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Travis Smith, Marvin McCauley, Ronald Mearns, Karl Baumeister

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This study was made to determine whether seismic data can be used to obtain satisfactory design earthwork for roadway excavation. The study shows an apparent correlation between seismic velocity and earthwork factor for the three metamorphic rock types studied. Application of this relationship will yield design earthwork factors which tend to agree more closely with field earthwork factors than those attainable by previous methods.

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HIGHWAY RESEARCH REPORT

CORRELATION OF SEISMIC VELOCITIES WITH EARTHWORK FACTORS

INTERIM REPORT NO. 2

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

CA-HWY-MR-632103 (2) 72-01

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

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

January 1972

Interim 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

INTERIM REPORT 2

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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REFERENCE: Smith, Travis; McCauley, Marvin; Mearns, Ronald; Baumeister, Karl; "Correlation of Seismic Velocities with Earthwork Factors, Interim Report 2."

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KEY WORDS: Earthwork factors, seismic velocities.

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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 opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

A report dated June 1971, entitled "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.

The study described in this report was made in Tuolumne County on Route 120 between Chinese Camp and the Tuolumne River. (See Fig. 1) The entire construction project was between Chinese Camp and Moccasin, but this report covers only the portion west of the Tuolumne River. The portion east of the Tuolumne River contained an unknown amount of imported borrow and therefore was excluded. This study correlates seismic velocities to field earthwork factors for metasedimentary rock, metaigneous rock, and serpentine. The Project Map (Fig. 2) shows the study area as subdivided by the plans, and identifies the prevalent rock type in each subdivision.

The total quantity of roadway excavation west of the Tuolumne River was about 672,000 cu. yds. The surplus excavation in this section, which had to be disposed of, amounted to about 117,000 cu. yds. more than contemplated in the design, or 17% of the total.

The seismic velocities of the material were determined by use of an Electro-Tech 12 channel seismic instrument. The wave energy was provided by explosives. The maximum length of seismic line was 185 feet.

The principal objectives of this research are:

1. To compare field earthwork factors and design earthwork factors.

2. To determine which construction procedures influenced field earthwork factors.

3. To determine whether earthwork factors can be correlated to seismic velocities.

CONCLUSIONS AND RECOMMENDATIONS

The average design earthwork factor for the study project was 0.95, while the corresponding field earthwork factor was 1.11, resulting in a discrepancy of 17%.

The harder rock had to be blasted down small enough for the scrapers which moved most of the material on this project. Under normal conditions, the smaller the maximum rock particle size the greater the earthwork factor.

Though most embankments were too rocky to test, the average measurable compaction was 94% compared to 90% required--in effect, lowering the field earthwork factor.

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Based on information obtained from this study, a graph was developed on which approximate earthwork factors were plotted against seismic velocities for each of three types of rock present in this project. (See Fig. 3.) The results seem to indicate that there is no simple straight line relationship between seismic velocity and earthwork factor. Apparently the rate of increase in earthwork factor for an increase in seismic velocity is greater in the lower velocity ranges (which occur where the material is softer and relatively inelastic) than it is in the upper velocity ranges where the seismic velocity appears to increase at a much faster rate than does the earthwork factor.

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 diminishing the magnitude of error, especially when compared to previous methods.

It is recommended that the curves in Figure 3 be used on a trial basis, where applicable, to help determine design earthwork factors. The subsequent data will probably result in revisions and additions to the original curves but the basic validity can best be determined by trying the method.

Prerequisites for a successful check on the method 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 material in the areas to be excavated, (d) knowledge of the geologic structure of the material to be excavated, and (e) sufficient seismic data.

CONSTRUCTION METHODS

The project was nearly completed when the field investigation for this study began. Construction methods and details were obtained from the Resident Engineer and the inspectors on the project.

The metaigneous rock was the hardest material encountered on the project and generally required blasting. The metasedimentary rock and serpentine required blasting in the lower, less weathered portions of the deeper cuts.

Most of the material was moved by large scrapers although some was moved by truck trailers or dozers. Since the scrapers were used in practically all cuts, the harder rock had to be blasted small enough to be picked up by the scrapers. Most of the compaction was achieved by hauling equipment although segmented type compactors were used. Water was added for compaction of the broken rock as well as the soil. A major portion of the fill

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could not be tested for compaction because it was too rocky. The average compaction by test was 94%, while the specifications called for 90% minimum.

PROCEDURE

The plans divided the section of roadway between the west end of the job and the Tuolumne River into 9 zones, each of which was assigned an earthwork factor. The project map (Fig. 2) shows the locations of these zones.

In order to determine the volume of surplus in the embankments where material was wasted, a stadia survey was conducted. A resurvey of apparent variations in the cuts was also made. There were about 14,000 cu. yds. of over excavation due to widening of some benches, while slides amounted to about 1,000 cu.yds.

Excavation and embankment quantities were calculated using data from the stadia survey and from previous surveys. These calculations were made using an existing computer program which does not have provisions for correcting volumes for horizontal curvature of layout line. It was necessary to correct for horizontal curvature at the curve west of the Tuolumne River. As a result, 7,000 cubic yards were added to the volume of the embankment and 7,000 cubic yards were subtracted from the volume of excavation. Without these corrections, the calculated field earthwork factor for zone 9 would have erroneously appeared to be 5% lower.

The load counts when checked against actual earthwork volumes agreed only if the study project were divided into three parts. These were zones 1 through 3, 4 through 6, and 7 through 9. For this study the project was therefore subdivided in this manner.

In combining these zones, equations could be written equating the embankment plus surplus in any one of the three subdivisions to the sum of the products of the excavated volumes in each zone and their respective field earthwork factors (F = field e.w.f.).

