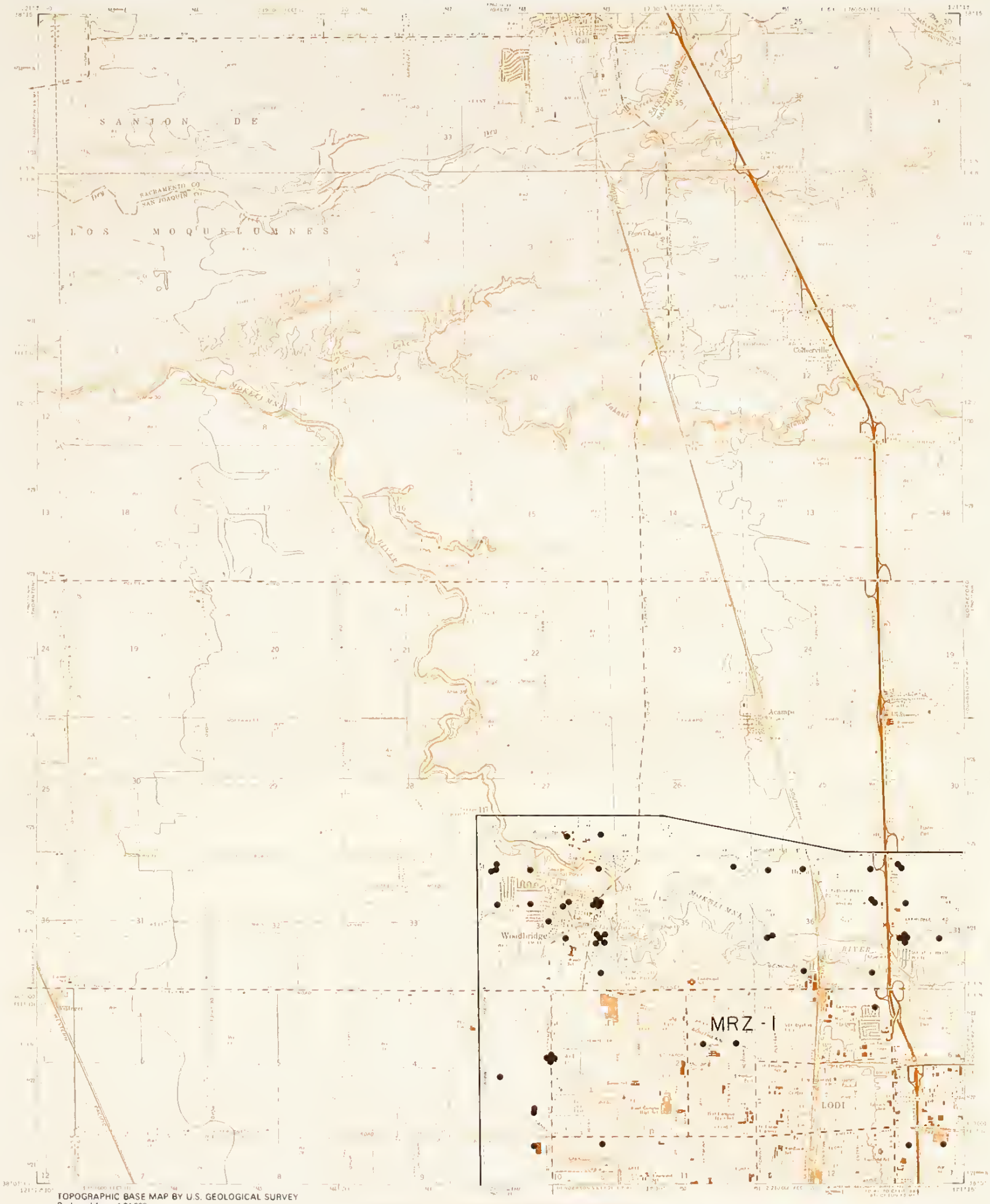


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## EXPLANATION

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LODI NORTH, CALIF

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## Stockton–Lodi P–C Region

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CLEMENTS QUADRANGLE

SPECIAL REPORT 160 PLATE 3

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## EXPLANATION

● DRILL HOLE

PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
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CLEMENTS, CALIF

# MINERAL LAND CLASSIFICATION MAP
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## Stockton–Lodi P–C Region

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LOCKEFORD QUADRANGLE

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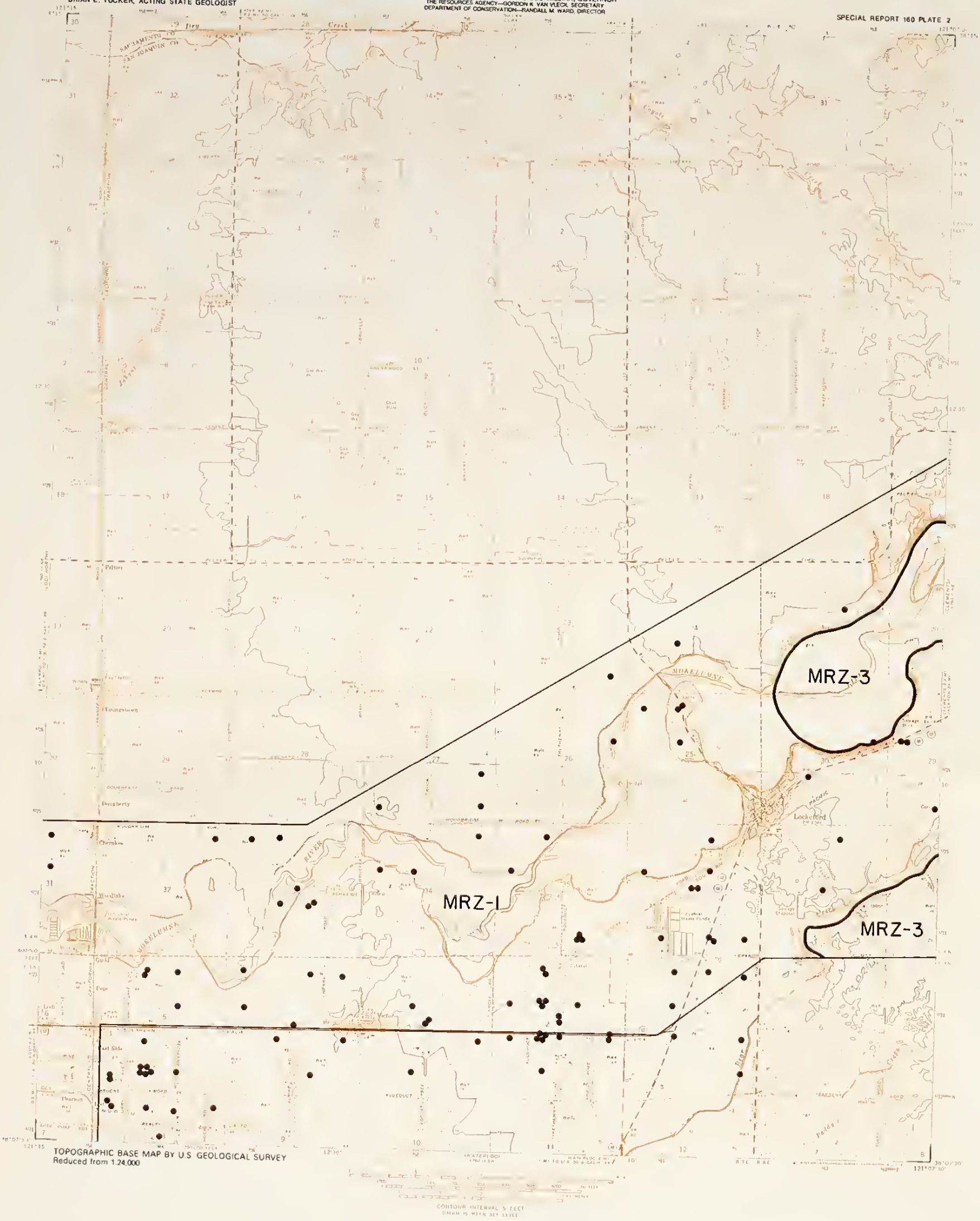


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## EXPLANATION

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LOCKEFORD, CALIF

# MINERAL LAND CLASSIFICATION MAP
## AGGREGATE RESOURCES ONLY
## Stockton–Lodi P–C Region

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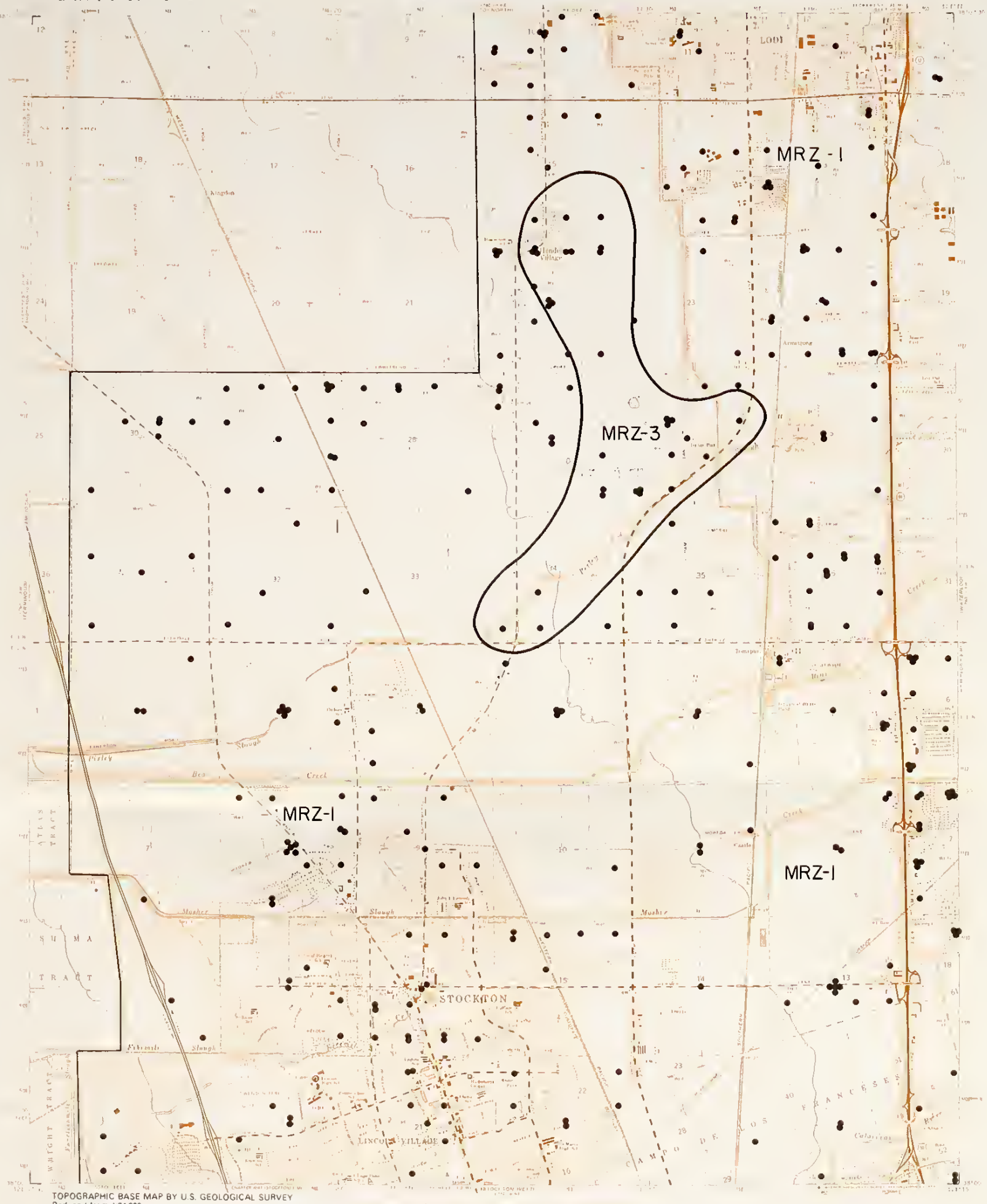


