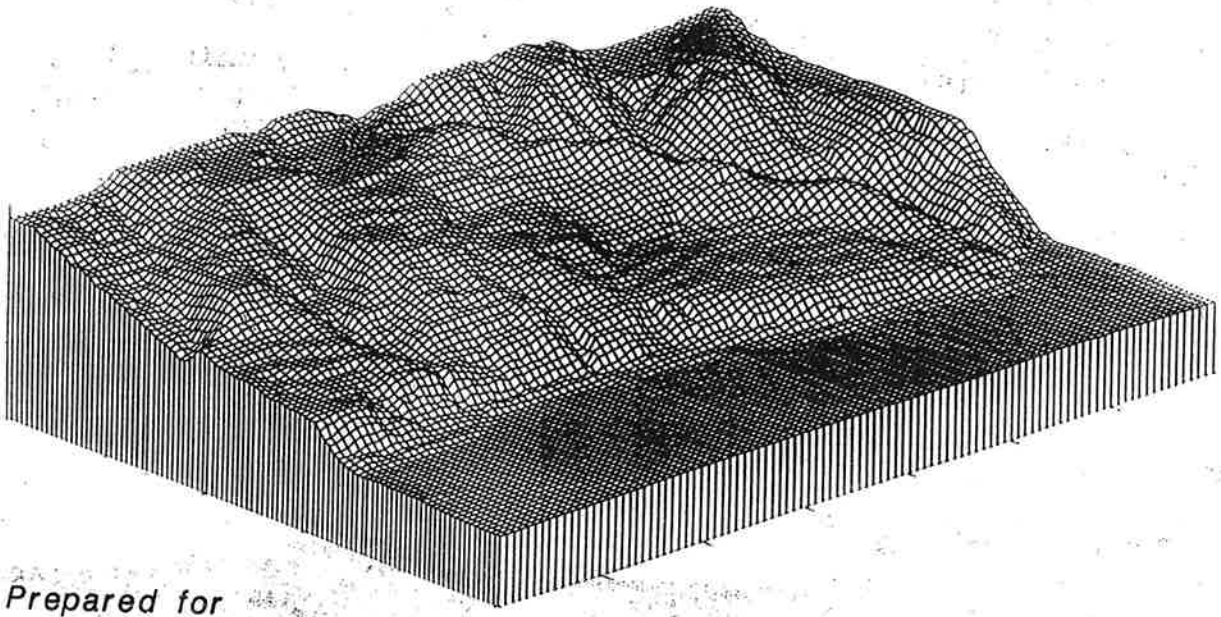
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A Geotechnical Engineering Evaluation

Big Rock Mesa

Malibu, California



Prepared for

LOS ANGELES COUNTY IMPROVEMENT DISTRICT 2629 R2
Malibu, California

Prepared by

BING YEN & ASSOCIATES
Irvine, California

FEBRUARY 1992

COUNTY OF LOS ANGELES

DEPARTMENT OF PUBLIC WORKS

900 SOUTH FREMONT AVENUE
ALHAMBRA, CALIFORNIA 91803-1331
Telephone: (818) 458-5100

THOMAS A. TIDEMANSON, Director

ADDRESS ALL CORRESPONDENCE TO:
P.O.BOX 1460
ALHAMBRA, CALIFORNIA 91802-1460

February 26, 1992

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Dear Librarian:

BIG ROCK MESA LANDSLIDE
TRANSMITTAL OF FINAL GEOTECHNICAL REPORT

Enclosed is the Final Geotechnical Engineering Evaluation Report and accompanying Data Volume for the Big Rock Mesa landslide area.

If you have any questions, please contact Mr. Fady Mattar of this Division at (818) 458-4336.

Very truly yours,

T. A. TIDEMANSON
Director of Public Works

CARL L. BLUM
Assistant Deputy Director
Planning Division

AH:km
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BING YEN & ASSOCIATES, INC.
Geotechnical Consultants, Established 1979

February 26, 1992

Mr. T. A. Tidemanson
Director of Public Works
900 South Fremont Avenue
Alhambra, CA 91803-1331

SUBJECT: **Geotechnical Engineering Evaluation of Big Rock Mesa**
Transmittal of Final Report

Dear Mr. Tidemanson:

Transmitted herewith are six (6) copies of the final geotechnical engineering report and the accompanying data book for the Big Rock Mesa Landslide.

We are pleased to have had the opportunity to conduct this investigation and to present this report to the citizens of the Improvement District.

Sincerely,
BING YEN & ASSOCIATES, INC.

Bing C. Yen, Ph.D., RGE #917
President

Enclosures

39 Musick Avenue, Irvine, CA 92718 Tel. (714) 583-1919 Fax: (714) 583-1763

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The successful completion of this project has been a team effort by the staff of Bing Yen & Associates, Inc. (BYA) and a large number of people who contributed throughout the course of this project. Special appreciation is due to Messrs. Michael Anderson, Stuart Hodgkins and Faddy Mattar, former and present Project Managers of the Improvement District 2629R2 (CI) for their coordination and support. Valuable assistance is also acknowledged from various other County divisions and personnel, including: Messrs. Mike Johnson and Jaral Vahabnezhad of the Materials Division; and various employees of the Planning, Flood and Road Maintenance, Design, Survey, Construction, and the Hydraulic Water Conservation Divisions. The citizens of the Big Rock Mesa and their representatives, Big Rock Improvement Committee (BRIC), provided valuable input in defining their needs and in focusing the direction of the project progress through a number of meetings with BYA. Their effort and understanding is gratefully acknowledged. BYA also wishes to thank the citizens of the Big Rock Mesa who frequently call us to report their observations and extended their courtesy to BYA staff during the course of this investigation.

The work on geology and structural geology presented in this report was primarily due to the tireless effort of Dr. James Anderson who, assisted by BYA staff, mapped hundreds of acres of the study area and who reviewed literally hundreds of references and prepared the treatise on geology detailed in Appendix B. Appreciation is due also to Dr. Perry Ehlig who provided valuable engineering geology input and constructive review throughout the project. BYA also wishes to acknowledge that valuable information was gained through discussions with Mr. Don Michael, and through his past work on the project area. A number of consulting firms have made their working file available to us, including the Rodine Company, Slosson & Associates, and William Cotton and Associates, to whom we offer our thanks.

Finally, the diligent effort of the following BYA project team members is acknowledged: Dr. Bing C. Yen, Principal-in-Charge and Project Director; Mr. Glenn Tofani, Principal Investigator; Dr. Bill T. D. Lu, Principal and Technical Advisor; Mr. Greg Silver, Project Engineer and Task Leader; Dr. Tim Lam and Mr. Stavros Chrysovergis, Project Engineers; Messrs. Daniel McNary, Da Cheng Wu, and Mr. Jason Holcomb, Staff Engineers; Mr. Berge Basmadjian, Cartographer; and Ms. Joyce Tisdale, Technical Typist.

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EXECUTIVE SUMMARY

This executive summary highlights portions of a geotechnical engineering report prepared by Bing Yen & Associates, Inc. (BYA) for the Big Rock Mesa (BRM) area. Of necessity, this summary presents a concise and somewhat simplified overview of the report. All statements contained in this summary are subject to the contents of the entire report. For a full and complete understanding of any of the subjects discussed in this summary, one should read the report in its entirety.

The geotechnical engineering work performed by BYA for County Improvement District No. 2629R2 (CI) has focused on five primary objectives: (1) assess, maintain and improve the dewatering system, (2) identify and analyze major surface and subsurface features affecting the gross stability of the area, (3) evaluate the potential for enlargement of the 1983 landslide towards the west in an area commonly referred to as the Western Extension, (4) evaluate the prevailing factor(s) of safety against deep-seated landsliding in the BRM area including the Western Extension, and (5) identify mitigation alternatives and analyze their costs and benefits. To achieve these objectives, BYA has performed the following:

1. Observed, maintained and improved (renovated and cleaned) 18 dewatering wells, 47 hydrauger systems, 33 slope inclinometers and other geotechnical measuring devices such as standpipe and pneumatic piezometers and a multipoint borehole extensometer (MPBX);

2. Drilled, cored and examined a total of 2,256 feet of core samples from five deep boring locations;

3. Converted the five deep borings into dewatering wells and installed 3 new hydraugers along the Pacific Coast Highway (PCH). Together with other existing dewatering facilities, this resulted in a combined removal of 93.7 million gallons of groundwater from BRM since November 1988 when BYA began to participate in the field work with the Department of Public Works;

4. Completed 10,980 feet of high resolution gamma ray logging and 3,900 feet of dip meter and other geophysical loggings in the BYA drilled deep borings and in selected existing wells and instrumented borings;

5. Reviewed and synthesized available reports of previous geologic and geotechnical investigations of BRM and records of past development;

6. Provided consultation to the CI regarding surface drainage improvements;

7. Identified and analyzed subsurface geologic structures, landslide surfaces and past slope failure mechanisms;

8. Mapped and characterized geologic features and groundwater conditions to develop a hydrogeologic model for BRM;

9. Assessed present state(s) of gross stability and evaluated static factors of safety under various groundwater conditions;

10. Evaluated the stability of the BRM area when subjected to various potential earthquakes (seismic loading) and evaluated the potential for seismically induced movement;

11. Evaluated mitigation options with preliminary cost-estimates; and

12. Prepared this report.

Background

The main BRM landslide encompasses approximately 136 acres. An area of about 79 acres immediately to the west is commonly referred to as the Western Extension. Gross movement of the BRM landslide was first widely recognized in 1983. In December 1983, at the request of area residents, the County formed CI 2629 to conduct a geotechnical investigation and install landslide mitigation measures. An emergency dewatering program was implemented and 14 wells and 34 hydraugers were installed to supplement the then-existing 4 wells and 13 hydraugers. The emergency system lowered the high water level which had existed at the onset of the landsliding. When BYA started work for the CI in late 1988, only 7 of the 18 existing wells and 21 of the 47 hydraugers were producing.

Total production had decreased to 66,000 gallons per day (gpd) and was decreasing at a rate of about 16,000 gpd per year. If this decline had continued, the total projected current production rate (December 1991) would be only about 17,000 gpd. After renovation of the existing wells, an immediate 146% increase was achieved in well production. By renovating the wells, cleaning the hydraugers and adding new deep dewatering wells, production rates have increased and approximately stabilized to an average rate of about 72,000 gpd. This dewatering effort has further reduced groundwater levels at the site.

Physiographical & Geologic Setting

The BRM area is essentially comprised of two major areas: the main slide area and the Western Extension. The main slide area encompasses the main BRM landslide which is often referred to as the main slide, or the Main Mesa landslide. The boundaries of the main slide area encompass the Central, Headscarp, Bluff and Southeast Regions. The South-facing Slope Region is located within the Western Extension. These various physiographic regions are depicted in Figure 2-1.4. As discussed in that figure, these regions are defined by their geomorphological and tectonic features and observed distress trends. For illustration purposes, the regional boundaries are depicted as discrete lines. In reality, these boundaries are transitional in nature and are not necessarily delineated by lines as indicated on the map.

It is important to note that the stability of the various regions is inter-dependent. Stability improvement or deterioration in one region will likely have similar effects on adjacent regions. The inter-dependency of the various regions should be recognized as a given condition for the BRM area.

The principal rock units exposed in the BRM area are sedimentary rocks of the Sespe, Vaqueros and Topanga formations. The Sespe and Vaqueros formations have relatively low permeability and are often overlain by comparatively more permeable rocks of the Topanga formation. These sedimentary rocks have been intruded by volcanic dikes and sills, fractured by past tectonic activities and deformed by prehistoric and historic landslide activities. In the BRM area, the more permeable Topanga formation is generally located inland from the bluff with the less permeable Sespe formation located along the bluff. The contact between the two formations dips steeply northward (i.e., down into the hillside). These conditions tend to trap groundwater within the mesa. In this respect, subsurface conditions at BRM can be characterized as a bowl which traps and holds water which infiltrates into the subsurface, mainly from septic effluent, irrigation, and rain. Extensive geophysical sounding at existing and new borehole/well locations, together with surface geologic mapping, slope inclinometer data, and borehole information enabled BYA to develop a better understanding of the subsurface structure and slide mechanisms than was previously possible. However, it should be cautioned that BRM is probably one of the most geologically complicated sites along the coast of California. There are many remaining uncertainties, in spite of the seemingly high number of borings at the site, most of which were carried out either in an emergency manner (hence, lack of documentation) or during litigation (hence, redundancy).

The so-called Western Extension is not an extension of the main BRM landslide. There is no convincing evidence that the Western Extension has undergone mass movement. The term "Western Extension" is a misnomer. Based on our current understanding of subsurface geologic structures, the gross stability of the overall Western Extension area depends in part upon the stability of the main BRM landslide. In other words, as long as movement of the main BRM landslide doesn't occur, the Western Extension is unlikely to develop a south-southeast component of movement. However, the above statement does not apply to the South-facing Slope Region, where historical and prehistorical landslides have occurred.

In the BRM area, major faults generally trend east-west (roughly parallel to the coastline) and predominantly dip in a northerly direction. A number of cross-faults also occur in the BRM area. The east-west trending, north-dipping faults and north-trending cross faults, generally speaking, act as groundwater barriers which compartmentalize the groundwater and complicate dewatering efforts.

Seismically, the north-dipping Shoreline fault located approximately along PCH is considered to be a branch of the Malibu Coast fault (MCF) system, which is a potential source of earthquake shaking. The magnitude of the maximum credible earthquake associated with the MCF is about 6.5, which, together with the Anacapa fault zone to the south and southwest of BRM, dominate the seismic stability of the BRM area.

Groundwater

Bounded by the Las Flores fault system in the north, the Shoreline fault in the south and the surrounding ridgelines and canyons (Piedra Gorda and Rockpoint Canyons), BRM forms a well defined groundwater basin. Rainfall and imported water (septic tank effluent and irrigation) are the primary sources of groundwater recharge. The recharging groundwater infiltrates along the least resisting paths (notably, the fractured sedimentary rocks and/or fissured intrusive basalt channels) to fill the bowl-shaped groundwater basin. The rise of groundwater above the primary (basal) slide surfaces at depth and/or perched within the locally less permeable stratum are the primary causes for gross and local instability. In general, if groundwater levels rise, the factor of safety decreases.

BYA has taken various steps to improve the performance and capacity of the dewatering system during this investigation. At the present time, the total average production rate from 21 hydraugers and 15 wells is about 72,000 gpd. It should be noted that, although the pump capacity of the current dewatering system is capable of removing more groundwater than the current production rate, the production rate is limited by other factors such as the spacing and depths of the wells and the permeability of the rock formations through which the wells penetrate.

Groundwater levels in the BRM area have been reduced, especially in the vicinity of the new wells. Groundwater removed by the dewatering system is now discharged into the improved surface drainage system implemented by the CI in 1990-1991. However, even with the five additional deep dewatering wells and all of the tens of millions of gallons of water which has been removed from the subsurface, and in spite of the nearly five years of drought (1986 to present), groundwater levels are still well above the basal slide surfaces in the majority of the BRM landslide area. The stability of the main BRM landslide area can be significantly improved if the current existing groundwater levels are further reduced. The benefits of such an action would be widespread.

It is important to note that the existing dewatering system cannot significantly further reduce existing groundwater levels. Current area-wide groundwater levels are in an approximate steady state condition. What this means is that after nearly five years of drought, the production rate of the current dewatering system and the present groundwater levels as a result of the dewatering system closely correspond to a steady state condition with respect to the current groundwater recharge from rainfall and domestic water usage. In other words, the present dewatering system is removing about as much water as is currently being added by septic tank effluent, irrigation, and rainwater infiltration. This condition has important implications for the future stability of BRM.

First, it means that the existing dewatering system cannot significantly further reduce groundwater levels in the main slide area. Most of the wells were installed during the 1983 emergency dewatering program. They are widely spaced and many are not deep enough to further reduce groundwater levels. Second, it means that when normal rainfall levels return to the BRM area, groundwater levels will rise. The results of a groundwater analysis suggest that, with the existing dewatering system properly maintained, an average rainfall year (16 inches) will result in a groundwater rise of about 2.3 feet per year. Theoretically, this means that ten consecutive years of normal rainfall will result in a 23-foot rise in average groundwater levels (and reduce the factor of safety in the Central Region from 1.25 to about

1.2) and 20 consecutive years of normal rainfall will cause a 46-foot rise (and reduce the gross factor of safety of the main slide area to about 1.15).

These estimations of the effect of normal rainfall on the gross factor of safety of the main slide area are based on the assumption that the total daily average water consumption (imported water) will remain at the average level of 132,000 gpd.

Consecutive wet years (wetter than normal) will cause greater increases in groundwater levels and thus reduce the factor of safety of the primary slide surface of the BRM landslide further and at greater rates. For example, the groundwater model indicates that a series of three consecutive wet seasons with return periods of 10 years (24-in./yr.), 25 years (32 in./yr.) and 50 years (36 in./yr.) will result in an average rise of 21.7 feet in groundwater levels in the BRM landslide area (and reduce the gross factor of safety of the main slide mass from 1.25 to 1.20). It should be noted that there are limitations to these predictions, and that these limitations are due in large part to our imperfect understanding of subsurface conditions throughout the region and the limits of geotechnical science. These limitations are discussed in detail in the report.

The groundwater and geotechnical engineering analyses indicate that if the current factor of safety of the main slide mass is to be maintained (or increased), additional mitigation measures are needed. The assumption underlying this statement is that normal rainfall will, sooner or later, return to BRM.

Stability Considerations

Through the review of available data of previous investigations by others, analysis of BYA's deep exploration borings, additional geophysical data, instrumentation monitoring, and field mapping, the configurations of the main BRM landslide were developed with a higher degree of certainty than heretofore possible. In addition to assessing the stability of the main slide area and the Western Extension, stability analyses were also performed on a number of subregions based on the developed landslide configurations and observed movement characteristics. These subregions are shown in Figure 2-1.4 and include:

1. The Central Region of the main BRM landslide which is bounded by the Headscarp Region in the north and the Bluff Region in the south.

2. The Southeast Region of the main BRM landslide which is bounded approximately by the Inland fault in the west. This region was distressed in early the 1970's, slid with the main mass during 1983 and is currently showing signs of perceptible movements that need to be closely monitored.

3. The Bluff Region of the main BRM landslide which is bounded by the Central Region to the north and the Shoreline fault and Pacific Ocean to the south. This Region has numerous conjugated shear planes and cracks as a result of the 1983 movement.

4. The Headscarp Region of the main BRM landslide which is the steep slope area just north of the Central Region.

5. The South-Facing Slope Region which is located along the bluff in the Western Extension area.

Two- and three-dimensional slope stability analyses were used to evaluate the existing (December 1991) factors of safety of the primary slide surfaces of the main BRM landslide and the various subregions. A wide range of factors were considered in performing the stability analyses. Such factors included the surface topography, the configuration of the slide surfaces, groundwater levels within the landslide mass, strength characteristics along the slide surfaces, observed crack patterns and last, but certainly not least, engineering judgement. The factors of safety derived from the stability analysis are listed below. Also included is a column entitled "Maximum Attainable Factor of Safety" which is as an idealized state in which all of the rocks or aquifers above the basal slide surface are assumed to have been drained, i.e., there is no free water surface above the deepest slide surface. Although theoretically possible, such a condition may be economically prohibitive. This idealized condition represents, technically, the maximum factor of safety attainable without massive grading or any active retaining systems. This concept is important because it represents our estimate of the probable stability ceiling of each region by dewatering alone. As indicated, with the possible exception of the Western Extension, it is unlikely that any region will be able to achieve a factor of safety of 1.5 or above.

REGION	PREVAILING FACTOR OF SAFETY (1991)	MAX. ATTAINABLE FACTOR OF SAFETY BY DEWATERING/ SEWERING
BRM Landslide Area:		
* Basal Slide Surface of Main Slide Mass	1.25	1.4 +
* Central Region	1.25	1.4 +
* Southeastern Zone	1.2	1.4
* Eastern Bluff	1.2	1.4
* Central Bluff	1.2	1.3
* Western Bluff	1.2	1.4
* Headscarp Area	1.0+ to 1.2	Site Specific
Western Extension:	1.25+	1.4 +
* South-Facing Slope	1.1	Site Specific

As the above table indicates, the best estimated prevailing factor of safety based on calculations for the main slide mass above basal slide surface is 1.25. The prevailing factors of safety for the Southeast, Bluff, Headscarp and South-Facing Slope Regions are all less than 1.25. The confidence level for the factors of safety discussed above is judged to be within ±0.05. Factors of safety of 1.2 or less are marginal. They do not provide a sufficient stability reserve against potential adverse conditions such as unknown adverse subsurface conditions and consecutive heavy rain years. Slow creep movement can and does occur in areas with a factor of safety of 1.2 or less. The stability of an area with a factor of safety approximately 1.1 is especially precarious. Future movement is most likely to first occur in such areas. Since the prevailing factors of safety in many regions are low, additional mitigation efforts and preventive measures are needed to increase the margin of safety and to minimize the consequences of future reactivation.

The regional seismicity setting is such that the near-field strong motions originating from the Malibu Coastal/Anacapa fault zones control the site stability and not the more distant major active faults such as the San Andreas or Newport-Inglewood faults. Conventional pseudostatic stability analysis is inappropriate for near-field strong motion effects on slopes. Our seismic evaluation used a much more sophisticated, state-of-the-art approach based on seismic-induced permanent displacement analysis using similar near-field strong motion records which were scaled to be equivalent to a 6.5 magnitude design earthquake along the Malibu Coast fault. Estimated movements under such seismic loadings were calculated. The results indicate that maximum accumulative displacements on the order of 2.3 and 1.1 feet can occur in the Headscarp and Bluff Regions under present conditions, respectively. The Central Region is not significantly affected by near field seismic shaking. Rockfall along the bluff and initiation of landsliding along the headscarp areas should be anticipated.

The Sierra Madre earthquake (M=5.8) of June 1991 and the Malibu earthquake (M=5) of January 1989 caused an increase of hydrauger discharge of 11% and 16%, respectively. These events underscore the importance of seismic-induced pore pressure increases which can potentially endanger the stability of the area. However, there is not enough information available at this time to estimate the magnitude of seismically induced pore pressures and the resulting decrease in stability. But, its exacerbating effect on the stability of the BRM area in general and the Bluff and Headscarp Regions (when saturated), in particular, should be noted.

Stability Enhancement & Mitigation Options

It is essential that all area residents realize that a factor of safety is, by its nature, transient i.e., a factor of safety is not a fixed, permanent number. As conditions change, so does the relative factor of safety, (i.e., the stability) of the area. If groundwater levels are allowed to rise, the factor of safety will decline. In an area such as BRM, which has been subjected to tectonic activities and ancient and recent landslide episodes, the rocks are inherently weak and broken up. Future instability, should it occur, is likely to reactivate along the surfaces of past movements or through the planes of least resistance within the broken rocks. The geologic structure is such that the water which infiltrates into the ground tends to become trapped within the mass. The potential for future movement is real if groundwater is allowed to rise.

The factors of safety shown in the above table, though different in the various regions, are mutually dependent. For example, failures of the Headscarp Region will add additional driving forces to the main mass; failure of the bluff will result in lessening the support of the Central Region; movement of the main slide mass will reduce its buttressing effect on the Western Extension, and damage the homes on the Bluff and on PCH. The factors of safety in the above table are low. They should be a constant reminder to the citizens of the shared responsibility to minimize groundwater recharge. They also indicate the need for additional mitigation measures.

Because of the complex geology of the area, no single mitigation measure is a panacea for all of the differing stability problems in the various regions. The CI has taken the essential first step in significantly lowering groundwater levels on an area-wide basis. However, the existing dewatering system cannot achieve much more than it already has. If the currently existing stability in the BRM area is to be maintained and improved, additional mitigation measures are required. Some of these mitigation measures can be area-wide. Others must be tailored to the specific characteristics of a given region. Because of the inter-dependency of the various regions, stability improvements in one region will benefit other regions. The extent to which the stability of the area(s) should be improved is a collective decision for the CI property owners and their government. It is one which involves a balancing of the risks the owners are willing to bear versus the costs of the various potential mitigation measures.

BYA has investigated various potential mitigation options which range from ways to increase the strength of the clay gouge along slide surfaces, to active retaining schemes, to passive underground dewatering galleries that consist of shafts, tunnels and hydraugers. However, BRM is unique, both geologically and physiographically. BRM is bounded by steep bluff and headscarp zones with a rather extensive gentle mesa in between. With the desirable climate and ocean view, the land values are high. Considering factors such as the high traffic volume along PCH, the limited space between bluff and oceanfront homes, the large number of existing houses on the mesa and depth and size of the landslide, conventional re-grading or buttressing type of stabilization options do not appear to be feasible. The two potential mitigation measures offering the most wide-spread benefits are an additional dewatering system and a sewage collection system. These are discussed in more detail below.

Additional Dewatering

The gross stability of the Central Region, the Southeast Region, and certain portions of the Bluff Region can be substantially improved by additional active dewatering to lower the overall groundwater levels below the basal rupture surfaces of the main slide mass. Additional active dewatering will not directly address the specific mitigation needs of the Headscarp Region, the South-facing Slope Region and the central portion of the Bluff Region. These are areas where perched groundwater conditions either exist or are likely to develop. In addition, in most of the Headscarp Region, the overall groundwater table is already below the critical slide surfaces of the BRM landslide.

In addition to substantially improving the stability of the Central Region, the Southeast Region and certain portions of the Bluff Region, additional active dewatering also provides the following advantages:

- Significantly lowering the groundwater table will increase the capacity reserve of the subsurface materials to receive additional recharge due to successive wet years and/or unexpected increases in domestic water usage, thus, minimizing the potential of future rises in groundwater levels and the risk of reactivating the landslide.

- For obvious economical and practical reasons, the additional dewatering system cannot be so closely-spaced as to eliminate the potential recharge cones of septic effluent infiltration from individual lots. However, the implementation of such a system for the intended purpose of lowering area-wide groundwater levels will reduce the risk of local lot-specific instability, especially for those lots adjacent to and downstream from the new dewatering locations.