For zones 1 through 3, the following equation was developed:

$$\text{Embankment} + \text{surplus} = 74,000 = 14,000\,F_1 + 8,570F_2 + 46,200F_3$$

For zones 4 through 6, the following equation was developed:

$$\text{Embankment} + \text{surplus} = 268,000 = 32,700F_4 + 16,700F_5 + 191,000F_6$$

For zones 7 through 9, the following equation was developed:

$$\text{Embankment} + \text{surplus} = 404,000 = 40,000F_7 + 32,000F_8 + 290,000F_9$$

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By visually classifying the material in the cuts, the following assumptions could be made:

$$F_1 < F_8 < F_2 \text{ and } F_3$$

$$F_2 = F_4$$

$$F_5 = F_6 = F_7$$

The unknowns F_1, F_2, and F_3 were estimated by first determining their relationship with each other based on type of material in the cuts. F_1 and F_2 were then assigned values of 1.00 and 1.10, respectively (based on past experience with these materials) and by substitution of these values in equation 1, an approximate value for F_3 of 1.10 was obtained.

Equation 2 can then be solved by substituting F_5 for F_6 and 1.10 for F_4. This gives a value of 1.11 for F_5, F_6, and F_7. F_8 was assigned a value of 1.03 based on the quality of the material in zone 8 in comparison with that in zones 1 and 2. Substituting 1.11 for F_7 and 1.03 for F_8 in equation 3 results in a value of 1.13 for F_9. The following table shows the approximate field earthwork factors in comparison with the design earthwork factors.

Table 1.

Zone	Design E.W.F.	Approx. Field E.W.F.
1	0.85	1.00
2	0.90	1.10
3	1.00	1.10
4	0.85	1.10
5	1.00	1.11
6	0.90	1.11
7	1.00	1.11
8	0.90	1.03
9	1.00	1.13

The rock in the various zones was identified by inspection of the cut surfaces and seismic investigations were made alongside the cuts.

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Cross-sections were taken through the cut areas and interfaces of the various strata were plotted as per interpretation of seismic data and were 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 range of seismic velocities could thus be ascertained for any particular cut.

On this basis equations can be developed using percentage of cut volume in each seismic velocity range as a multiplier for the earthwork factor for 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 earthwork factor for the zone. For example, for the metasedimentary cuts, using E_2, E_5, E_7, and E_{10} for the earthwork factors for the material that had seismic velocities of roughly 2,000, 5,000, 7,000, and 10,000 f.p.s., respectively, four equations can be set up:

Zone 5: $0.35\ E_2 + 0.65\ E_5 = 1.10$

Zone 6: $0.22\ E_2 + 0.425\ E_5 + 0.355\ E_{10} = 1.10$

Zone 7: $0.155\ E_2 + 0.47\ E_5 + 0.375\ E_7 = 1.10$

Zone 8: $0.30\ E_2 + 0.65\ E_5 + 0.05\ E_7 = 1.03$

Solving these equations and plotting seismic velocity versus earthwork factor gives a curve that is concave upward. Plotting the seismic velocities as ordinates on a logarithmic plot versus earthwork factor on an arithmetic plot, the curve approximates a straight line.

Earthwork factors for various seismic velocities were similarly derived for the metaigneous material and the serpentine. The resulting curves (seismic velocity versus approximate earthwork factor) when plotted on semi-log paper approximated straight lines with slight upward concavity. The metaigneous material studied in this report has a curve that is in very close agreement with the values for the granitic rock in the previous report.

While the field earthwork factors used in this study are considered to be fairly accurate, as stated previously, they are based on some assumptions that had to be made because of insufficiently exact load count data. The fact that three types of material had to be considered also added to the difficulty. In spite of this, compared to the magnitude of the discrepancies which often occur between design and field earthwork factors, the probable error in this study would have to be considered relatively small. As a starting point for determination of a correlation between seismic velocity and earthwork factors, it should serve a very useful purpose.

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GEOLOGICAL DESCRIPTION OF CUTS

Sta. 1587 to 1596 (in Zone 1)

The cuts in this area are in highly weathered and fractured serpentine that grades into harder material at greater depths.

Sta. 1613 to 1619 (in Zone 2)

This smaller area is made up mostly of highly weathered and fractured metaigneous rock which ranges from moderately hard to friable. Very hard metamorphosed intrusive rock cut by several small steeply dipping faults crops out at the west end of the cut.

Sta. 1620 to 1629 (in Zone 3)

This area comprises variable rock types of varying hardness. Most of the rock is hard, highly fractured serpentine, but there are pockets of extremely friable material. Some hard to friable foliated metaigneous rock is present. The center portion of the cut along the eastbound lane is very hard metamorphosed intrusive rock. The easterly 200 ft. of the cut on both sides of the roadway is in moderately soft, strongly foliated serpentine. The foliation planes dip steeply.

Sta. 1643 to 1652 (in Zone 4)

Along the eastbound lane, nearly all the material is highly weathered and fractured, foliated, moderately hard to friable metaigneous rock.

Along the westbound lane the easterly half of the cut is in serpentine, mostly hard, but fractured and foliated; however, some of the serpentine is highly weathered and friable. The westerly half of the cut is in metaigneous rock both right and left of centerline. This material breaks into small fragments. Along the eastbound lane there is hard metasandstone with some interbedded slate. The dip is somewhat flatter and the rocks are less closely jointed. Also the rock mass is more indurated than on the westbound lane side.

Sta. 1719 to 1726 (in Zone 8)

Along both sides of the highway the rock consists of moderately hard to hard, fractured, weathered sandstone. There is some fresh sandstone with thin interbeds of thinly foliated claystone and siltstone that dip steeply (80°-85°); the strike, as in the previous cut, is parallel to the highway. Right of centerline at Sta. 1722+90 a steeply dipping fault brings slatey rocks into contact with sandstone.