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LODI SOUTH, CALIF

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## Stockton–Lodi P–C Region

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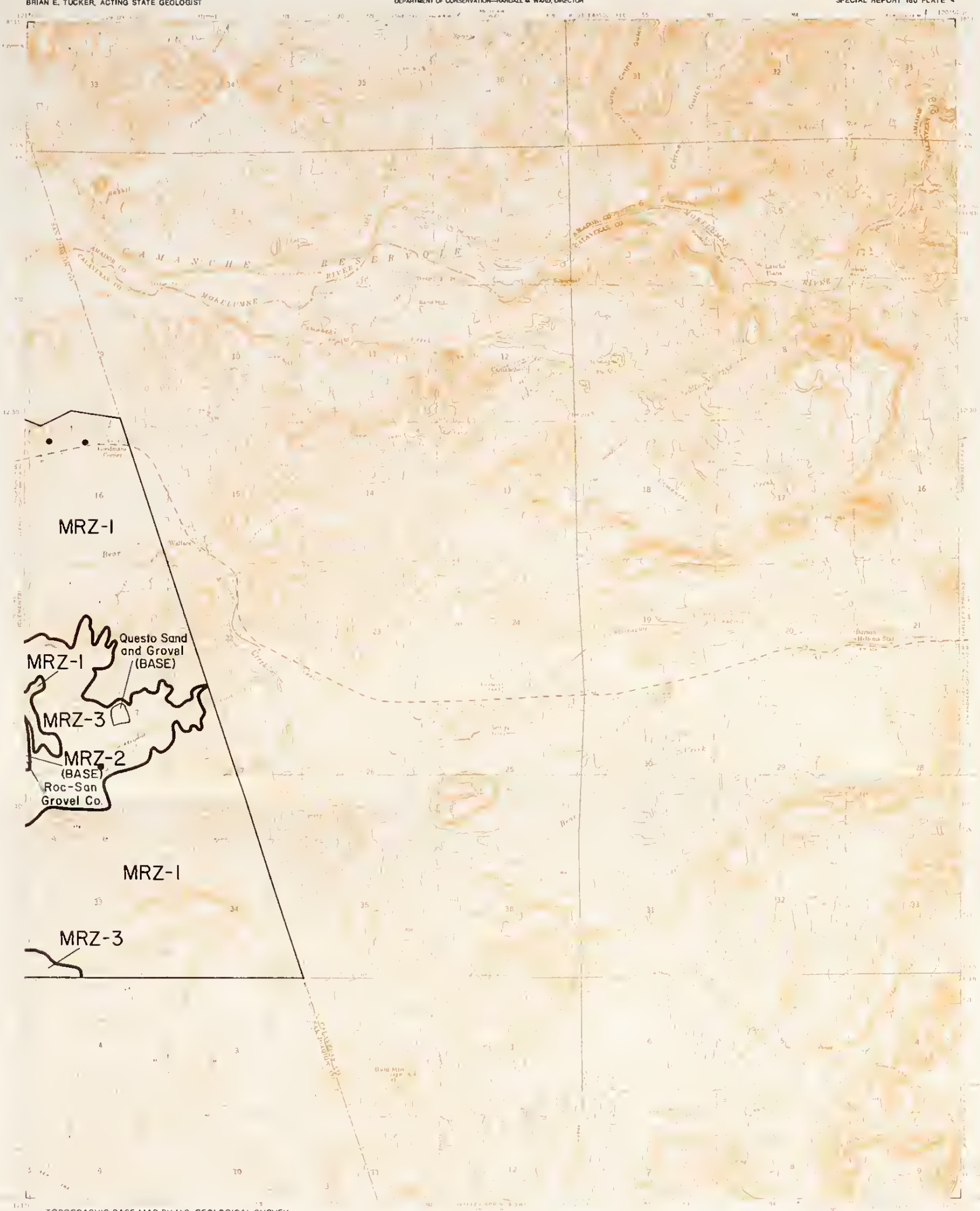


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## EXPLANATION

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WALLACE, CALIF

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LINDEN QUADRANGLE

SPECIAL REPORT 160 PLATE 7

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## EXPLANATION

● DRILL HOLE

PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
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LINDEN, CALIF

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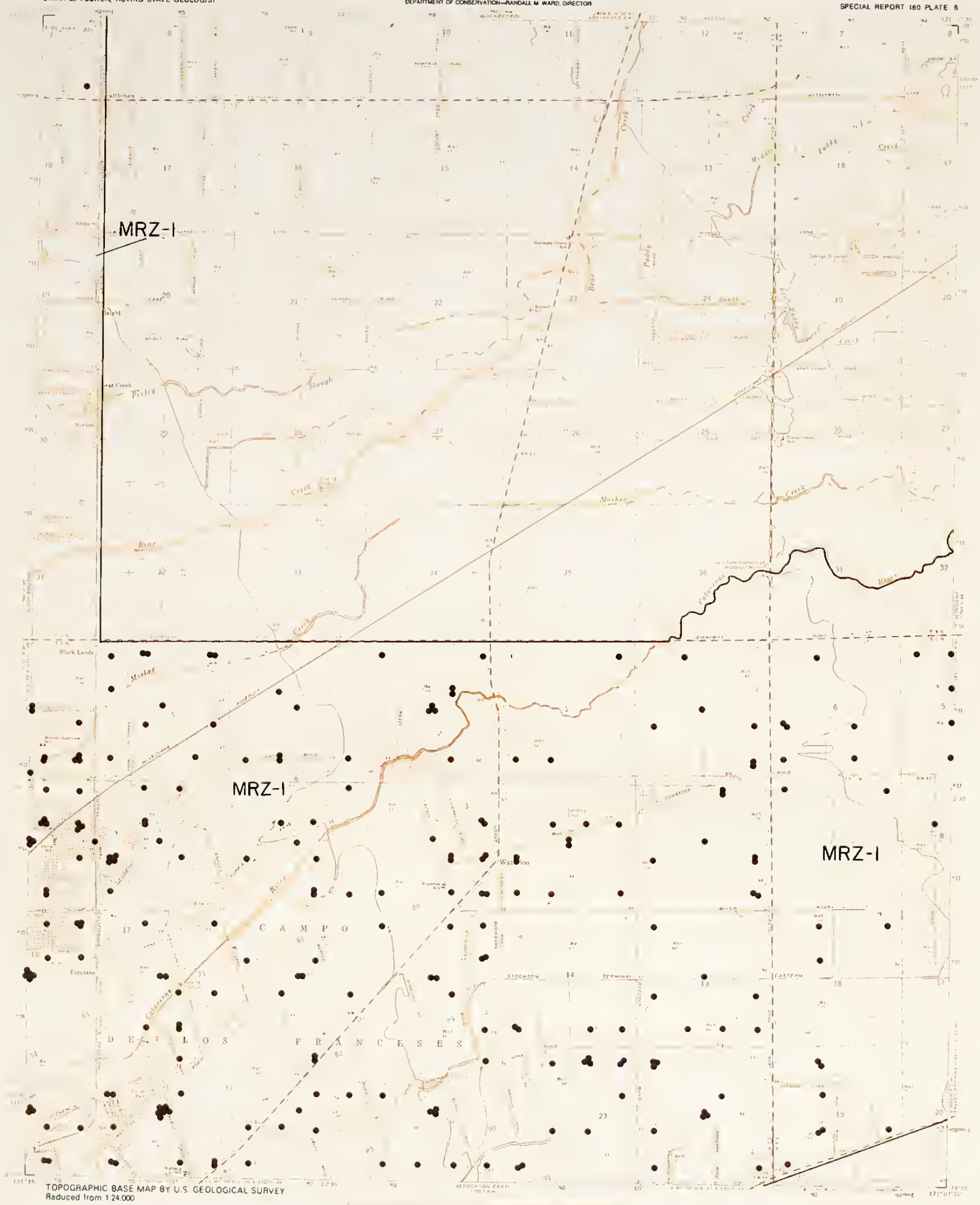


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## EXPLANATION

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See text for additional explanation of MRZ Symbols

N

WATERLOO, CALIF.

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STOCKTON WEST QUADRANGLE

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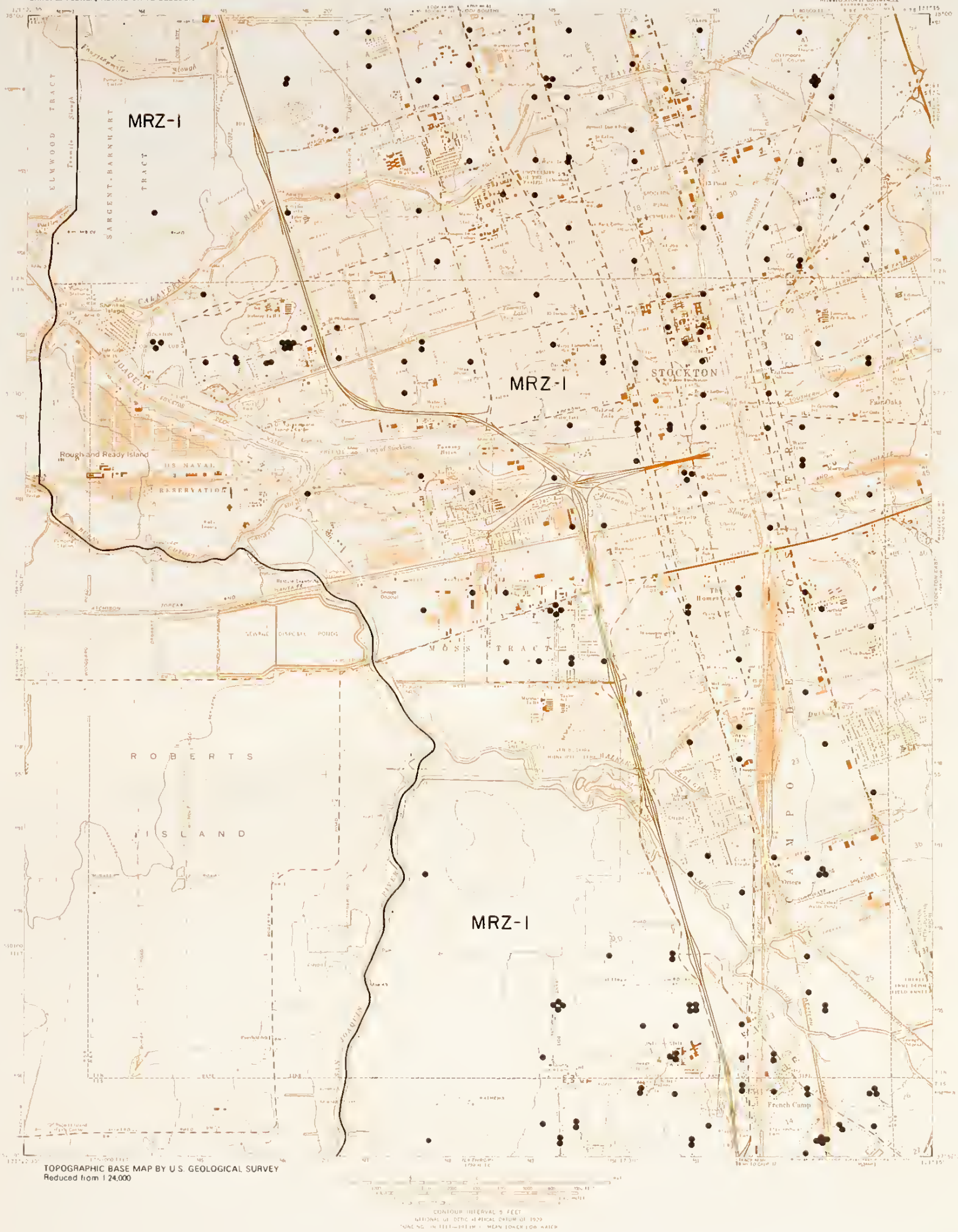