- The additional dewatering system will reduce the risk of seismic-induced pore pressure increase in the Bluff Region and decrease the seismically induced permanent displacement in general.

- The increase in gross stability from active dewatering also provides a margin of stability reserve, in areas without perched groundwater conditions, to compensate for the potential stability degradation due to seismic-induced excess pore pressure within the slide mass.

An additional dewatering system (best estimate cost of about $2.5 Million) would consist of new wells and the deepening of some existing wells.

Sewage Collector System

The installation of a sewage collector system will eliminate the effluent recharge which, in an average year (16 inches of rainfall), contributes more than 60% of the total recharge to the groundwater in the BRM area. By eliminating sewage effluent recharge, the installation of a sewage collector system will provide the following benefits:

1. Reduce groundwater table rise which will occur during successive normal and above normal rainy seasons.

2. Reduce the saturation of subsurface materials, thus increasing their storage capacity to accommodate increased recharge from successive wet years.

3. Eliminate the cones of infiltration emanating from individual septic/seepage pits which cannot be eliminated by a dewatering system (such as the current dewatering system of widely-spaced wells and hydraugers). The elimination of these cones will also have the beneficial effect of improving the local stability of individual lots, especially in the Headscarp Region, Bluff Region and the South-Facing Slope Region in the Western Extension.

4. Minimize the potential of seismic-induced excess pore pressure and the associated potential instability.

As indicated previously, current area-wide groundwater levels are in an approximate steady state condition. When normal rainfall returns to the area, groundwater levels will rise. The rise in groundwater will be even greater during consecutive above-average rain years. A sewage collection system will significantly reduce further increases in the groundwater table due to average and above average rainfall. This will benefit the entire BRM area. As is true for the existing dewatering system, a sewage collection system will not significantly further reduce the current basin-wide groundwater levels. This is because the groundwater basin has the basic shape and drainage characteristics of a bowl, i.e., water which is allowed to infiltrate into the basin basically gets trapped there.

The benefit of eliminating cones of effluent infiltration is particularly important in areas where perched groundwater conditions prevail or could develop. The development of perched groundwater is critical in areas such as the Headscarp Region, the South-Facing Slope Region, and the Bluff Region in the vicinity of Cross Sections B-B' and C-C'. In all of these areas, the prevailing factors of safety are very low, and any additional accumulation of local perched groundwater due to the presence of cones of effluent infiltration can seriously reduce their precarious stability even further. Besides these specific regions, a sewer system would also significantly benefit any other areas where shallow perched groundwater conditions could develop. Dewatering wells will generally not be an effective mitigation measure in terms of mitigating/preventing perched groundwater conditions. If an area-wide sewer system is not implemented, it is strongly recommended that a local pre-packaged on-site treatment/storage facility be installed with the treated effluent being disposed of offsite in a non-slide area. Off-site disposal of the effluent will avoid the adverse affects of septic-effluent-induced perched groundwater conditions in the various regions/neighborhoods discussed above. A sewage collection system will have definite beneficial results. Such a system will not solve all of the area's stability problems. As indicated earlier, no single mitigation measure, whether it be wells, hydraugers, or sewers, can.

Mitigation Option Summary

Considering all of the various constraints, on an overall basis, the most viable mitigation options for potential use by the residents of the CI are as follows:

1. An additional dewatering system.

2. A sewage collection system.

3. Crack filling throughout the BRM area, and especially in the Headscarp Region (everywhere), Bluff Region (especially in the vicinity of Cross Section E-E') and South-Facing Slope Region in the Western Extension, including collaboration among neighbors to implement a continuing crack filling/surface drainage program.

4. Maintain and improve surface drainage of individual lots.

5. Use rocknets to restrain debris and/or debris fences to divert the impact of debris flow with respect to potential rockfalls and mudflow hazards, especially in the Headscarp and Bluff Regions.

SECTION 1.0

INTRODUCTION

1.1 GENERAL

This report represents the results of a geotechnical engineering evaluation of the Big Rock Mesa (BRM) area performed for the County Improvement District 2629R2 (CI) by Bing Yen & Associates, Inc. (BYA). This report summarizes project information and completed work, including assessments of static and seismic stability as well as an evaluation of mitigation options for consideration by the community.

1.2 OBJECTIVES AND SCOPE

Upon consultations with the CI and meetings with the citizens' representatives known as the Big Rock Improvement Committee (BRIC), the following primary project objectives/tasks were established:

1. Investigate the BRM subsurface features which allowed the 1983 main slide to occur, even though the apparent geologic surface structure appears to be grossly favorable and should have inhibited such movement, i.e., to understand why and how the slide movement culminated in 1983 prior to developing a rational mitigation scheme(s);

2. Evaluate the potential movement of the area commonly referred as the Western Extension and its inter-relationship with the stability of the main BRM landslide mass;

3. Evaluate the effectiveness of the existing dewatering system and maintain and improve the system during the course of this investigation;

4. Evaluate the overall or gross factors of safety of the BRM area and other subsidiary regions in the area under prevailing conditions;

5. Based on the findings generated from the above tasks, identify remediation options which could further enhance the site stability together with a preliminary cost estimate and benefit discussion.

To accomplish these objectives/tasks, BYA has performed the following:

- Reviewed and synthesized available reports regarding past development, and previous geologic and geotechnical investigations of BRM;

- Drilled, continuously cored and examined a total of 2,526 feet of soil and rock samples from five deep boring locations;

- Completed over 10,780 feet of high resolution gamma ray, 3,900 feet of dip meter, other geophysical logging in the deep borings, and selected existing wells and instrumented borings;

- Observed, maintained and improved (renovated and cleaned) 18 existing dewatering wells, 42 hydraugers and monitored 33 slope inclinometers and other existing instrumentation (pneumatic piezometers and a multi-point borehole extensometer - MPBX);

- Converted the 5 deep borings into dewatering wells, installed 3 new hydraugers and cleaned hydraugers along PCH, resulting in a combined removal of 93.7 million gallons of groundwater from BRM since November 1988 when BYA began to participate in the field work with the Los Angeles County Department of Public Works (DPW);

- Provided consultation to the CI regarding surface drainage improvement;

- Identified and analyzed subsurface geologic structures, landslide surfaces and past slope failure mechanisms;

- Mapped and characterized surface geologic features and identified rock types and orientations in the project area;

- Evaluated the hydrogeologic setting and groundwater conditions of the BRM area to develop a preliminary model to estimate the change in groundwater level as a function of rainfall and effluent recharge;

- Assessed the present state of stability and evaluated static factors of safety under various groundwater conditions;

- Assessed the state of stability under seismic loading and the potential for seismically induced movement;

- Evaluated mitigation options and presented preliminary cost estimates; and

- Prepared this report.

1.3 REMARKS

Although this study represents the most comprehensive attempt to date to achieve the intended objectives, the following remarks must be taken into consideration the information contained in this report:

1. The BRM area is geotechnically complex and is complicated by many local factors which are beyond the scope of this study. Stability analyses presented in this report, by necessity, only address large areas such as the main BRM landslide area, Western Extension and various major subregions. Thus, the stability analyses presented in this report are not lot-specific. This investigation has not focused on lot-specific problems, localized instabilities, or the smaller surficial slides and rockfalls which have

been recognized on the Mesa.

2. The complexity of geologic and subsurface conditions make extrapolation of data from widely-spaced discrete points (e.g., borings and instrumented data) difficult. The different subregions are characterized by varying subsurface structures, groundwater conditions and geotechnical considerations based on information generated from these discrete locations. Thus, the data and results generated from this study, though more comprehensive, will require refinement when and if additional data becomes available.

3. The stability of the BRM area is interdependent in nature, i.e., the stability of one part of the area will affect the adjacent parts which, in turn, will affect more parts of the area. This is an important and fundamental concept which must be recognized when evaluating the present and future stability. The stability of the area (expressed as a calculated factor of safety) is transient in nature, i.e., it may vary depending on factors such as groundwater changes and regrading, which may occur. If groundwater levels rise, the factor of safety (i.e., stability of the area) will fall. Thus, it is the shared responsibility of the area's residents to minimize stability risks and to optimize mitigation efforts.

1.4 CONTENT

Section 2.0 provides a description of general background information of the BRM area with respect to its physiography, climate, vegetation and site development history as well as available project data. A general description of tasks and results of BYA's field investigations and laboratory testing programs are summarized in Section 3.0. Geologic and seismic environments that affect the static and seismic stability of the area are presented in Section 4.0. A more comprehensive treatise of geology and structural geology is included in Appendix B. The characterization of the 1983 BRM landslide and subsequent development are presented in Section 5.0. Hydrogeologic setting and groundwater conditions along with recharge/infiltration analyses are described in Section 6.0. Static stability analyses with estimated prevailing factors of safety and maximum factors of safety attainable by dewatering are presented in Section 7.0. Seismic stability analysis and calculated seismic-induced displacements are summarized in Section 8.0. Mitigation options and cost estimates are presented in Section 9.0 for the citizens' consideration.

SECTION 2.0

BACKGROUND INFORMATION

2.1 SETTING PHYSIOGRAPHY

As shown by the Site Location Map in Figure 2-1.1, the Big Rock Mesa (BRM) area is located on Santa Monica Bay, approximately seven miles west of the City of Santa Monica and within the eastern margin of the recently incorporated City of Malibu.

The area and lots included within the County Improvement District No. 2629R2 (CI) are shown on Figure 2-1.2. Figure 2-1.3 shows a 3-dimensional view depicting the ground surface features. Topographically, the study area extends approximately 5,000 feet in an east-west direction along the coast, and about 3,000 feet in the north-south direction. A narrow beach - 100 to 150 ft. wide at low tide - extends along the shoreline. Pacific Coast Highway (PCH) is located just inland of the beach at an elevation of ± 25 ft. above Mean Sea Level (MSL). Immediately inland of PCH, a steep cliff, or bluff, rises to elevations of ± 150 ft. and ± 300 ft. in the eastern and western portions of the mesa, respectively. The average overall slope gradient of the bluff typically ranges from 35° to 40°. To the northwest, the ground surface rises in a stair-stepped manner to an elevation of ± 800 ft. at an average overall gradient of approximately 20°. Local slope gradients are steeper and average approximately 35°.

Towards the western portion of the study area north of the bluff, the ground surface rises somewhat more uniformly at an average gradient of ± 20° to the ridge crest existing at an elevation of ± 900 ft. The average gradient of the ground surface from the shoreline to the ridge crest is typically on the order of 22°.

From the shoreline, the seafloor slopes gradually out to a water depth of approximately 30 feet at a distance of ± 1,000 ft. from shore. At this distance, the gradient steepens and the typical water depth reaches about 60 ft. at a distance of about 1,300 ft. from shore.

The study area in BRM can be subdivided into several physiographic regions as shown on Figure 2-1.4. These regions are defined by their physiographic, geomorphic, and geotechnic characteristics. These regions consist of 1) the Central Region, 2) the Bluff Region, 3) the Headscarp Region, 4) the Southeast Region, 5) the Western Extension, and 6) the South-Facing Slope Region within the Western Extension. It should be noted the subregions shown in Figures 2-1.4 are for analysis and illustration purposes. Actual boundaries of these subregions are transitional in nature and cannot be divided by lines on the map. The characteristics of the regions are further expounded upon in Sections 4.0, 5.0, 6.0 and 7.0 from the viewpoints of geology, slide characteristics, hydrogeology and stability, respectively.

The BRM study area is essentially comprised of two major areas: the main slide area and the Western Extension. The main slide area encompasses the BRM landslide which was observed to be in progress in 1983. In this report, the BRM landslide is interchangeably referred to as the main slide, or the Main Mesa landslide. The boundaries of the main slide

area encompass the Central, Headscarp, Bluff and Southeast Regions. As will be discussed in detail in subsequent swections, the so-called Western Extension area is not an extension of the Main Mesa landslide.

The Main Mesa slide boundaries are constrained fairly conclusively by major ground cracks and survey data. The main mesa landslide, which consists of about 136 acres, is roughly bordered by the Shoreline fault to the south, ground cracks on a ridge south of Piedra Gorda Canyon to the north, an unnamed stream channel east of Rockpoint Canyon to the west and ground cracks just west of Piedra Gorda Canyon to the east. A 3-dimensional view of the primary slide surface is shown in Figure 2-1.5. The slide surface configuration and depths were defined by slope indicators, deep borings and other data. It is estimated that there was about 41 million cubic yards of material involved in the 1983 slide. Discussions of the main BRM landslide slide surface and the 3-dimensional slope stability analysis are given in Sections 5.0 and 7.0, respectively.

The BRM landslide is composed of faulted blocks and deep-seated landslides and that have undergone different movement histories in the past (see Appendix B). These differential movements are primarily responsible for forming the present stepped like topography. One of these blocks comprises the Southeast physiographic region (see Figures 2-1.4 and 2-1.6). This region is bounded by the north-south trending Inland Lane fault to the west and the reactivated landslide boundaries to the north, south and east. The region is somewhat isolated from the Central Region and the central portion of the bluff by the Inland Lane fault (see Appendix B), its hydrogeologic characteristics (see Section 6.0) and its recent movement history (see Section 5.0).

The Central Region consists of the Central Mesa. It is bounded by the Bluff to the south, the Headscarp Region to the north, the Inland Lane fault to the east, and the main BRM landslide boundary to the west.

The Bluff Region exists at the southern boundary of the main reactivated sliding area, while the Headscarp Region, as the name implies, encompasses the area in and adjacent to the northern boundary, or headscarp of the Main Mesa landslide. The Bluff Region is defined by a complex series of shallow landslides occurring in the bluff face and a series of major ground cracks exhibited at the top of the bluff and along Roca Chica Drive. The Headscarp Region includes the steep slope area in and around the northern boundary of the BRM landslide. The headscarp zone encompasses recent and prehistoric satellitic landslides, including the Hansch landslide, which occurred and/or reactivated during the 1983 main BRM landslide.

As shown in Figure 2-1.4, two physiographic regions are delineated west of the main landslide boundary - the Western Extension region and the South-Facing Slope Region within the Western Extension. The Western Extension area was suspected by previous investigators (Appendix A) to have moved contemporaneously with the main BRM landslide of 1983 which initiated further investigation. The boundaries of this zone, based on geomorphic interpretation and by the recent findings of BYA, extend from the main sliding boundary to the east, Rockpoint Canyon to the west, the North Fault to the north, and the Shoreline Fault to the south. The South Facing Slope within the Western Extension area is defined by the presence of a shallow landslide complex encompassing the "Love Slide" extending approximately from Seaboard Road to PCH.

2.2 SITE DEVELOPMENT HISTORY

To determine a development history for the mesa, BYA reviewed available records, photos and aerial photos from the early 1900's to the present. The results of this review, summarized in Table 2-1, indicate that prior to the 1940s little development had occurred. By the year 1947, the present day roadways within the first tract had been constructed along with several homes. Home development continued at a steady and increasing pace through 1980. The rate of homes constructed in the BRM area increased the demand of imported water (see Figure 2-2.1). The increase in effluent contributed to the rise of groundwater level within the basin, despite intermittend dewatering efforts. Table 2-1 chronologically documents significant events while supporting information is listed in Appendix A-1, General References.

2.3 OVERVIEW OF 1983 MAIN BRM LANDSLIDE

As summarized in Table 2-2, documented deformations were noted in late 1971 to early 1972. The deformation was primarily confined to the Southeastern Region of the main slide. By the Spring of 1980 four areas of distress were identified (2 on the mesa and 2 along PCH) that closely corresponded to locations where pavement offsets occurred during movement of the main BRM landslide in 1983. These data provide an indication that some movement of the Main Mesa landslide might have been initiated by early 1980. Following the spring of 1980, reported distresses significantly increased coincident with near record rainfall. By approximately September of 1983 movements of the entire Main Mesa landslide was widely recognized. After massive emergency dewatering effort funded by the CI and initiated in 1983, the main BRM landslide was arrested, although deformation monitoring indicated that movement of the main BRM landslide as a whole continued through 1985 and by 1986 had been reduced to small discrete deformations, especially in the Southeast Region. Portions of satellite slides in the Headscarp Region (in the vicinity of the Hansch property) however, continue to exhibit small but perceptible creep-type movements up to the present.

2.4 CLIMATE, RAINFALL AND VEGETATION

2.4.1 Climate and Rainfall

The climate of the landslide area plays a key role in controlling the amount of water usage and groundwater recharge which occurs - both naturally through rainfall, and artificially through irrigation and sewage effluent. Comprising rainfall, temperature, wind, and relative humidity patterns of the area, the climate impacts upon the amount of moisture which evaporates from the groundsurface and evapotranspires from plants.

The Big Rock Mesa area experiences a temperate, semi-arid, sub-Mediterranean type of climate. Seasonal temperature variations are relatively small, with mean summer and winter temperatures of 67° and 59°, respectively. Daily highs and lows typically fluctuate ± 10° F. from these mean temperatures.

Wind in the study area is typically light in the mornings, but often increases to more than 5 knots onshore breeze by early to mid-afternoon before subsiding once again in the evening. The relative humidity of this onshore breeze typically varies from 40% to 70%.

During the Fall and Winter months between September and January, the onshore breeze may be periodically interrupted for several days by a strong seaward flow of air referred to locally as the "Santa Ana Winds". These winds are typically warm (± 75°F.) and dry (Relative Humidity = ± 20%) with average velocities on the order of 25 knots and gusts can be in excess of 50 knots.

The long-term average annual rainfall for the general area is estimated to be on the order of 16 inches. This estimate is based upon 114 years of rainfall data obtained from the Los Angeles County Flood Control District (LACFCD), Stations 447 A & C (which are located at similar elevations in the nearby Las Flores and Carbon Canyons), LACFCD Station 577 in downtown Los Angeles and LACFCD Station 1239 existing in the BRM area (see Table 2-3). This rainfall data has been plotted on an annual, bi-annual, tri-annual and quad-annual basis in Figures 2-4.1 through 2-4.4. These figures indicate historical rainfall cycles which are important due to the fact that the average groundwater residence time in large landslides such as BRM landslide can exceed one year. Further discussion and analyses along with geotechnical ramifications of rainfall are contained in Section 6.0.

2.4.2 Vegetation

The type and distribution of vegetation in and around the slide area is significant in that it affects both the amount of irrigation water which is used, as well as the amount of rainfall and irrigation water which is evapotranspired and therefore prevented from recharging the groundwater table.

Indigenous vegetation in the area consists of both naturally occurring and cultivated plants and trees. The natural vegetation consists primarily of drought tolerant varieties of sage, buckwheat and ceanothus, with several other types of chaparral scattered about the slopes. Native grasses consist primarily of foxtail, rye and wild oats. Coast live oak and scrub oak trees are also common in the area with pepper, alder, cottonwood and sycamore trees found in several of the canyons.

The density, distribution and type of ground cover in the study area - both indigenous and domestic - have been evaluated from aerial photographs, and site reconnaissance. The results of this evaluation are presented in Figure 2-4.5. It should be noted that the earlier aerial photos (e.g., 1928) showed the vegetation was much more sparse than that of recent years.

2.5 REVIEW OF AVAILABLE INFORMATION

Numerous geotechnical and/or geological investigations of the BRM area or portions thereof have been conducted by various consultants, government agencies and academia (e.g., theses). The earliest investigations were generally undertaken in order to define the general geology of the region and, on a more localized level, to identify the most promising locations of water supply wells. Later, in the 1960's and 70's, most investigations were undertaken in support of the residential development of the area. Beginning in the early to mid-1970's, an increasing number of these investigations dealt with distressed structures. D. A. Evans, Inc.'s report of 1986 was the most recent and extensive investigation prior to the present evaluation.

As part of this investigation, BYA has collected and reviewed all available information as well as over several hundred geotechnically related documents. These documents dating back to the early 1900's are listed chronologically in Appendix A-1. Because of the number of reports involved, no individual citation or references are made in this report unless otherwise noted. Data from these previous works have been utilized as much as feasible or appropriate to meet the objectives of the present investigations. Where gaps in the existing data were found to exist, which are many, they were filled as effectively as the budget and time would allow by additional exploratory work and testing.

TABLE 2-1
SUMMARIZED TABLE OF SEQUENCE OF DEVELOPMENT IN BIG ROCK MESA

DATE	DEVELOPMENT	SOURCE
1900	Only one house was noted on the U.S.G.S. Base Map of Big Rock. It was located near the present-day location of the Inland Lane cul-de-sac. A dirt road was visible following the present location of Big Rock Drive to this house. A cart path was also present following the shoreline at the base of the seacliff.	U.S.G.S. Map
1910	The cart path along the shoreline was upgraded to a single lane roadway with periodic turnouts.	Photograph
1932	Pacific Coast Highway was widened to 30 feet.	
1933	Original house on the mesa is gone. Another house is visible in the Central Mesa. Ten beach houses were visible along the shoreline within the present interpreted slide limits.	Aerial photo
1947	All present day roadways within Tract 13562 had been completed. Approximately eight houses had been completed on the mesa, and approximately 30 beach houses were present.	Aerial photo
1952	A total of ten houses were present on the mesa itself with approximately 40 beach houses along Pacific Coast Highway.	Aerial photo
1955	Approximately four houses were present on the lower mesa, and eleven houses were on the upper mesa. Seventy beach houses were present along Pacific Coast Highway.	Aerial photo
1960	A total of approximately 14 houses were visible on the lower mesa and fifty-five houses were present on the upper mesa, in addition to 80 houses along the beach.	Aerial photo
1963	Approximately 90 houses were completed on the upper mesa with fifteen on the lower mesa, along with 90 beach houses.	Aerial photo

TABLE 2-1

SUMMARIZED TABLE OF SEQUENCE OF DEVELOPMENT IN BIG ROCK MESA
Page Two

DATE	DEVELOPMENT	SOURCE
1967	Continued development resulted in 102 houses on the upper mesa, 56 on the lower mesa and 95 beach houses by this time.	Aerial photo
1970	76 houses were present on the lower mesa, 102 on the upper mesa and 100 along the beach.	Aerial photo
1975	107 houses present on the upper mesa and 96 present on the lower mesa. The number of homes between Piedro Gorda and Rockpoint Canyons was approximately 105.	Aerial photo
1980	216 houses were present on the mesa. 105 houses on the upper mesa along with 111 on the lower mesa. A total of 108 beach houses were present along Pacific Coast Highway.	Aerial photo

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA

Date	Deformation/Movement Reported	Location	Source
Late 1960 - Early 1961	Identified several small landslides within the mesa.	(Undev.) Tract 26263 and 27463	Don Michael
Mid-1962	Concluded that a portion of the upper mesa had collapsed sometime in the distant past.	(Undeveloped) Tract 26263	Moore & Tabor
Mid-1962	Geologic review which expressed observations as to possible existence of larger scale landsliding within the area.	(Undeveloped) Tract 26263	L.A. County Geologist
Jan. 7, 1966	Identified the Big Rock Mesa area as a large, relatively deep-seated inactive landslide which toed-out along the shoreline.	Big Rock Mesa	John Merrill
Winter/Spring 1968-1969	Several surficial slides along seacliff due to exceptionally heavy winter rains.	Seacliff adj. to Big Rock Mesa	Caltrans
Jan. 11, 1972	Slow deformation of the outer 10 feet of the seacliff. Failure was evidenced by a series of tension cracks across the back portion of the pad for Lot 4, Tract 27463. Additional mud and debris flows onto PCH were observed.	20282 Inland Lane	Moore & Tabor
Feb. 1972	Numerous cracks (up to 3/4 of an inch) were observed. Majority of the offsets were in a southerly direction towards PCH. Residence had been severaly damaged by ground movement which had been occurring for several years and involved much of the tract. Remedial measures were advised to prevent more extensive movement.	20218 Piedra Chica Road	Macintosh & Macintosh

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Two

Date	Deformation/Movement Reported	Location	Source
July 5, 1972	If pumping of the "Inland Well" should cease for 3-6 months, intability of bedrock materials is probable.	Big Rock Mesa	Arthur Keene (LA Cty. Chief Engineering Geologist)
August 1972	Identified six landslides and 15 seepage locations along the Bluff.	Bluff adjacent to Big Rock Mesa	Lamar-Merrifield
March 1973	Identified over 40 cracks ranging in width from hairline to 1-inch.	Tracts 27463, 26263	Lamar-Merrifield
Oct. 1974	An investigation of distress on residence was conducted. Borings excavated to 54 feet encountered no groundwater.	20218 Piedro Chica Road	Lockwood-Singh & Associates
March 1975	A surficial failure occurred along Bluff face in the Western Extension area below 20676 Rockpoint Road. This failure occurred within a larger and deeper-seated slide mass. Apparently was triggered by +/- 4 inches of rainfall in previous 96 hours.	Below 20676 Rockpoint Rd.	N/A.
Winter of 1977-1978	Approximately 34" of precipitation over a 4-month period resulted in severe erosion in canyons and surficial landslides along seacliff.	Big Rock Mesa	Aerial photo (3/8/78)
Winter of 1977-1978	Heavy winter rains and elevated groundwater levels precipitated a rash of subsequent slope failures and other reported distress.	Big Rock Mesa	N/A.
April 1978	A surficial failure occurred along the slope below 20404 Little Rock Way.	20404 Little Rock Way	Geosoils, Inc.