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Sta. 1692 to 1705 (in Zone 5 & 6)

Dark slate is the predominant rock type between the above stations. The nearly vertically dipping slates are moderately hard but thinly foliated with abundant ravelling, and tend to be blocky from jointing. A small area of moderately hard metasandstone and metaconglomerate is present at the west end of the cut. The uppermost part of the cut on the eastbound side is in slightly metamorphosed sandstone with some metaconglomerate.

Sta. 1710 to 1717 (in Zones 7 & 8)

Along the westbound lane there is a steeply dipping (85°+) closely jointed, thinly foliated slaty rock with abundant ravelling. Two bedding plane slipouts have occurred near the easterly end.

Sta. 1744 to 1752 (in Zone 9)

The eastbound lane side consists of a very high irregular cut face. Most of the material is basic metaigneous rock and varies from extremely hard fresh rock to highly weathered and friable material. The rock mass is cut by a very prominent steeply dipping joint set. Blocks tend to fall out of the cut face along these joints. The weathered material can readily be crushed with a hammer. Some sedimentary rock is present at the west end of the cut.

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Figure I

LOCATION MAP

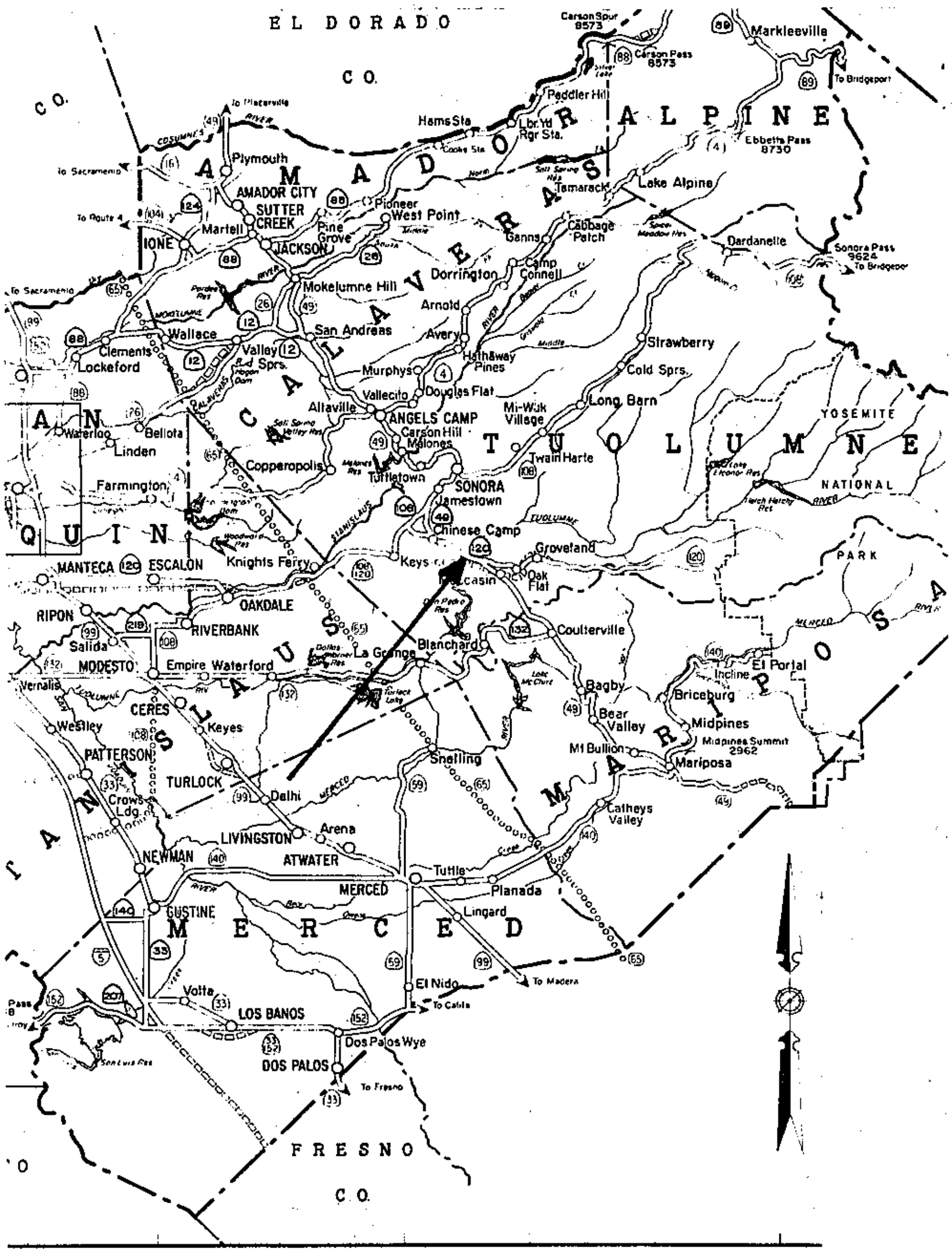
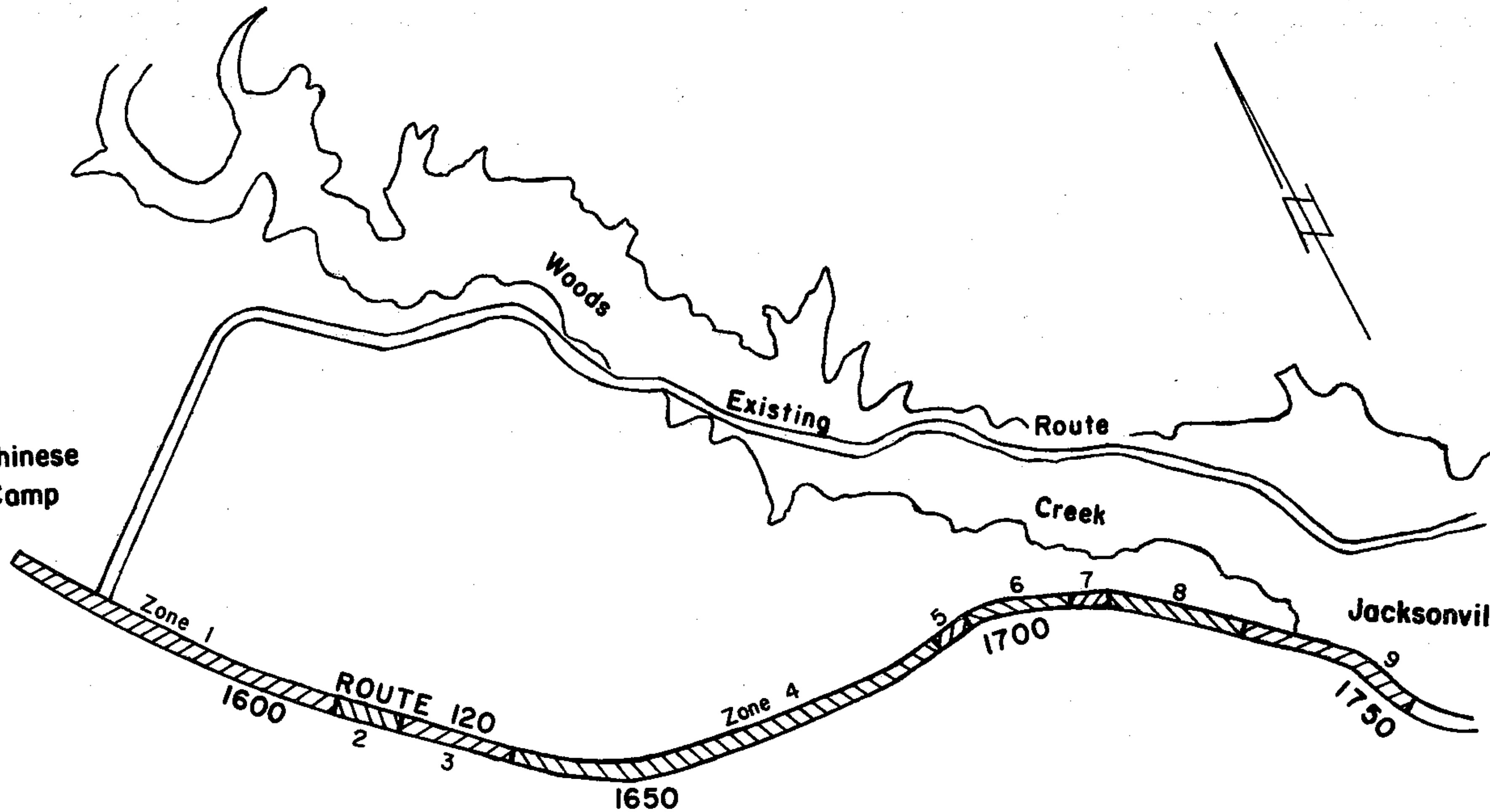