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STOCKTON WEST, CALIF

## EXPLANATION

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STOCKTON WEST QUADRANGLE

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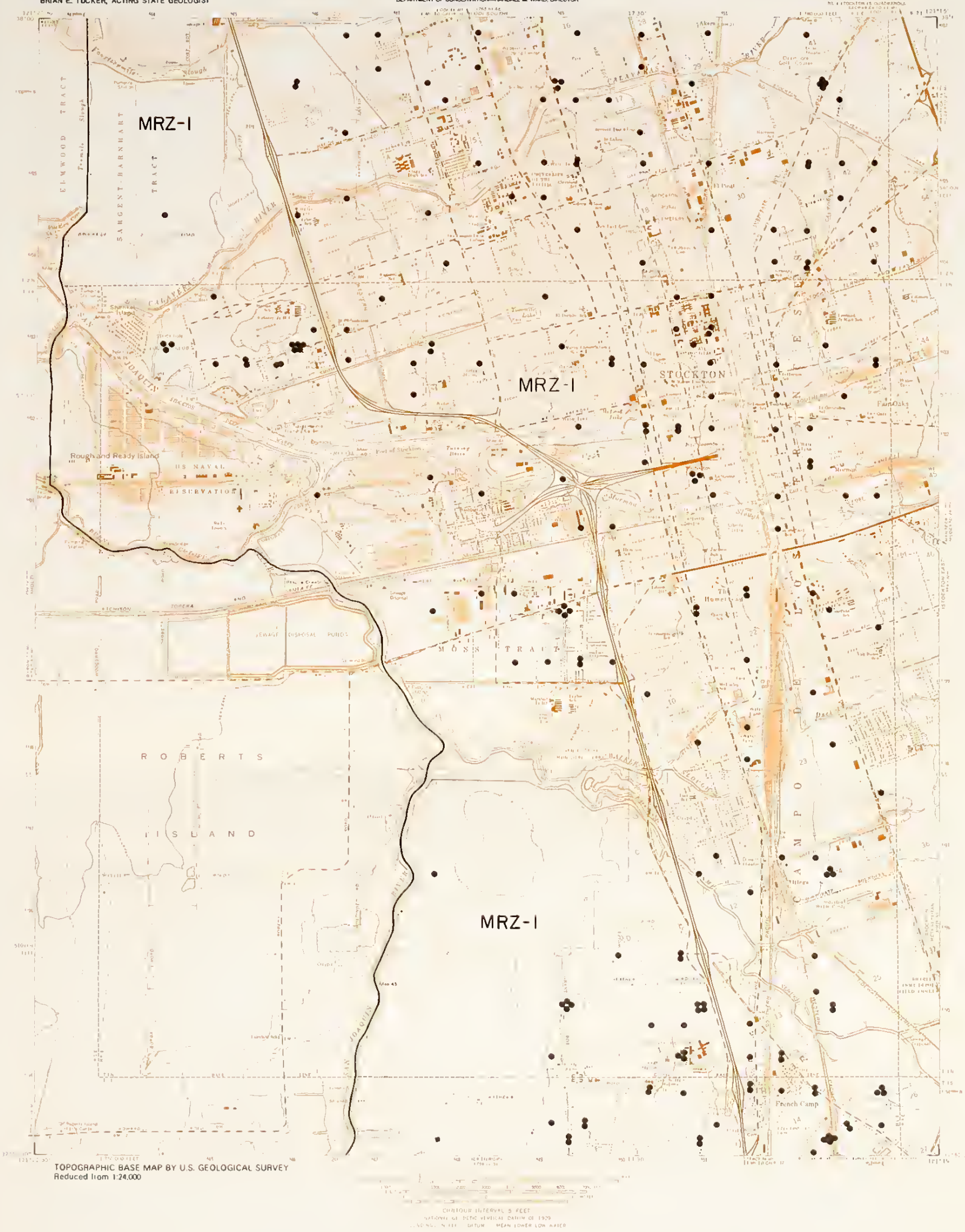


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STOCKTON WEST, CALIF.

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N

# MINERAL LAND CLASSIFICATION MAP
## AGGREGATE RESOURCES ONLY
## Stockton–Lodi P–C Region

By
Laurel S. Jensen and Michael A. Silva
1988

PREPARED IN COMPLIANCE WITH THE SURFACE MINING AND RECLAMATION ACT OF 1975, ARTICLE 4, SECTION 2761

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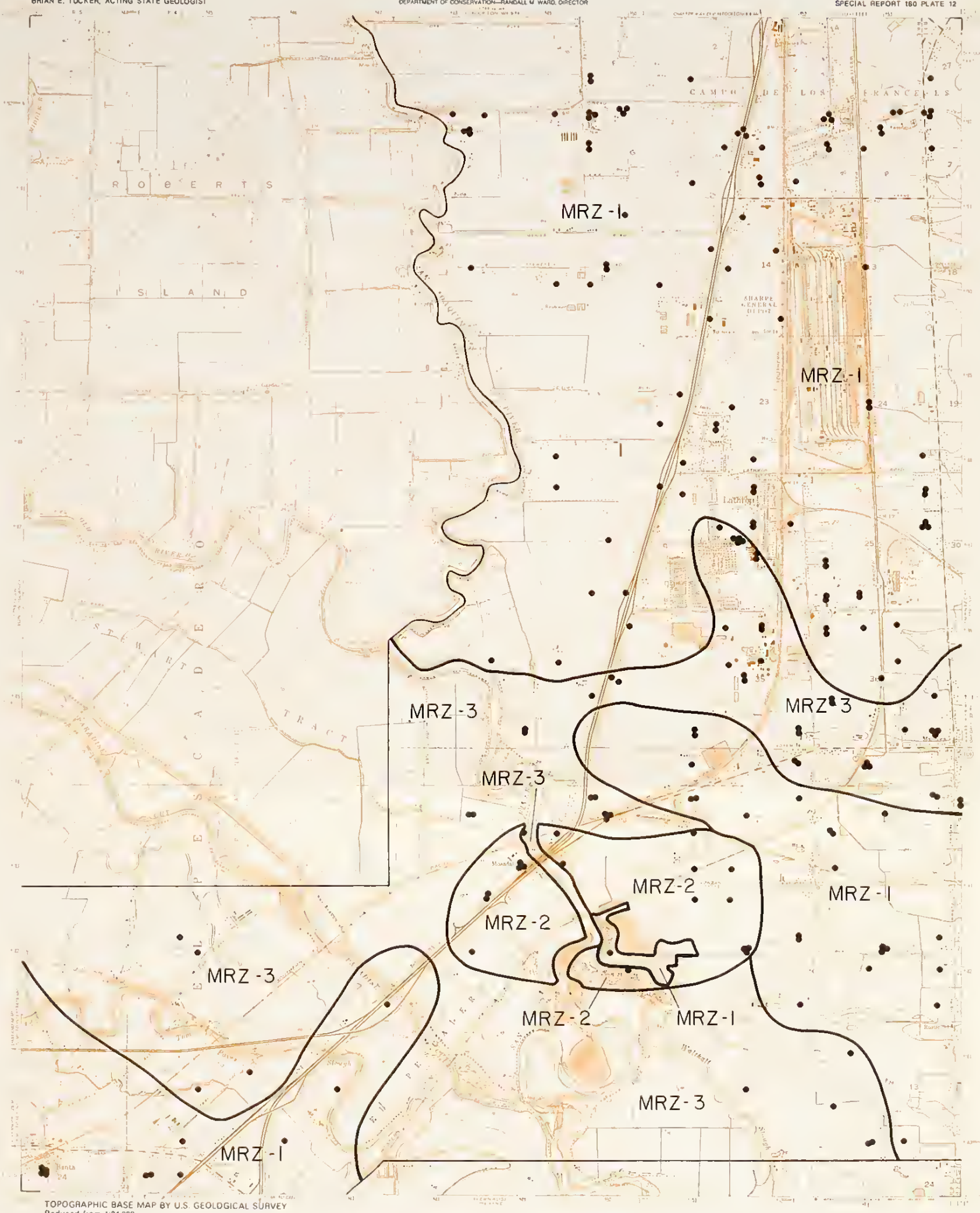
LATHROP QUADRANGLE

SPECIAL REPORT 160 PLATE 12




TOPOGRAPHIC BASE MAP BY U.S. GEOLOGICAL SURVEY
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LATHROP, CALIF

**EXPLANATION**

● DRILL HOLE

PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
Boundaries established from data supplied by the Office of Planning and Research with modifications developed from information supplied by local government and other sources

MRZ-2

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UNION ISLAND QUADRANGLE

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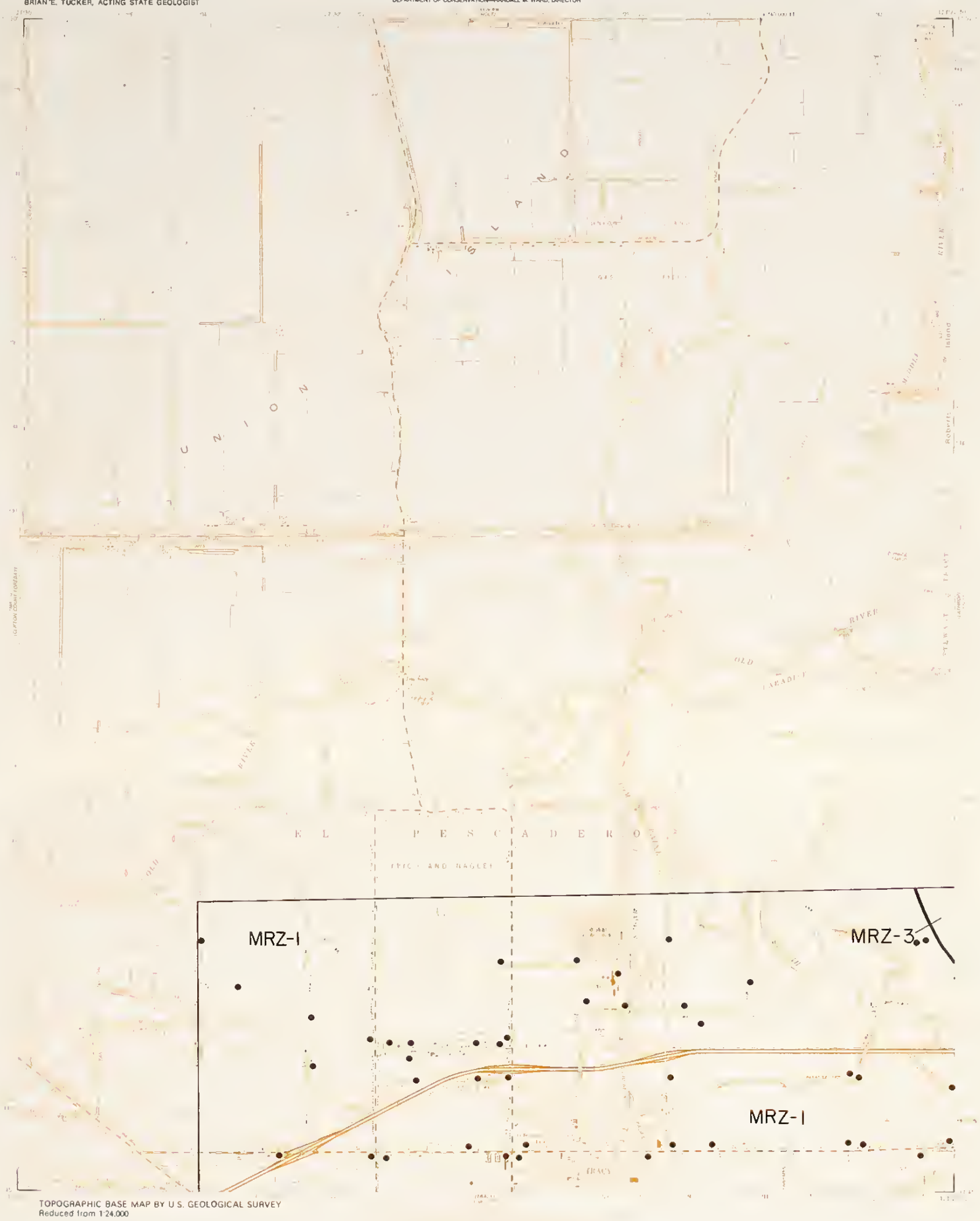