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Three

Date	Deformation/Movement Reported	Location	Source
May 1978	Minor ground cracking was noted near the top of the seacliff in the Western Extension area.	20542 Seaboard Road	N/A.
June 1978	A large failure occurred along the seacliff of 20674 Rockport Way. This failure undermined the residence which was located on this lot - necessitating its abandonment.	20674 Rockport Way	H.G. Adams, Consulting Geologist
Oct. 1978	Minor structural cracking was noted at the residence located at 20358 Big Rock Drive.	20358 Big Rock Drive	N/A.
Dec. 1978	Extensive slope failures occurred on the slopes below the Roca Chica cul-de-sac and 20520 Seaboard Road, most likely to due +/- 1" of rainfall over the previous 72 hour period.	20520 Seaboard Rd./ below Roca Chica cul-de-sac	Ralph Stanet Don Michaels
Winter of 1979-1980	Intensive rains resulted in several mud and debris flows along the seacliff at Big Rock Mesa. Several deeper seated deformations along the bluff were noted in the weeks following these periods of intense rain.	Seacliff adjacent to Big Rock Mesa	L.A. County
Feb. 1980	Water Service main for 20316 Pacific Coast Highway ruptured.	20361 Pacific Coast Highway	
May 1980	Two areas along PCH were observed to be experiencing bulging or uplifting of the pavement between 19958 and 20006 P.C.H.	Big Rock Area	L.A. Cty. Geology Section

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Four

Date	Deformation/Movement Reported	Location	Source
May 1980	Minor settlement and cracking were observed at 20632 West Big Rock Drive. This settlement was determined to be due to saturation of the underlying soils.	20632 West Big Rock Drive	L.A. Cty. Geology Section
May 1980	Minor settlement and cracking were observed in the roadway. It was determined that the settlement was due to saturation of the underlying fill.	Intersection of Big Rock Drive & Rockport Way	L.A. Cty. Geology Section
Early 1980	A failure occurred along the seacliff below 20130 Rockport Way. Kovacs-Byer & Assocs. installed 2 slope inclinometers to define the failure configuration.	20130 Rockport Way	Kovacs-Byer & Assocs.
Sept. 1980	Water service main at 20140 Pacific Coat Highway ruptured.	20140 PCH	
Sept. 1980	Caltrans published a report on landslides along PCH in Malibu. This report noted two areas of uplift, in addition to the growth of an old landslide and development of 5 new failures along the bluff.	PCH adjacent to Big Rock Mesa	Caltrans
March 1981	An investigation of distress was performed on the residence located at 20540 Seaboard Road by Lockwood-Singh & Assocs. It was determined to be a localized problem resulting from creep and/or settlement of the underlying fill.	20540 Seaboard Road	Lockwood-Singh & Assocs.

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Five

Date	Deformation/Movement Reported	Location	Source
Sept. 1981	A crack inspection was performed by the firm of Kovacs-Byer on the driveway and tennis court at 20600 Rockcroft Way. It was concluded that those cracks resulted from differential settlement on the lot.	20600 Rockcraft Way	Kovacs-Byer & Assocs.
Dec. 1981	An investigation into distress to the residence at 20693 Big Rock Drive was performed by Kovacs-Byer & Associates. It was determined by visual inspection that cracks on the walls and ceiling of the residence were attributed to differential settlement of the underlying fill.	20693 Big Rock Drive	Kovacs-Byer & Assocs.
May 1982	A report by Lockwood-Singh & Assocs. was submitted regarding distress to the residence at 20484 Roca Chica Drive. It concluded that the distress was due to a localized failure of inadequately compacted underlying soils. Underpinning of the residence was recommended as a means of repair.	20484 Roca Chica Drive	Lockwood-Singh & Assocs.
Sept. 1982	The firm of Kovacs-Byer & Assocs. recommended underpinning to repair the distress at 20693 Big Rock Drive.	20693 Big Rock Drive	Kovacs-Byer & Assocs.
March 1983	Repairs to the residence at 20765 Big Rock Drive was observed. These repairs consisted of underpinning of the corner of the residence due to 1" to 2" of differential settlement.	20765 Big Rock Drive	Kovacs-Byer & Assocs.
June 27, 1983	A leak was discovered in the underground 10-inch water main adjacent to 20537 Little Rock Way.	20537 Little Rock Way	

TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Six

Date	Deformation/Movement Reported	Location	Source
July 21, 1983	A leak developed in the 30-inch water main adjacent to 20358 Pacific Coast Highway	20358 PCH	
July 26, 1983	The residence at 20693 Big Rock Drive was reinspected and it was noted that the distress at the residence had worsened since the last inspection. It was also noted that the movement suggested earth movement in a southeasterly direction.	20693 Big Rock Drive	Kovacs-Byer & Assocs.
August 3, 1983	Inspection of the residence noted that cracks up to 2" had redeveloped in the southwesterly portion of the house. It was determined that an ancient landslide underlying the house had been reactivated.	20484 Roca Chica	Lockwod-Singh & Assocs.
August 17, 1983	Leaks were discovered in the 30-inch and 10-inch water mains adjacent to 20466 Pacific Coast Highway and 20537 Little Rock Way, respectively.	20466 PCH & 20537 Little Rock Way	
August 22, 1983	An inspection on the residence revealed distress occurring in the rear yard, retaining wall and throughout the residence.	20520 Seaboard Road	Kovacs-Byer & Assocs.
August 26, 1983	The firms of Kovacs-Byer & Assocs. and GeoPlan both independently sent letters to the County Chief Geologist warning of massive ground movement involving the entire mesa.	Big Rock Mesa	Kovacs-Byer & Associates / GeoPlan

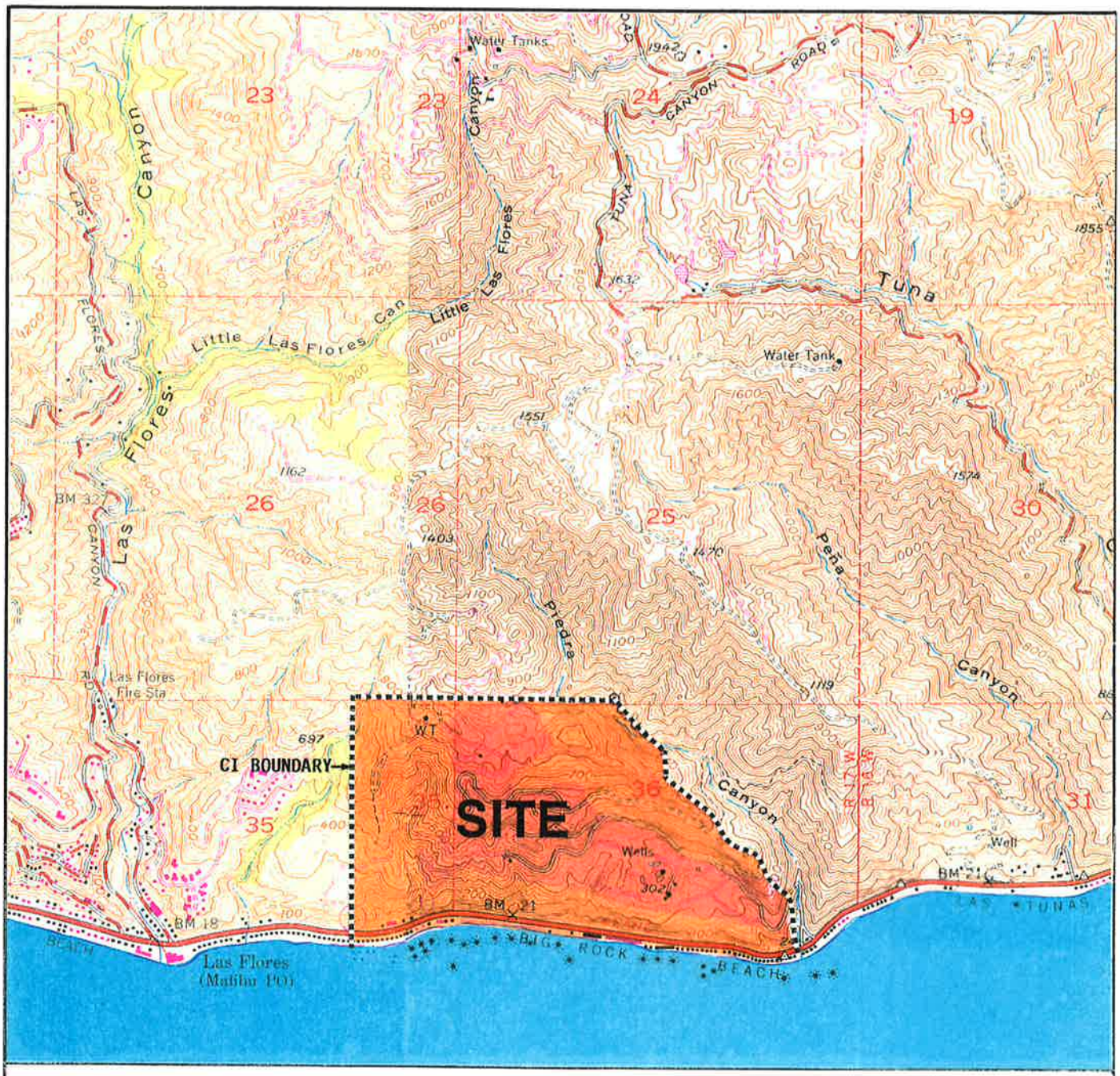
TABLE 2-2
SUMMARIZED TABLE OF DISTRESS/DEFORMATION ACTIVITY IN BIG ROCK MESA
Page Seven

Date	Deformation/Movement Reported	Location	Source
Sept. 6, 1983	The County Engineer sent a letter to area residents notifying them that the landslide mass under Big Rock Mesa had been reactivated.		
Sept. 1983	During this month, one leak in a 6-inch water main near 10575 Seaboard Road and three leaks in service connections at 20212, 20300 and 20308 PCH were discovered.	Pacific Coast Hwy.	
Oct. 1983	During this month, four leaks were reported in water mains on the Mesa at 20585 and 20616 Seaboard Road and on Inland Lane and Little Rock Way. In addition, a 30-inch water main experienced a leak adjacent to 20212 and 20526 PCH. A letter issued by the L.A. County Water Works Div. on 10/27 indicated there were three leaks on the 30-inch main and 21 leaks on smaller mains in the BRM area.	Big Rock Mesa	

TABLE 2-3

RAINFALL DATA BASE

YEAR OF RECORDS	LOCATION, DISTANCE TO BRM (Miles)	STATION NO.	ESTIMATED STATION ELEV. (Ft.)
1877 to 1939	Downtown L.A. = 30	577	417
1939 to 1964	Las Flores Cyn. = 1.5	LACFD 447	138
1964 to 1986	Carbon Cyn. = 2	LACFD 447C	50
1986 to 1991	On-Site	1239	720



Base map from U.S.G.S. 7.5' series (topographic)
Malibu and Topanga Quadrangles, CA

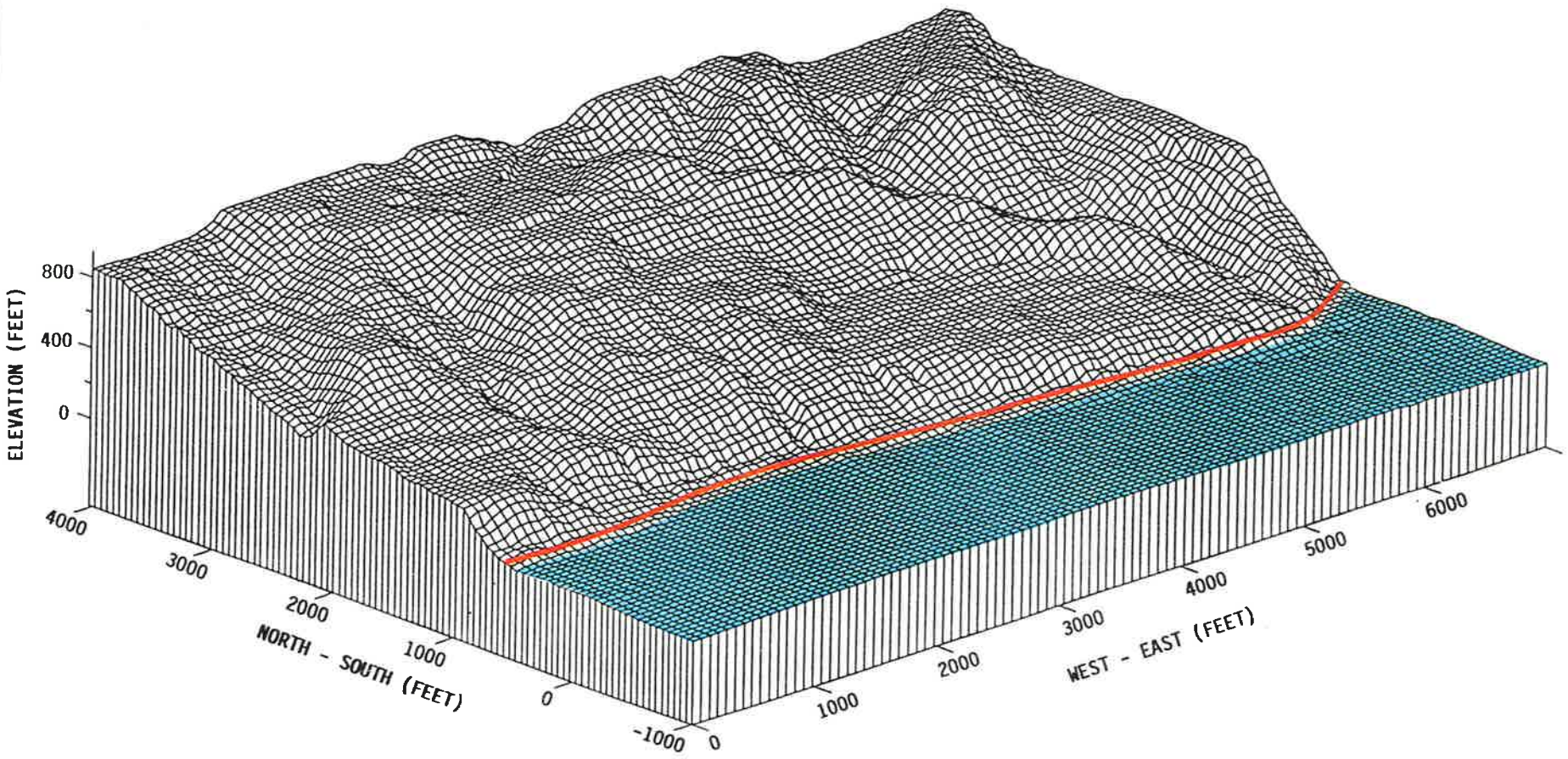
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SITE LOCATION MAP

FIGURE 2-1.1



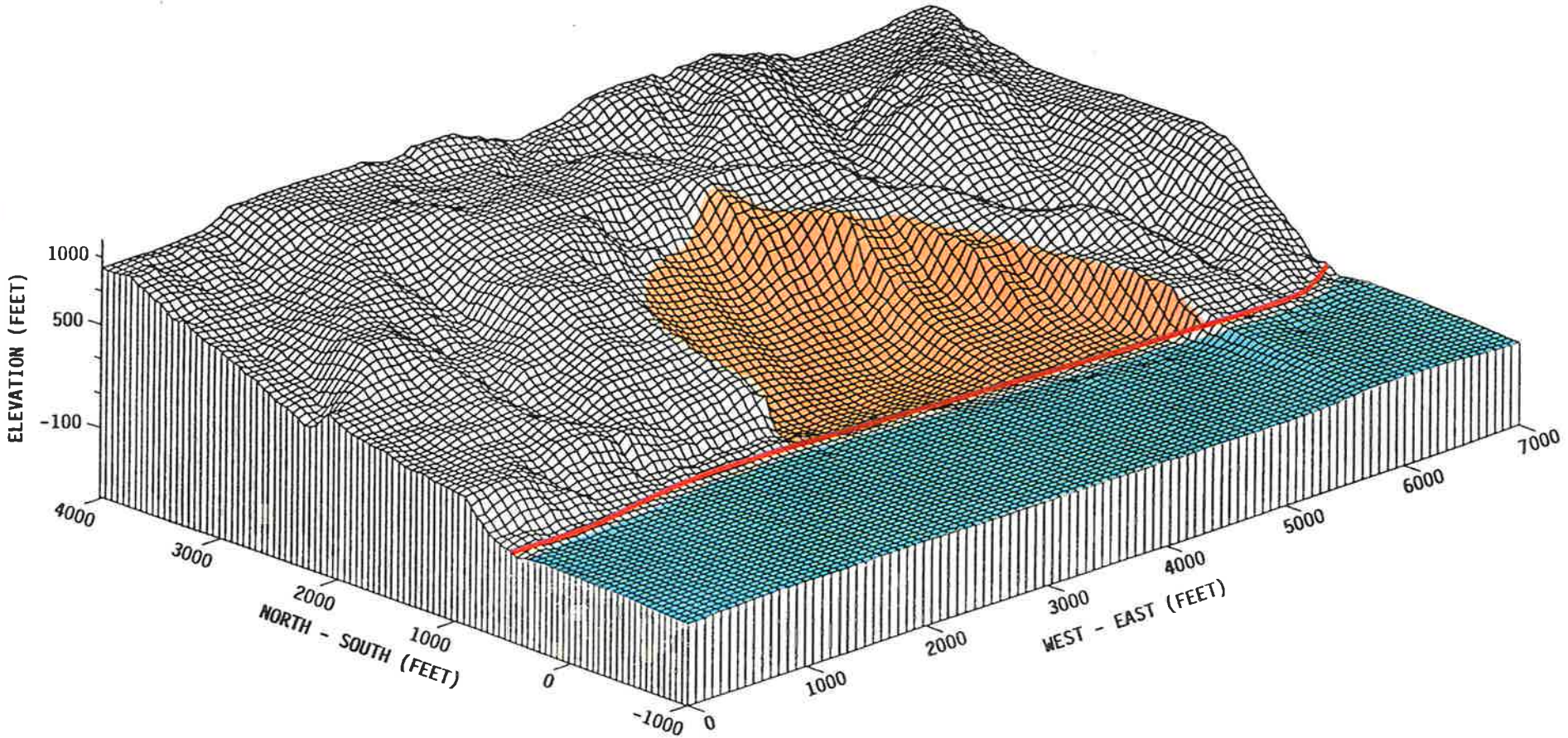
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

3-DIMENSIONAL VIEW OF GROUND SURFACE FEATURES

FIGURE 2-1.3



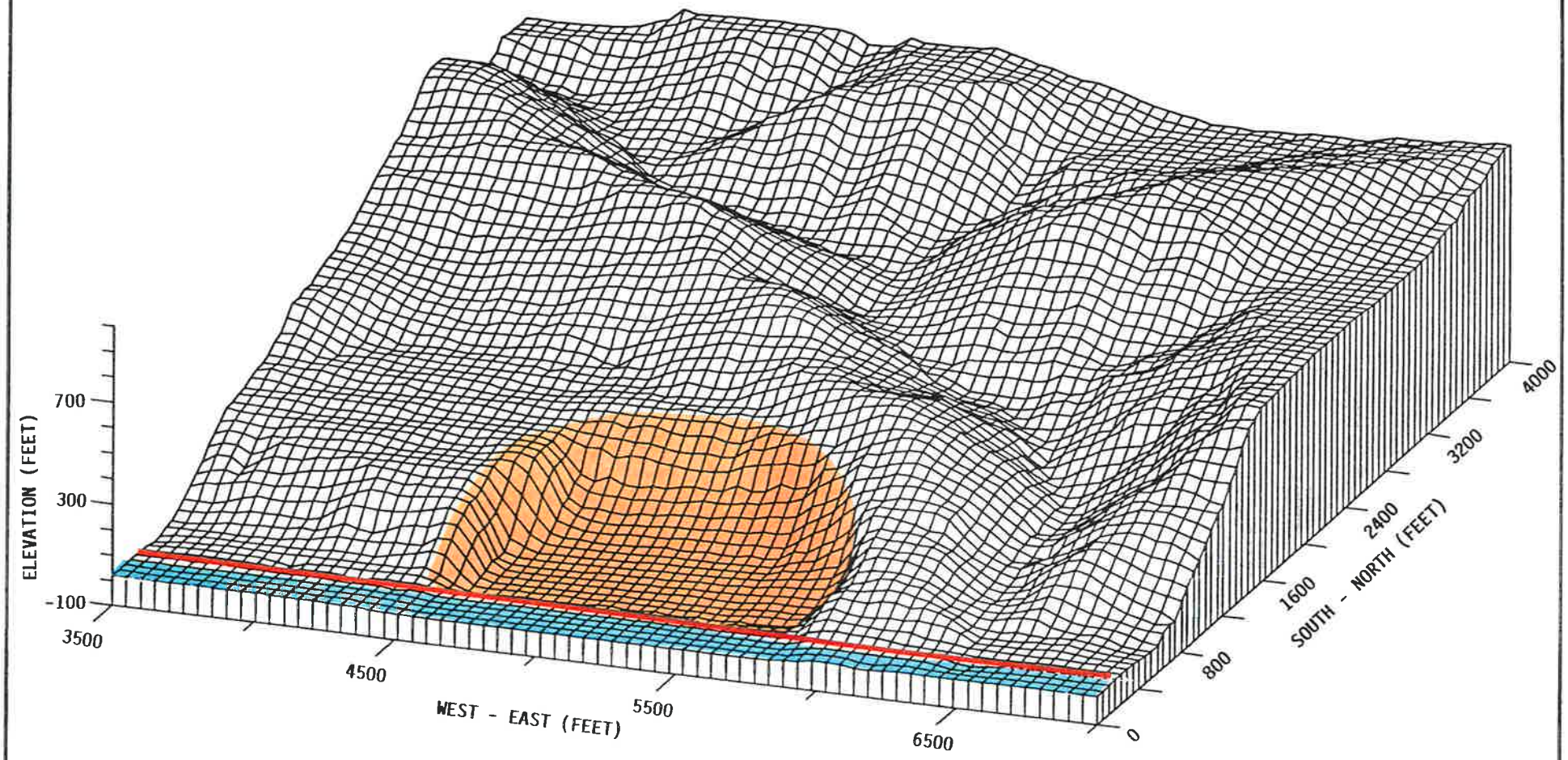
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

3-DIMENSIONAL VIEW OF MAIN MESA SLIDE SURFACE

FIGURE 2-1.5



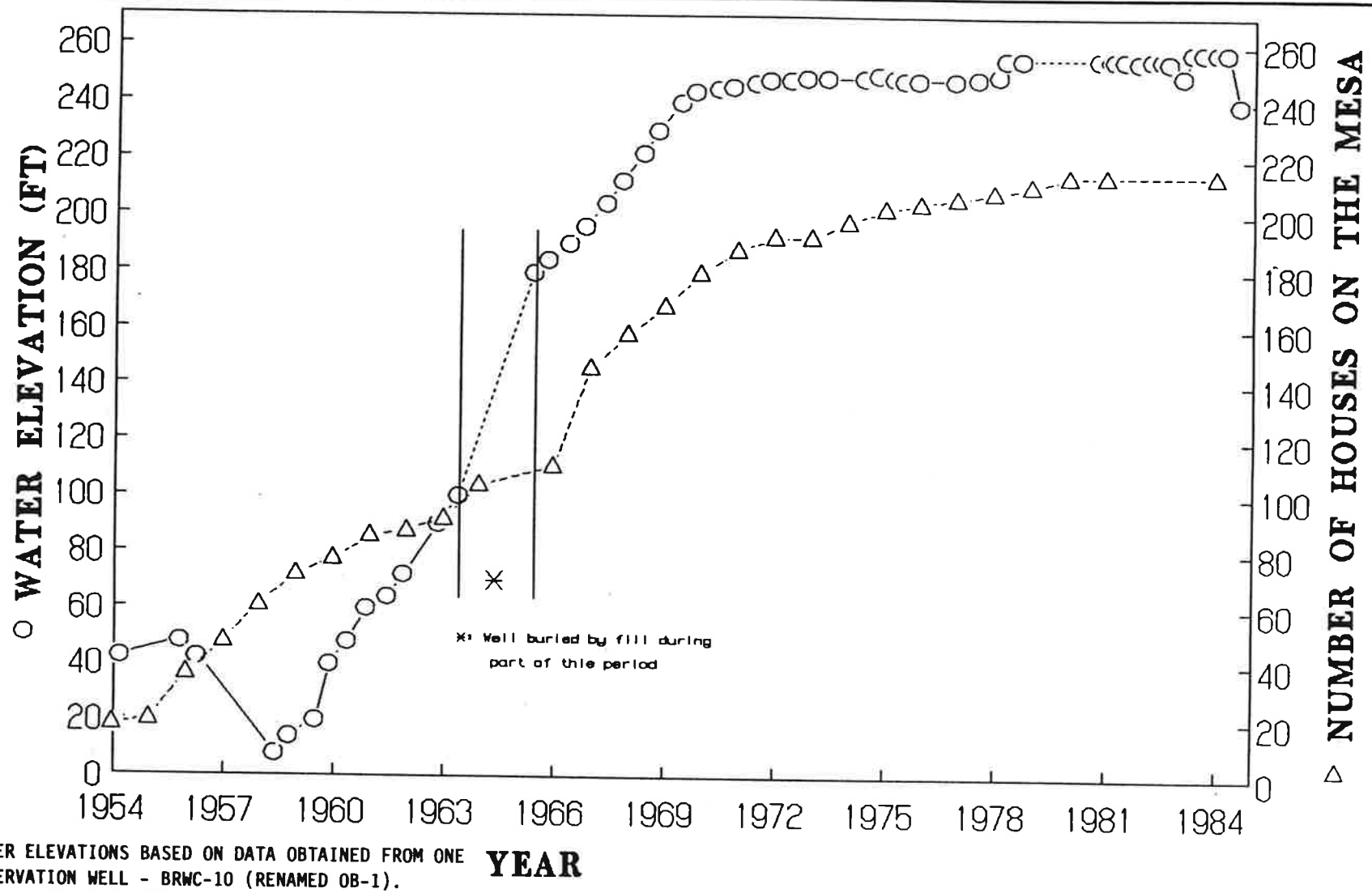
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

3-DIMENSIONAL VIEW OF SOUTHEAST REGION SLIDE SURFACE

FIGURE 2-1.6



NOTES:

a. WATER ELEVATIONS BASED ON DATA OBTAINED FROM ONE OBSERVATION WELL - BRWC-10 (RENAMED OB-1). IT IS LOCATED IN THE CENTRAL MESA AREA NEAR BYA-1. OB-1 IS THE ONLY WELL IN THE BRM AREA THAT HAS A COMPLETE DATA HISTORY AS SHOWN ABOVE.

b. HOUSES ON PCH NOT INCLUDED.

