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November 2005, Division of Research and Innovation

HIGHWAY RESEARCH REPORT

CORRELATION OF SEISMIC VELOCITIES WITH EARTHWORK FACTORS

FINAL REPORT

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

CA-HY-MR-2103-4-72-37

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration November, 1972

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

November 1972

Final Report
M&R 632103

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

CORRELATION OF SEISMIC VELOCITIES

WITH EARTHWORK FACTORS - FINAL REPORT

Travis Smith
Principal Investigator

Marvin McCauley
Ronald Mearns
Co-Investigators

Karl Baumeister
Analysis & Report

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

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ACKNOWLEDGEMENTS

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This investigation was made in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Agreement Number F-07-92.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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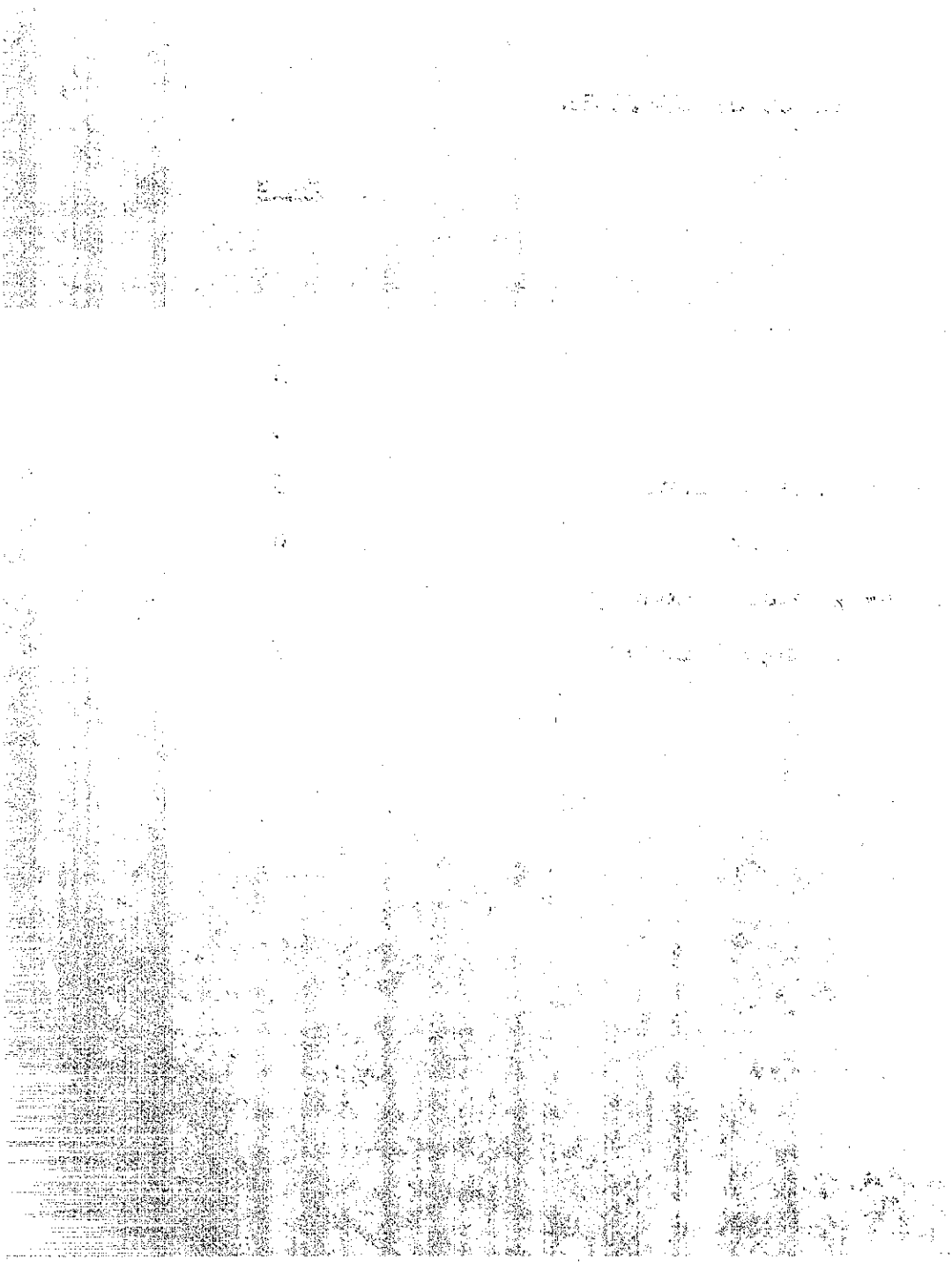

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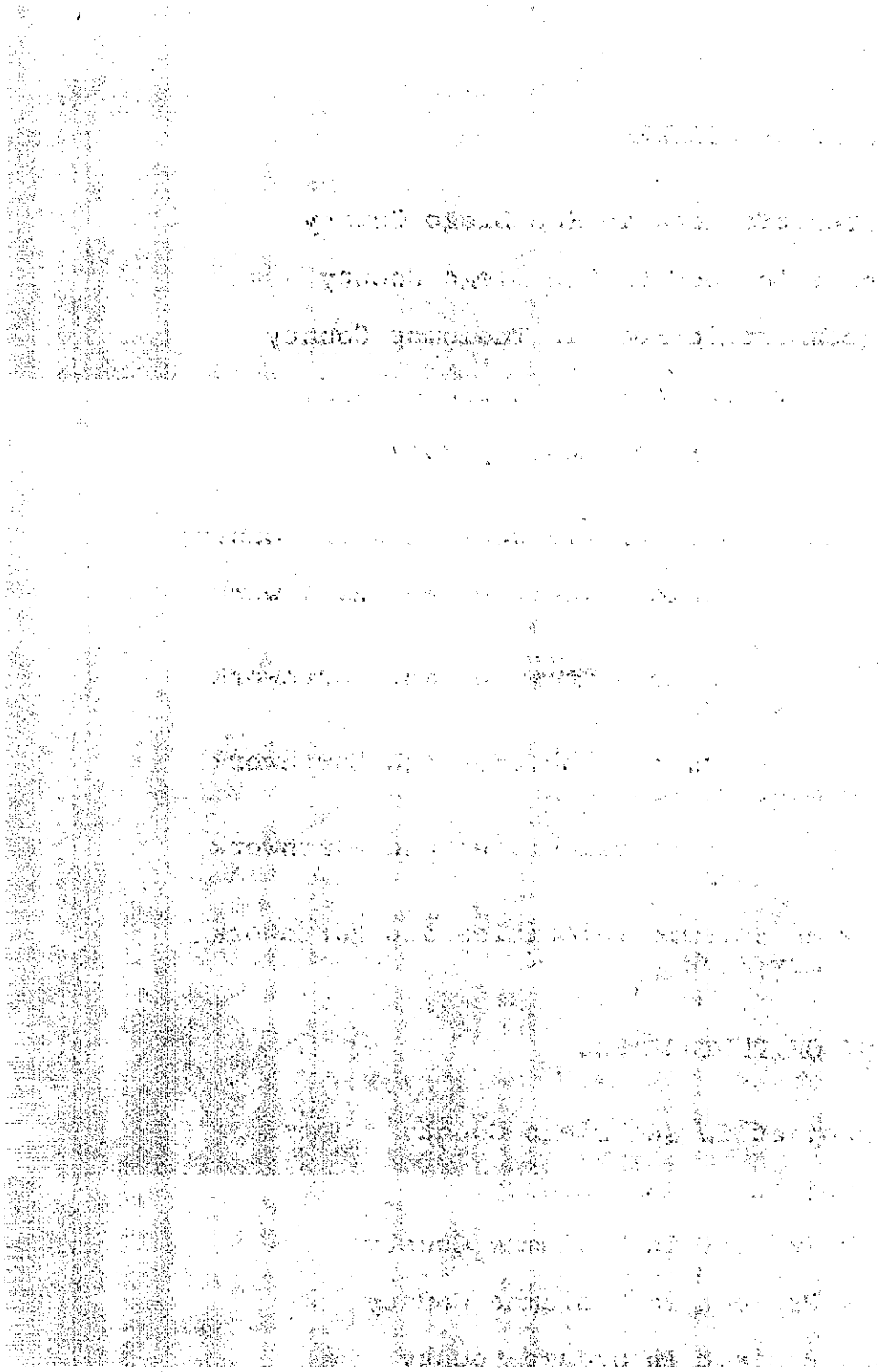

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Introduction

The principal objectives of this research study are to:

(1) Determine if earthwork factors can be correlated to seismic velocities.

(2) Determine the relationship between field earthwork factors and design earthwork factors.

(3) Determine which construction procedures had the greatest influence on final earthwork quantities.

A report dated June 1971 titled "Correlation of Seismic Velocities with Earthwork Factors," described the study of a construction project in San Diego County and correlated seismic velocities to field earthwork factors for granitic rocks. (See Figures 1 and 2).

Another report dated January 1972, titled "Correlation of Seismic Velocities with Earthwork Factors, Interim Study #2," described a study of a construction project in Tuolumne County on Route 120 between Chinese Camp and the Tuolumne River. The study correlated seismic velocities and field earthwork factors for metasedimentary rock, metaigneous rock and serpentine. (See Figures 3 and 4).

A third report, dated May 1972, titled "Correlation of Seismic Velocities with Earthwork Factors, Interim Study #3," described a study of a construction project in Orange County on Route 91 between 1.7 miles east of Anaheim and the Riverside County line. (See Figure 5).