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UNION ISLAND, CALIF

## EXPLANATION

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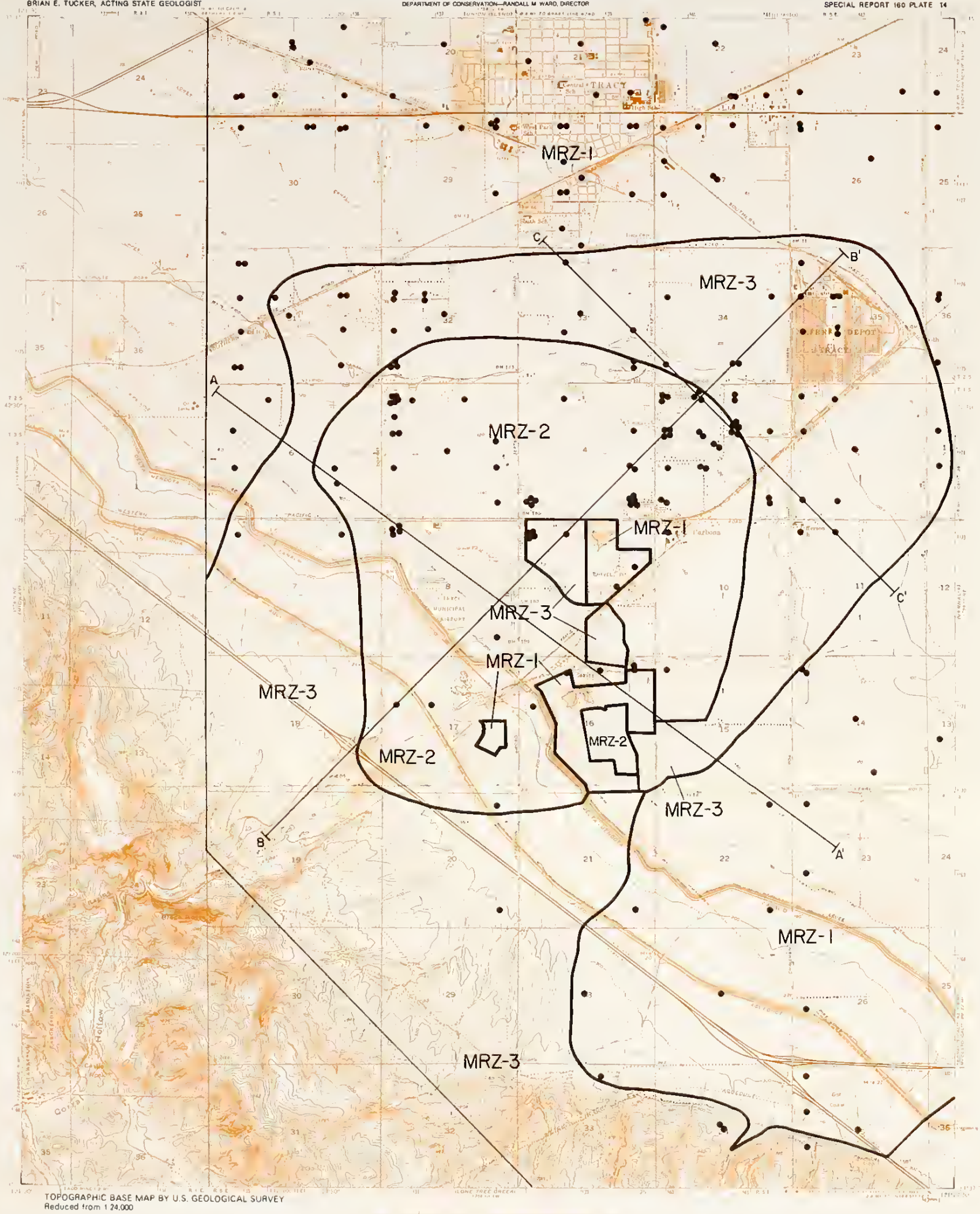


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TRACY, CALIF

## EXPLANATION

● DRILL HOLE

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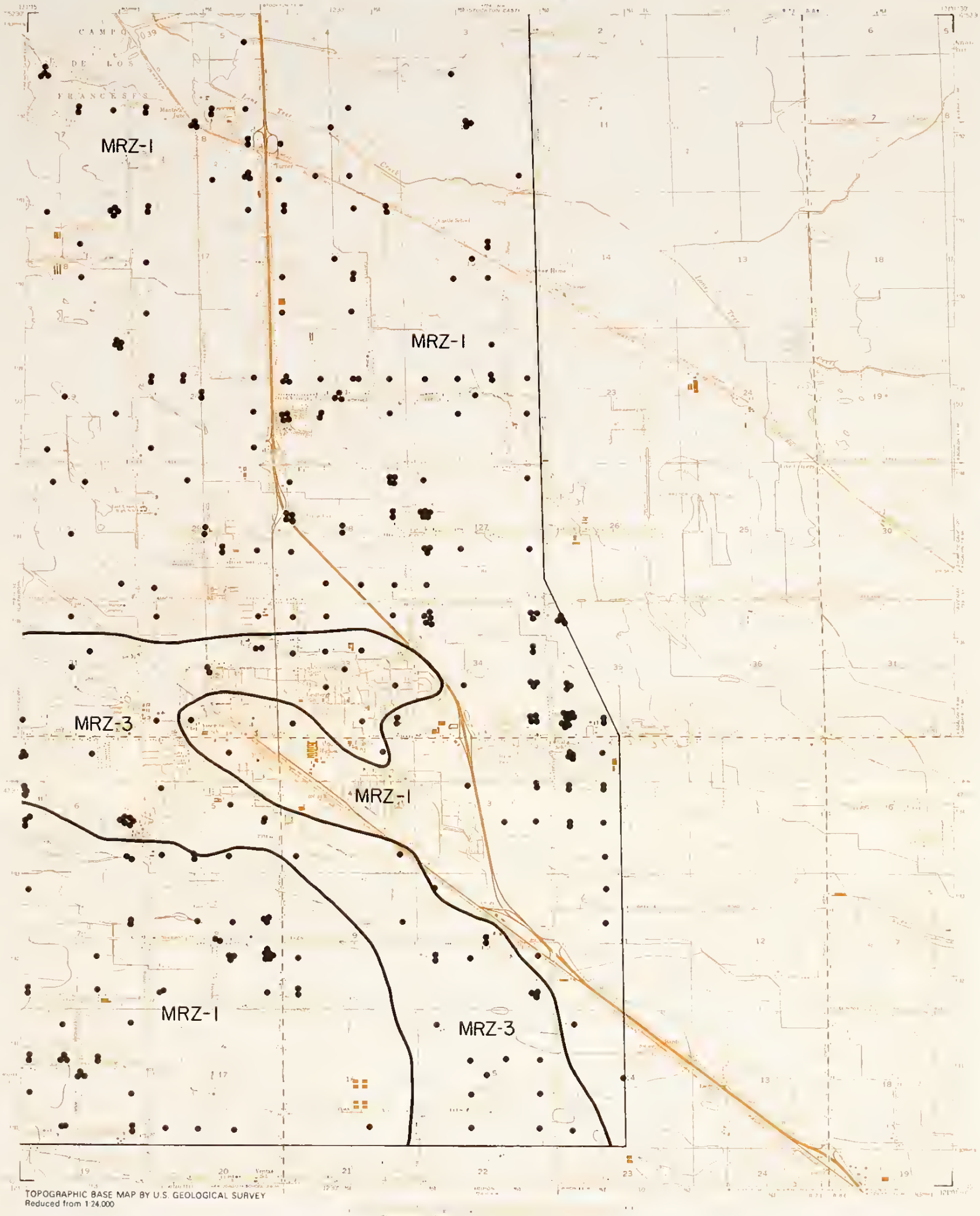
MANTECA QUADRANGLE

SPECIAL REPORT 160 PLATE 13

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MANTECA, CALIF

**EXPLANATION**

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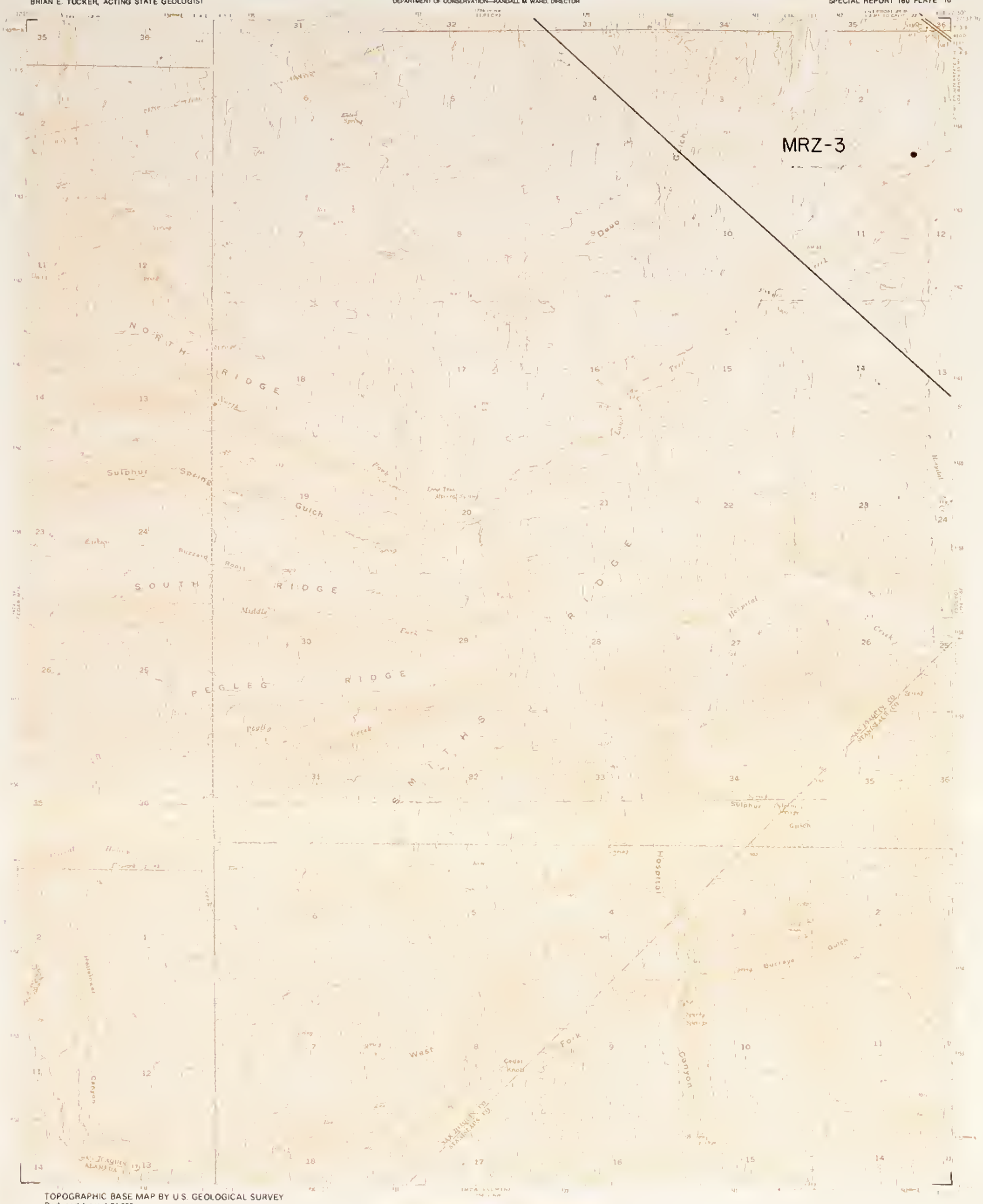