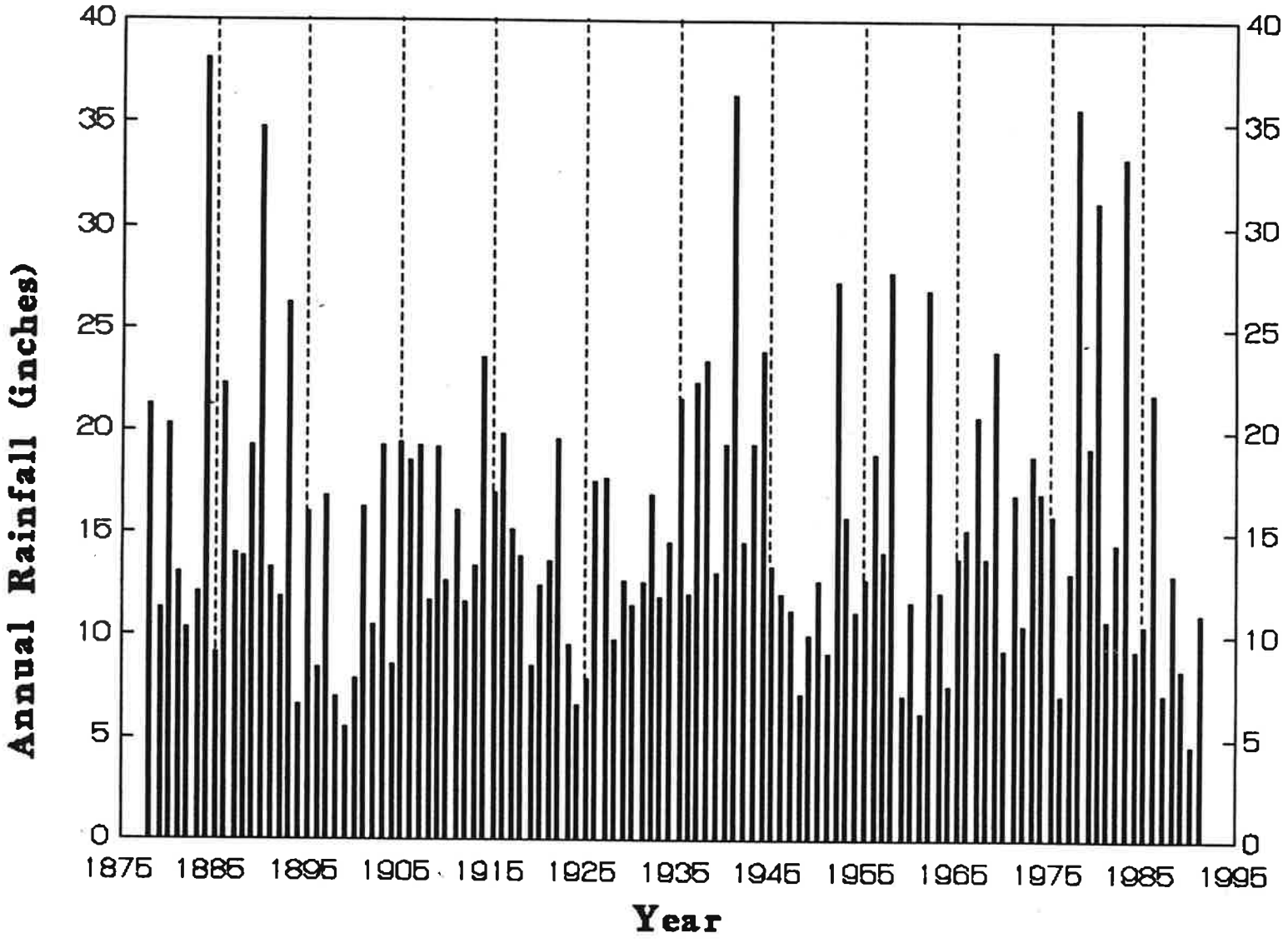
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PROJECT NO.: 49-97D | DATE: DECEMBER 1991

RELATIVE GROUNDWATER LEVEL TRENDS WITH RESPECT TO HOME DEVELOPMENT

FIGURE 2-2.1



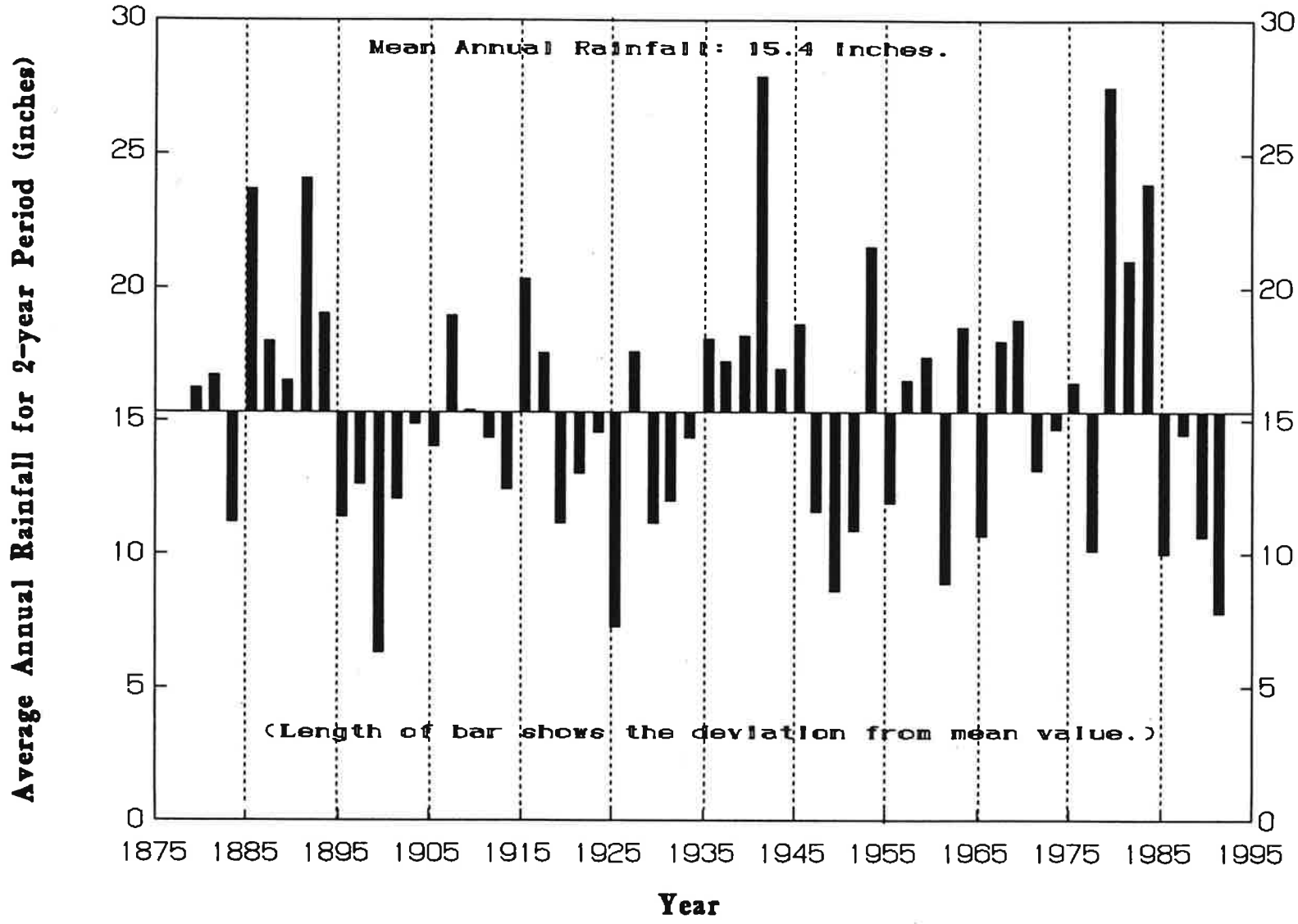
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

114 YEAR REGIONAL ANNUAL RAINFALL RECORD

FIGURE 2-4.1



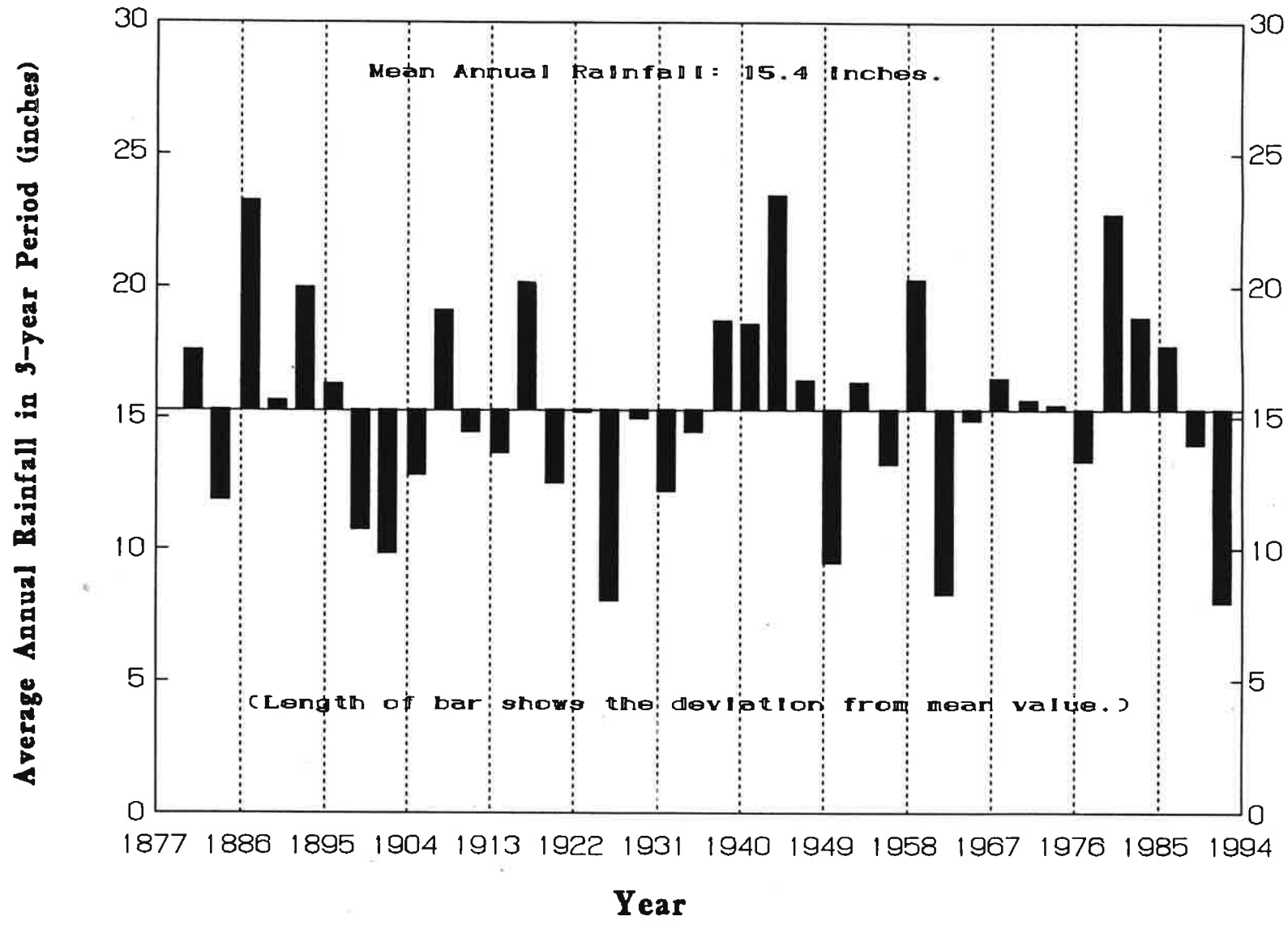
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

DEVIATION OF REGIONAL ANNUAL RAINFALL FROM MEAN VALUE: 2-YEAR INTERVALS

FIGURE 2-4.2



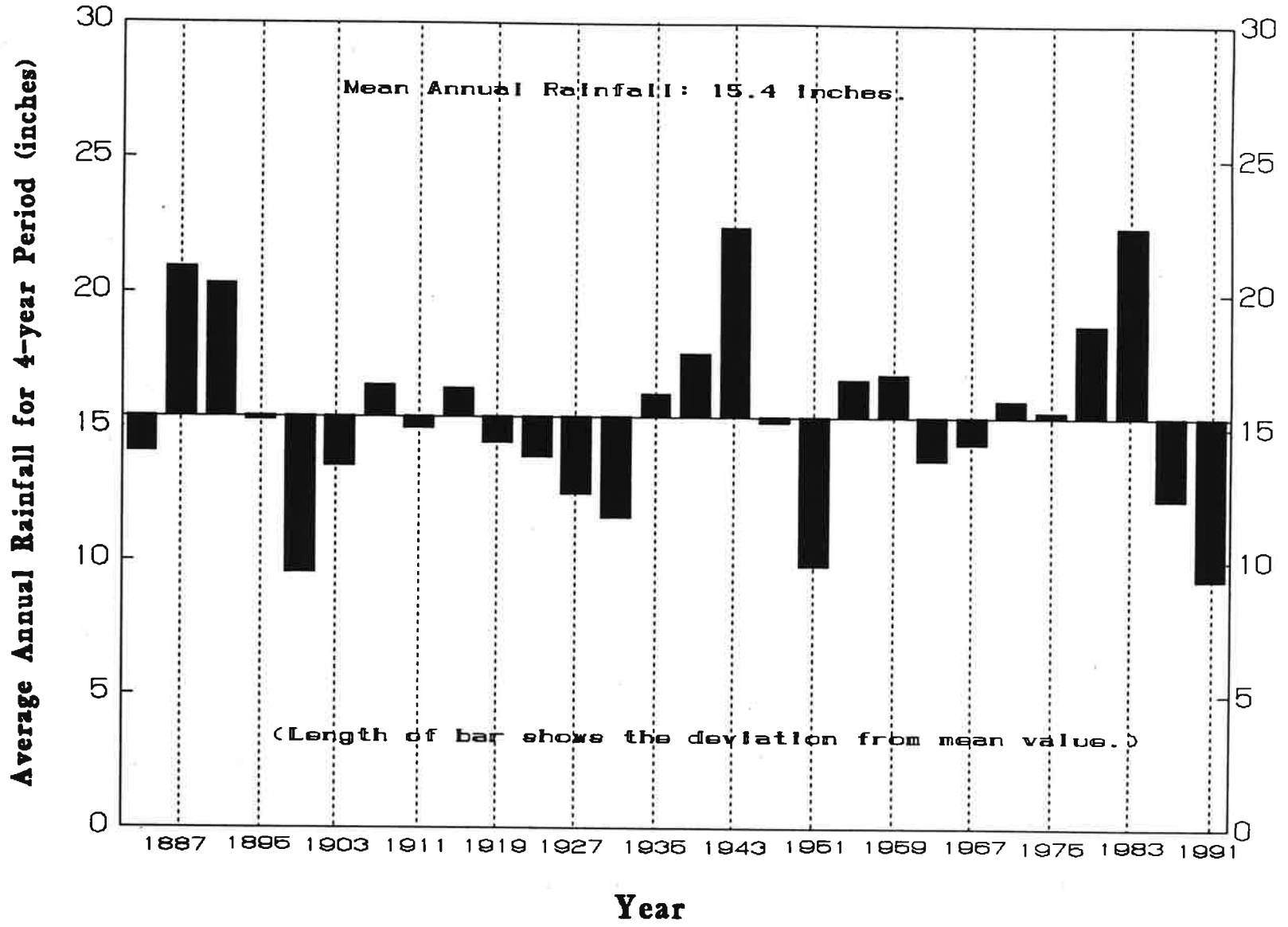
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

DEVIATION OF REGIONAL ANNUAL RAINFALL FROM MEAN VALUE: 3-YEAR INTERVALS

FIGURE 2-4.3



BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

DEVIATION OF REGIONAL ANNUAL RAINFALL FROM MEAN VALUE: 4-YEAR INTERVALS

FIGURE 2-4.4

EXPLANATION

- NATURAL SAGE OR CHAPPAREL
- LAWN (UNATURAL/WATERED)
- SHRUBS-BUSHES (UNATURAL/WATERED)
- TREES
- BARREN LAND (NO GROUND COVER)
- GRASS (NOT WATERED/NATURAL)
- HOMES AND ROADS

0 400 800 FEET

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

VEGETATION MAP

FIGURE 2-4.5

SECTION 3.0

FIELD INVESTIGATION & LABORATORY TESTING

3.1 GENERAL

To achieve the goals of the investigation, BYA performed various field investigations, carried out a comprehensive laboratory testing program and installed, observed and maintained the following dewatering facilities and geotechnical instrumentation, including:

1) Drilled 5 continuous cored deep borings 4 (BYA-1, 3, 4 and 5) in the main slide area, and 1 (BYA-2) in the Western Extension area;

2) Completed 7,220 lineal feet of gamma ray, dip meter, acoustic velocity, spontaneous potential, dual inducation and caliper loggings in all of the deep BYA borings and two instrumentation borings (SP-5A and SP-17A) along with 7,660 lineal feet of gamma ray logging in 25 accessible slope inclinometer holes and dewatering wells.

3) Installed 4 deep slope inclinometers (SP-5A, 8A, 17A and BYA-5A) and 7 multi-stage pneumatic piezometers (BYA-2A, 3A, 4A, 5A, SP-5A, 8A and 17A) at strategic locations throughout the mesa;

4) Performed an assessment evaluation of the existing 18 dewatering wells as of November 1988 and thereafter renovated 12 of them.

5) Installed 5 deep dewatering wells adjacent to the 5 BYA core borings;

6) Completed an innovative cleaning and probing program for all producing hydraugers along PCH;

7) Installed three hydraugers in seep areas along the eastern and central bluff;

8) Performed pumping and recovery tests of selected wells;

9) Observed and analyzed instrumentation systems from November 1988 until the present;

10) Observed and maintained dewatering systems from November 1988 until the present;

11) Provided input to DPW on various temporary and permanent surface drainage systems in the BRM area;

12) Performed miscellaneous investigations, such as vegetation mapping, crack and deformation measurements, along with the installation of tiltmeter arrays in selected areas; and

13) Conducted a comprehensive laboratory testing program.

3.2 DEEP BORINGS

In order to better define the subsurface conditions in critical areas of BRM, five deep borings were drilled to obtain continuous core samples. The locations for the borings were strategically chosen to maximize the subsurface data from both structural geologic and sample retrieval standpoints and to be in areas where construction of adjacent deep dewatering wells would benefit the BRM area. General descriptions of the borings are contained in the following sections, however, more detailed descriptions of the lithology are contained in the boring logs (Appendix C). The correlation of these logs with other available geotechnical data and their interpretation are discussed in Appendix B.

BYA-1

BYA-1 is located near the terminus of Royalstone Drive in the Central Region (see Figure 3-2.1) at a surface elevation of about 280. The main reasons for placing a continuous core boring in this location were twofold: 1) available data suggests that the depth to the basal slide plane is below the lowest elevation of local slope inclinometers and thus confirmation was needed, and 2) it is in the general central area where the piezometric head above the slide plane was anticipated to be greatest.

Due to the poor quality of rock mass, drilling difficulties occurred at a depth below approximately 230 feet (El. 50). Here, frequent collapse of the borehole required that the casing be simultaneously advanced with the drill operations preventing continuous rock coring. Consequently, only drill cuttings were logged from a depth of 230 until a depth of about 364 feet (El. 50 to -84). Due to increasing problems with borehole collapse the boring was halted in May 1989. Drilling then resumed in June 1990 with the use of an air-rotary type rig. The drill bit was successfully advanced utilizing the air rotary rig to a depth of 498 feet (El. -218). Although sample recovery was not possible, two important field observations were noted during the air rotary advancement as described in the following paragraph.

Starting at a depth of approximately 200 feet, strong artesian pressures were noted and correlated with adjacent observation wells (see Figure 3-2.2). These artesian pressures continued to rise with drilling depth until reaching a depth of 400 feet where the water levels in the boring dramatically dropped. This drop in water elevation simultaneously occurred with an increase in drilling resistance. These two observations tend to indicate that the basal rupture surface was at a depth of approximately 400 feet (Elev. -120). This interpretation will be discussed in more detail in Section 5.0.

As stated above, the quality of the rock mass appeared to increase significantly below a depth of 400 feet (El. -120). Consequently, upon completion of the air rotary operations at a depth of 498 feet (El. -218) the mud rotary core rig was brought back to the site to continuously core a 20 foot section between 498 and 520 feet (El. -218 to -240). The boring was completed in June of 1990.

BYA-1 encountered basalt in the upper 96 feet of the boring (El. 280 to 185). The surface trace of the basalt was subsequently mapped for several hundred feet and was later interpreted to be a thick sill. Below the upper basaltic sill poor quality sandstone and occasional siltstone recognized as Sespe formation were encountered. These findings helped focus subsequent surface mapping and drilling programs.

BYA-2

This boring was the only boring that BYA was able to perform in the Western Extension area because of constraints due to access via public roads and budgetary considerations. The terminus of Cool Oak Way was chosen as the location for this boring because of its proximity to the main slide area and satellite slide surfaces to the south, and its proximity to Well W-18 which has always been one of the greatest producers. In addition, a nearby slope inclinometer/ piezometer (SP-21) and a survey monument (BRM-128) provided additional instrumentation in the vicinity of the boring for checking groundwater and potential surface movement.

Drilling for BYA-2 began on May 3, 1990 and was completed on May 21, 1990. The boring (surface elevation of about 664) was drilled to a total depth of 481 feet. The upper 180 feet (El. 660 to 480) predominantly consisted of massive sandstone of the Topanga formation, below which the boring encountered an approximately 100-foot thick basaltic intrusion which separates a finer grained Topanga Formation sequence existing from approximately 290 to 385 feet (El. 275 to 380). Below a depth of 385 feet (El. 279) Sespe formation sandstone and siltstone were encountered and continued to elevation 179 ft. where the boring was terminated.

Approximately 60 percent of the upper 300 feet (El. 660 to 360) of core samples exhibited an RQD of 0 with an average weighted RQD of 13. The lower 181 feet (El. 360 to 179) recorded less than 25 percent of core with an RQD of zero with an average weighted RQD of 34. However, numerous shear and gouge zones were encountered along the length of the entire drill core. Artesian pressures were not encountered in BYA-2 as in BYA-1 and constant water level monitoring from an adjacent standpipe indicated no water level change during drilling operations. A deep well was installed adjacent to the corehole and the cored hole was converted into a monitoring well (BYA-2A) in which 3 pneumatic piezometers were installed.

BYA-3

BYA-3 is located at the terminus of Pinnacle Way approximately 200 feet east of the western boundary of the BRM landslide at a surface elevation of 510. This location was chosen due to the lack of subsurface and ground water data in the general area. The location enables correlation of the findings of BYA-3 across the Main Mesa to BYA-2.

Exploration for BYA-3 began on May 30, 1990 and was completed by June 13, 1990. The boring was drilled to a total depth of 500 feet (El. 10). The upper 104 feet (El. 510 to 406) of the boring encountered massive sandstone of the Topanga formation, although one thick zone of sedimentary/tectonic breccia was found from a depth of 31 to 53 feet (El. 479 to 457). Red to greenish sandstone and siltstone of the Sespe formation were found below the Topanga formation, but, as found in other borings, the contact was intruded by basalt. Sespe formation strata were encountered until a depth of approximately 464 feet (El. 46) where a diabasic intrusion interrupts the sedimentary sequence. The diabase intrusion continues from a depth of 464 feet (El. 46) until the base of the boring at Elev. 10.

Rock quality in the Topanga formation sandstone and the basaltic intrusion separating the Sespe and Topanga formations is relatively poor, exhibiting an average weighted RQD of approximately 14. Rock quality increases markedly in the Sespe formation - average weighted RQD of 51 - until the diabasic intrusion is encountered at the base of the boring, whereby the rock quality significantly decreases.

Several shear and breccia zones were noted to a depth of approximately 180 feet (El. 330). Sheared breccia and gouge zones were significantly less apparent between approximately 180 feet to the base of the boring (El. 330 to 10). The basal rupture surface was interpreted to be located at the base of the basalt intruded along the Topanga-Sespe formation contact.

BYA-4

The location for BYA-4 (Elev. 360) was chosen for the same reasoning as previously described for BYA-1 and, in addition, it provided a mid-way check point between BYA-1 and the Main Mesa boundary (crack zone) to the northwest. Its lithology, together with that of BYA-2 and 3, helped to correlate structural geological interpretations of the area between the Western Extension and the Main Mesa in this region.

BYA-4, drilled from August 23, 1990 to September 5, 1990, encountered sandstone and siltstone of the Topanga formation intruded by basalt in the upper portion of the boring along with siltstone and sandstone of the Sespe formation in the bottom portion of the boring. The Topanga formation rocks encountered in BYA-4 consisted of massive sandstone with minor siltstone interbeds in the upper 150 feet (El. 360 to 210), and primarily finer grained siltstone beds from 150 to 193 (El. 210 to 167). Below 193 feet (El. 167) the sedimentary rocks were intruded by a thick body of basalt which continued to a depth of approximately 285 feet (El. 75). The basalt intrusion was found to separate the Sespe and Topanga formations. Siltstone and sandstone of the Sespe formation were found from a depth of 285 feet (El. 75) until the base of the core at 505 feet (El. -145).

As found in other borings, the Topanga formation and basaltic intrusions contain several zones that are highly sheared and shattered. However, the Sespe formation (below a depth of 285 feet) appears relatively more fractured and brecciated. Specifically, numerous zones of tectonic breccia with clayey gouge were encountered from the upper Sespe contact to the base of the boring at Elev. -145. This data corresponds with the rock quality data which indicates very poor rock quality in both the lower part of the Topanga formation and throughout the Sespe formation. RQD values in the upper 200 feet (El. 360 to 160) average approximately 47 with zones of zero RQD occurring in about 5 percent of the core. The bottom 305 feet (El. 160 to -145) indicates a weighted average RQD value of approximately 8 with over 60 percent of this portion of the core exhibiting zero values. The basal rupture surface was interpreted to be located at the base of the thick basaltic intrusion existing between the Topanga and Sespe formations.