Figure 2



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

PROJECT MAP

Scale: 1" = 2000'

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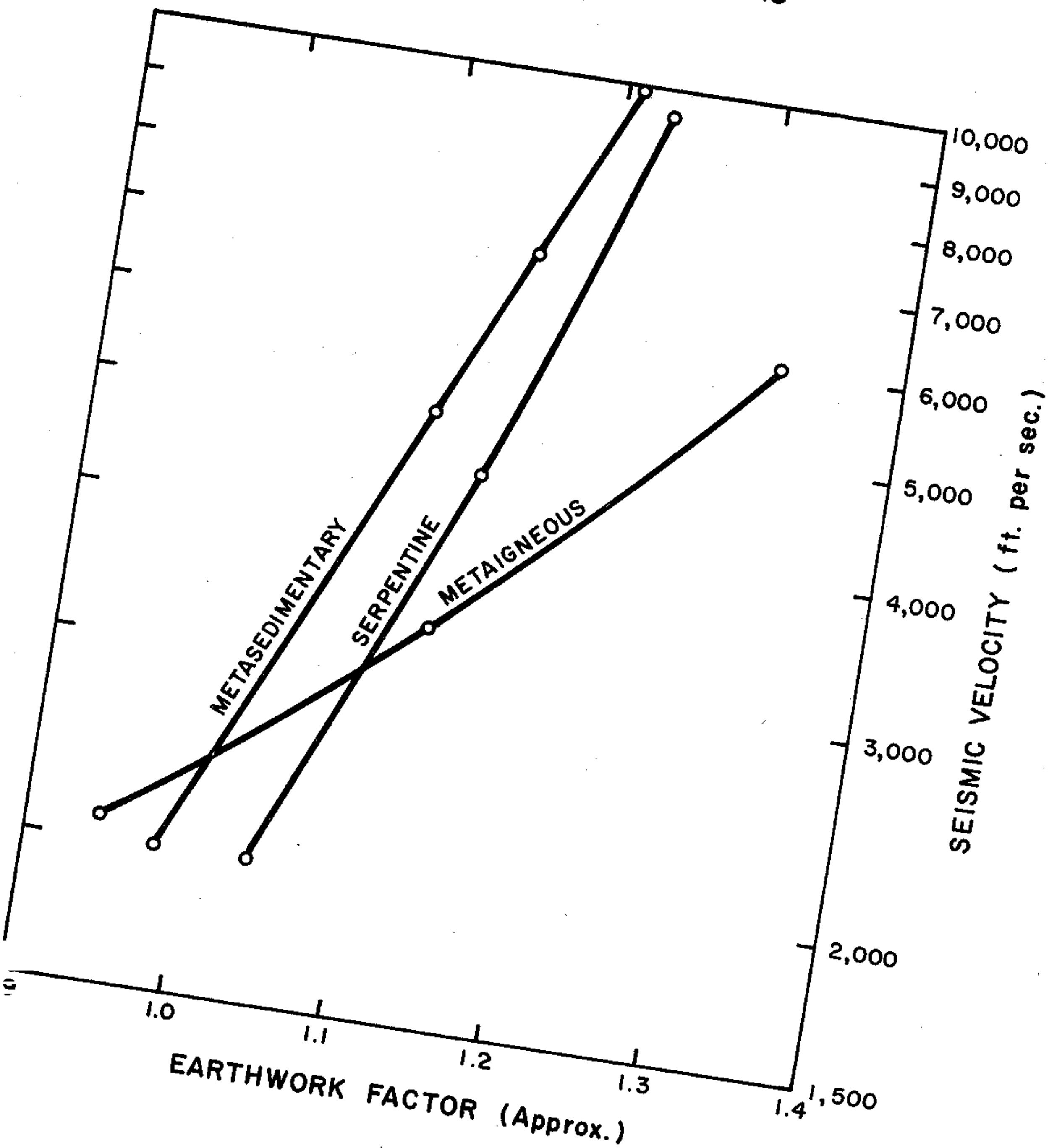
Figure 3