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## EXPLANATION

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LONE TREE CREEK, CALIF

# MINERAL LAND CLASSIFICATION MAP
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## Stockton–Lodi P–C Region

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VERNALIS QUADRANGLE
SPECIAL REPORT 160 PLATE 15

TOPOGRAPHIC BASE MAP BY U S GEOLOGICAL SURVEY
Reduced from 1:24 000

**EXPLANATION**

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PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
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VERNALIS, CALIF

# MINERAL LAND CLASSIFICATION MAP
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## Stockton–Lodi P–C Region

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LATHROP QUADRANGLE

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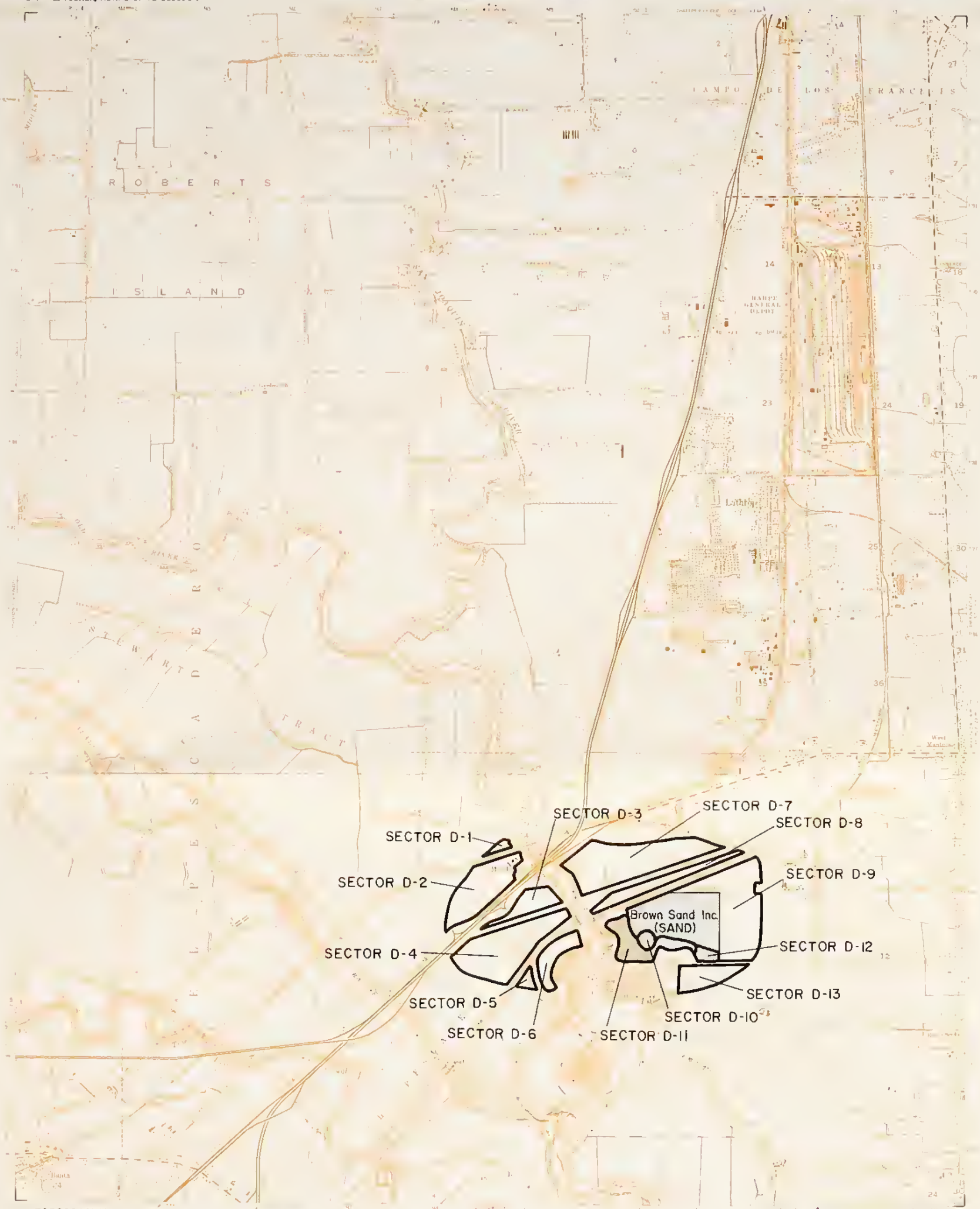


TOPOGRAPHIC BASE MAP BY U.S. GEOLOGICAL SURVEY
Reduced from 1:24,000

LATHROP, CALIF

EXPLANATION

Sector boundary

Properties owned or controlled by aggregate producers

N

# Aggregate Resource Sectors
## Stockton-Lodi P-C Region

By
Laurel S. Jensen and Michael A. Silva

1988

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JULYO QUADRANGLE

SPECIAL REPORT 160 PLATE 17

TOPOGRAPHIC BASE MAP BY U S GEOLOGICAL SURVEY
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## EXPLANATION

● DRILL HOLE

PRODUCTION-CONSUMPTION REGION BOUNDARY AND OUTER BOUNDARY OF AREAS SUBJECT TO URBANIZATION AND LIMIT OF AREA CLASSIFIED
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SAN JOSE, CALIF

# MINERAL LAND CLASSIFICATION MAP
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## Stockton–Lodi P–C Region

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VERNALIS QUADRANGLE

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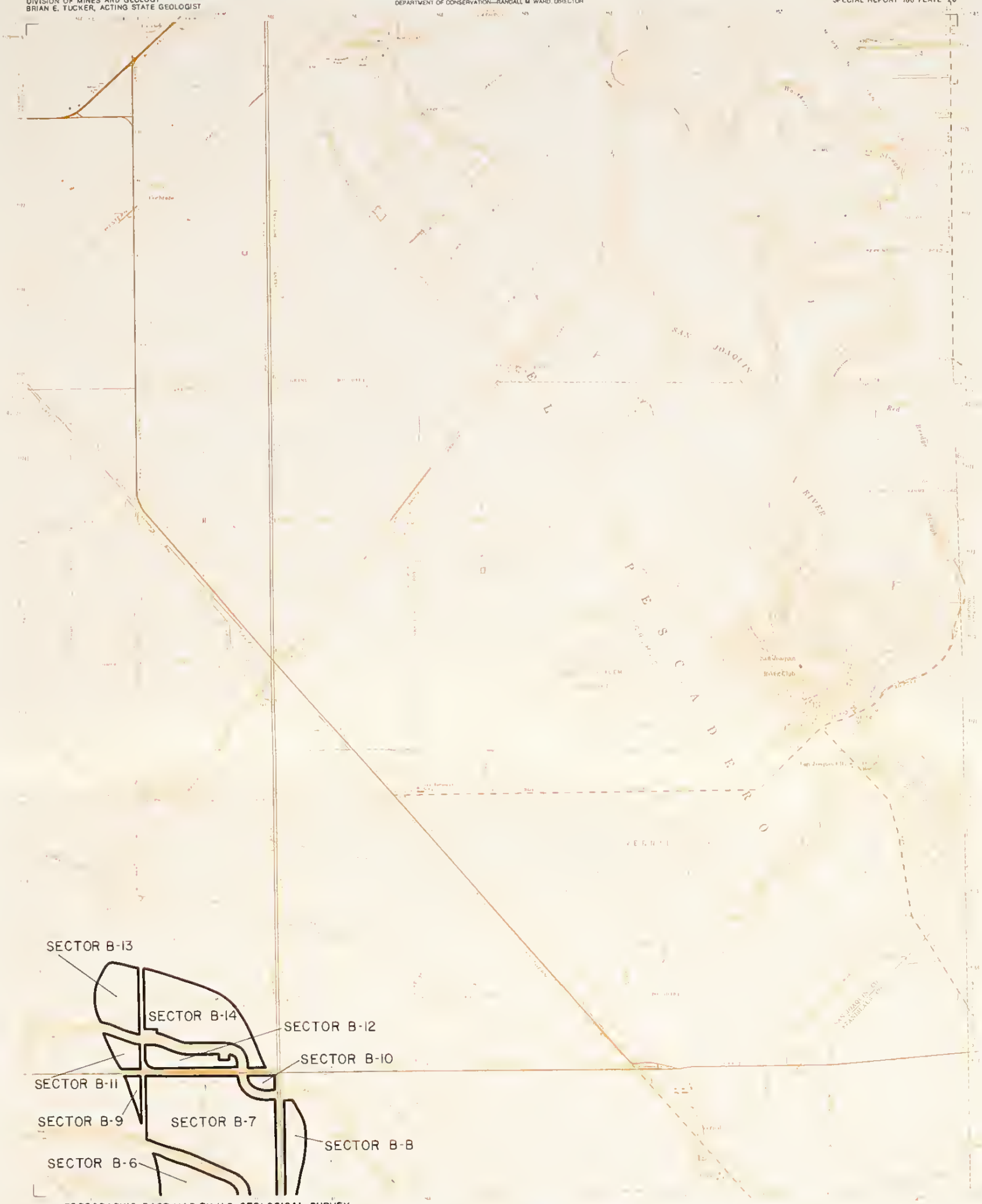