BYA-5

BYA-5 was drilled to a total depth of 334 feet between January 16, 1991 and February 1, 1991. The location as shown on Figure 3-2.1 is in the Southeast Region on Rockport Way, approximately 100 feet southeast of inclinometer SP-3A at a surface elevation of about 185. This location was chosen for slide plane confirmation, sample retrieval and the need for a dewatering well east of the Inland Lane fault; an area of importance which will be discussed in further detail in subsequent sections of the report.

Artesian pressures were encountered below a gouge zone at a depth of approximately 253 feet (El. -68). Flow rates exceeding several gallons per minute (gpm) were noted for several hours. Artesian pressures dissipated below a depth of about 260 feet (El. -75). Based on both past instrumentation deformation data and the rock mass condition, the basal rupture surface is believed to coincide with gouge and fractured zones at depths of approximately 170 ft. and 200 ft (El. 15 and -15).

The boring encountered sandstone, siltstone and conglomerates of the Sespe formation in the upper portion of the boring to a depth of approximately 211 feet (El. -26), below which rocks from the Vaqueros formation were encountered. However, a thick diabase intrusion was encountered within the Sespe formation from a depth of 20 to 40 feet (El. 165 to 145). Vaqueros formation sandstone and siltstone were identified to a depth of approximately 317 feet (El. -132) where basalt was encountered to the base of the boring.

Significant shear and gouge zones were encountered approximately between the depths of 170-180, 199-200, 209-210, 238-240 and 259-261 feet (El. 15 to 5, -14 to -15, -24 to -25, -53 to -55 and -74 to -76, respectively).

3.3 GEOPHYSICAL SOUNDINGS

To aid in the interpretation of the subsurface data a series of geophysical tests were performed on each BYA deep continuous core boring. These included dipmeter, caliper, high resolution gamma logging, spontaneous potential, and dual induction. This same suite of tests was also performed by BYA on two borings drilled by William Cotton and Associates (WCA) and designated as SP-17A and SP-5A. Acoustic velocity testing was also included for the suite of tests performed in the WCA borings.

Although the subsurface data obtained from BYA's continuous-core borings was extremely valuable in completing the project objectives, the borings still only represent data from five discrete points over a study area that incorporates about 215 acres, including approximately 136 acres in the Main Mesa and 79 acres in the Western Extension area. Consequently, BYA performed gamma logging on 25 accessible slope inclinometers and selected wells across the mesa. These additional gamma ray soundings were performed on slope inclinometers SP-3A, 5A, 8A, 9A, 10, 16, 16A, 17A, 20, 21, 22, 23, 24, 26, 27A, 28, 29, 30, 32, 33, and dewatering wells W-4, 7, 9, 10 and 18. Processed data plots for all of the soundings are contained in the Data Book, which, although a separate volume, is an integral part of this report. Locations of the soundings are shown in Figure 3-2.1.

The geophysical logs were instrumental in structural geologic analyses and interpretation. Specifically, the high resolution gamma ray logs of the drilled holes helped to define the intrusions of basalt and diabase which served as marker beds in correlating the subsurface structures. The dipmeter data was instrumental in identifying major geologic discordances as discussed in Appendix B.

3.4 LABORATORY TESTING

A focused laboratory program to evaluate the strength characteristics of intact, fractured and gouge materials from each formation was performed by BYA. The program consisted of the following:

- 6 suites of slow displacement rate controlled direct shear tests (.05"/hr.) performed on gouge material from each geologic formation, and 3 suites of direct shear tests on gouge material with 3 different chemical additives;
- 5 multi-stage consolidated undrained (CU) tests (0.08%/min.) with pore pressure measurements of fractured and gouge materials from each formation;
- 1 ring shear test with simulated stress history of overconsolidation;
- 49 unconfined compression tests on both jointed and intact rock samples from all formations;
- 54 brazilian tensile tests on both fractured and intact rock samples from all formations; and
- Numerous indices testing on select gouge and failure plane materials including Atterberg limits, thin section analysis, X-ray diffraction, Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS).

Laboratory results are contained in Appendix D and are summarized below.

3.4.1 Laboratory Results

3.4.1.1 Shear Strength

Shear strength test results from both triaxial testing and direct shear testing are plotted together for each formation on Figures 3-4.1 through 3-4.3. The results indicate that basalt samples tested had friction angles ranging from approximately 22 to 27.5 degrees, while the friction angle range for the Sespe formation and Topanga formation were from 17 to 29 degrees and 38 to 40 degrees, respectively. Sespe formation strengths however, were divided into two zones: an upper bound friction angle ranging from 27 to 29 degrees, and a lower bound friction angle ranging from 17 to 18 degrees. In general, the gouge samples with higher clay contents comprise the lower bound strength envelope. More shear strength testings were performed on Sespe formation and Basalt samples because a majority of the slide surfaces are located within these materials (see Figures 7-2.1 through 7-2.6).

One should be cautious of the limitations of laboratory testing. Variations can result from sampling procedures, miscellaneous sample disturbances and details of laboratory equipment stiffness. Equally important is the significance of selecting representative samples which are not contaminated by drag shear and mixing with adjacent material. This is especially true of the gouge material which may locally have a lower strength than the tested results indicate, due to contamination of the sample. On the other hand, these clays may not be continuous throughout the entire length of the slide surface because of the fault blocks and intrusives (see Sections 4.0 and Appendix B). To evaluate a lower bound residual strength, ring shear testing was performed using the "purest" clay gouge that could be found. The test incorporated a total shear displacement in excess of 2 feet and a simulated stress history of over-consolidation. This involved the determination of the liquidity index of the bulk clay sample from which the over-consolidation ratio is estimated. The bulk sample was then broken up and mixed with water to a consistency approaching the liquid limit. The sample was then slowly normally consolidated in the ring shear apparatus, then rebounded to achieve the over-consolidation ratio with respect to its estimated mean effective confining stress. The sample was then sheared, until a constant shearing resistance is achieved under the corresponding vertical stress. After the testing, the sample moisture content is redetermined to check the liquidity index of the field sample. The results of these tests are shown in Figure 3-4.4, indicating a lower bound residual friction angle of 8-10 degrees.

One possible option of slope stabilization is by the addition of chemicals to the soils. Consequently, direct shear tests were performed to evaluate the alteration of shear strength by the addition of chemical additives such as: 2% aluminum nitrate, 2% sodium metasilicate and 2% of potassium fluoride to Sespe gouge material. As can be seen from Figure 3-4.5, the shear strength of Sespe gouge generally increases with the addition of chemical additives.

3.4.2 Index Testing

To evaluate the clay type of the gouge materials and assist in the shear strength interpretation for the stability analyses, X-ray diffraction, SEM and EDS tests were performed on samples of representative gouge material from each formation. The results indicate that all of the gouge materials, with the exception of the basaltic gouge, contain smectite and illite. The basaltic gouge was found to be largely composed of altered chloritic clays. The clay composition of each sample tested is summarized in Table 3-1.

These clay contents are significant from a geotechnical engineering perspective in the following aspects:

1) The presence of smectite (montmorillinite) and chloritic clays in the Sespe and basaltic gouge materials suggest a lower bound shearing strength similar to those of plastic clays.

2) A significant decrease in smectite concentration was noted in the Topanga and Vaqueros formation gouge materials as compared with the samples tested from the Sespe and basalt samples. This is significant in that it suggests sections of the failure surface in the Topanga and Vaqueros formations have relatively higher shear strengths.

To assist in lithological interpretations and structural geologic interpretation, thin sections from igneous rock samples taken at BYA-1, through 5, as well as surface outcrops were examined (see Figures 3-4.6 and 3-4.7). Of particular interest was the diabase, a medium grained hypabyssal intrusive equivalent of basalt that rose from depths as magma but solidified in dikes and sills. Other less numerous intrusions of basalt were also examined including those by Mr. E. D. Michael (Consulting Engineering Geologist), contracted through BYA. Some of the samples were noted to have been extensively altered (Figure 3-4.6) to expansive clay minerals. As previously mentioned, altered clays were also noted by X-ray diffraction testing.

The intrusion of diabase and basalt into the sedimentary rock formations of the BRM area occurred during extensive volcanic activities in the middle Miocene (± 15 million years before present). Thin section analyses results as well as gamma ray soundings - as previously described - were used to help identify and extrapolate the basalt and diabase intrusions across the mesa. These intrusions served as useful markers that facilitated understanding of the geologic structures and tracing of past landslide surfaces at BRM.

Atterberg limit testing was performed on 14 gouge materials selected from all five continuous core borings to represent gouge materials from each formation. The results in general indicate that the gouge materials possesses low to medium plasticity. Liquid limit values range from approximately 30 to 50 while corresponding PI values range from approximately 10 to 30 for all samples. These results summarized on Figure 3-4.8 and contained in Appendix D do not correlate well with the results of the x-ray diffraction or the low residual strength obtained from ring shear tests. However, it should be noted that gouge zones from which the Atterberg limit data was taken contained some silt and fine sand which most likely resulted in the decrease in plasticity.

3.4.3 Unconfined Compression and Brazilian Testing

To characterize the strength characteristics of intact and fractured rock samples within the landslide mass both unconfined compression and Brazilian tests were performed on selected samples from each formation. Testing results are contained in Appendix D while average values are contained in Table 3-2 and 3-3. The values obtained from the testing were used to serve as a reference for joint strength estimations.

3.5 PIEZOMETER AND INCLINOMETER INSTALLATIONS

Four slope inclinometers and 7 multi-stage pneumatic piezometers were installed in various locations throughout the mesa (see Figure 3-2.1). To save costs, three of the four slope inclinometers were installed in 1989 by taking advantage of three exploratory holes drilled by William Cotton and Associates. These holes, labeled SP-17A, SP-5A and SP-8A, were all in areas where existing slope inclinometers installed by Evans earlier, had already been sheared off. Consequently, since the depth to the basal rupture slide was already known these locations were determined to be ideal for the detection of on-going or future movements. The fourth slope inclinometer was installed approximately 100 feet south of SP-3A in the Southeast Region. This inclinometer made use of BYA-5's deep continuous corehole. It was installed because the Southeast Region is one of the most sensitive areas in the mesa (as will be discussed in Sections 5.0, 6.0 and 7.0). This inclinometer, labeled BYA 5A, was installed in April 1991.

Due to the fact that groundwater data was needed wherever it could be viably obtained, multi-stage pneumatic piezometers were installed in the same corehole as the slope inclinometers utilizing a single-stage installation technique developed by BYA. The technique as illustrated in Figure 3-5.1 consists of attaching multi-stage pneumatic piezometers to the outside of the slope inclinometer pipe at pre-determined depths. The entire assemblage is then lowered down the core hole and then is backfilled with a designed cement-water mixture. Due to the fact that the distance from the initial pneumatic piezometer diaphragm to the edge of the corehole is less than approximately one inch and that the vertical distance between the piezometer tips generally is on the order of one hundred feet, the grout not only provides a medium from which piezometric pressures can be measured but also isolates the individual tips so that pressure gradients can be detected.

Pneumatic piezometers were also installed without slope inclinometers in three of the four BYA borings (BYA-2A, 3A and 4A). These piezometers were installed in a similar fashion as the combination slope inclinometer piezometers. The piezometers were installed adjacent to the BYA dewatering wells to monitor the groundwater response during pumping and recovery tests (see Figure 3-5.2).

3.6 WELL AND HYDRAUGER RENOVATIONS AND INSTALLATIONS

3.6.1 Existing Dewatering Well Renovations

The first stage of BYA's groundwater and dewatering system evaluation consisted of assessing the performance of the existing 18 dewatering wells as of November 1988 (W-1 through W-18). The results of the performance assessment indicated that the dewatering wells needed cleaning and that several of the existing pumps were non-functional or producing at anomalously low rates. Consequently, 12 potentially productive wells were chosen for a well renovation program. The program completed by BYA and its subcontractors in December 1988 through February 1989 generally consisted of:

- Running a pump test with the existing pump;
- Pulling the pump and checking its condition;

- Mechanically and/or chemically treating the well casing to remove deposits that were blocking the perforations;
- Flushing the well;
- Performing downhole video camera work to confirm the adequacy of the cleaning and to observe any deformations in the casing;
- Installing a pump and performing a pump test;
- Using the rate obtained from the pump test to appropriately size a new pump;
- Installing a sized pump with a pump guard to eliminate existing timers;
- Replacing the drop pipe and well cover when necessary; and
- Periodic observation/measurement.

The total well production increased by 146% immediately after the well renovation program.

3.6.2 Dewatering Well Installation

Following renovation of the existing wells, the adequacy of the dewatering well system was evaluated. This evaluation showed, among other things, that most of the wells were not deep enough and/or in the right locations to effectively lower the piezometric head acting on the basal rupture surface. In addition, only two dewatering wells existed in the Western Extension area. Consequently, BYA implemented the 5-boring exploration program in conjunction with the installation of 5 dewatering wells.

The five deep dewatering wells were constructed at locations adjacent to the five deep BYA borings. The five wells have been equipped with pump systems and control boxes and are currently producing.

All wells except for BYA-1 were installed approximately 50 to 100 feet away from the BYA continuous core holes. BYA-1 was installed by reaming out the corehole, while BYA-2, 3, 4 and 5 were installed in separate holes. Drilling the second (well) hole enabled the exploratory corehole to be used for the placement of pneumatic piezometers.

To quickly obtain the desired well depths an air rotary drilling rig was utilized. Following attainment of the target depths the well was constructed utilizing standard well construction procedures. Details regarding the construction of the BYA dewatering wells and piezometers are shown in Figure 3-6.1.

3.6.3 Hydrauger Installation

Groundwater seeps have been observed in the bluff area dating back to the early 1960's and possibly even earlier. However, after years of dewatering, the number of observable seeps has significantly decreased. In addition, several areas that were thought to be seeps disappeared within several months of installation of the hydrauger collection system along

PCH in 1990. Following completion of the collection system two somewhat persistent seeps were still noted: one in the eastern section of the bluff (across from 20058 PCH) and one in the central area of the bluff (across from 20288 PCH).

In response to the above observations, BYA installed three hydraugers (BYA-6, -7 and -8) in the seep area locations (see Figure 3-2.1). The hydraugers were installed in June 1991 utilizing a small, track mounted, water rotary, horizontal drilling machine. The drains were then constructed to typical Caltrans standards as shown on Figure 3-6.2. The drains were successful in alleviating the local seep problems. However, it is uncertain if the seeps will re-emerge (especially in the Southeastern Region) during wet seasons.

3.6.4 Hydrauger Renovations and Probing.

Due to the fact that hydraugers have been found to become less effective over time due to clogging from sediment and/or chemical precipitates, periodic cleanings are needed. In the case of hydraugers installed in active slide areas the cleanings have a second use in that they provide data as to whether the drain has been severely distorted or sheared off.

Two cleaning operations have been performed: One was performed by the County of Los Angeles Department of Public Works in 1988 and one by BYA in 1991. BYA utilized an alternate cleaning method which consisted of pumping water at high pressures through a rigid pipe fitted with a nozzle selected for its output/pressure ratio and spray angle. The work was completed with assistance from a DPW crew. The cleanings were limited to currently producing drains along PCH. The probing length for each of the producing drains is shown on Figure 3-2.1. As can be seen from Figure 3-2.1, several drains appear to have been sheared off or obstructed at relatively short lengths within the Bluff zone.

Based on correlations with observable surface crack patterns and the geologic structure present in the bluff area, it is probable that some of the hydraugers were obstructed or sheared off due to deformation within the bluff zone. The 1991 hydrauger renovation increased the total hydrauger output over 40% imediately after cleaning. This data is tabulated in the Data Book.

During the hydrauger renovation BYA discovered that one of the hydrauger drains (HD-30) had been completely clogged by chemical precipitates. Scanning Electron Microscopic examination performed on a sample of the deposits within the hydrauger indicated that the substance was calcium carbonate (see Figure 3-6.3). Repeated probings with the cleaning system were successful in dislodging enough of the crystal to allow flow out of an adjacent grout tube pipe. However, the cleaning did not fully remove the crystal. This finding is important in that crystal growth could in the future lead to reduced production of the hydraugers and consequent build-up of piezometric head leading to local instability. Periodic maintenance of the hydraugers is required. The interval between cleanings should be no longer than 2 years.

3.6.5 Groundwater Quality

BYA also performed water quality tests during this investigation and the results are included in the Data Book. BYA performed bacterial density tests (total and fecal coliform as well as fecal enterococcus) on groundwater discharge from hydraugers HD-9 and HD-28 along

with surfactant testing (to direct household soaps and residues) on discharge from dewatering wells W-2, W-17, BYA-1 and BYA-3. The bacterial testing indicated that bacterial densities were either low or non-detectable (MPN/100 ml <2). This is in contrast to water samples taken earlier by others (e.g. Michael, 1984) where fecal coliform bacteria was detected in samples retrieved from dewatering wells W-2,, W-8, W-9, W-12 and W-13. It should be noted, however, that these samples were retrieved when groundwater levels were considerably higher than those found in 1991. The surfacant testing results also indicated non-detectable concentration levels (< .25 mg/l). The low bacterial densities and surfacant concentrations found in the 1991 water samples most likely are the result of the longer time and distance required for the effluent to reach the dewatering discharge points.

3.7 PUMPING AND RECOVERY TESTING PROGRAM

Recovery tests were performed on wells BYA-1, W-1, W-3, W-8, W-13, W-15, W-16 and W-17 in 1991. The recovery testing program was initiated when it was judged that all of the wells had reached steady state pumping levels and all of the groundwater levels had stabilized by shutting off the aforementioned wells and recording the rise in water and piezometric levels in the well itself and all adjacent piezometers. All water and piezometric levels as well as hydrauger flow rates within the anticipated radius of influence of the wells were recorded prior to the initiation of the test. Wells were shut off in a progressive manner with wells in similar formational materials being shut off at the same time. To supplement the data obtained from the recovery testing program, a limited pumping test program was initiated. Pumping tests were performed on Wells BYA-1 and BYA-3 in 1991. Detailed data are on file and/or in the Data Book. Several incidents of vandalism impeded the testing operations and affected results. A summary of the testing results are given in Section 6.0.

3.8 OBSERVATION AND MAINTENANCE OF INSTRUMENTATION SYSTEMS

To monitor deformation levels and trends at BRM, 33 slope inclinometers (over 7400 lineal feet of casing) were monitored on a quarterly basis along with an eight-position extensometer (MPBX). The extensometer was installed by BYA in the eastern section of the bluff in 1986 while the slope inclinometers were installed by various different consultants throughout the mesa (see Figure 3-8.1).

3.8.1 Slope Inclinometer Monitoring

The slope inclinometers were monitored with a biaxial digitilt sensor, model number 50325, manufactured by Sinco. Readings were taken at two foot intervals and recorded by a computer driven data acquisition system developed by BYA. The inclinometer probe is calibrated prior to each set of readings. The data acquisition and calibration systems provide one of the most modern and reliable systems in existence for monitoring slope inclinometers. However, apparent movements are still interpretive and could be caused by one or a combination of various sources. These include landslide or related ground movement, ground deformation unrelated to landsliding, localized movement or settling of the inclinometer casing backfill, etc.

To facilitate the interpretation of slope inclinometer data three different sets of plots were prepared: 1) the first set of plots shows the absolute shape of the inclinometer casing as

recorded in our first monitoring in September 1988 and/or the next available reading subsequent to the September 1988 reading, 2) the second set of plots shows a sequence of readings over four time periods 1988-89, 1989-90, 1990- 91 and 1988-91 (as available data permits), and 3) the third set of plots shows individual plots over a specific time period where movement is suspected from the interpretation of the first two sets of plots.

All three sets of plots are significant in interpreting the slope inclinometer data. The first set of plots showing the absolute shape of the casing (or deviation from vertical) is significant in interpreting apparent movement along the casing since the accuracy and resolution are both progressively reduced as the degree of casing lean becomes greater. The second set of plots indicates whether any apparent movement has been progressive. These types of plots are also helpful in assessing the probability of "lean type" movements being real. The third type of plot indicates both a time frame for any movements and provides a detailed plot as to the bearing of these movements. The aforementioned series of plots combined with BYA's data acquisition and calibration systems enables BYA to distinguish individual slide surface breaks at magnitudes as small as .05 inch.

In general, over the three year period in which BYA performed instrumentation monitoring, small discrete movements were indicated by the slope inclinometer plots. The total magnitude of the movements is on the order of .05 to .3 inch and occurred mainly in slope inclinometers along PCH and the bluff. Movement was also indicated in the Hansch slide area. Slope inclinometer movements recorded by BYA are contained in the Data Book and are discussed and summarized in further detail in Section 5.0 of this report.

3.8.2 Extensometer Monitoring

The eight-position extensometer was installed to detect movements in the Bluff area of the Southeast Region of the mesa by BYA prior to its engagement by the CI. This instrument has been monitored on a periodic basis since September of 1986. Monitoring consists of measuring the pin deformation of each strand (position) relative to a reference head. Deformations are recorded with a specially adapted digital micrometer and are plotted with respect to the direction of movement (either towards or away from the bluff face). Deformation plots are contained in the Data Book. In general, the movements recorded so far are small and within the level of accuracy of the system.

3.9 OBSERVATION AND MAINTENANCE OF DEWATERING SYSTEMS

In order to measure changes in both piezometric levels and dewatering production, BYA performed the following tasks: (1) measured the production rate of 12 dewatering wells on a monthly basis (the number of total producing wells was increased to 16 when BYA-2, 3, 4 and 5 came on line), (2) measured production rate of 47 hydraugers on a monthly basis until March 1991 when DPW took over this task, (3) measured water levels in 33 standpipes on a quarterly basis, (4) measured piezometric levels in 4 pneumatic piezometers on a quarterly basis (measurements from 4 additional piezometers were taken after the construction of the pneumatic piezometers adjacent to dewatering wells BYA 2,3,4 and 5), and (5) inspected and maintained active dewatering wells on a routine and as-needed basis. Piezometer locations and dewatering facility locations are shown on Figure 3-8.1.

The dewatering trend for the hydraugers, although improved by two cleanings, has been steadily declining over the last several years, while the overall dewatering from wells has been significantly increased over the last three years. Based in part on the above, and considering recent groundwater trends relative to the total volume of imported water (master meter readings taken by DPW), it is our belief that a steady state condition exists between groundwater inflow and outflow of the BRM groundwater basin. These trends are summarized and discussed in detail in Section 6.0 of this report while processed data plots are presented in the Data Book.

3.10 SURFACE DRAINAGE

In a coordinated attempt with DPW to reduce infiltration of rainfall, BYA consulted with DPW regarding surface drainage improvements. To provide a basis for these recommendations BYA superimposed various crack maps and conducted field mapping to identify critical infiltration areas.

Recommendations for temporary improvements were provided for the winter rainy seasons of 1988-89 and 1989-90 prior to the construction of the DPW storm drain system for the CI. The recommendations consisted of providing input to reduce high concentrated runoff in potential infiltration areas, using devices, such as flexible, temporary storm drain pipe, asphalt repaving, construction of interceptor drains, replacement of plastic and sand bags in existing interceptor drains, and crack infilling. BYA also provided geotechnical input into the surface drainage system (storm drain collection system, horizontal drain collection system, and well discharge collection system) designed and implemented by DPW. Recommendations included: 1) construction of additional storm drain lines to reduce runoff in geotechnically sensitive areas, 2) alignment modification recommendations to avoid geotechnical hazardous areas, 3) design modifications of the horizontal drain collection system to facilitate future monitoring, and 4) varied suggestions to improve the well discharge collection system. These recommendations were implemented by DPW for the CI.

3.11 MISCELLANEOUS FIELD INVESTIGATIONS

3.11.1 Vegetation Map and Rain Gutter Survey

In an attempt to better understand the evapotranspiration and infiltration characteristics, BYA completed a vegetation mapping program and rain gutter survey. Vegetation mapping was performed in 1991 and consisted of mapping six different categories of vegetation throughout the BRM area. The rain gutter survey was originally performed in 1989 and has been modified and updated in 1991. The survey distinguished between homes that did and did not have rain gutters. The data from these two field studies is discussed in more detail in Section 6.0 of this report.

3.11.2 Pacific Coast Highway (PCH) Deformation Field Reconnaissance

To aid in the assessment of the lateral slide boundaries and to confirm the type of deformation occurring in this area, a field reconnaissance was made of the existing homes

along Pacific Coast Highway and in the surf zone, including a limited scuba diving effort to examine the seafloor and reef rock. The results of the reconnaissance are discussed in Section 5.0 of this report.

3.11.3 Tiltmeter Arrays

In response to field observations in the area of Dewatering Well W-18, and in a four-home area north of Little Rock Way, BYA installed two tiltmeter arrays. Tiltmeters are essentially extremely sensitive electronic levels capable of detecting changes in the slope of the ground surface. The tiltmeters were installed in thermally insulated underground vaults and are monitored via a battery operated data acquisition system.

The first array (3 tiltmeters as shown in Figure 3-2.1) was installed around W-18 in October 1989 to investigate the trend of potential ground movement, if any, in the area. The second tiltmeter array (also shown on Figure 3-2.1) was installed just north of 20431 and 20415 Little Rock Way in order to investigate the mechanism of reported on-going distress in the area. The second tiltmeter array was installed and monitored in December 1989. The second array indicated potential local deformation of the Headscarp Region which could affect homes located downslope from the Headscarp Region if the minute deformation develops into slope failure.

Processed deformation plots from the tiltmeters are contained in the Data Book, while the results of the monitorings are discussed in Section 5.0 of this report.