RELATIONSHIP BETWEEN SEISMIC VELOCITIES AND EARTHWORK FACTORS



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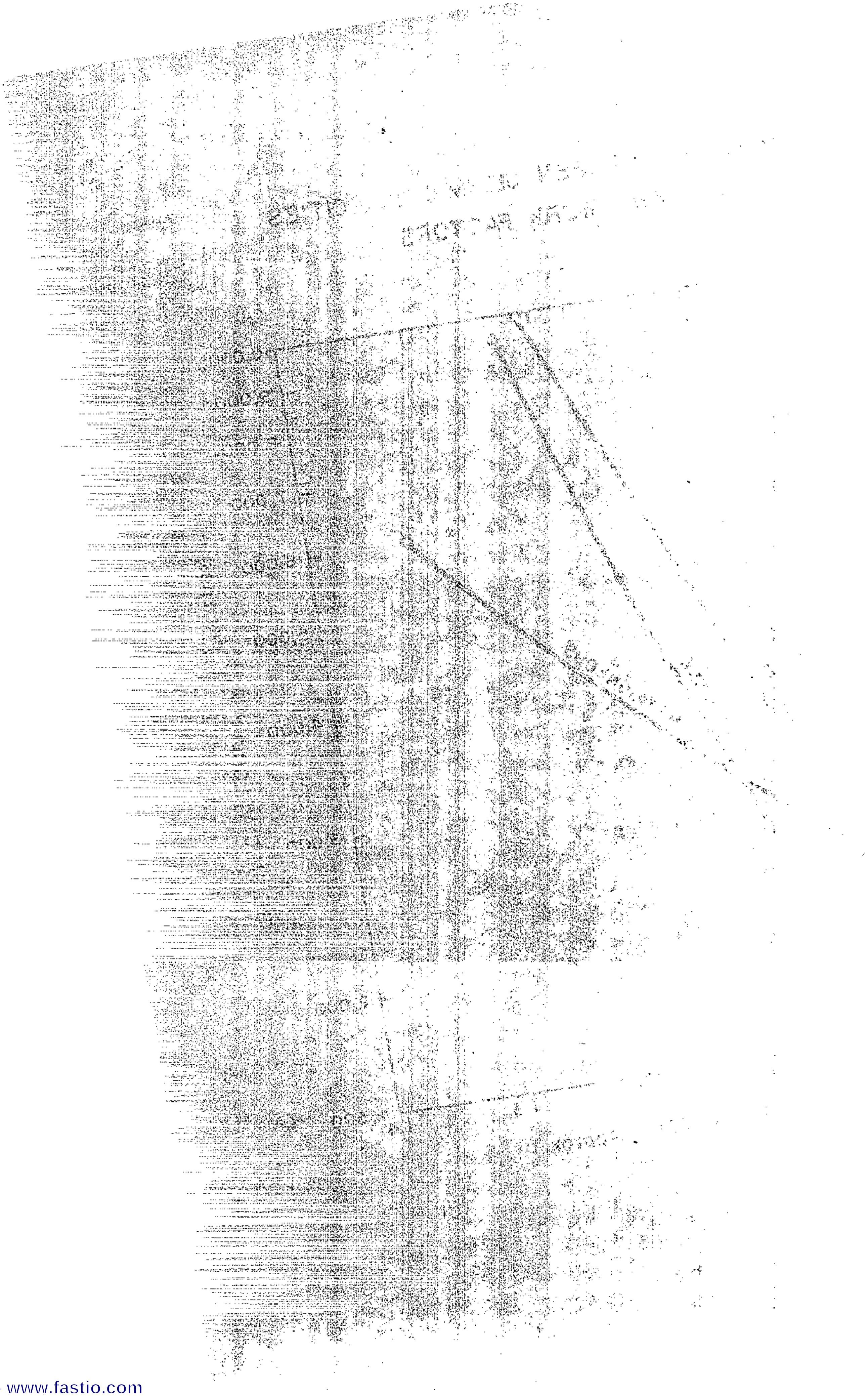