A minor supplementary study was made on Road 06-Ker-178 PM 33.4/37.8 during October 1971. This study was made on a construction project in granitic rock. The findings were combined with results included in the first interim report in preparing the discussion of granitic rocks for this report.

An important objective of a large earthwork project is to place into the embankment all the material that is excavated. This would be possible if the effect of varying types of materials, subsidence of original ground, different construction methods, degree of compaction, unforeseen deviations from designed slopes, and shrinkage or swell of the excavated material were predictable.

The increase or decrease in volume of the excavated material can be taken into account by applying an earthwork factor. The earthwork factor is a ratio expressing the number of cubic yards of embankment resulting from one cubic yard of excavation. An earthwork factor less than 1.0 indicates a shrinkage; an earthwork factor greater than 1.0 indicates a swell.

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District personnel involved in determining the design earthwork factor in all eleven highway districts were queried on present procedures for determining earthwork factors.

The majority of the districts indicated that the principal methods used by each to derive design earthwork factors are materials investigations, records of past construction projects in similar materials, and experience. One district determines design earthwork factors by using a ratio of the percent "relative compaction" of the material to be excavated to an estimated percent relative compaction of the same material compacted into the embankments.

In recent years the California Division of Highways has made increasing use of shallow seismic refraction studies for design purposes. By the use of this method, under favorable circumstances, it is possible to obtain a relatively clear picture of the subsurface conditions.

In 1966 and 1967, two of the California Highway Districts, working independently, attempted to correlate seismic velocities with earthwork factors in granitic rock. Based upon a review of the data obtained, it was determined that there was a reasonable correlation. Since this evaluation, this department has been providing information for earthwork factors from seismic velocities on granitic rock to all districts upon request.

The demand for this type of information has increased rapidly, and we are now receiving requests for earthwork factor estimates in a variety of rock types. This study provides information needed to evaluate the validity of earthwork factors obtained from seismic refraction velocities on igneous, sedimentary, and metamorphic rock.

A Bison Model 1570 signal enhancement seismograph instrument was used for determining the seismic velocities in the study of granitic rock. The impact used to generate shock waves was a 10-lb. sledgehammer striking an aluminum plate. The Electro-Tech 12-channel seismic instrument was used in the other studies, the energy being supplied with explosive charges.

Conclusions and Recommendations

There was found to be a reasonable correlation between seismic velocity and earthwork factor for all the types of rock studied. Graphs were developed showing this relationship. (See Figures 7 through 11).

For granitic material there appeared to be a range of values (See Fig. 7) between a minimum and maximum earthwork factor, the maximum variation being plus or minus 3% from a median curve.

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The apparent deviation may be explainable through differences in compaction and/or simply the greater amount of data allowing more opportunity for deviation. Though this curve is plotted from a greater quantity of data, the seismic velocities in the projects used were generally less than 8000 fps. Therefore, some upward extrapolation of the curve may be necessary until more data in the higher velocity ranges can be obtained.

The curves in Figures 8, 9 and 10 show the graphs for three types of metamorphic rock: metasedimentary, metaigneous and serpentine. The metasedimentary rock consisted of slate and metasandstone. There appears to be a close agreement between the curve for metaigneous rock and the lower limit curve for granitic rock. The curve for serpentine is roughly parallel to that for metasedimentary rock, but gives earthwork factors that are about 5% higher for similar seismic refraction velocities.

Figure 11 shows the curve for sedimentary rock (sandstone with some shale) which is colinear with the curve for metasedimentary rock due to the close similarity in seismic characteristics. The velocity range for the sedimentary rock was between 1,000 and 3,500 fps while the range for metasedimentary rock was 2,000 to 10,000 fps.

The foregoing comparisons illustrate the important fact that the type of rock affects the shape and slope of the seismic velocity versus earthwork factor curve.

In all the relationships derived between seismic velocity and earthwork factor, settlement of the area under the embankment was neglected as it was considered to be of comparatively minor significance. Therefore, settlement does not need to be considered when using these graphs unless it is thought to have a very significant effect on the earthwork factor.

Based on information obtained in this study, the relationship between seismic velocity and earthwork factor is nonlinear and varied with the type of material. The rate of increase of earthwork factor for a given increase in seismic velocity is much greater when a material is soft and inelastic (in the lower velocity ranges) than when it is extremely hard and dense (in the upper velocity ranges).

A comparison of field earthwork factors versus design earthwork factors for the projects studied is as follows:

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		Design EWF	Emb.	Exc.	Field EWF
Interim Study #1 Granitic Rock (San Diego)	Area 1:	1.15	1,745,000	1,396,000	1.25
	Area 2:	1.10	1,896,000	1,663,000	1.14
	Area 3:	1.00	2,703,000	2,526,000	1.07
Interim Study #2 Metamorphic Rock		0.95	746,000	672,000	1.11
Interim Study #3 Sedimentary Rock		0.91	6,633,000	6,658,000*	1.00
Supplementary Study Granitic Rock (Kern Canyon)		1.12	1,824,000	1,585,000	1.15

*Estimated excavated material used for aggregate base has been deducted

The greatest difference, approximately 17%, occurred in the metamorphic rock. The smallest difference, approximately 2.6%, occurred in the supplementary study of granitic rock in Kern County. The designers on this project had consulted with the Resident Engineers on three adjacent construction projects in the same material, and studied the seismic data and materials tests in arriving at a design earthwork factor.

Construction practices can have a considerable effect on field earthwork factor. The practices that have the greatest influence on field earthwork factor are those that affect the particle size of the excavated material and those that affect the degree of compaction of the embankment.

The method of excavation (i.e., ripping, blasting, etc.) can have an effect on the earthwork factor inasmuch as it affects maximum rock size and grading. The greater the maximum size of rock, the smaller the earthwork factor, assuming relatively uniform grading. Where relatively large rock from one excavation and relatively small rock from another excavation are mixed in an embankment, the earthwork factor should be smaller than if they are placed in separate locations. The greater the range in grading, assuming relatively uniform grading, the smaller the earthwork factor.

The method of compaction has a considerable effect on the earthwork factor. The greater the relative compaction, the smaller is the resulting earthwork factor.

Even when embankments are built to grade, loss of rock by rolling down the slope or large rocks protruding out of the slope surface can have an effect on calculated field earthwork factors if they

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are not taken into account. Fill slopes that deviate from those shown in the plans can influence calculated field earthwork factors if they are not considered.

Overexcavation or slides and underexcavation can have an effect on the calculated field earthwork factor if they are not accounted for.

Because of the many variables involved, it is improbable that an exact method can be developed for estimating the design earthwork factor. However, use of seismic data for this purpose appears to show considerable promise in yielding reliable design earthwork factors.

Implementation

It is proposed to distribute this report to the various Highway Districts in order to provide them with the necessary information for determination of design earthwork factors from seismic data.

This Department will provide seismic data to the Districts and will be available to assist District personnel in determining design earthwork factors based on seismic data.

It is proposed that pilot projects be implemented wherein the correlations between seismic data and earthwork factor developed from this study will be used to determine the design earthwork factor on proposed construction projects. These construction projects will then be monitored to determine how closely the field earthwork factor agrees with the design earthwork factor. As data from these projects become available, the seismic velocity versus earthwork factor graphs can be up-dated as required.

Prerequisites for a successful check on this method of analysis are (a) accurate load count information that indicates where excavated material is placed, (b) accurate figures for cut and embankment volumes, (c) a fairly uniform type of material in the areas to be excavated, (d) knowledge of the geologic structure of the material to be excavated, and (e) sufficient seismic refraction data.

JOB SYNOPSIS

Project in Granitic Rock - SAN DIEGO COUNTY

Blasting was required in about 90% of the excavation and transportation was largely by conveyor belt, which handled rocks up to four feet in size. Decomposed granite and "shot" rock were mixed to make a more dense embankment. Compaction was done

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largely by the hauling equipment though two-segmented type rollers were also used. Compaction in the areas that were not too rocky to test averaged 95% versus 90% required.

The plans for this project were divided into three zones, each having its own design earthwork factor. For purposes of comparison, field earthwork factors were calculated for each of the zones from the earthwork quantity sheets.

Cross-sections were taken through the cut areas, and interfaces of the various strata were plotted as per interpretation of seismic refraction data and identified by seismic velocities. The volumes of excavation per stratum were computed for all the cuts. The proportion of excavated material that fell within a certain seismic velocity range could thus be ascertained for any of the three zones.

On this basis, equations were developed using percentage of cut volume in each seismic velocity range as a multiplier for the earthwork factor in that velocity range. The summation of the products of the individual earthwork factors multiplied by the corresponding percentage of material within the velocity ranges can be equated to the field earthwork factor for each of the three zones. This process yielded three simultaneous equations which were solved to determine field earthwork factors corresponding to certain ranges of seismic refraction velocities. A semi-log plot of seismic velocity versus earthwork factor for this project provided the "lower limit" curve in Figure 7. The "upper limit curve" in this graph was provided by a plot of the values determined in the Kern County study. The median curve is plotted halfway between the upper and lower limits. The median curve should be used for estimating design earthwork factors when information is lacking with regard to probable construction methods and their influence on relative compadtion or density of embankment.

Granitic Rock - KERN COUNTY

In the comparative study of granitic rock in Kern County, the cut was made mostly by means of presplitting. Scrapers and trucks were used about equally to move the material. Compaction was accomplished in much the same manner as in San Diego County.