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VERNALIS, CALIF

EXPLANATION

Sector boundary

Properties owned or controlled by aggregate producers

N

# Aggregate Resource Sectors
## Stockton–Lodi P–C Region

By
Laurel S. Jensen and Michael A. Silva

1988

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TRACY QUADRANGLE

SPECIAL REPORT 160 PLATE 19R

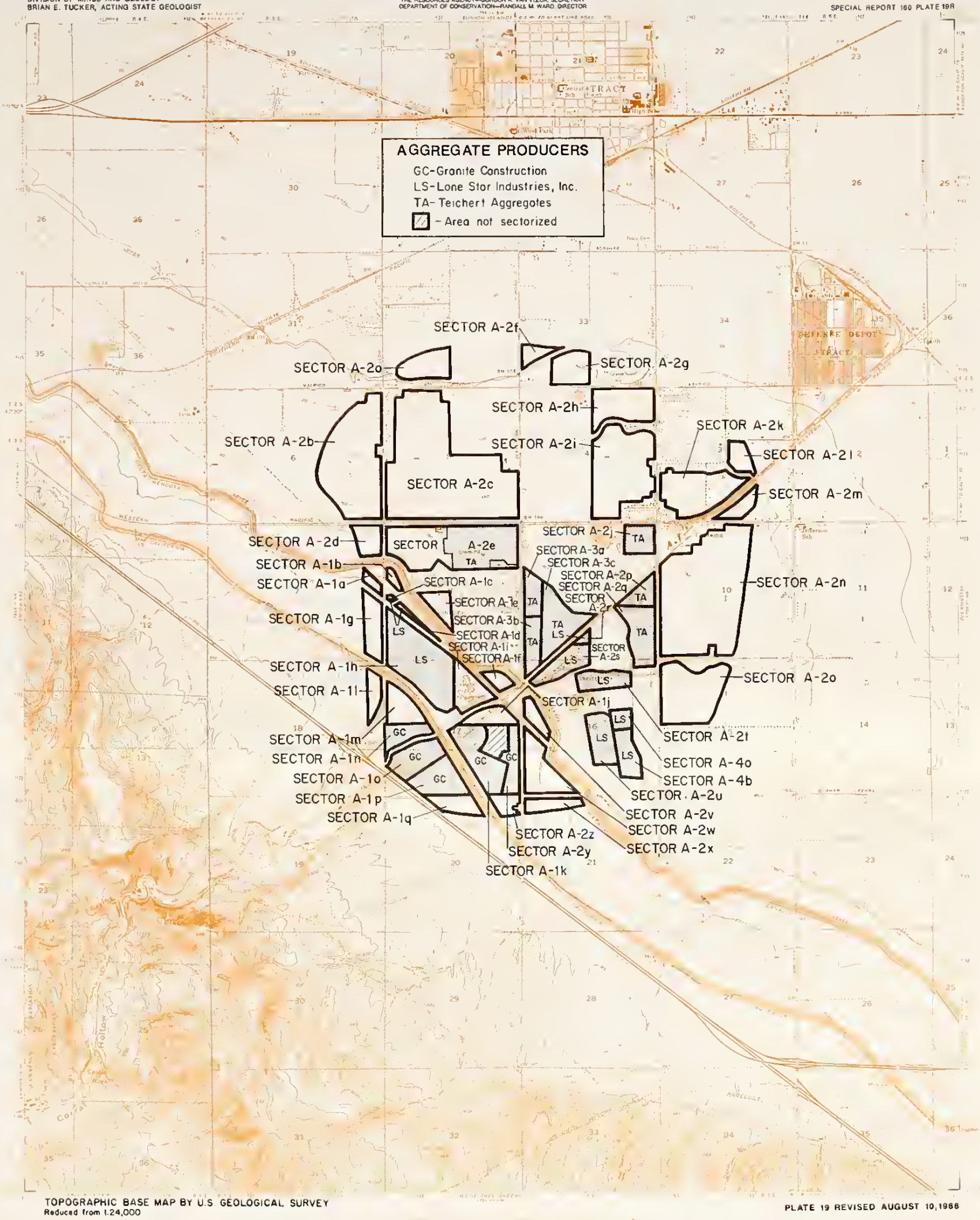


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PLATE 19 REVISED AUGUST 10, 1988

TRACY, CALIF.

EXPLANATION

Sector boundary

Properties owned or controlled by aggregate producers

N

# Aggregate Resource Sectors
## Stockton–Lodi P–C Region

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SPECIAL REPORT 160
PLATE 25

## EXPLANATION

| | | | |
|---|---|---|---|
| QUATERNARY | RIVER CHANNEL ALLUVIUM | Q | Recent river deposits of sand, silt & gravel |
| | MODESTO FM | Qm | Arkosic alluvium of gravel, sand & silt |
| | RIVERBANK FM | Qr | Arkosic alluvium, primarily sand with pebbles, gravel & some interbedded fine sand and silt |
| | TURLOCK LAKE FM | Qtl | Arkosic alluvium, mostly fine sand, silt and clay with some pebbles of granitic and metamorphic rocks |
| TERTIARY | LAGUNA FM | Tl | Arkosic alluvium, gravel, sand and silt; pebbles of quartz and metamorphic fragments |
| | MEHRTEN FM | Tm | Andesitic conglomerate, sandstone, siltstone, and claystone |

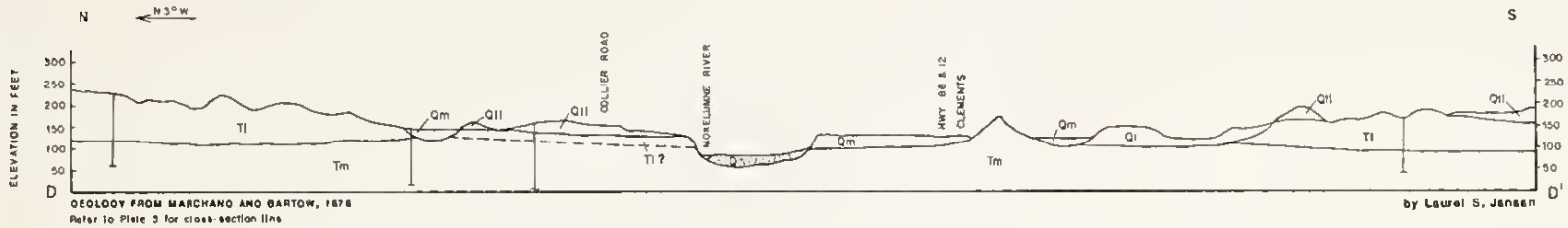
VERTICAL EXAGGERATION 10:1
SCALE IN FEET
0 2000

## SYMBOLS

Geologic units suitable for use as PCC-grade aggregate (MRZ-2 areas)

Geologic contact; dashed where inferred

Drill hole; indicates approximate depth and location; wavy cross-arm denotes bottom of hole is below cross-section limit




GEOLOGY FROM MARCHAND AND BARTOW, 1976
Refer to Plate 3 for cross-section line

by Laurel S. Jensen

GENERALIZED GEOLOGIC CROSS-SECTION ACROSS THE MOKELUMNE RIVER NEAR CLEMENTS (D-D')

# MINERAL LAND CLASSIFICATION OF PORTLAND CEMENT CONCRETE AGGREGATE IN THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

by

Laurel S. Jensen and Michael A. Silva

1988

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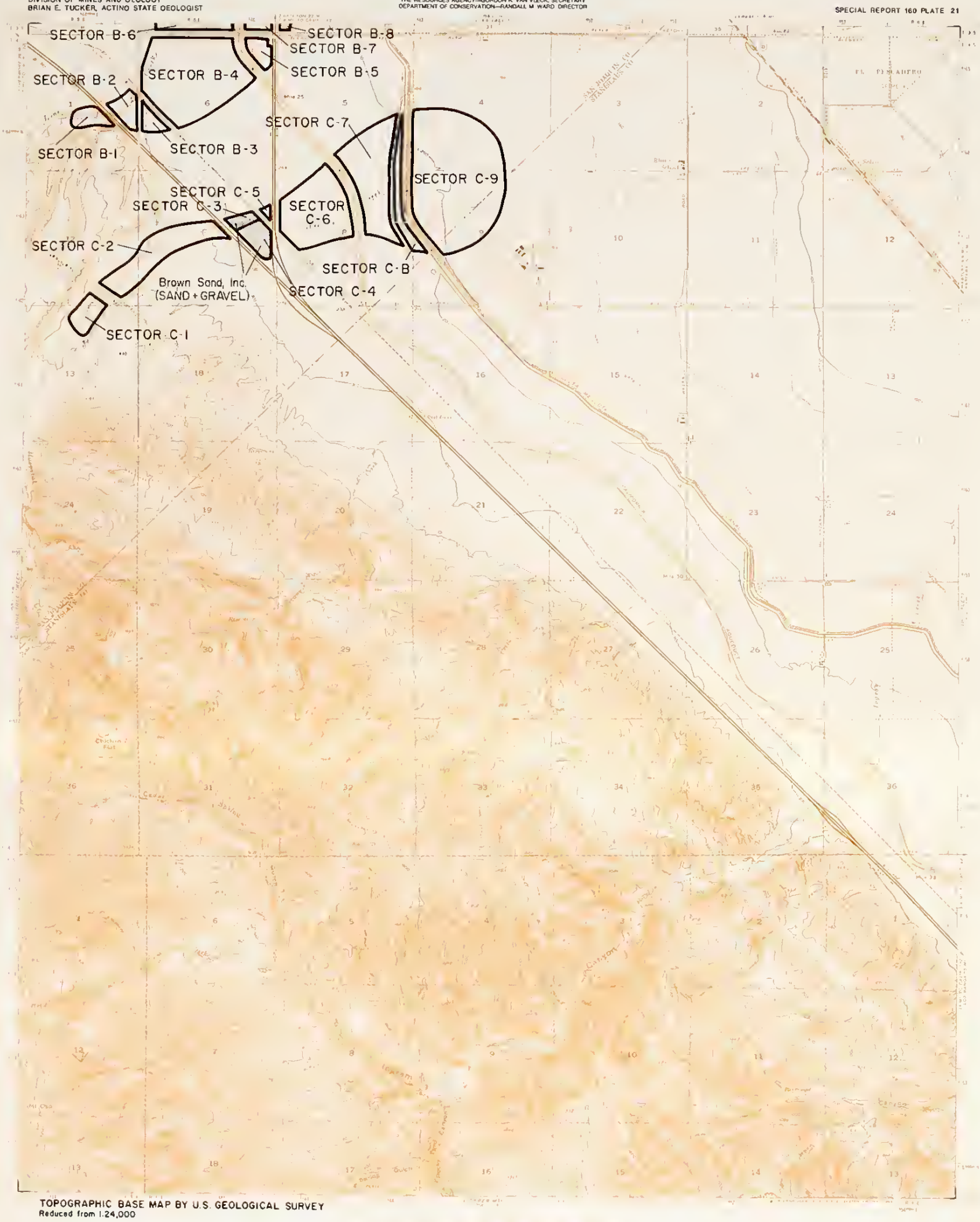
SOLYO QUADRANGLE
SPECIAL REPORT 160 PLATE 21