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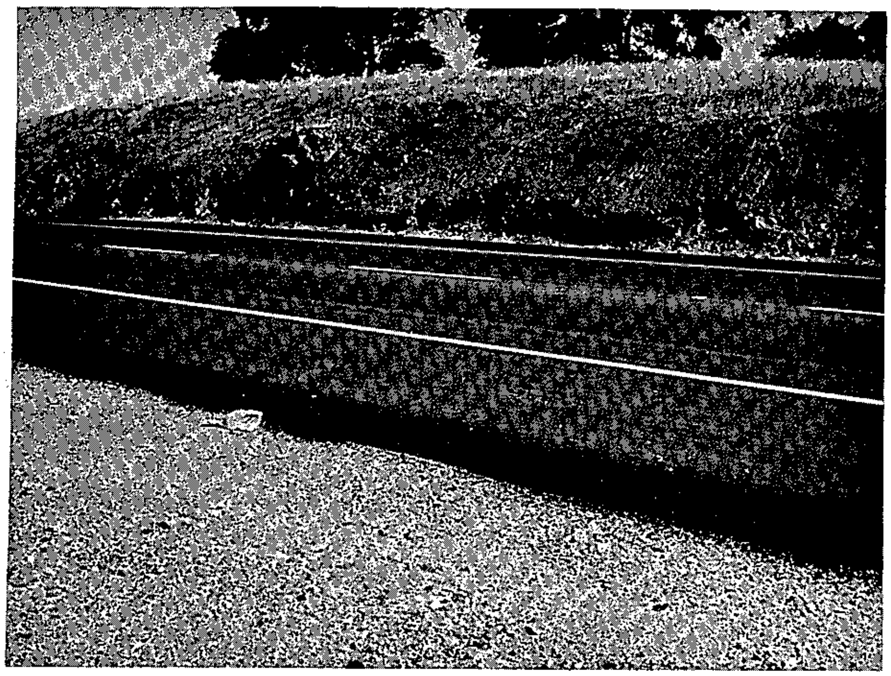
Sta. 1592 Rt.



Sta. 1616 Lt.

Plate 1

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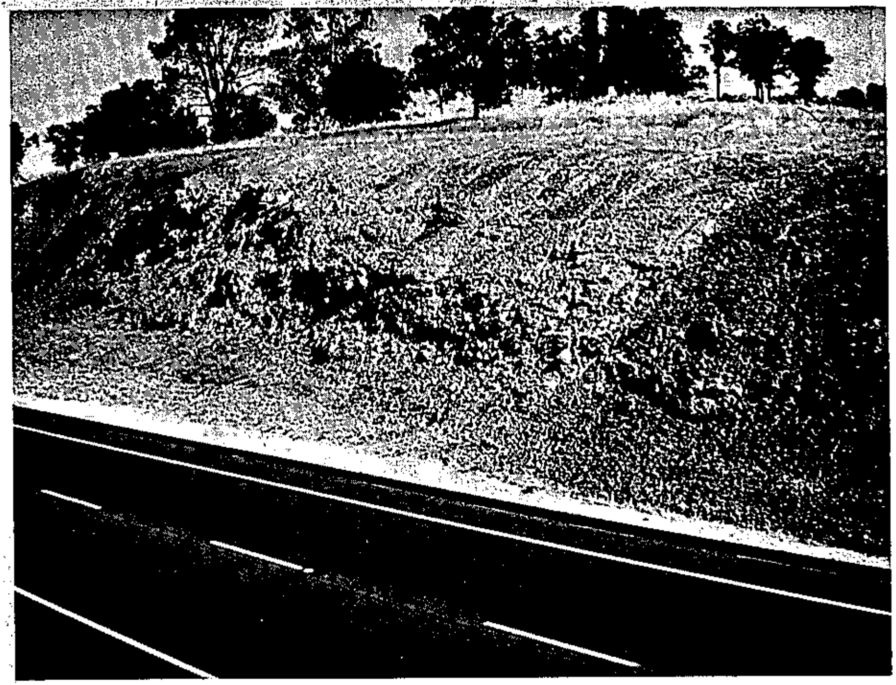

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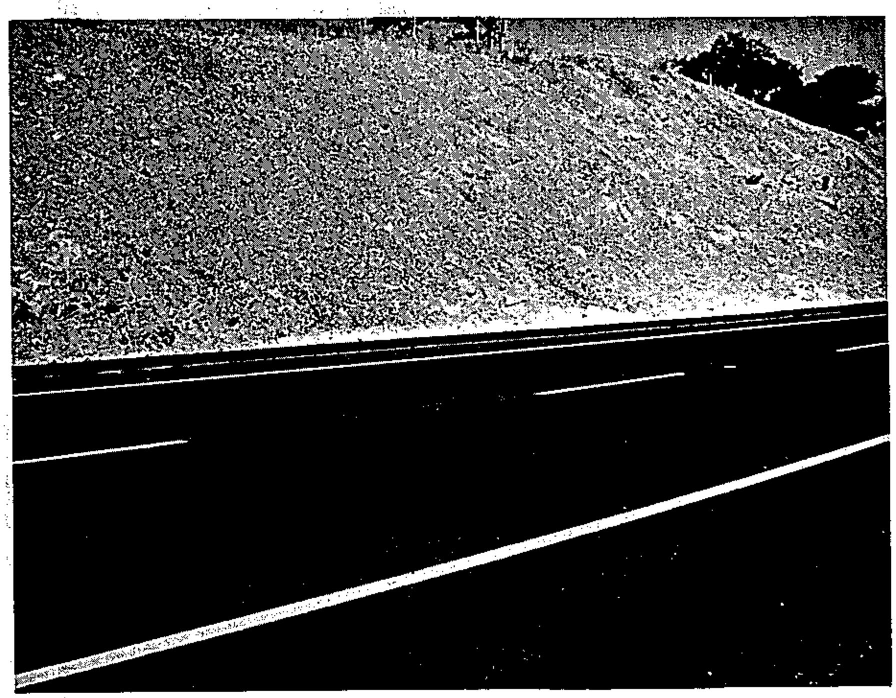

Sta. 1623 Rt.