The comparative study in granitic rock in Kern County was analyzed using methods similar to those used in San Diego County. Similar seismic refraction velocities were found to correspond to field earthwork factors that were about 5% higher than those for the San Diego County project. This is indicated by the "upper" and "lower" limit curves in Figure 7. Part of this difference is explainable by the difference in average relative compaction (95% S.D. vs 93% Kern).

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Project in Metamorphic Rock - TUOLUMNE COUNTY

The project in metamorphic rock in Tuolumne County required blasting in much of the area that had metaigneous rock as well as the deeper serpentine and metamorphic rock cuts. Most of the hauling was by scraper although some work was done by trucks and dozers. Most of the compaction was achieved by hauling equipment although segmented type compactors were also used. The areas that were not too rocky to test averaged 94% relative compaction versus 90% required.

The area between the beginning of this project and the Tuolumne River was divided into nine zones for design purposes and each zone was assigned a design earthwork factor. The project map (Fig. 5) shows the limits of the various zones.

A stadia survey was made to accurately determine the volumes of embankment in the waste areas and the volumes of excavation in areas of overexcavation and slides. Excavation and embankment quantities were calculated using data obtained from the stadia survey and from previous surveys.

Field earthwork factors were determined for the various zones by equating the sums of the products of excavation in each zone and their respective earthwork factors to embankment volumes. A comparison of the approximate field earthwork factors in the various zones with the design earthwork factors showed the field earthwork factors to average 16½% higher.

The rock in the various zones was identified by inspection of the cut surfaces and seismic refraction investigations were made alongside the cuts. After separating areas according to rock type, an analysis for each rock type (metasedimentary, metaigneous and serpentine) was made in the same manner as was done on the granitic rock projects and semi-log plots of seismic velocity versus field earthwork factor were developed.

The curve for metaigneous material (Fig. 8) is in very close agreement with the lower limit curve for granitic material. The metasedimentary and serpentine curves (Figures 9 and 10) were approximately parallel but the serpentine gave earthwork factors about 5% higher for the same seismic velocities.

Project in Sedimentary Rock - ORANGE COUNTY

Excavation of the sedimentary rock in the Santa Ana Canyon project was mostly by scrapers although truck trailers and dozers were also used. The rock, mainly sandstone, was generally easily rippable. Compaction was achieved by hauling equipment and 2-axle pneumatic and steel-tired compactors. The average relative compaction was 94% with 90% required.

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The project was contoured and cut volumes computed by means of aerial topography data taken before and after construction. Embankment volumes were computed using the as-designed fill sections (revised as necessary for field changes) superimposed on the original ground as determined from aerial topographic data.

The physical and seismic characteristics of weathered sedimentary and metasedimentary rock were assumed to be similar based on previous experience. Several extrapolations of the curve for metasedimentary rock (Fig. 9) were used as trial curves. Using the seismic velocities and the corresponding excavated volumes, the curve that was found to be most compatible with the seismic data for this project was a straight line downward extrapolation of the metasedimentary rock curve on a semi-log plot.

Figure 11 shows the graph for sedimentary rock between the seismic velocities of 1,000 and 3,500 fps, the range of velocities in the excavated material.

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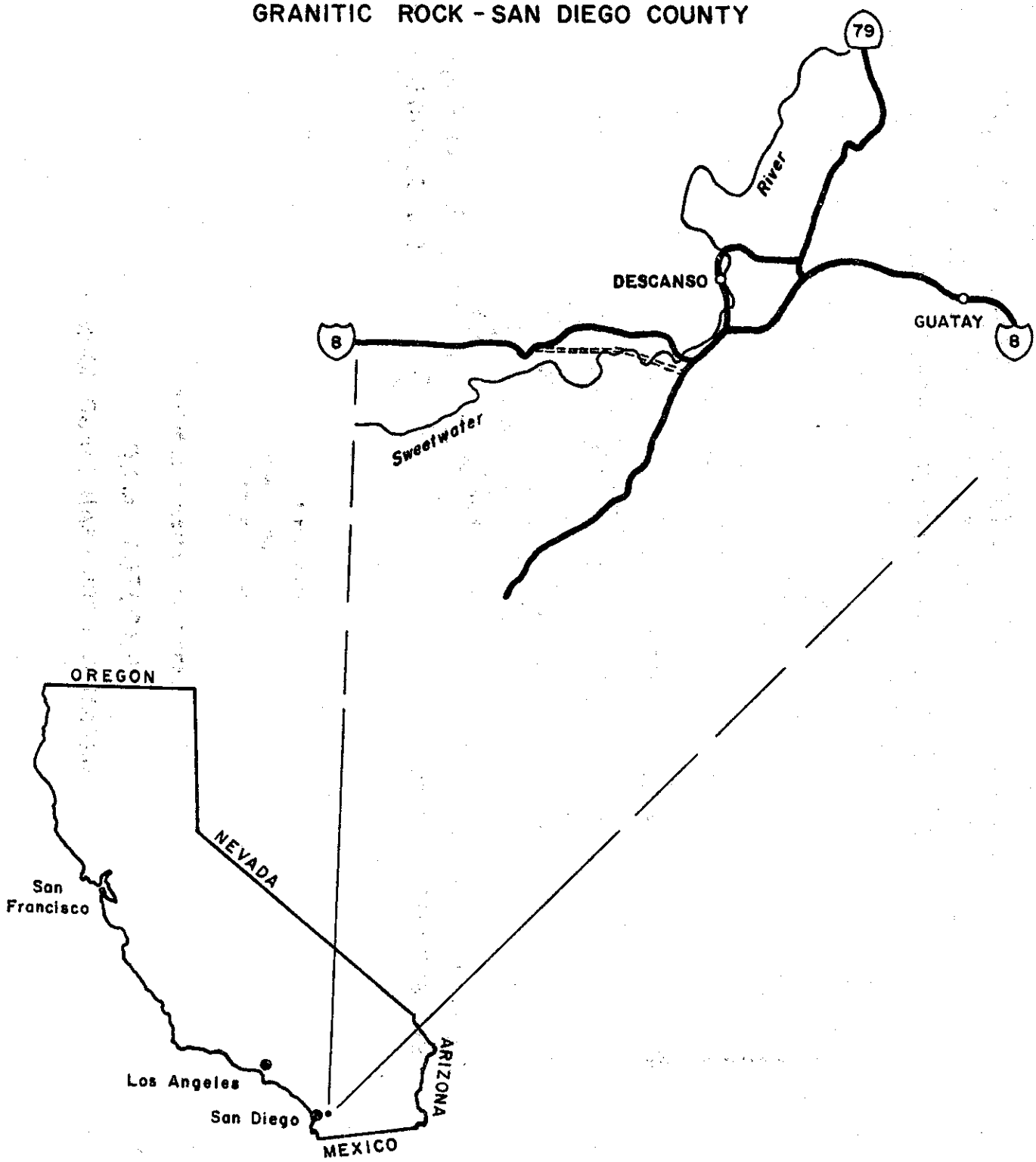
Figure 1

LOCATION MAP

GRANITIC ROCK - SAN DIEGO COUNTY



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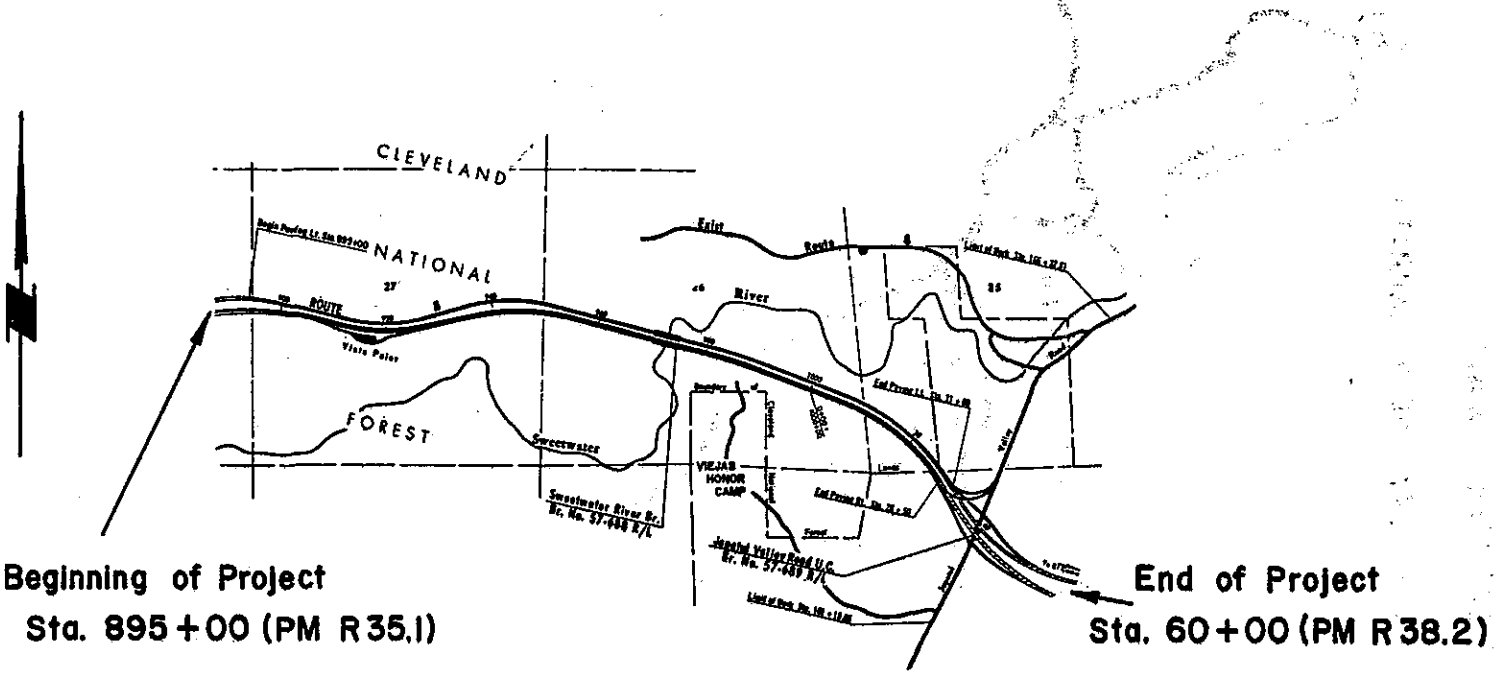
IN SAN DIEGO COUNTY BETWEEN 5.8 MILES EAST OF
WEST VICTORIA DRIVE AT ALPINE AND
0.4 MILE EAST OF JAPATUL VALLEY ROAD