TABLE 3-1

MINERALOGICAL COMPOSITION OF GOUGE MATERIALS

FORMATION	SAMPLE LOCATION	SMECTITE	ILLITE	KAOLINITE	CHLORITE	CALCITE	QUARTZ
Topanga	BYA-3 @ 146'	40%	40%	- -	- -	5%	15%
Sespe	BYA-5 @ 148'	90%	10%	- -	- -	- -	- -
	* *	70%	- -	30%	- -	- -	- -
Basalt	BYA-5 @ 209'	25%	- -	- -	75%	- -	- -
Vaqueros	BYA-5 @ 221'	20%	70%	10%	- -	- -	- -

NOTE:

** : Surficial sample taken from the Southeast Region.

TABLE 3-2

AVERAGE UNCONFINED COMPRESSIVE STRENGTH
OF INTACT AND FRACTURED ROCK SAMPLES

FORMATION	SANDSTONE		SILTSTONE		BASALT	
	TYPE I (psi)	TYPE II (psi)	TYPE I (psi)	TYPE II (psi)	TYPE I (psi)	TYPE II (psi)
Topanga	3780	850	3240	*	N/A	N/A
Sespe	2360	270	5830	230	N/A	N/A
Basalt	N/A	N/A	N/A	N/A	3400	480
AVERAGE**	3290	390	5400	230	3400	480
STANDARD DEVIATION	1310	310	3700	100	- 0 -	400

Abbreviations:

N/A = Not Applicable

* = No Sample

** = Average irrespects to different formations

Type I = Tests on samples which do not contain fracture features (joints, shears, bedding planes, etc.)

Type II = Tests on samples which contain fracture features (joints, shears, bedding planes, etc.)

NOTE:

Refer to Table D-2 and Figures IV-1 and IV-2 in Appendix D for number of tests and ranges of unconfined compressive strength values.

TABLE 3-3

AVERAGE TENSILE STRENGTH OF
INTACT AND FRACTURED ROCK SAMPLES

FORMATION	SANDSTONE		SILTSTONE		BASALT	
	TYPE I (psi)	TYPE II (psi)	TYPE I (psi)	TYPE II (psi)	TYPE I (psi)	TYPE II (psi)
Topanga	260	35	210	*	N/A	N/A
Sespe	290	40	530	50	N/A	N/A
Basalt	N/A	N/A	N/A	N/A	420	100
AVERAGE**	270	30	440	50	420	100
STANDARD DEVIATION	140	20	270	30	150	100

Abbreviations:

N/A = Not Applicable

* = No Sample

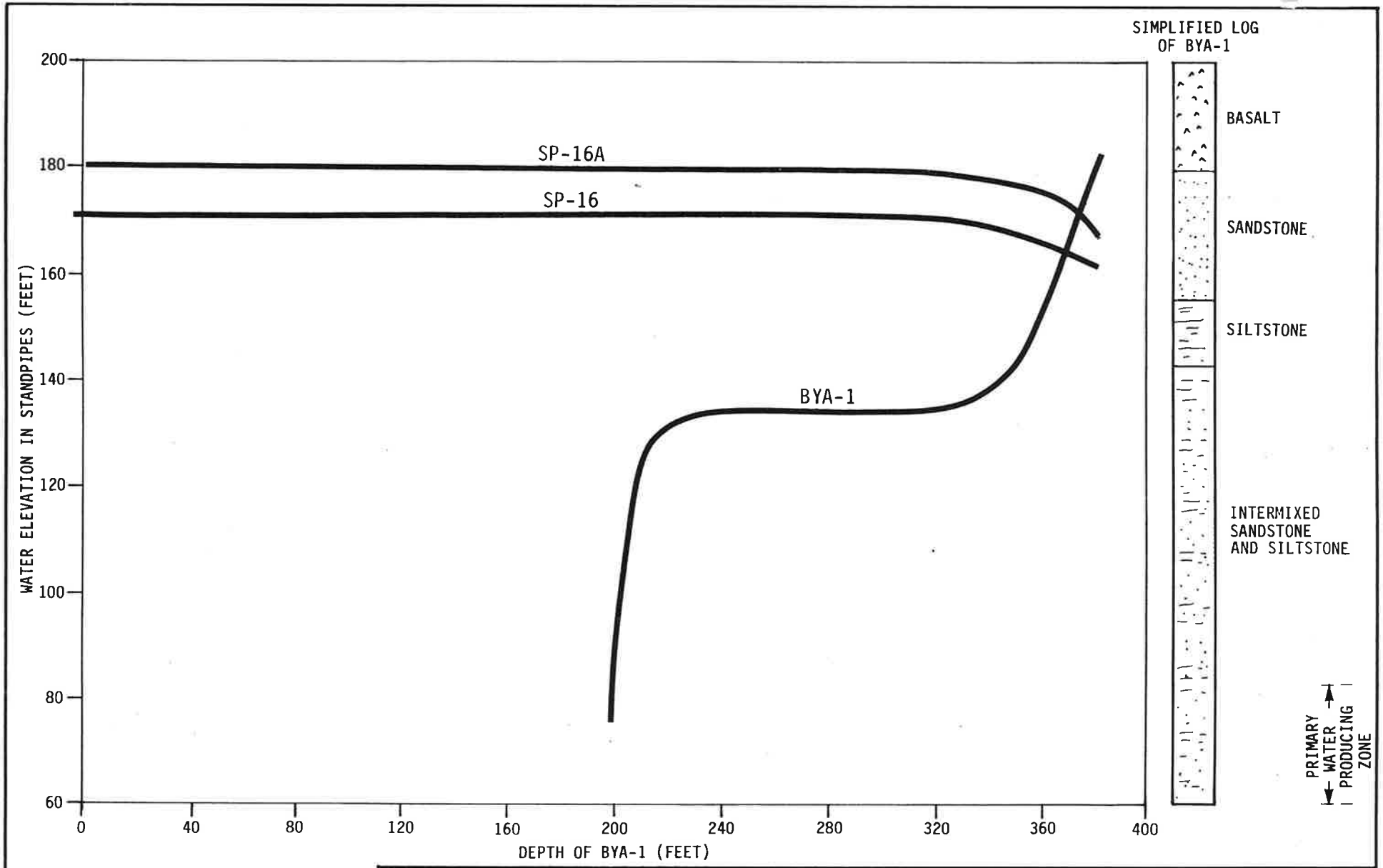
** = Average irrespects to different formations

Type I = Tests on samples which do not contain fracture features (joints, shears, bedding planes, etc.)

Type II = Tests on samples which contain fracture features (joints, shears, bedding planes, etc.)

NOTE:

Refer to Table D-2 and Figures IV-3 and IV-4 in Appendix D for number of tests and ranges of tensile strength values.



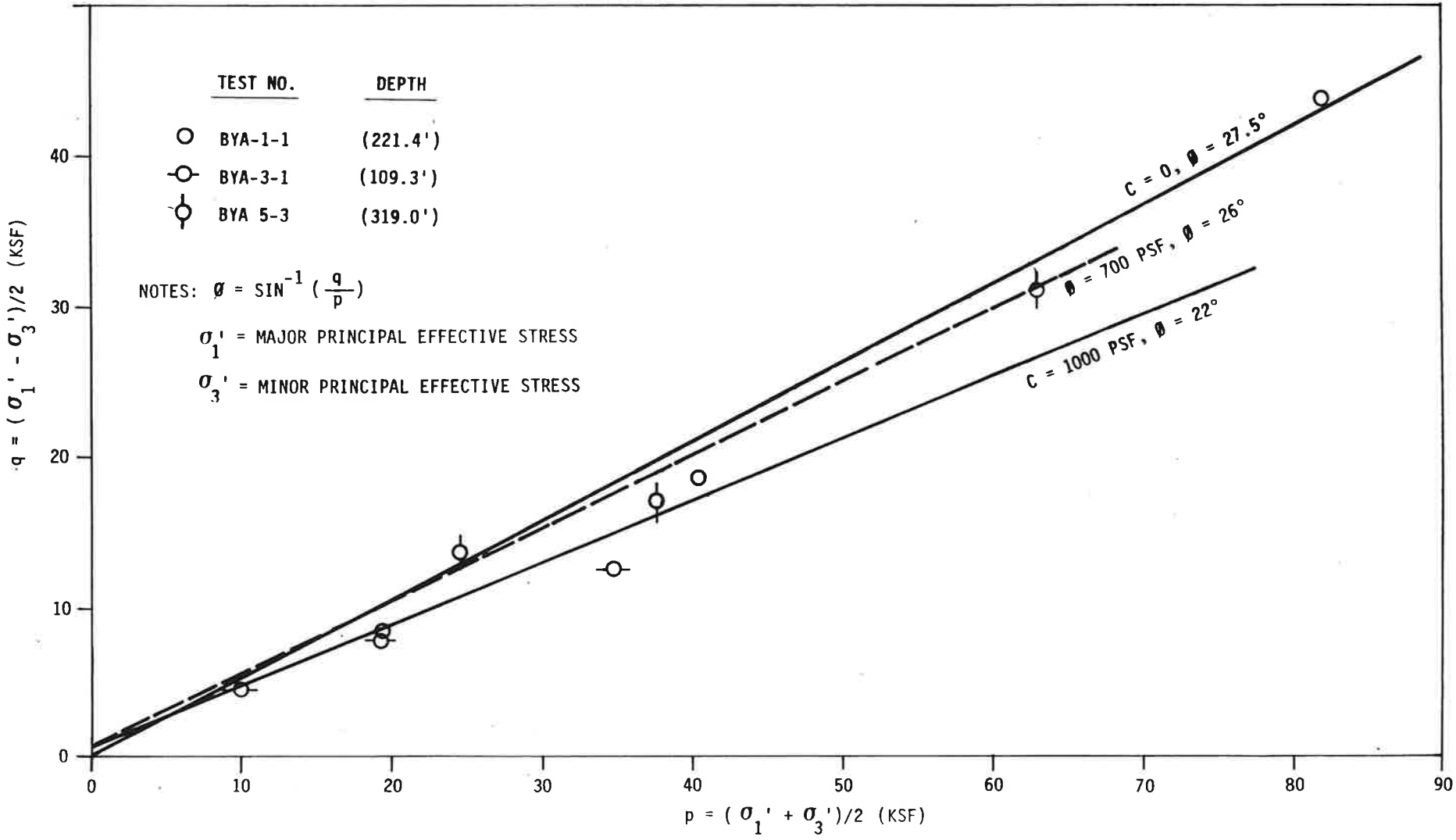
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WATER LEVEL RESPONSE DURING BYA DRILLING OPERATIONS

FIGURE 3-2.2



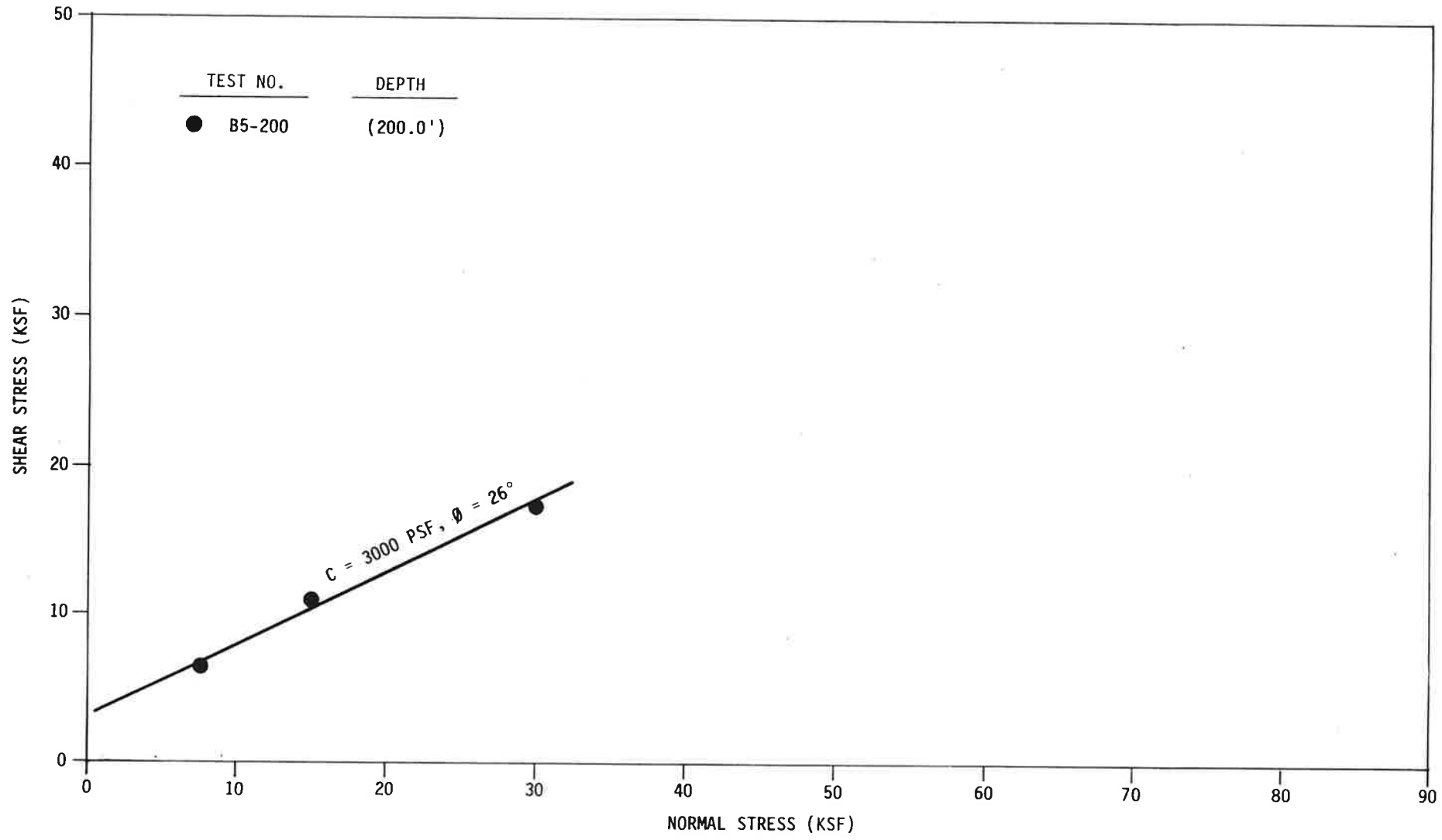
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TRAIXIAL TEST RESULTS-
BASALT

FIGURE 3-4.1(A)



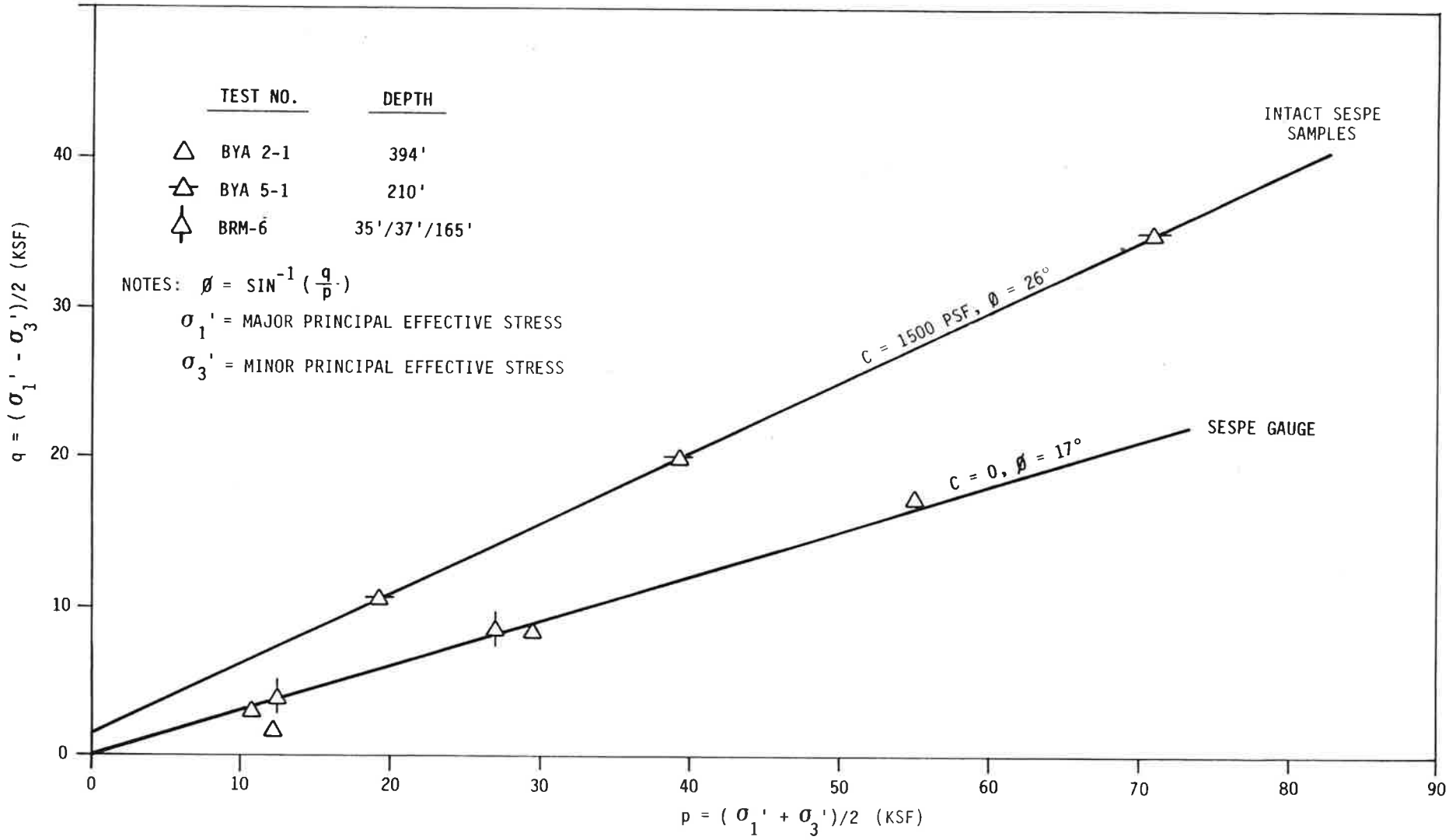
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DIRECT SHEAR TEST RESULTS-
BASALT

FIGURE 3-4.1(B)



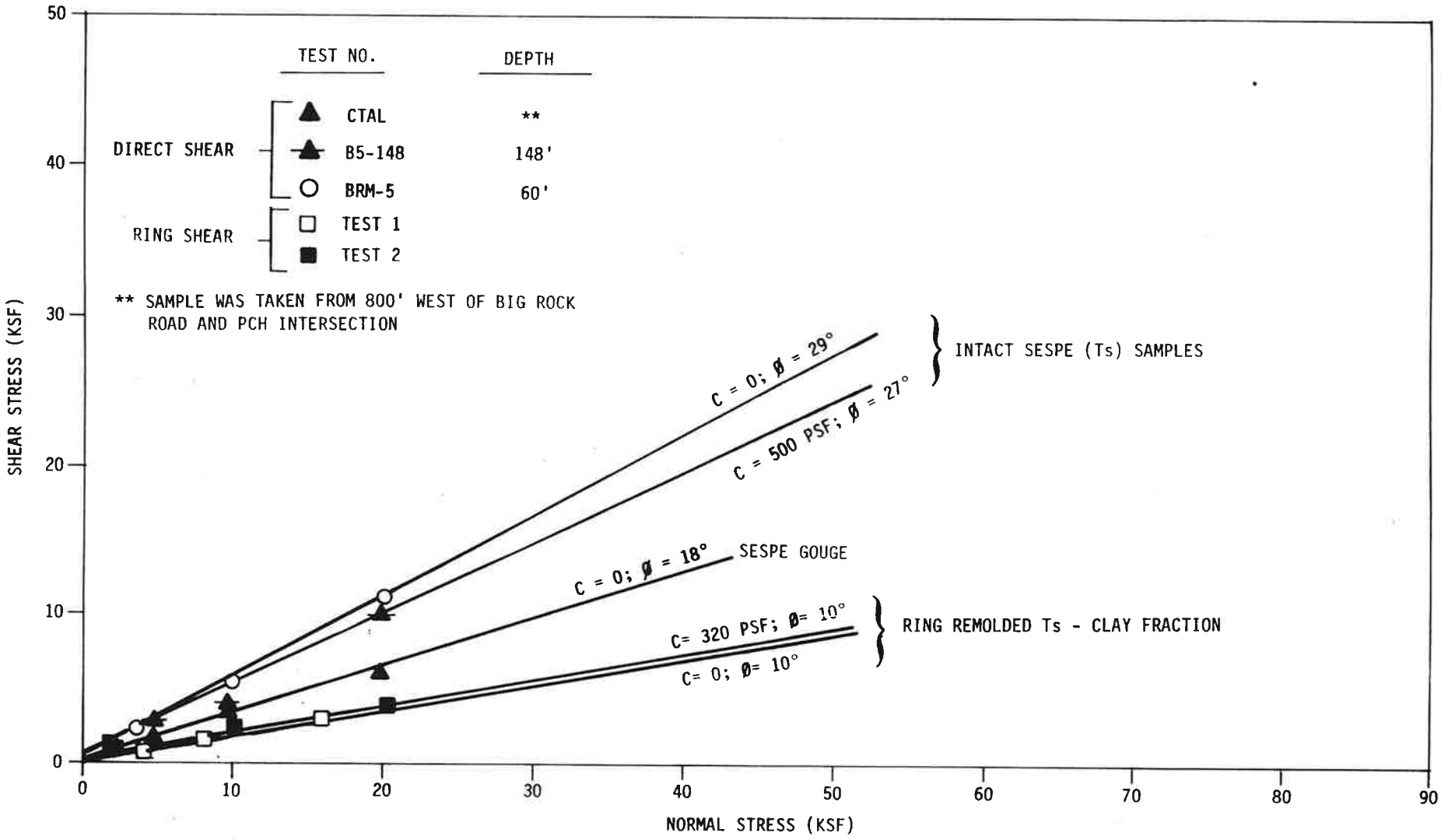
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TRIAXIAL TEST RESULTS-
SESPE FORMATION

FIGURE 3-4.2(A)



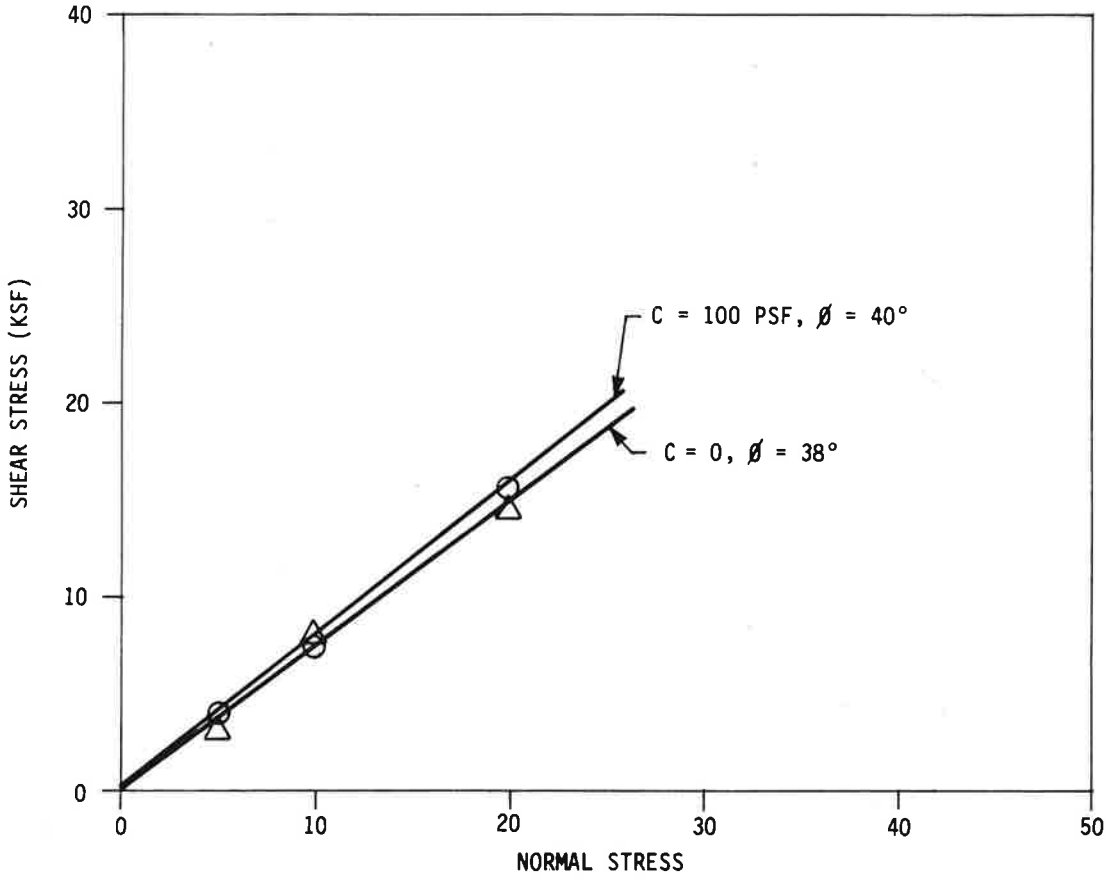
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DIRECT AND RING SHEAR TEST RESULTS-
SESPE FORMATION

FIGURE 3-4.2(B)