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SOLYO, CALIF

EXPLANATION

Sector boundary

Properties owned or controlled by aggregate producers

N

# Aggregate Resource Sectors
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SPECIAL REPORT 160
PLATE 22

## EXPLANATION

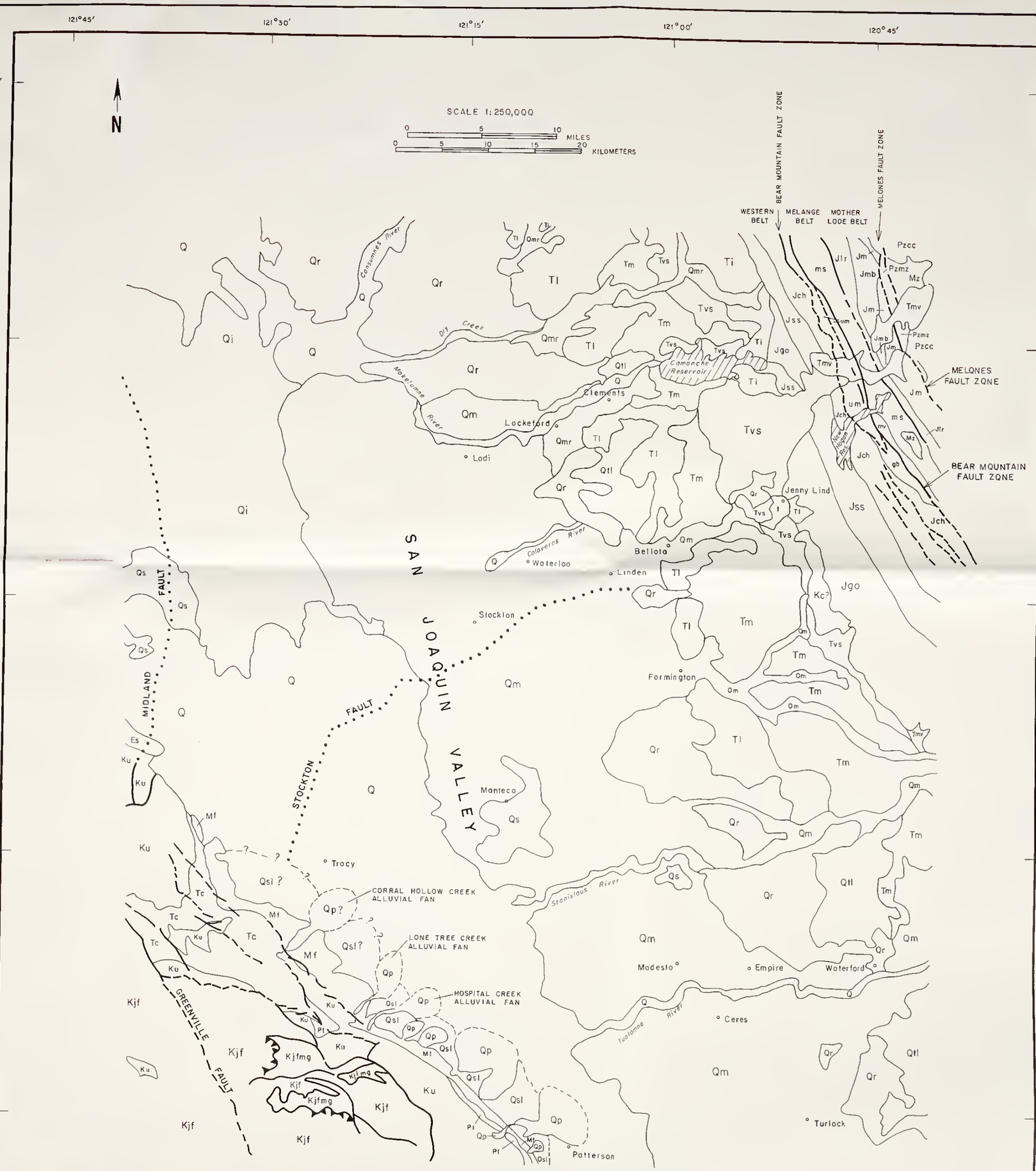
| Western Margin | San Joaquin Valley | Eastern Margin | Epoch or Period |
|---|---|---|---|
| Q Recent stream & basin deposits | Q Recent stream & basin deposits | Q Recent stream and basin deposits | **HOLOCENE** |
| Qp Patterson Alluvium; Coarse- to fine-grained stream, fan, and mud-flow deposits | Qt Intertidal deposits; Soft mud and peat deposited in marshes, swamps, and waterways | t Dredge tailings | |
| | Qs Windblown sand | | |
| Qsl San Luis Ranch Alluvium; Fine- to coarse-grained fan, mudflow, terrace, and floodplain deposits; Los Banos Alluvium; Coarse-grained terrace, pediment, and fan deposits | | Qmr Qm Modesto Formation; Arkosic alluvium of gravel, sand and silt; Qr Riverbank Formation; Arkosic alluvium, primarily sand with pebbles, gravel and interbedded fine sand and silt | **PLEISTOCENE** |
| | | Qtl Turlock Lake Formation; Arkosic alluvium, mostly fine sand, silt and clay with some pebbles of granitic and metamorphic rocks (Corcoran Clay member) | |
| Mf Carbona Formation & Qro Loma Formation; Plio-Miocene fanglomerate deposits, conglomerate, sandstone, siltstone | | Tl Laguna Formation; Arkosic alluvium, gravel, sand and silt; pebbles of quartz and metamorphic fragments | **PLIOCENE** |
| Tc San Pablo Group; Marine sedimentary rocks — sandstone, mudstone, siltstone, shale with minor tuff (Neroly and Cierbo Formations) | | Tm Mehrten Formation; Plio-Miocene, Andesitic conglomerate, sandstone, siltstone, and claystone; nonmarine | **MIOCENE** |
| | | Tmv Mehrten and Valley Springs Formations | |
| | | Tvs Valley Springs Formation; Rhyolitic tuff; sandstone, siltstone, claystone and conglomerate; nonmarine | |
| | | | **OLIGOCENE** |
| Es Kreyenhagen Formation; Sandstone, siltstone, mudstone, and diatomaceous shale; marine; Domengine Sandstone; Sandstone, mudstone, siltstone, lignite, and shale; marine; Meganos Formation; Sandstone, mudstone, minor conglomerate and coquina; marine | | Ti Ione Formation; Quartzose sandstone interbedded with kaolinitic clay | **EOCENE** |
| Pt Tesla Formation; Eocene-Paleocene, Quartzose sandstone, carbonaceous shale and siltstone; marine | | | |
| | | | **PALEOCENE** |
| Ku Moreno Formation; Organic shale, siltstone and sandstone; marine; Panoche Formation; Sandstone, shale, siltstone, and conglomerate lenses; marine | | Kc? Chico Formation? Sandstone, shale, siltstone, and conglomerate; marine | **CRETACEOUS** |
| Kjf Franciscan Complex; Undifferentiated melange, metagraywacke, argillite, chert, greenstone, metaigneous, shale, conglomerate, serpentinized ultramafic rocks | | | |
| Kjfmg Franciscan Complex; Metagraywacke and argillite | | | |
| | | | **JURASSIC** |
| | | Mz Mesozoic dioritic and granitic rocks | |

### Sierra Nevada Foothills System

| Western Belt | Melange Belt | Mother Lode Belt |
|---|---|---|
| Jch Copper Hill Volcanics; Metamorphosed mafic pyroclastic rocks | mv Metavolcanic rocks | Jm Mariposa Formation; Slate, meta-graywacke & metaconglomerate |
| Jss Salt Springs Slate; Gray slate, mica schist | ms Metasedimentary rocks; gb Gabbroic rocks | Jmb Brower Creek Volcanics; Mafic flows & pyroclastic rocks |
| Jgo Gopher Ridge Volcanics; Metamorphosed mafic to felsic pyroclastic rocks | | Jlr Logtown Ridge Formation; Metamorphosed mafic breccias, flows, pyroclastic and volcaniclastic rocks |
| um Ultramafic rocks; | um Ultramafic rocks | |
| | | **PALEOZOIC** |
| | | Pzmz Metamorphosed rock of unknown age; Greenschist and phyllitic rocks |
| | | Pzcc Calaveras Complex; Chert, argillite, and slate |

### SYMBOLS

- Geologic contacts
- Approximate geologic contacts
- Faults
- Approximate fault line
- Inferred fault
- Thrust fault




Geology compiled from: Bortugno, Wagner, and McJunkin, 1988, Wagner, Jennings, Bedrossian, and Bortugno, 1981

GENERALIZED GEOLOGIC MAP OF THE STOCKTON-LODI AREA

# MINERAL LAND CLASSIFICATION OF PORTLAND CEMENT CONCRETE AGGREGATE IN THE STOCKTON-LODI PRODUCTION-CONSUMPTION REGION

1988

by Laurel S. Jensen and Michael A. Silva

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DEPARTMENT OF CONSERVATION-RANDALL M. WARD, DIRECTOR

SPECIAL REPORT 160
PLATE 23

Deposits classified as MRZ-2.

| AGE | | | WESTERN MARGIN | SAN JOAQUIN VALLEY | EASTERN MARGIN |
|---|---|---|---|---|---|
| CENOZOIC | QUATERNARY | HOLOCENE | Q, Qp<br>O Recent stream & basin deposits<br>Op Patterson Alluvium; Coarse- to fine-grained stream, fan, and mudflow deposits | Q, Qi, Qs<br>O Recent stream & basin deposits<br>Oi Intertidal deposits; Salt mud and peat deposited in marshes, swamps, and waterways<br>Os Windblown sand | Q, t<br>O Recent stream and basin deposits<br>t Dredge tailings |
| | | PLEISTOCENE | Qsl, Qsl<br>Osl San Luis Ranch Alluvium; Fine- to coarse-grained fan, mudflow, terrace, and floodplain deposits<br>Los Banos Alluvium; Coarse-grained terrace, pediment, and fan deposits<br>Tulare Formation; (not exposed in area) Fine- to coarse-grained floodplain, fan, and terrace deposits; includes Corcoran Clay member | Interfingering of eastern and western margin formations | Qm<br>Om Modesto Formation; Arkosic alluvium of gravel sand and silt<br>Qr<br>Or Riverbank Formation; Arkosic alluvium, primarily sand with pebbles, gravel and interbedded fine sand and silt<br>Qtl<br>Otl Turlock Lake Formation; Arkosic alluvium, mostly fine sand, silt and clay with some pebbles of granitic and metamorphic rocks (Corcoran Clay member)<br>North Merced Gravels; (not identified in study area) Highly weathered coarse gravel and sand primarily derived from andesitic and metamorphic rocks |
| | TERTIARY | PLIOCENE | Mf<br>Mf Carbona Formation & Oro Loma Formation; Plio-Miocene fanglomerate deposits, conglomerate, sandstone, siltstone | | Tl<br>Tl Laguna Formation; Arkosic alluvium, gravel, sand and silt, pebbles of quartz and metamorphic fragments |
| | | MIOCENE | Tc<br>Tc San Pablo Group; Marine sedimentary rocks - sandstone, mudstone, siltstone, shale with minor tuff (Neroly and Cierbo Formations)<br>Tvs Valley Springs Formation; (exposed south of the area) Rhyolitic tuff, sandstone, siltstone, claystone, and conglomerate; nonmarine | | Tm<br>Tm Mehrten Formation; Plio-Miocene, Andesitic conglomerate, sandstone, siltstone, and claystone; nonmarine<br>Tvs<br>Tvs Valley Springs Formation; Rhyolitic tuff, sandstone, claystone and conglomerate; nonmarine |
| | | OLIGOCENE | ?<br>Sandstone of Poverty Flat; (not exposed in study area) Basal conglomerate, conglomeratic sandstone, sandstone, and claystone. | | ? |
| | | EOCENE | Es, Es, Es<br>Es Kreyenhagen Formation; Sandstone, siltstone, mudstone, and diatomaceous shale; marine<br>Domengine Sandstone; Sandstone, mudstone, siltstone, lignite, and shale; marine<br>Meganos Formation; Sandstone, mudstone, minor conglomerate and coquina; marine<br>Pt<br>Pt Tesla Formation; Eocene-Paleocene, Quartzose sandstone, carbonaceous shale and siltstone; marine | | ?<br>Auriferous Gravels (not shown on geologic map) River channel and bench gravel, pebbles, cobbles, and boulders of pre-Tertiary basement rock types, in places predominantly quartzose<br>Ti<br>Ti Ione Formation; Quartzose sandstone interbedded with kaolinitic clay |
| | | PALEOCENE | ? | | |
| | | | Ku<br>Ku Moreno Formation; Organic shale, siltstone and sandstone; marine<br>Ku<br>Panoche Formation; Sandstone, shale, siltstone, and conglomerate lenses; marine | | Kc?<br>Kc? Chico Formation? Sandstone, shale, siltstone, and conglomerate; marine |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MESOZOIC | CRETACEOUS | | | Kjf & Kjfmg | Kjf Franciscan Complex; Undifferentiated melange, metagraywacke, argillite, chert, greenstone, metaigneous, shale, conglomerate, serpentinized ultramafic rocks<br>Kjfmg Franciscan Complex; Metagraywacke and argillite | Mz | Mesozoic dioritic and granitic rocks (not shown on geologic map) |
| | JURASSIC | | | | | SIERRA NEVADA FOOTHILLS SYSTEM<br>**Western Belt**<br>Jch Copper Hill Volcanics; Metamorphosed mafic pyroclastic rocks<br>Jss Salt Springs Slate; Gray slate, mica shist<br>Jgo Gopher Ridge Volcanics; Metamorphosed mafic to felsic pyroclastic rocks<br>**Melange Belt**<br>mv Metavolcanic rocks<br>ms Metasedimentary rocks<br>gb Gabbroic rocks<br>**Mother Lode Belt**<br>Jm Mariposa Formation; Slate, metagraywacke & metaconglomerate<br>Jmb Brower Creek Volcanics; Mafic flows & pyroclastic rocks<br>Jlr Logtown Ridge Formation; Metamorphosed mafic breccias, flows, pyroclastic and volcaniclastic rocks | | |
| PALEOZOIC | | | | | um Ultramafic rocks<br>um Ultramafic rocks<br>Pzmz Metamorphosed rock of unknown age; Greenschist and phyllitic rocks<br>Pzcc Calaveras Complex; Chert, argillite, and slate | | |