Scale in feet

0 2000 4000

Length of Project = 3.1 miles

Figure 2

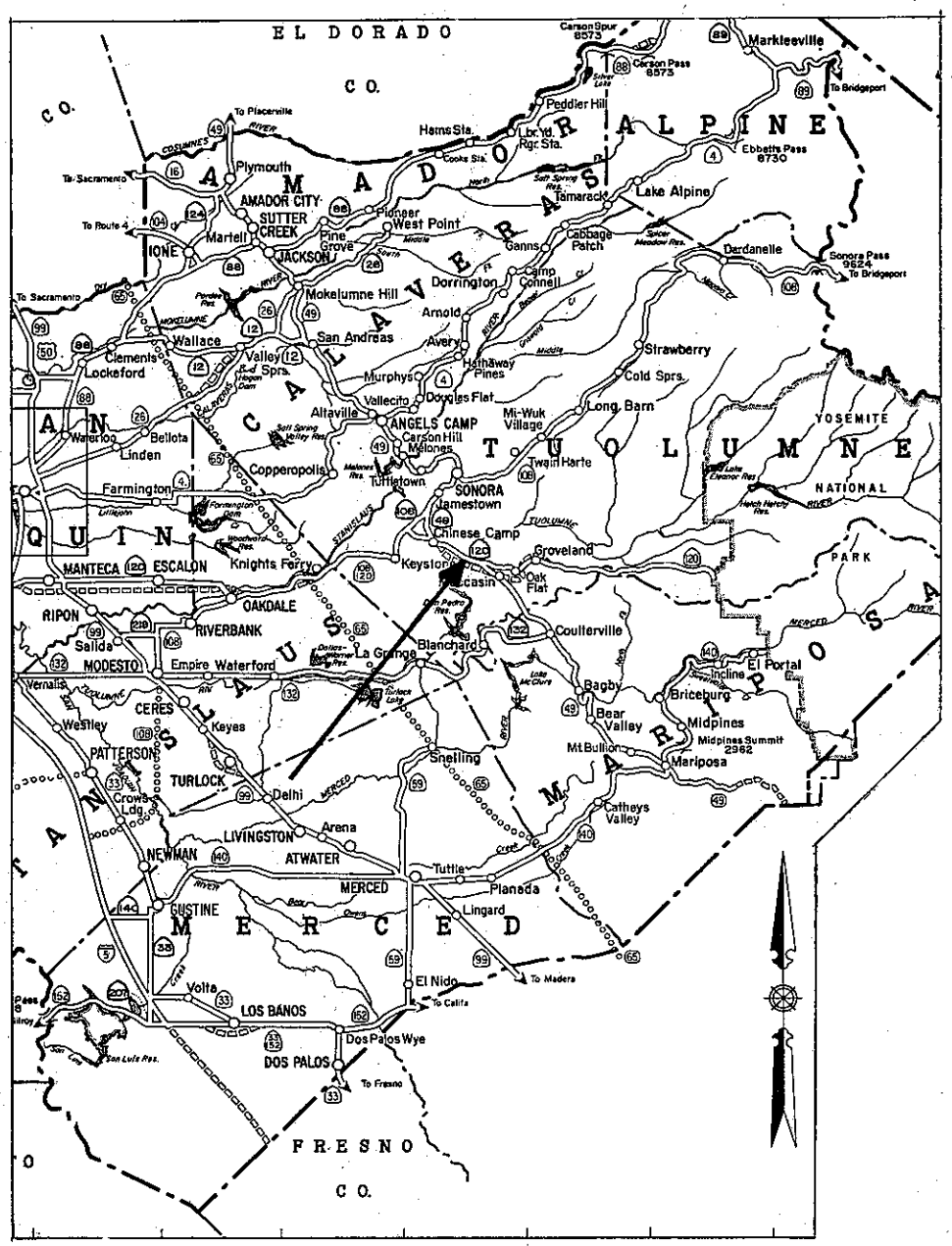
PROJECT MAP

GRANITIC ROCK - SAN DIEGO COUNTY

Figure 3

LOCATION MAP

METAMORPHIC ROCK - TUOLUMNE COUNTY



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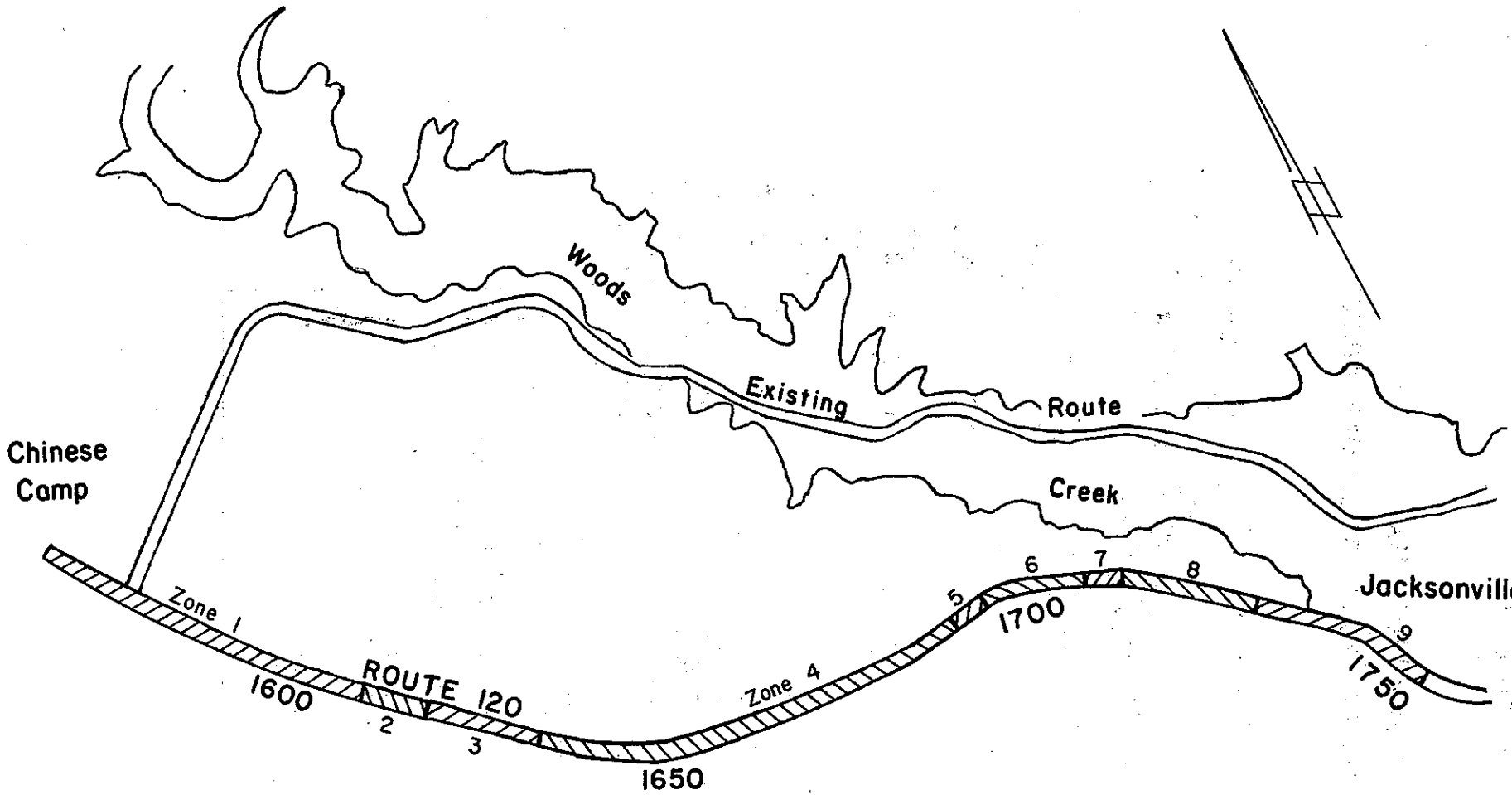