	TEST NO.	DEPTH	D_{50} (MM)
○	BYA-3	86'	0.35
△	BYA-4	108'	0.48

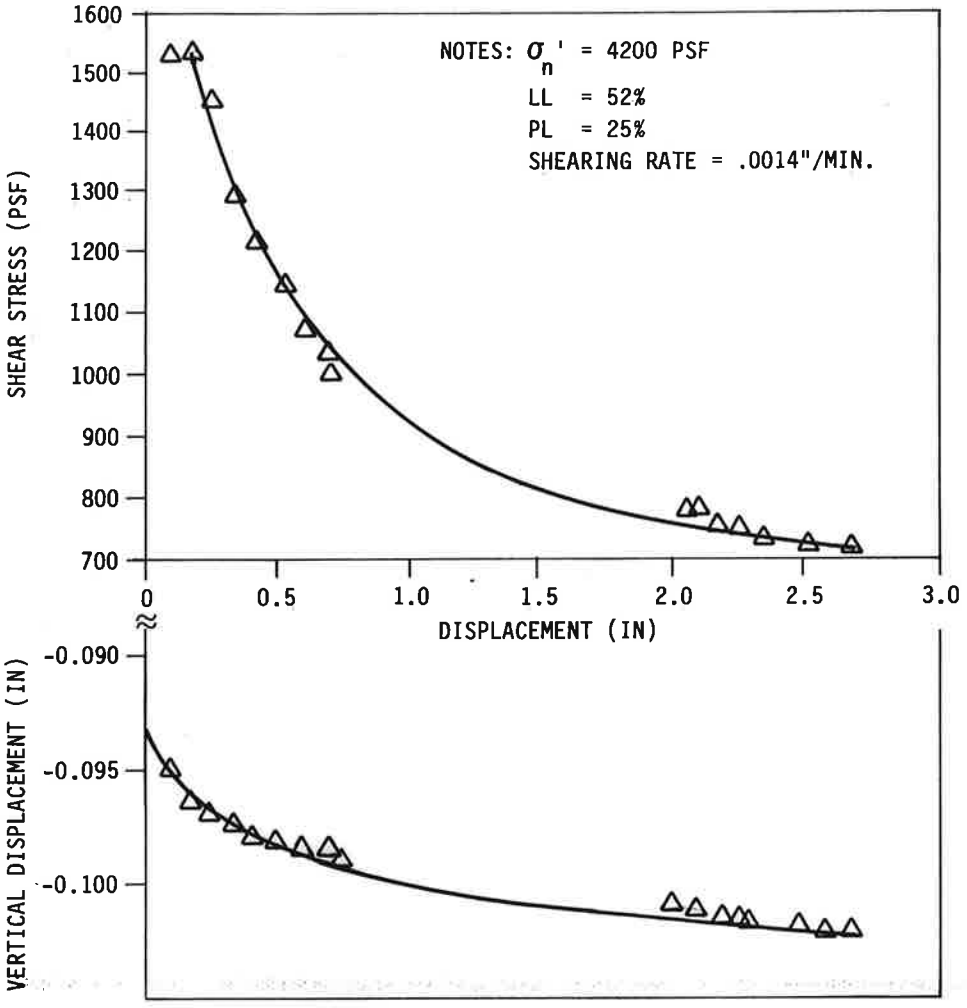
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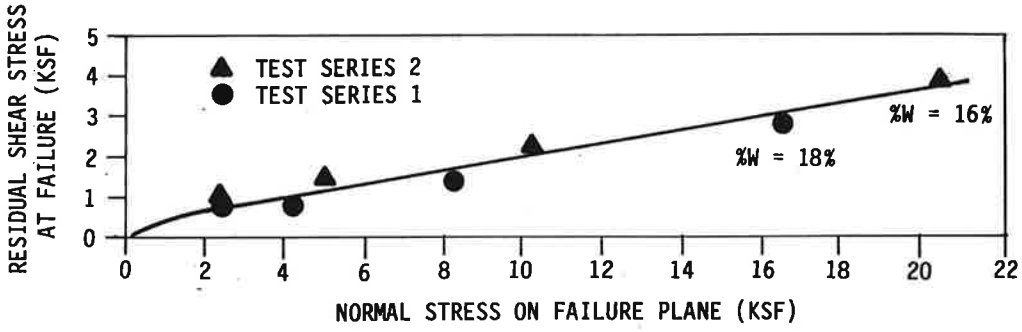
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DIRECT SHEAR TEST RESULTS-
TOPANGA FORMATION SANDSTONE

FIGURE 3-4.3

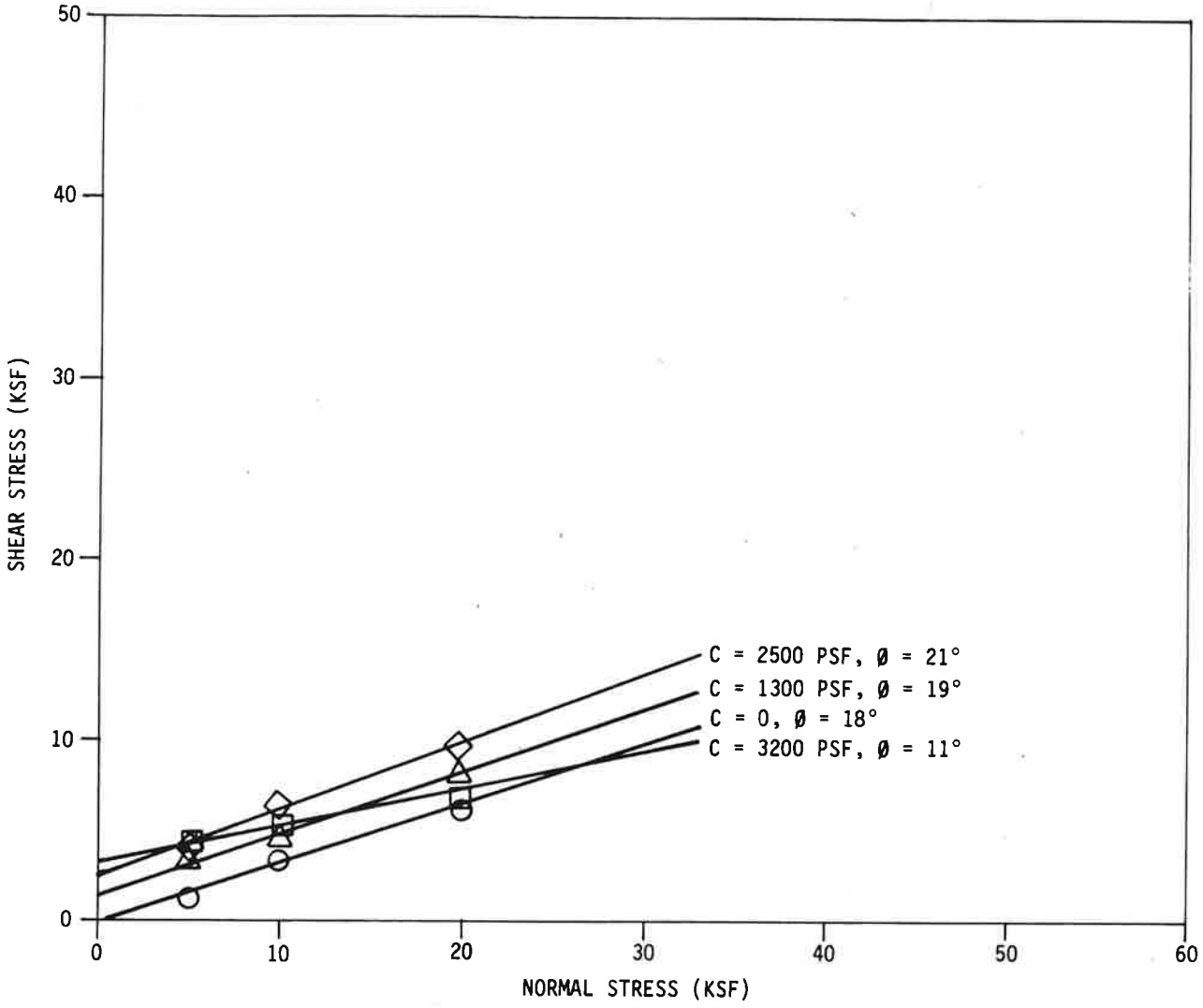


A. STRESS-STRAIN RELATIONSHIP OF RING SHEAR TEST



B. RESIDUAL SHEAR STRENGTH ENVELOP OF RING SHEAR TEST

BING YEN & ASSOCIATES		RING SHEAR TESTING RESULTS - SESPE GOUGE MATERIAL
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION		
PROJECT NO.: 49-97D	DATE: DECEMBER 1991	FIGURE 3-4.4



○ UNTREATED SAMPLE **

△ 2% ALUMINIUM NITRATE, $Al(NO_3)_3 \cdot 9\ H_2O$

□ 2% SODIUM METASILICATE, $Na_2SiO_3 \cdot 9H_2O$

◇ 2% POTASSIUM FLUORIDE, $KF \cdot 2\ H_2O$

** SAMPLE WAS TAKEN FROM 800' WEST OF INT. OF BIG ROCK DRIVE AND PCH.

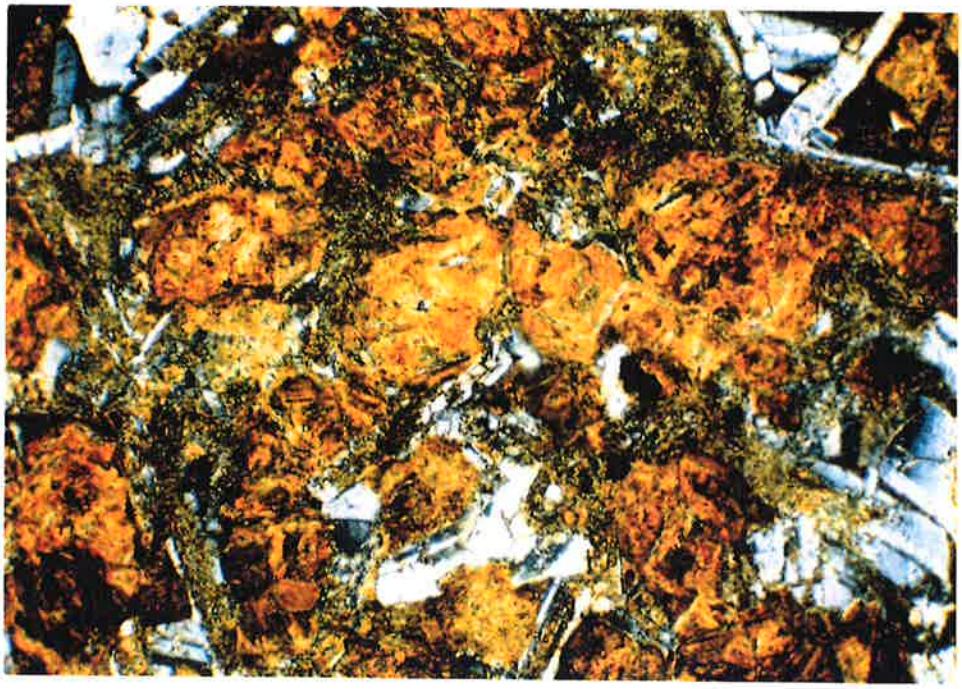
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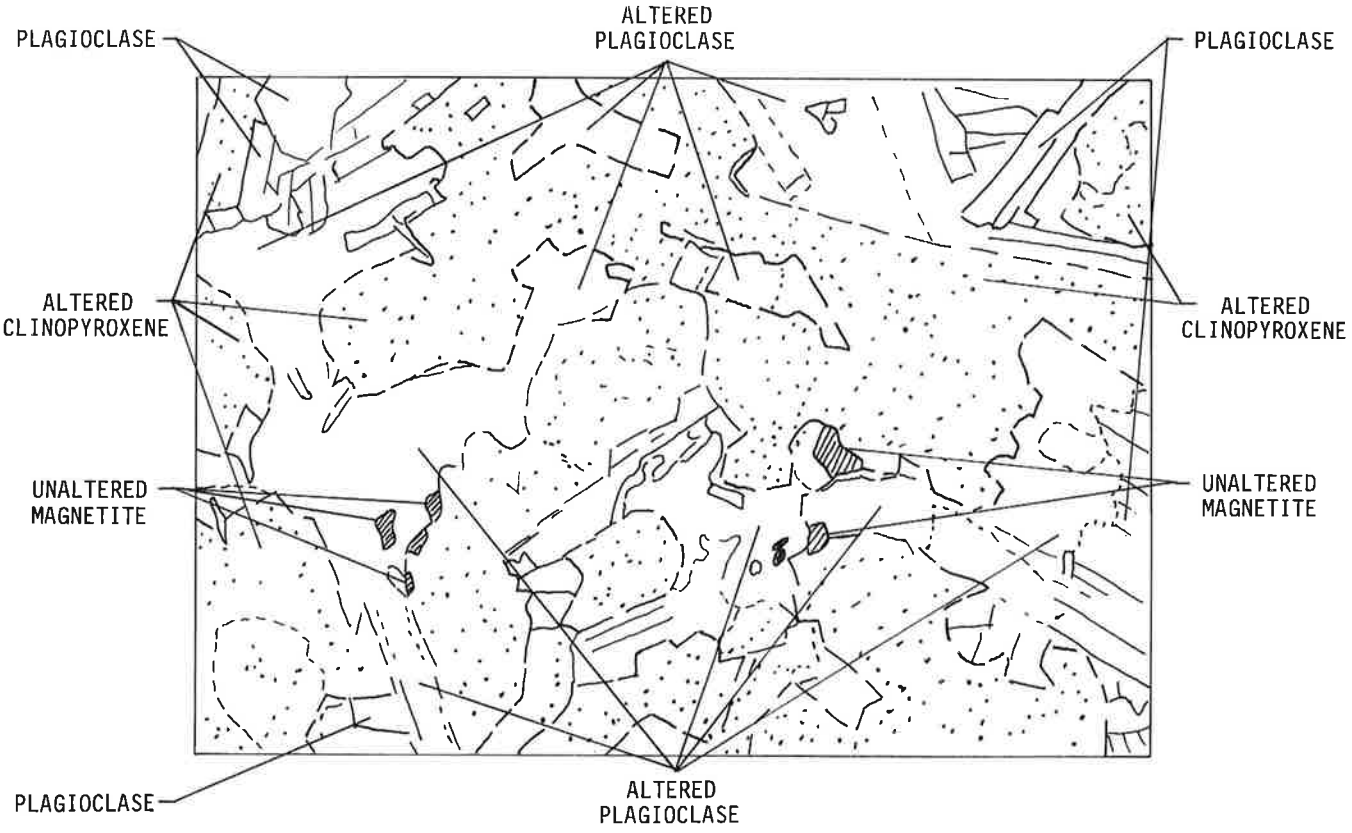
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DIRECT SHEAR TESTING RESULTS-
SESPE GOUGE WITH CHEMICAL ADDITIVES

FIGURE 3-4.5





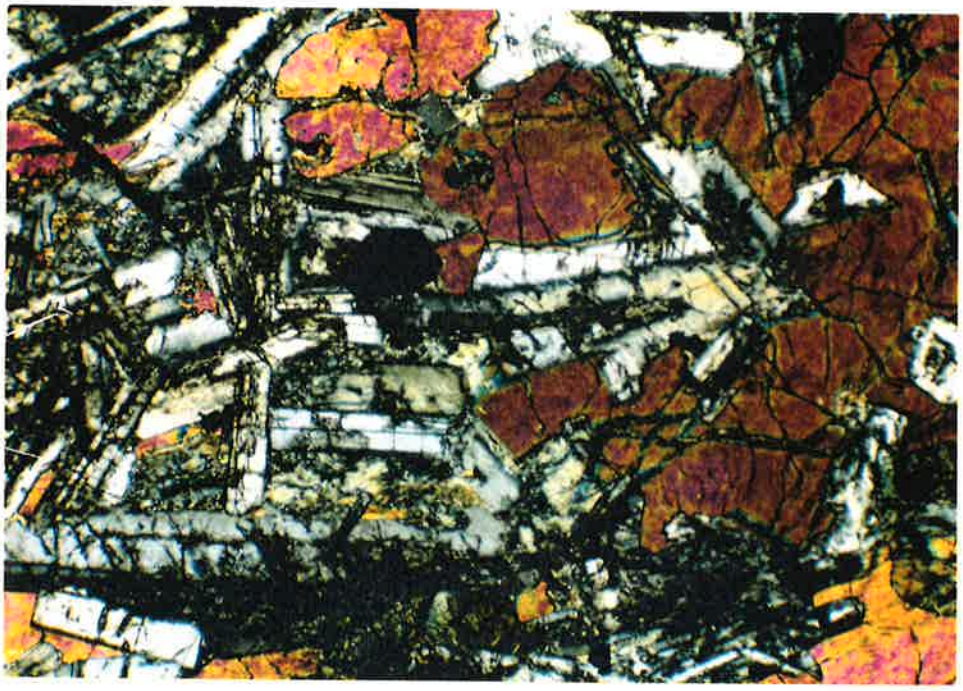
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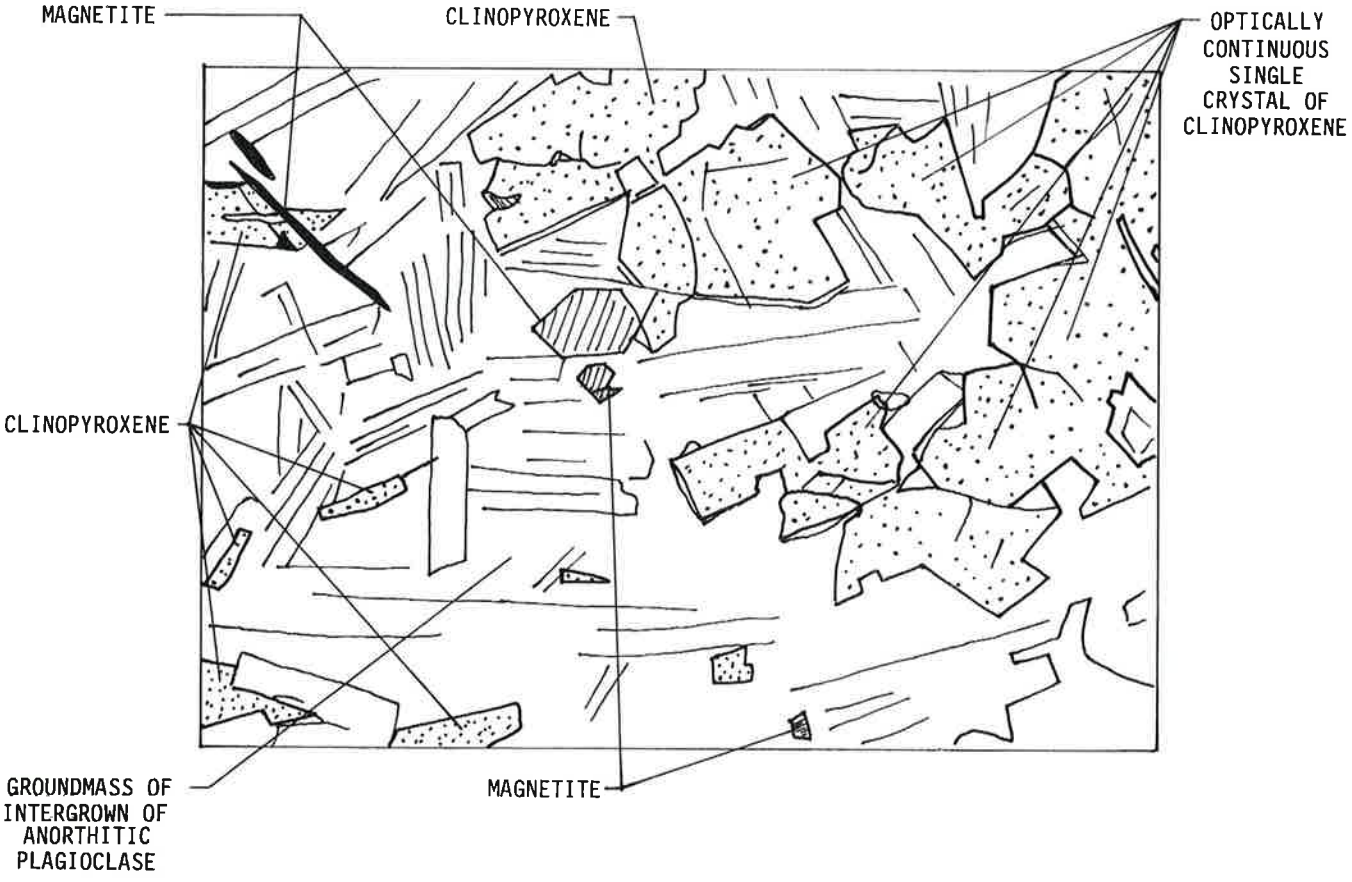
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TYPICAL ALTERED DIABASE
THIN SECTION
(MAG. 40X)

FIGURE 3-4.6





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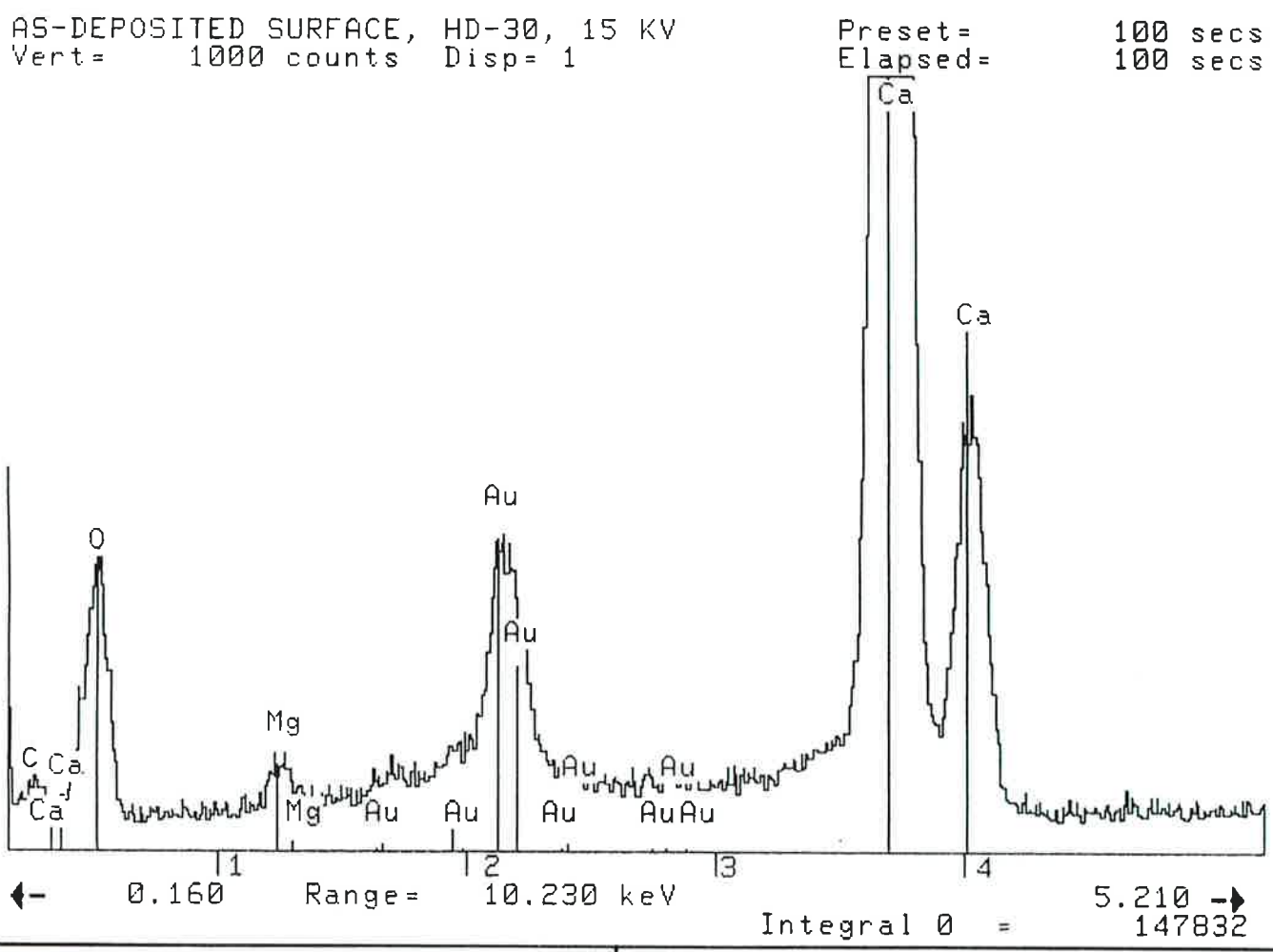
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LOCALIZED UNALTERED AREA WITHIN A GENERALLY ALTERED THIN SECTION OF BASALT (MAG. 40X)

FIGURE 3-4.7





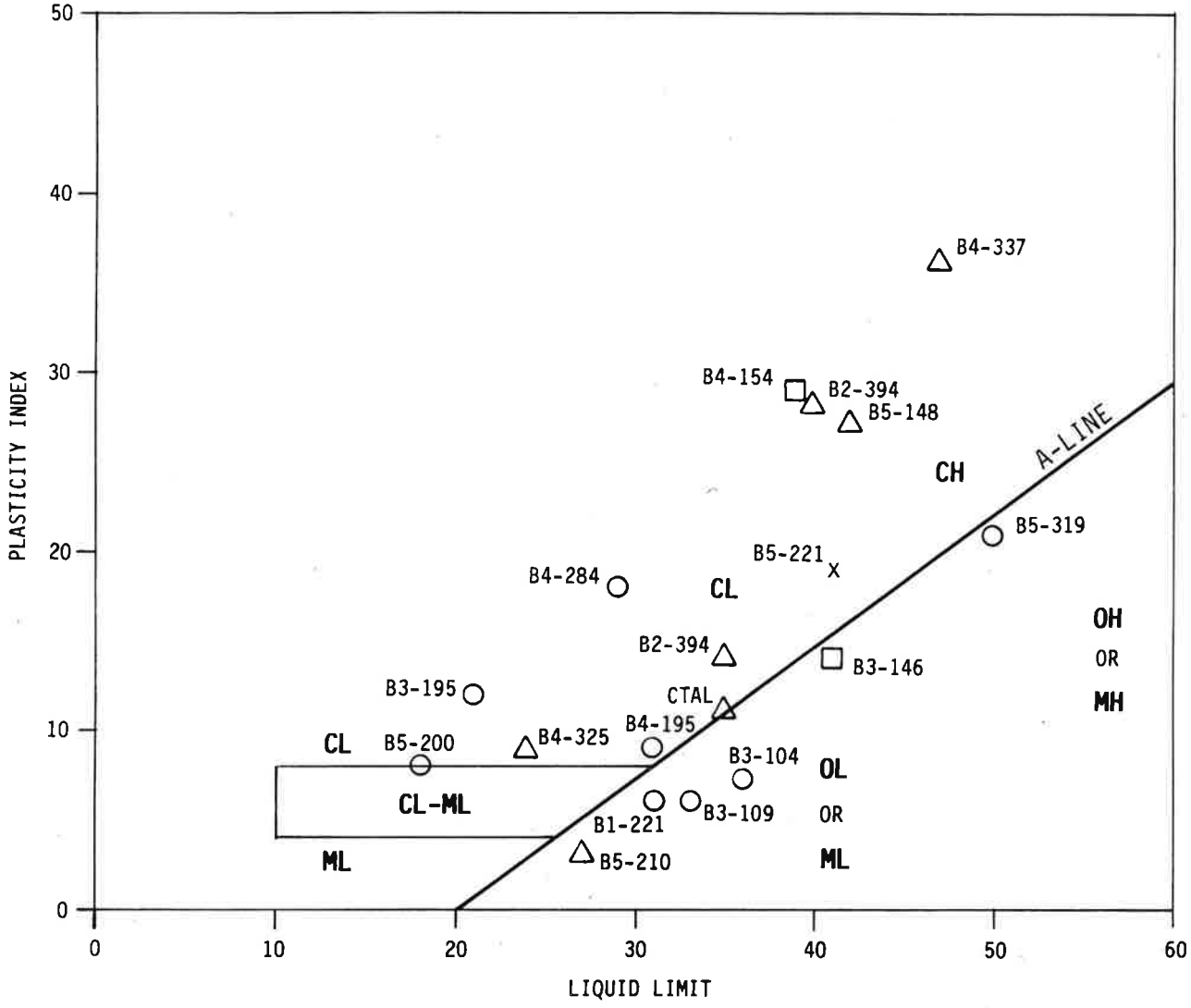
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$CaCo_3$ CRYSTAL GROWTH IN HYDRAUGER HD-30