(Compiled from: Marchand and Allwardt, 1981; Lettis, W.R., 1982; and Raymond, L.A., 1969).

Compiled by Laurel S. Jensen. See Plate 22 for Generalized Geologic Map.

## GENERALIZED GEOLOGIC COLUMN OF THE CENTRAL SAN JOAQUIN VALLEY

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by
Laurel S. Jensen and Michael A.Silva
1988

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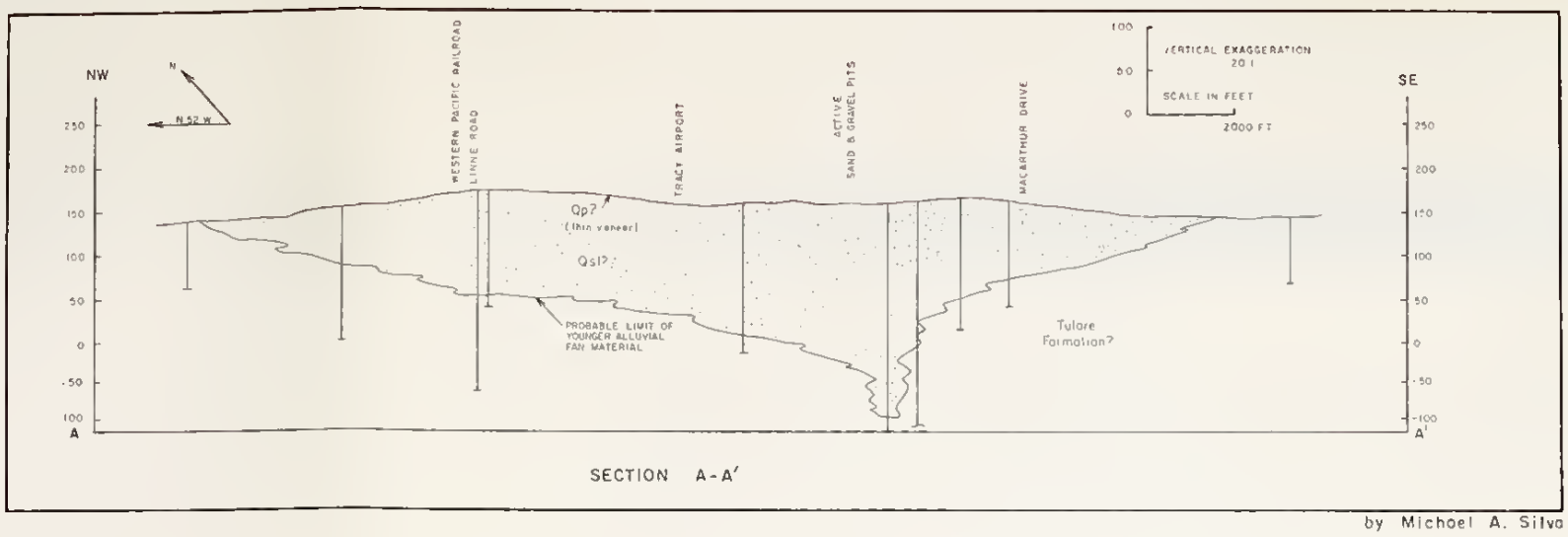
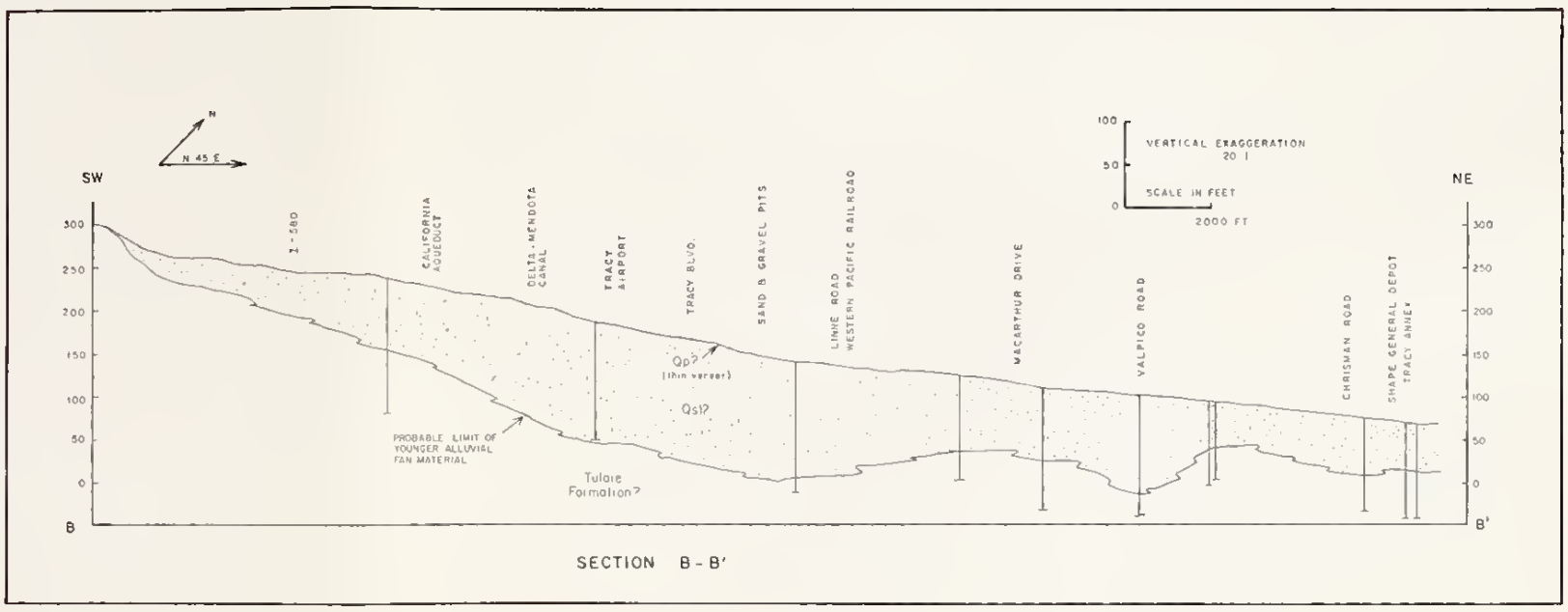


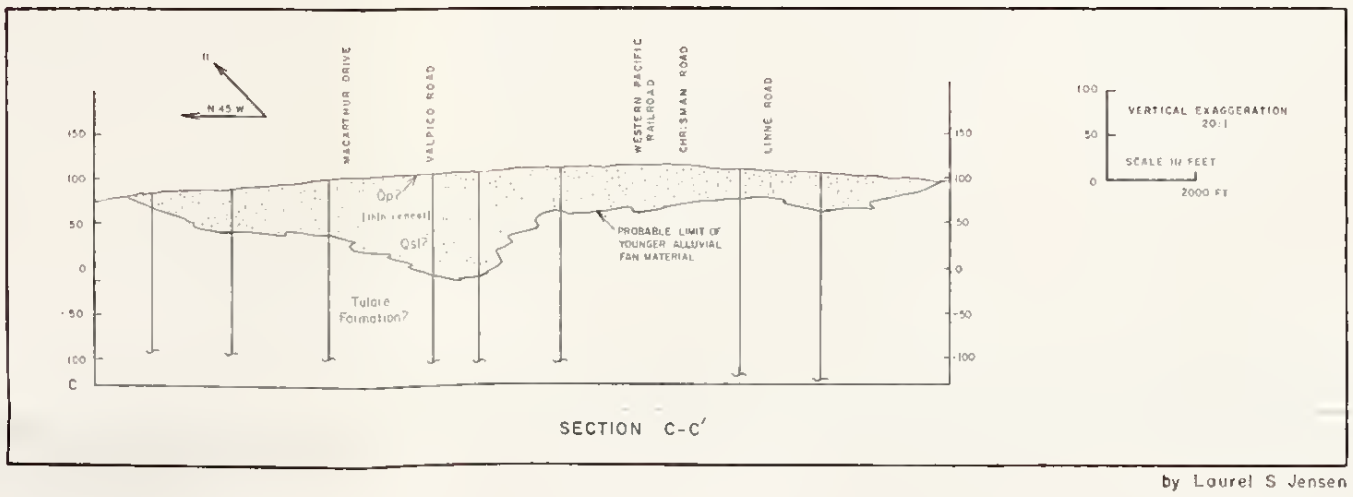

SECTION A-A'

by Michael A. Silva




SECTION B-B'

by Laurel S. Jensen




SECTION C-C'

by Laurel S Jensen

**EXPLANATION**

| | | | |
|---|---|---|---|
| QUATERNARY | Qp | Patterson Alluvium | Coarse- to fine-grained stream, fan, and mudflow deposits |
| | Qsl | San Luis Ranch Alluvium | Fine- to coarse-grained fan, mudflow, terrace, and floodplain deposits |
| | | Los Banos Alluvium | Coarse-grained terrace, pediment, and fan deposits |
| TERTIARY | | Tulare Formation | Fine- to coarse-grained floodplain, fan, and terrace deposits, includes Corcoran Clay member |

**SYMBOLS**

Geologic units suitable for use as PCC-grade aggregate (MRZ-2 areas)

Drill hole, indicates approximate depth and location, wavy cross-arm indicates bottom of hole is below cross-section limit

GENERALIZED GEOLOGIC CROSS-SECTIONS OF THE CORRAL HOLLOW CREEK ALLUVIAL FAN IN TRACY
(Refer to Plate 14 for section lines)

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