Figure 4

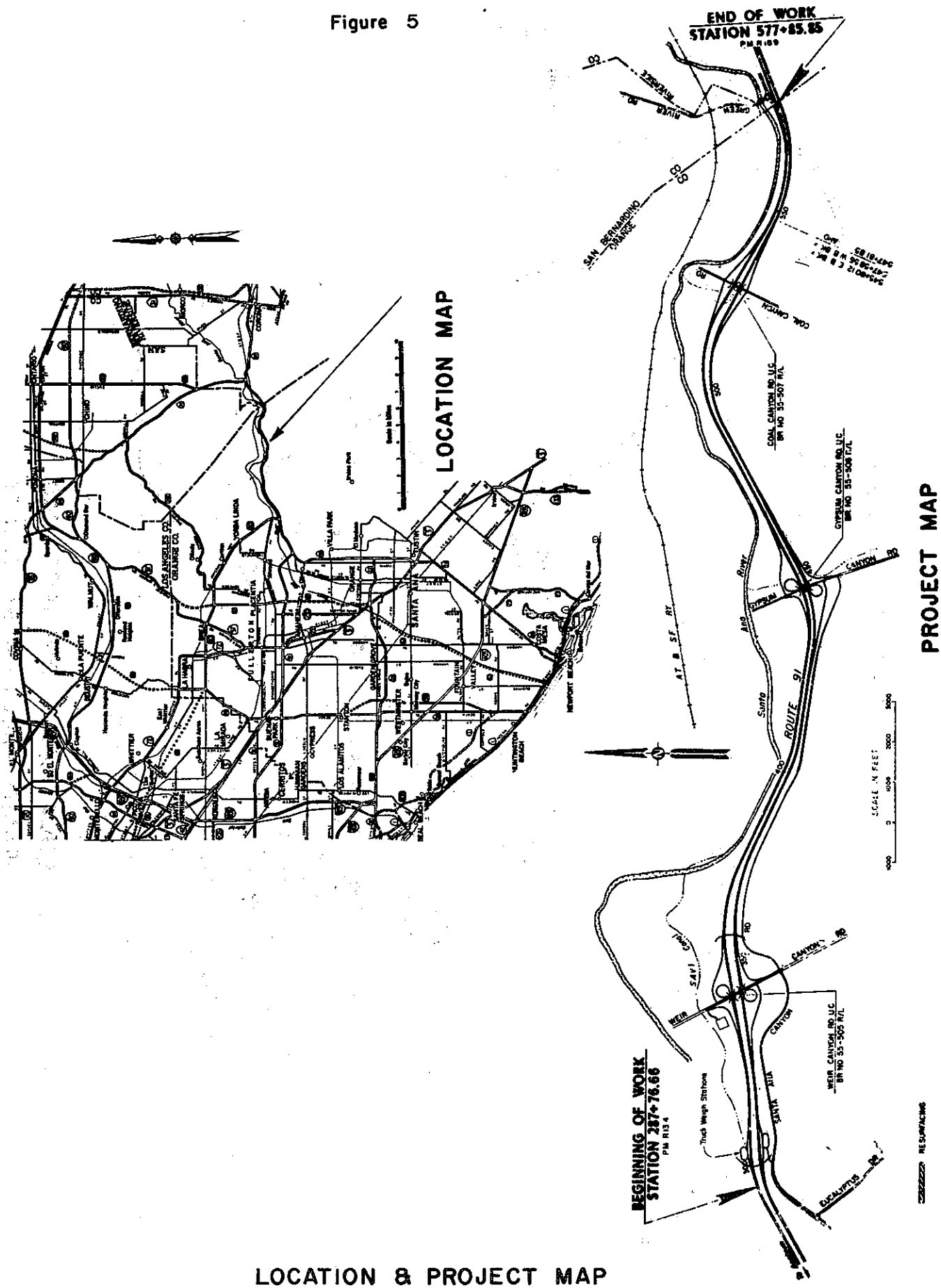
LOCATION & DESCRIPTION OF ZONES:

	LOCATION	GEOLOGICAL DESCRIPTION OF CUTS
ZONE 1	Sta. 1564 - 1610	Serpentine
ZONE 2	Sta. 1610 - 1619	Metaigneous
ZONE 3	Sta. 1619 - 1633	Serpentine with some metaigneous
ZONE 4	Sta. 1633 - 1691	Metaigneous with some serpentine
ZONE 5	Sta. 1691 - 1696	Metasedimentary
ZONE 6	Sta. 1696 - 1709	Metasedimentary
ZONE 7	Sta. 1709 - 1713	Metasedimentary
ZONE 8	Sta. 1713 - 1732	Metasedimentary
ZONE 9	Sta. 1732 - 1753	Metaigneous with some sedimentary

METAMORPHIC ROCK
TUOLUMNE CO.

PROJECT MAP
Scale: 1" = 2000'

Figure 5



LOCATION & PROJECT MAP
SEDIMENTARY ROCK
ORANGE COUNTY

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In Kern County between 3.1 miles east of China Garden Road
and 1.4 miles west of Borel Road, about 2 miles west of Bodfish