Plate 2

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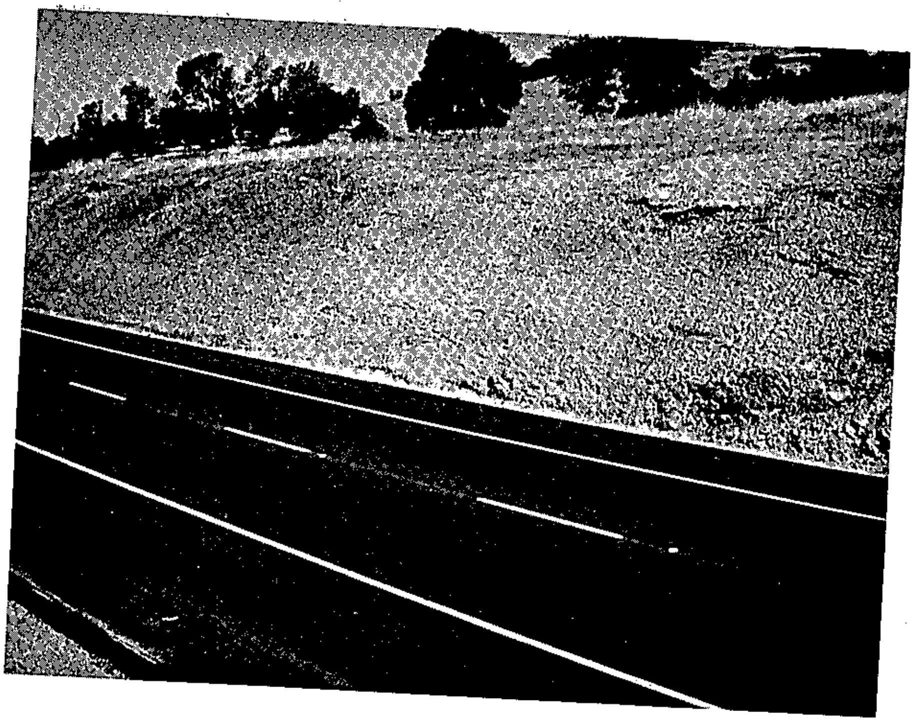
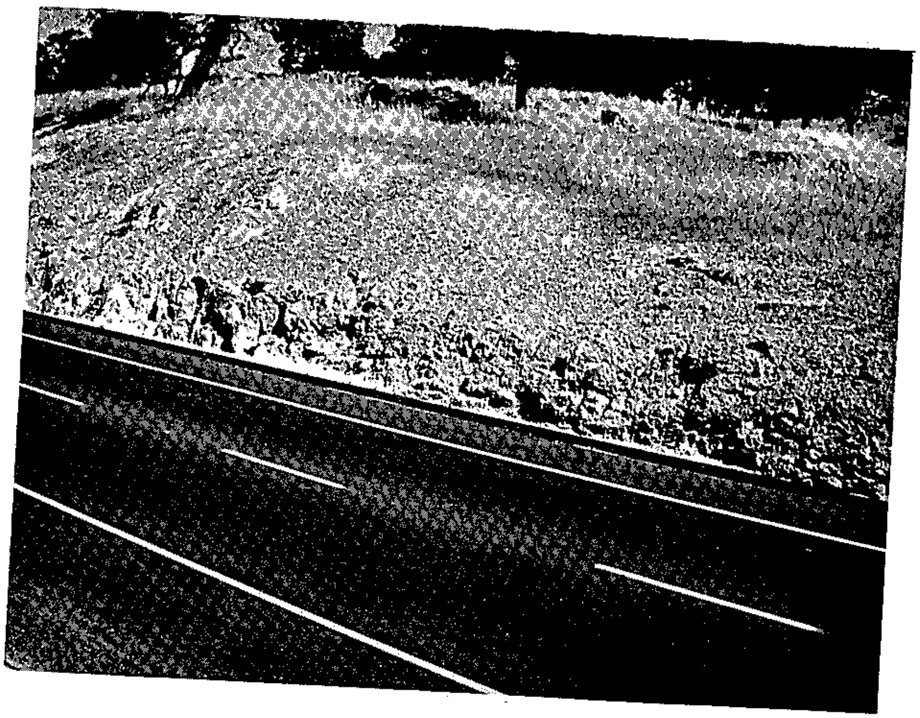


Sta. 1645 Lt.



Sta. 1649 Lt.