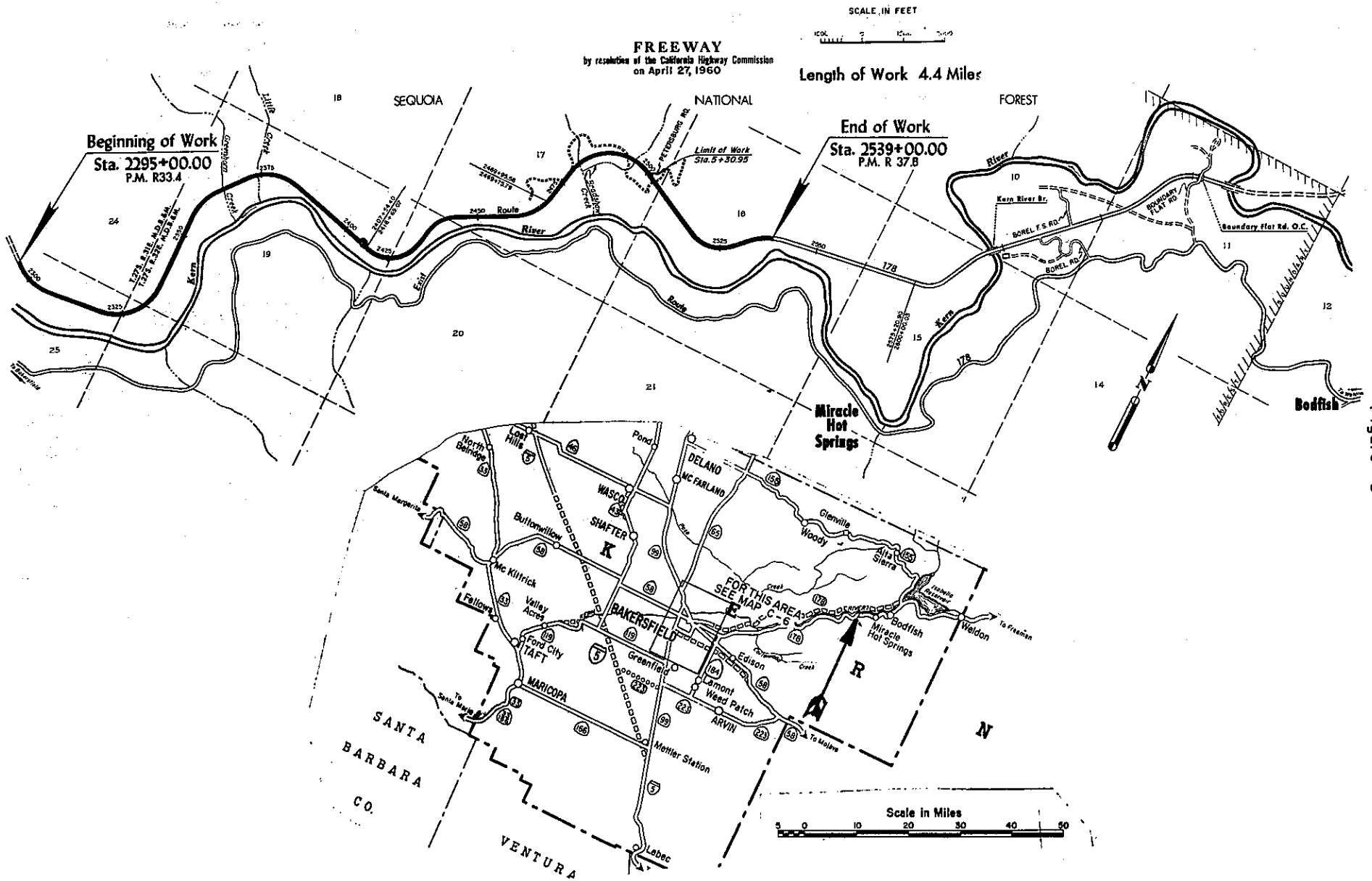

Figure 6

LOCATION & PROJECT MAP

GRANITIC ROCK - KERN COUNTY

Figure 7

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS GRANITIC ROCK

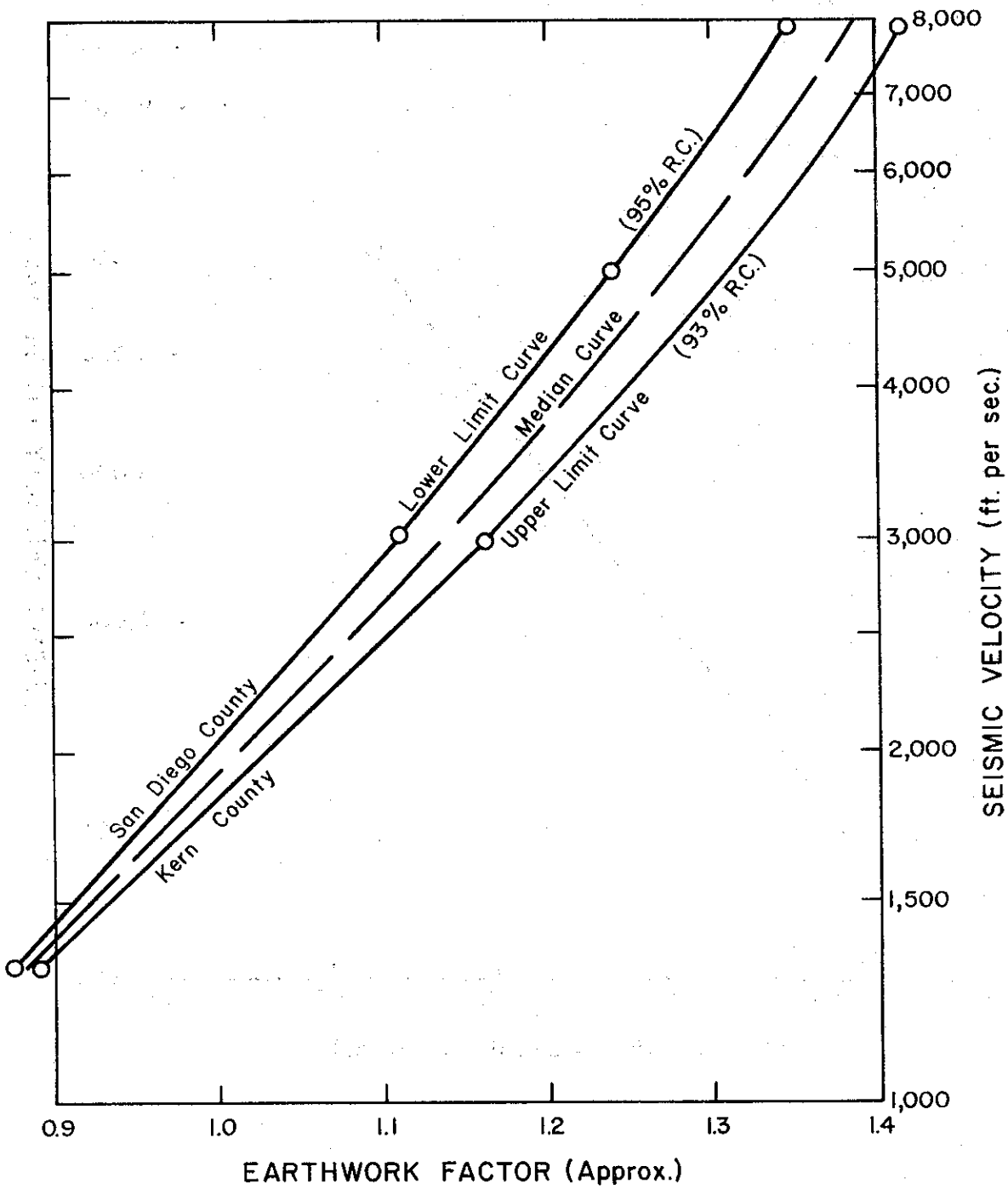

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Figure 8

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS METAIGNEOUS ROCK

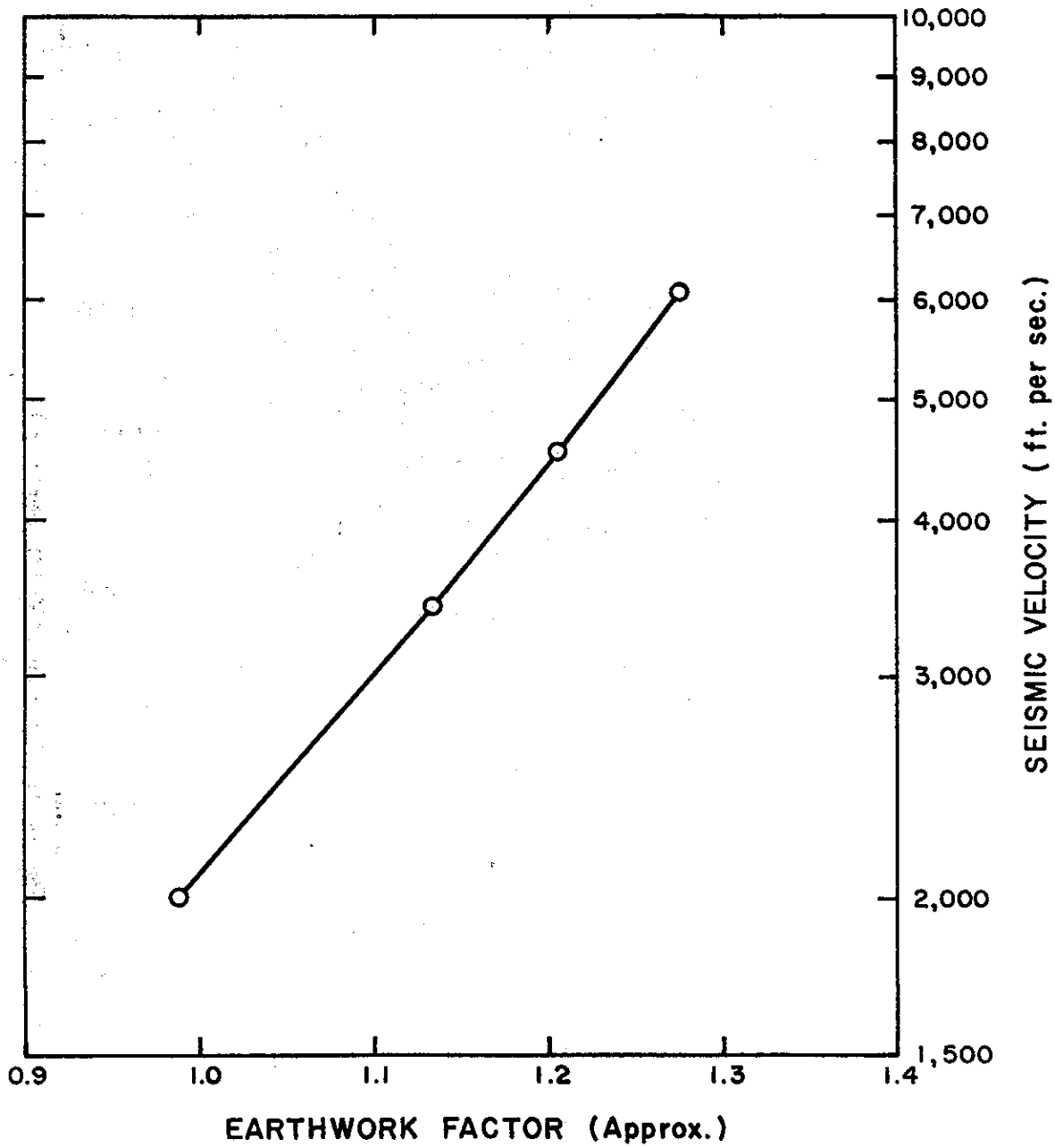

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Figure 9

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS FOR METASEDIMENTARY ROCK

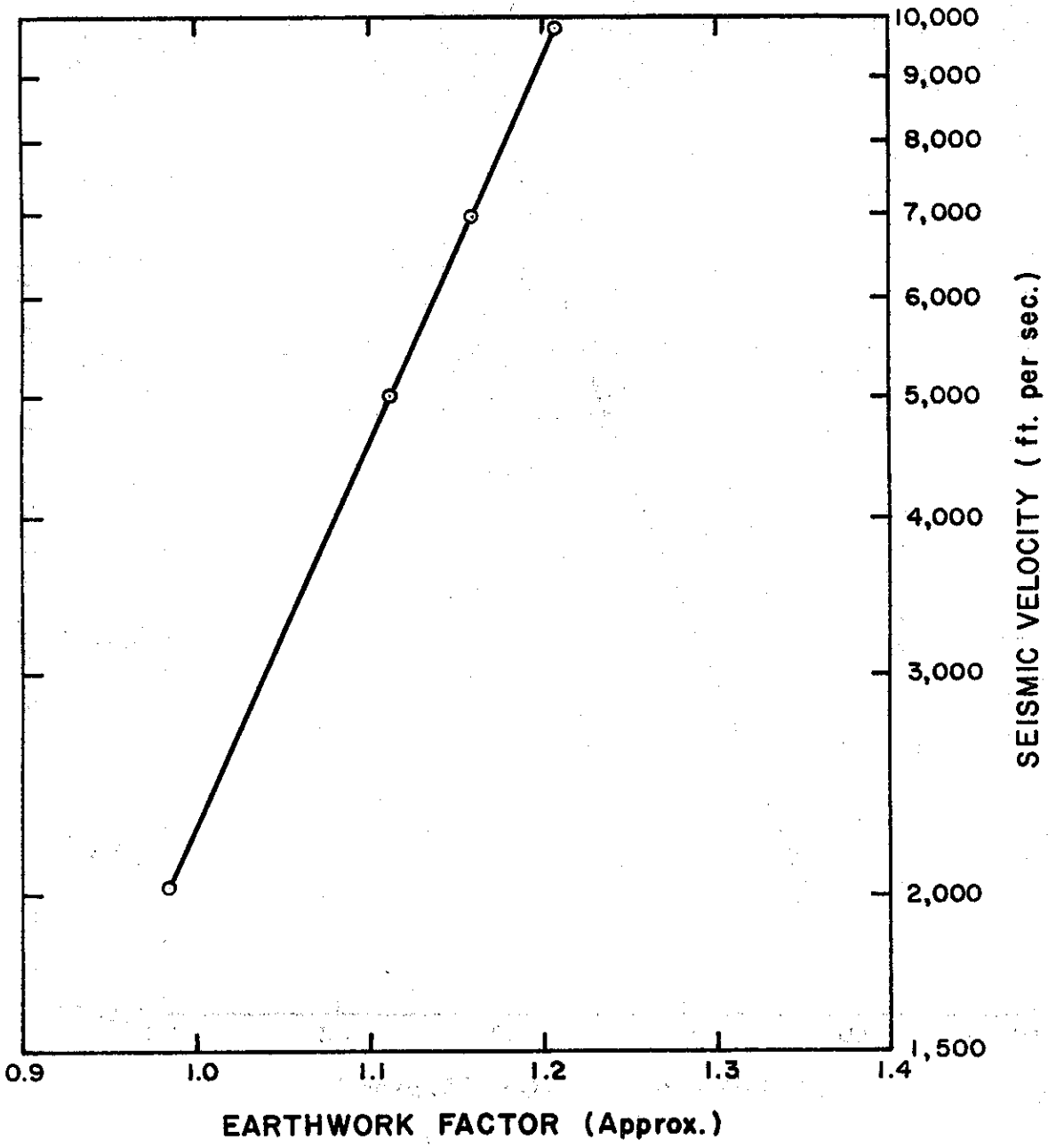

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Figure 10

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS SERPENTINE ROCK

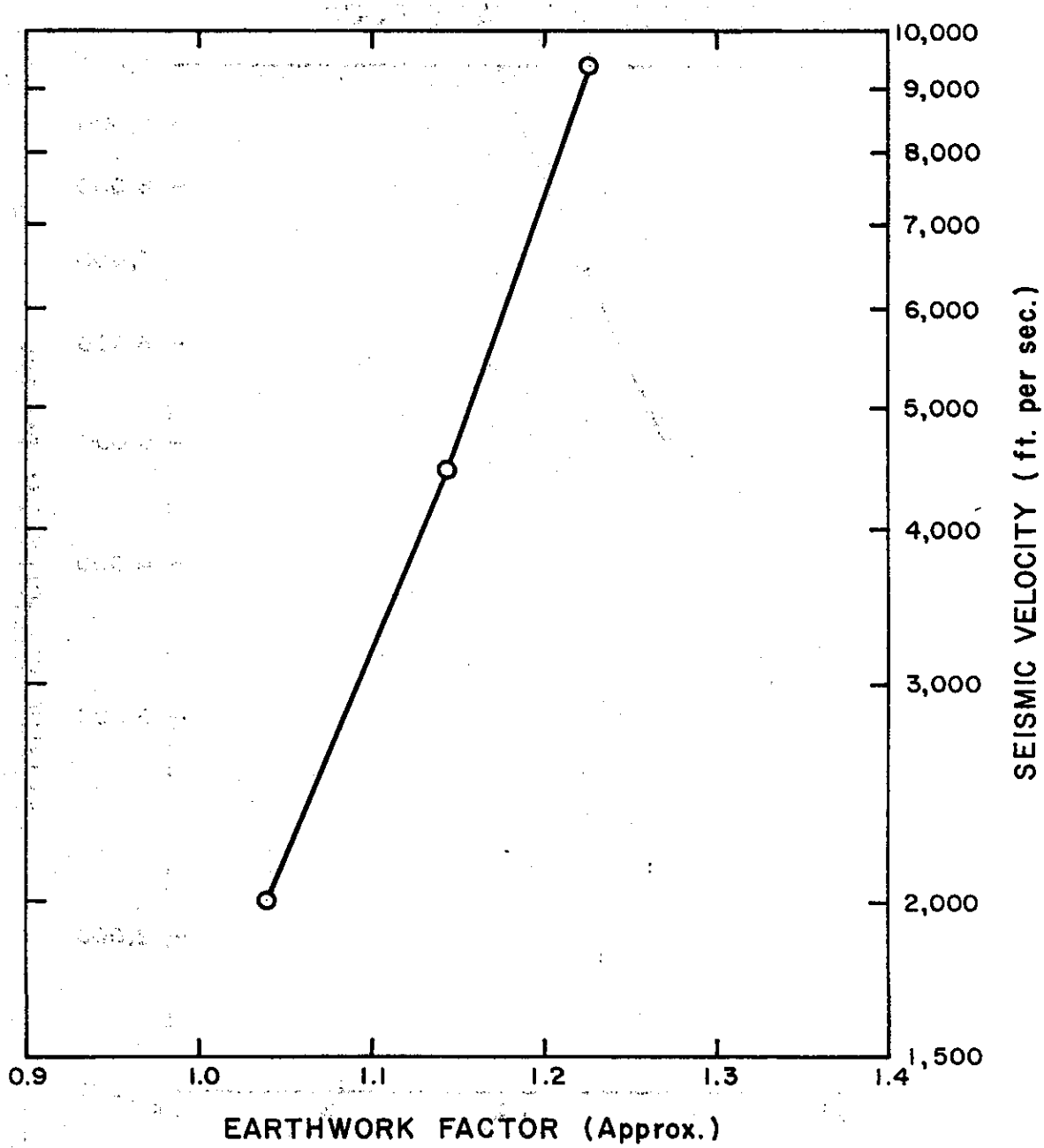

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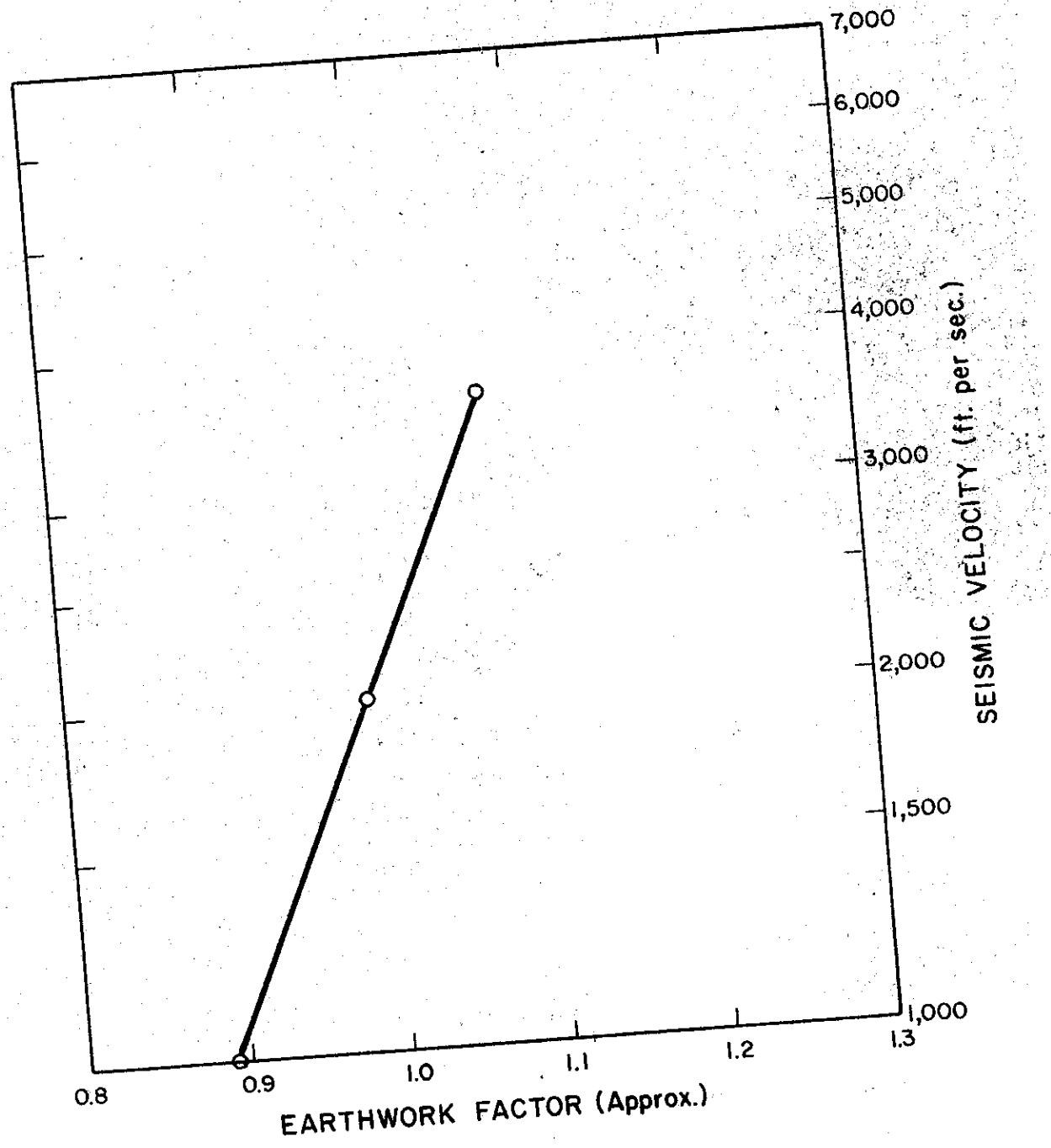
Figure 11

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS FOR SEDIMENTARY ROCK



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Granitic Rock Project in San Diego County