Plate 3

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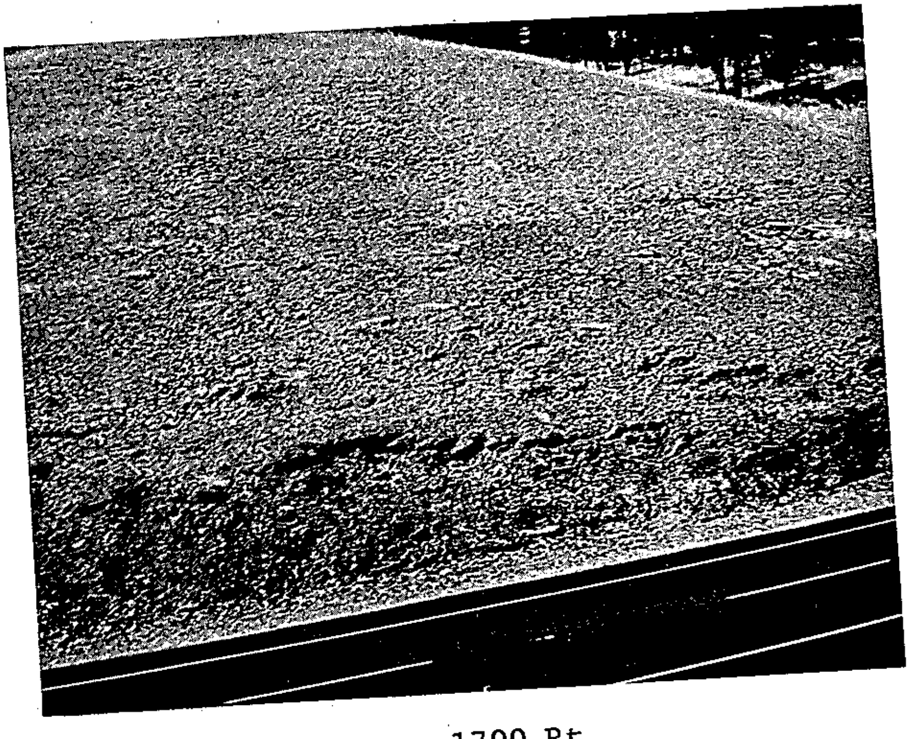
Sta. 1697 Rt.



Sta. 1700 Rt.

Plate 4

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Sta. 1711 Lt.

Sta. 1711 Rt.

Plate 5

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Sta. 1722 Lt.

Sta. 1746 Rt.

Plate 6

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Sta. 1747 Rt.

Sta. 1749 Lt.

Plate 7

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Sta. 1750 Lt.

Sta. 1751 Lt.

Plate 8

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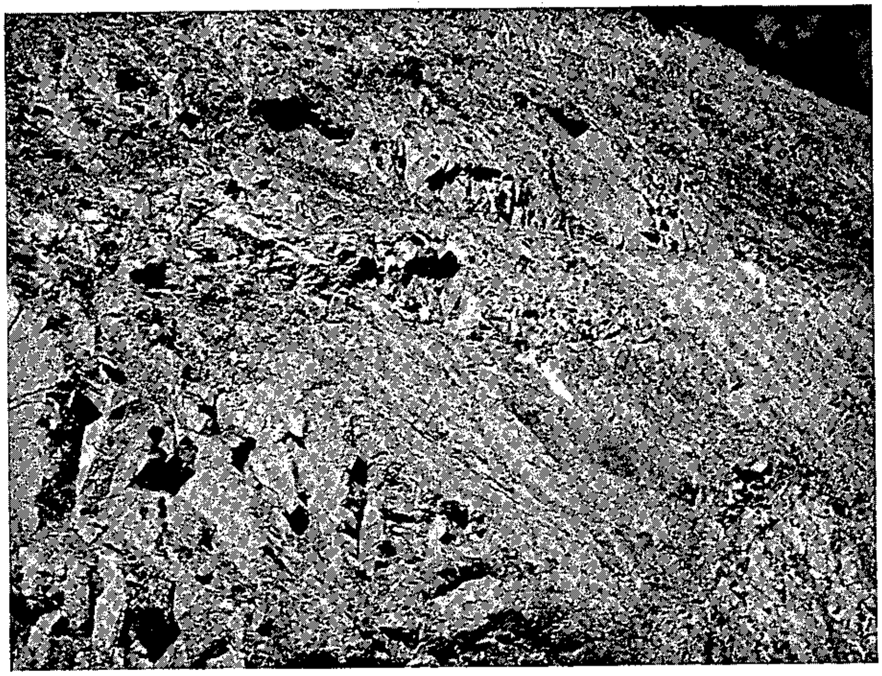
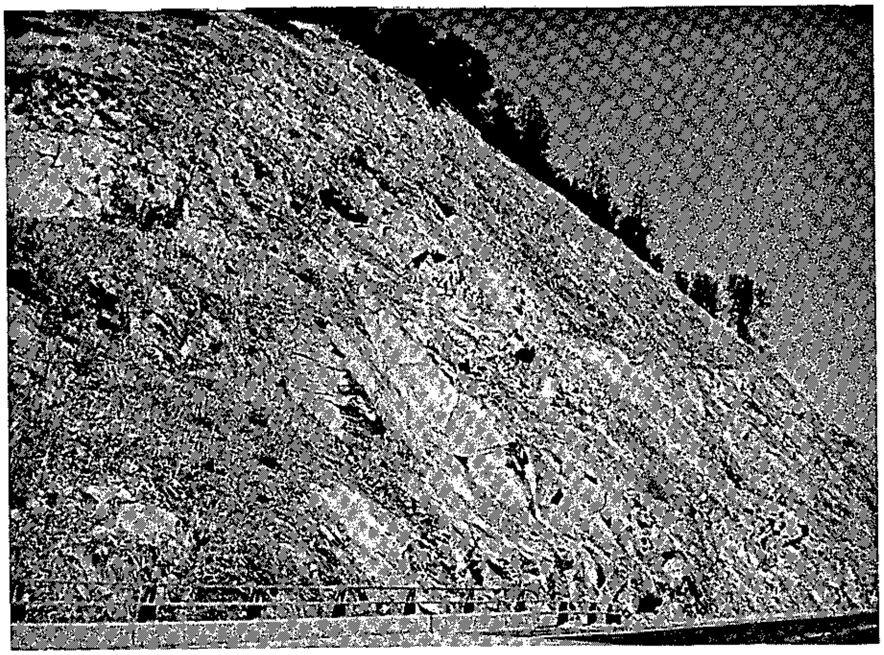


Sta. 1751+50 Rt.



Sta. 1753 Lt.

Plate 9

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