Plate 1

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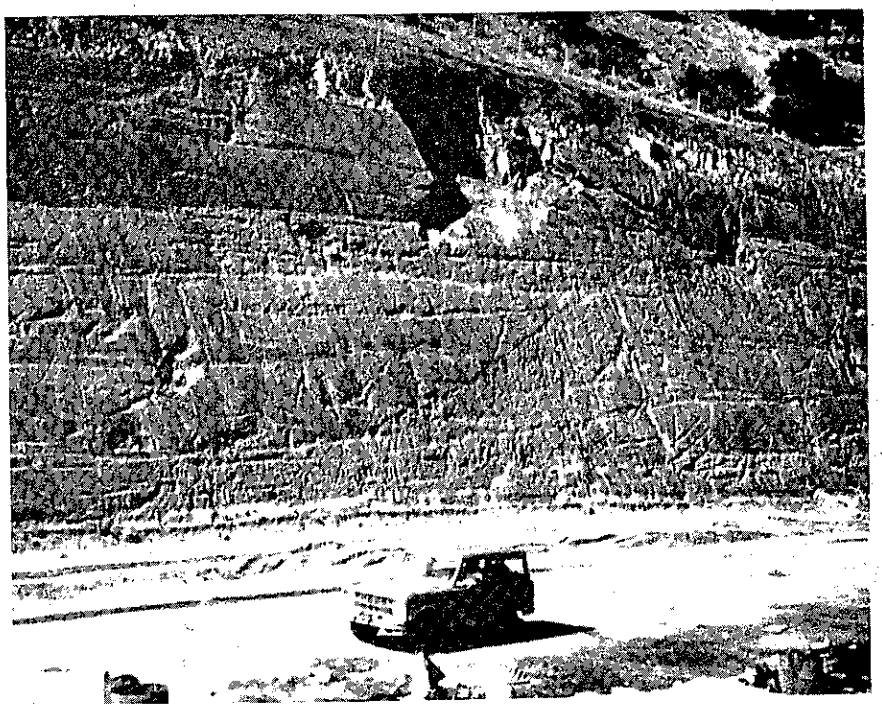

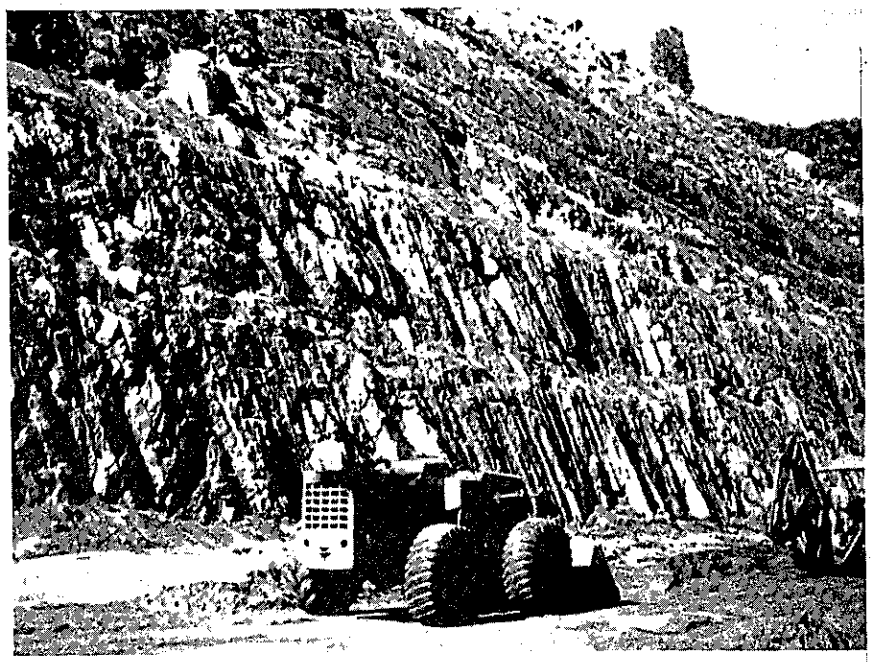

Granitic Rock Project in Kern County

Plate 2

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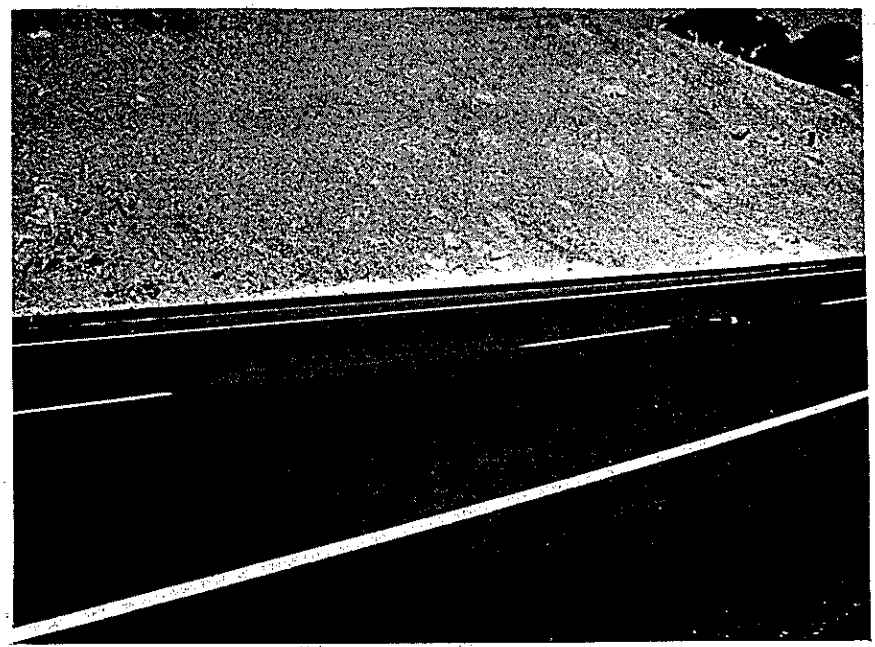

Sta. 1623 Rt. - Serpentine Cut

Sta. 1697 - Metasedimentary Cut

Metamorphic Rock Project in Tuolumne County

Plate 3

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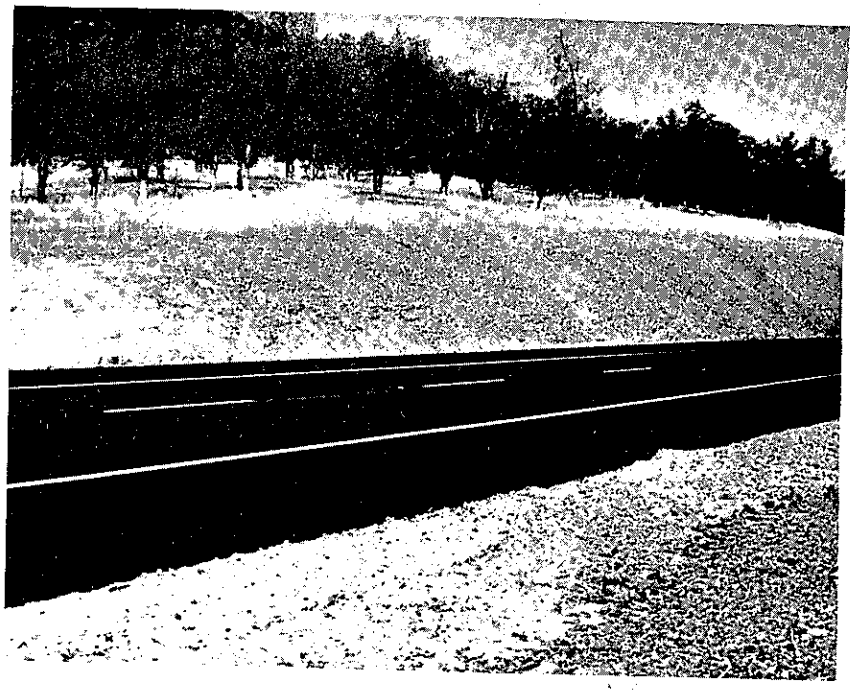

Sta. 1722 Lt. - Metasedimentary Cut

Sta. 1753 Lt. - Metaigneous Cut

Metamorphic Rock Project in Tuolumne County

Plate 4

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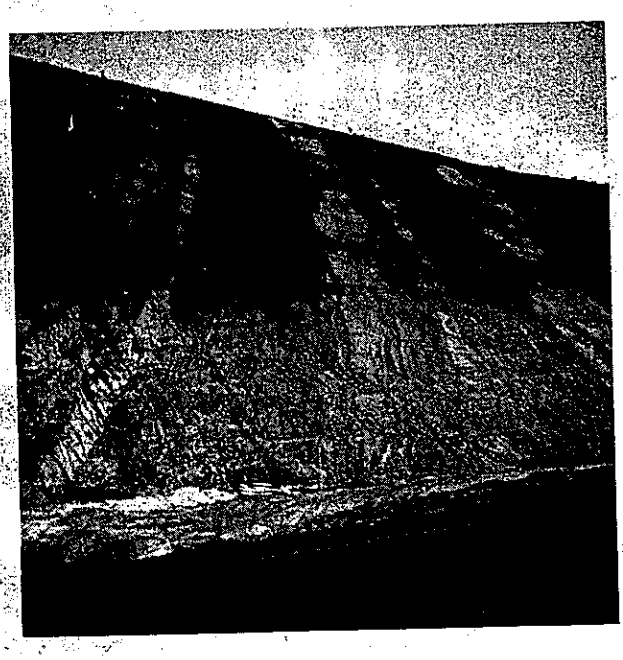

Sta. 370 Santa Ana Canyon Rd.

Laminated Shale and Sandstone Cut

Looking back at Sandstone Cut in Coal Canyon

Sedimentary Rock Project in Orange County

Plate 5

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