FIGURE 3-6.3



B4-284 BORING BYA-4, DEPTH 284'

△ SESPE

○ BASALT

□ TOPANGA (CLAY)

X VAQUEROS (CLAY)

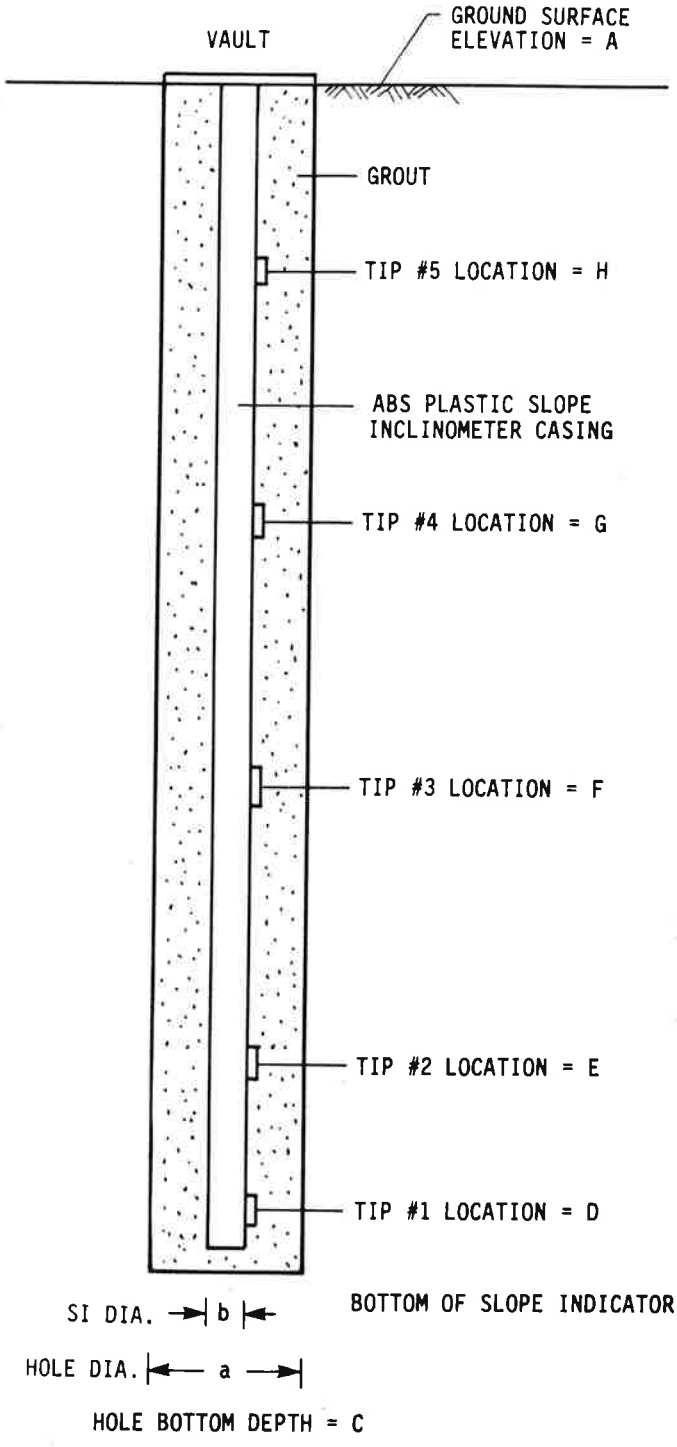
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ATTERBERG LIMIT SUMMARY OF GOUGE MATERIALS

FIGURE 3-4.8



SP-5A
A = 28 MSL
a = ±6"
b = 2.75"

	ELEVATION (MSL)	DEPTH (FEET)
B =	-122	150
C =	-122	150
D =	-122	150
E =	-72	100
F =	-22	50
G =	-	-
H =	-	-

NOTE: BOTTOM OF SLOPE INDICATOR CASING PERFORATED AFTER INSTALLATION.

SP-8A
A = 25 MSL
a = ±6"
b = 2.75"

	ELEVATION (MSL)	DEPTH (FEET)
B =	-175	120
C =	-175	120
D =	-175	120
E =	-45	70
F =	5	20
G =	-	-
H =	-	-

NOTE: BOTTOM OF SLOPE INDICATOR CASING PERFORATED AFTER INSTALLATION.

SP-17A
A = 540 MSL
a = ±6"
b = 2.75"

	ELEVATION (MSL)	DEPTH (FEET)
B =	300	240
C =	295	245
D =	300	240
E =	350	190
F =	300	140
G =	250	90
H =	200	40

NOTE: BOTTOM OF SLOPE INDICATOR CASING PERFORATED AFTER INSTALLATION.

BYA-5
A = 213 MSL
a = 3.2"
b = 1.9"

	ELEVATION (MSL)	DEPTH (FEET)
B =	-34	247
C =	-34	247
D =	-34	247
E =	16	197
F =	56	147
G =	116	97
H =	-	-

NOTE: INSTRUMENT PLACED INSIDE ROCK CORE CASING BEFORE CASING WAS REMOVED.

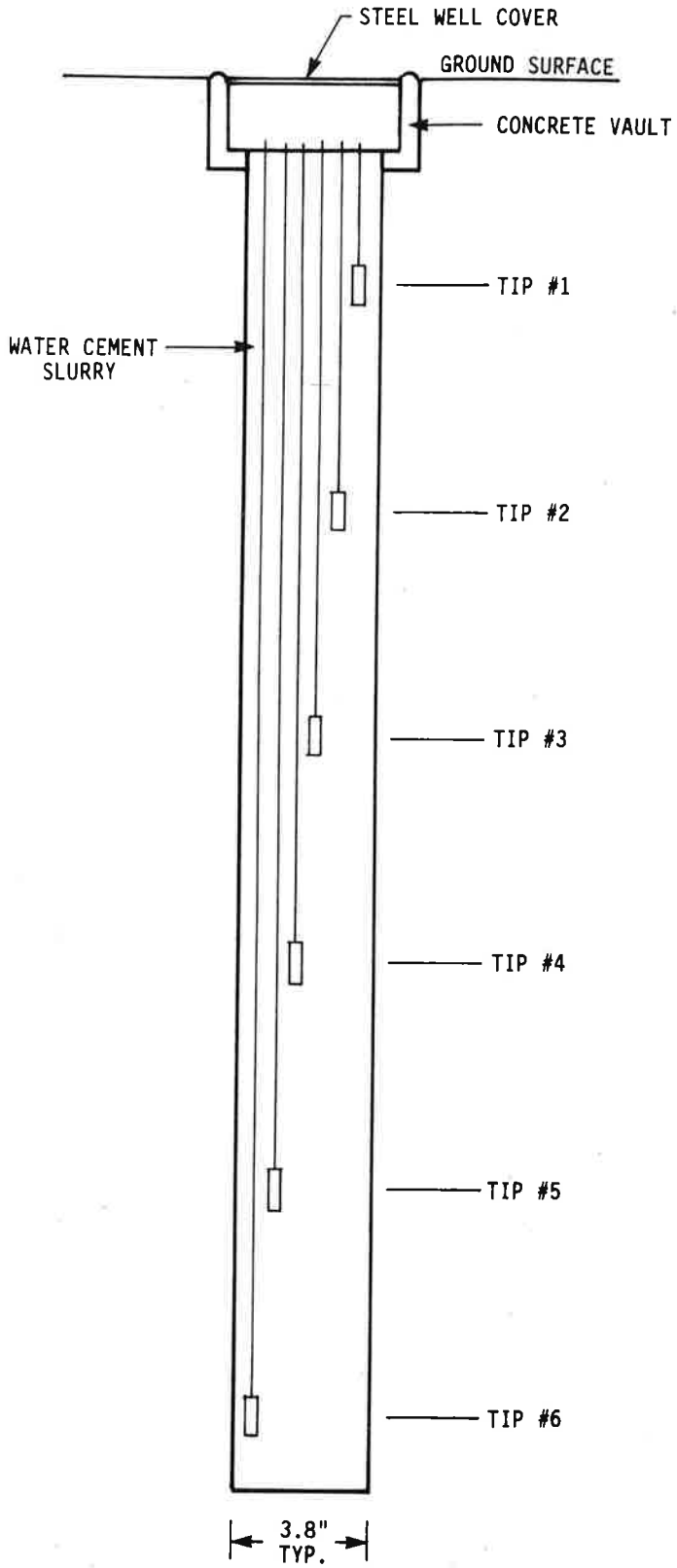
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TYPICAL BYA SI-PNEUMATIC PIEZOMETER INSTALLATION

FIGURE 3-5.1



BYA-2A

GROUND SURFACE ELEVATION = 664 MSL
TIP #1 DEPTH = 300
TIP #2 DEPTH = 250
TIP #3 DEPTH = 200

BYA-3A

GROUND SURFACE ELEVATION = 509 MSL
TIP #1 DEPTH = 17
TIP #2 DEPTH = 117
TIP #3 DEPTH = 217
TIP #4 DEPTH = 317

BYA-4A

GROUND SURFACE ELEVATION = 388 MSL
TIP #1 DEPTH = 111
TIP #2 DEPTH = 161
TIP #3 DEPTH = 211
TIP #4 DEPTH = 261
TIP #5 DEPTH = 311
TIP #6 DEPTH = 361

NOT TO SCALE

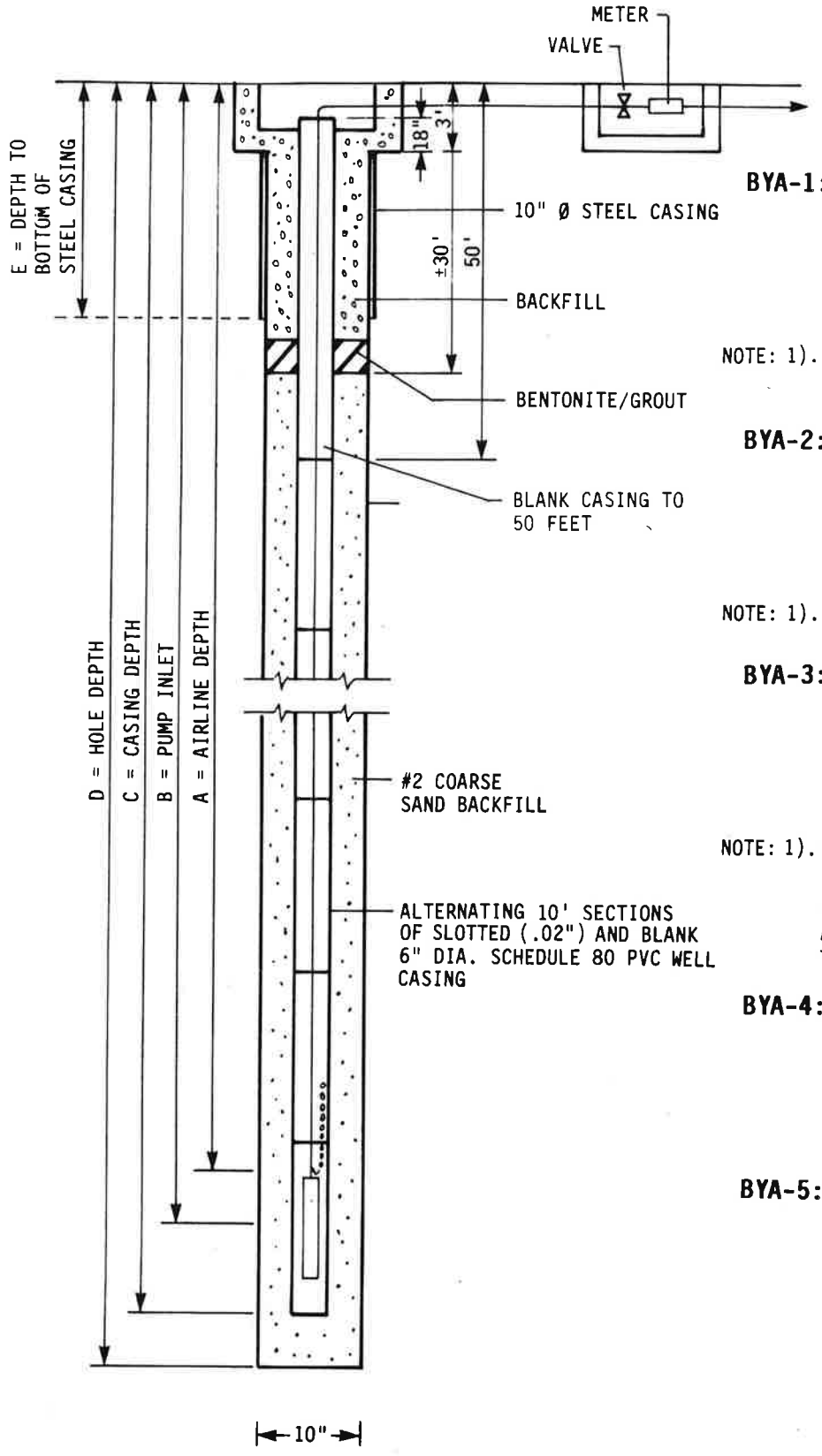
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TYPICAL BYA MULTI-STAGE PNEUMATIC PIEZOMETER INSTALLATION

FIGURE 3-5.2



BYA-1: SURFACE ELEVATION = 281'

A = 407' EL. = -126'
B = 409' EL. = -128'
C = 445' EL. = -164'
D = 500' EL. = -219'
E = 445' EL. = -164'

NOTE: 1). WELL AS CONSTRUCTED BY DRIVING 6 5/8" STEEL CASING TO DEPTH AND THEN PERFORATING CASING IN SITU.

BYA-2: SURFACE ELEVATION = 665'

A = 420' EL. = 240'
B = 422' EL. = 242'
C = 450' EL. = 215'
D = 486' EL. = 221'
E = 0' EL. = 665'

NOTE: 1). TOP 250' OF HOLE WAS DRILLED TO 12" DIAMETER.

BYA-3: SURFACE ELEVATION = 510'

A = 482' EL. = 28'
B = 483' EL. = 29'
C = 550' EL. = -40'
D = 560' EL. = -50'
E = 150' EL. = 360'

NOTE: 1). STEEL CASING PERFORATED IN SITU FROM 150 TO 10' BELOW GROUND SURFACE. 2). ALTERNATING BLANK AND PERFORATED CASING INSTALLED TO GROUND SURFACE.

BYA-4: SURFACE ELEVATION = 372'

A = 398' EL. = -26'
B = 400' EL. = -28'
C = 440' EL. = -68'
D = 560' EL. = -188'
E = 0 EL. = 372'

BYA-5: SURFACE ELEVATION = 189'

A = 398' EL. = -209'
B = 400' EL. = -211'
C = 420' EL. = -231'
D = 420' EL. = -231'
E = 150' EL. = 49'

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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

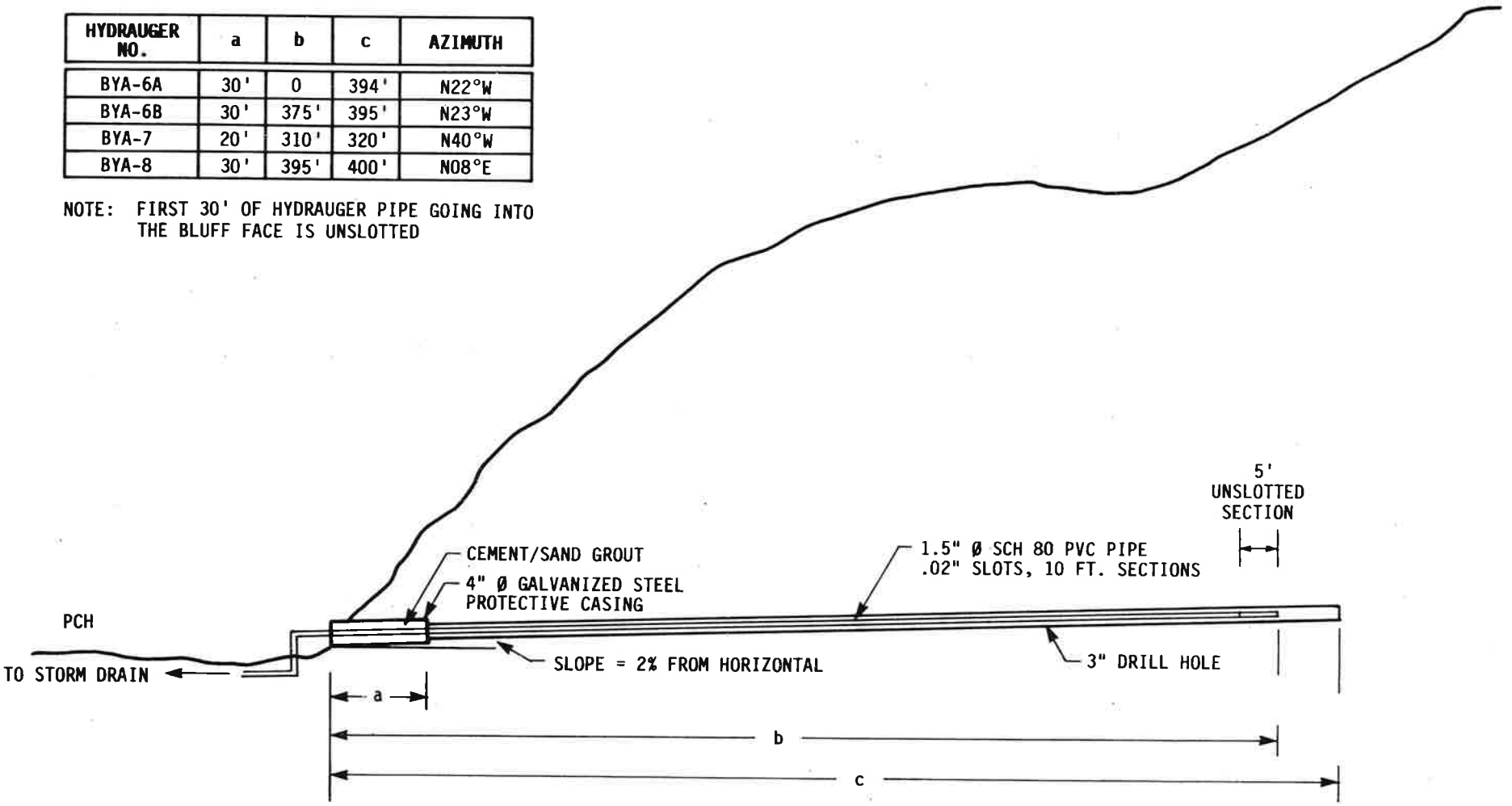
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TYPICAL BYA DEWATERING WELL INSTALLATION

FIGURE 3-6.1

HYDRAUGER NO.	a	b	c	AZIMUTH
BYA-6A	30'	0	394'	N22°W
BYA-6B	30'	375'	395'	N23°W
BYA-7	20'	310'	320'	N40°W
BYA-8	30'	395'	400'	N08°E

NOTE: FIRST 30' OF HYDRAUGER PIPE GOING INTO THE BLUFF FACE IS UNSLOTTED



NOT TO SCALE

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TYPICAL BYA HYDRAUGER INSTALLATION

FIGURE 3-6.2

SECTION 4.0

GEOLOGIC AND SEISMIC ENVIRONMENTS

4.1 GEOLOGIC SETTING AND FEATURES OF ENGINEERING SIGNIFICANCE

A detailed description of the geology and structural features of the BRM area is provided in Appendix B. General geologic setting and features of engineering significance are summarized herein to provide a basic framework for needed geotechnical and groundwater evaluations described in Sections 6.0 and 7.0.

4.1.1 Regional Setting

The BRM area is located at the extreme southern boundary of the Transverse Ranges Tectonic and Geomorphic Province. This province averages 30 miles in width and extends for over 300 miles in length from beyond San Miguel Island off the Ventura coast eastward into the Mojave Desert as shown in Figure 4-1.1. This province contains the Santa Monica, San Gabriel and San Bernardino Mountains and derives its name from their east-west alignment which is "transverse" relative to the orientation of most of the other regional geologic features. The southern boundary of this province is generally defined - west to east - by the Malibu Coast, Santa Monica, and Raymond Hill fault systems. These faults will be collectively referred to as the Santa Monica fault zone. The adjacent Shoreline fault forms the southern boundary of the BRM landslide area and is considered to be part of the east-west trending Malibu Coast fault zone.

4.1.2 Geologic Units and Geologic Map

The rocks exposed in the BRM area south of Piedra Gorda Canyon are Tertiary age sedimentary units that include the Sespe, Vaqueros and Topanga formations as well as volcanics in the form of intrusive basaltic and diabasic dikes and sills. The intrusive episode apparently occurred in upper Miocene time.

The areal distribution and lithology of these units are described on the geologic map shown in Figure 4-1.2. One particular point that requires specific mention is the differentiation of the intrusive basaltic and diabasic rocks from the sedimentary formations by the high resolution gamma logging. The identification of such rocks in conjunction with geologic mapping and continuous cores from the 5 deep borings provide a useful marker for identifying and tracing individual faults and slide surfaces which affect present and future stability.

As described in Appendix B, the detailed geologic map of BRM shown in Figure 4-1.2 was prepared based on interpretation of data in the project data files (including 22 different sources), available aerial photos (from 1928 to 1990), field mapping, sampling and in situ verification of existing data. This map, together with available core logs, gamma-logging, dipmeter logging and inclinometer data, made it possible to trace and interpret geologic structures which forms the primary basis for the geotechnical analyses of the BRM area.

The regional tectonics of the Transverse Range is complicated. This area has been subjected to multiple episodes of deformation under different stress regimes which have varied with time. These tectonic activities resulted in the observed structural features shown in Figures 4-1.2 and 4-1.3.

A generalized tectonic history is as follows:

1. Development of the Los Angeles Basin with sedimentary sequences that currently extend northward into the area now occupied by the Transverse Ranges to the approximate position of the Oak Ridge Thrust;

2. Broad uplift and erosion of the Sespe formation prior to deposition of the Topanga formation;

3. Extensional deformation after deposition of the Topanga formation in the forms of either low-angle detachment or high-angle normal faulting, with concurrent volcanic activities (intrusive basaltic/diabasic rocks) and clockwise rotation of the entire area;

4. Imbricate thrust faulting and concurrent folding of entire sequence along an east-west trend;

5. Continued movement along faults during uplift of the Santa Monica Mountains; and

6. Landsliding and satellite sliding.

These tectonic events have caused the rocks in the BRM area to be intensively fractured and mechanically sheared, brecciated or altered, as evidenced by the common local occurrences of mechanically weakened silty/shaley sequences in the Sespe, Vaqueros and Topanga formations as well as the basaltic/diabasic rocks that cross-cut the sedimentary rocks along faults. These weakened materials are often further changed by thermal and chemical alteration to clay, chlorite and serpentine minerals. Although fracturing and brecciation enhance permeability, the clay gouge materials reduce permeability and contribute to the development of perched or compartmentalized groundwater conditions.

4.1.3 Faults and Folds

All major faults trend generally east-west and are predominantly north-dipping (Figure 4-1.3). A number of cross-faults occur in the BRM area with north-northeast trends and variable dips. The generally east-west trending faults form an imbricate zone of stacked fault slices; the individual faults, however, probably represent at least three generations of deformation. The oldest of these are folded faults formed under extensional stresses with younger rocks overlying older across the fault planes; post-dating these are thrust faults of the Las Flores fault zone with associated folding along nearly parallel trends; the third are left-oblique slip faults of the Malibu Coast fault system with dominantly reverse dip-slip motion. Major faults with generally east-west trends are typically intruded by basalt or diabase. Cross-faults are less commonly intruded, particularly within the active landslide. Some of the cross-faults were primarily caused by landslide activities after the intrusive episodes of the Upper Miocene.

In general, the faults in the BRM area can be divided into three categories: thrust/reverse faults, faults with strike/slip components and north-trending cross faults (see figure 4-1.3). Thrust/reverse faults are characterized by hanging walls displaced upward with respect to the footwalls (i.e., usually older rocks thrust over the top of younger rocks). They are major east-west trending faults that include the Saddle, Las Flores, North, Big Rock Drive, Seacliff and Bluff faults. The faults with strike/slip components are also major faults generally trending east-west with relatively steep dips. These faults include the Shoreline and Seaboard faults. North-trending cross faults in the BRM area are relatively short and numerous, and generally are characterized by high-angle dips and are predominantly north-east trending. These faults include the Rockpoint, Love and Inland faults. The configurations and mechanisms of movement as well as magnitudes of past movement of these faults and folds are detailed in Appendix B.

The faults are both likely planes of weakness and groundwater barriers. Major characteristics of the faults in the BRM area are summarized below:

1. East-west trending north-dipping faults and north-trending cross faults tend to act as groundwater barriers to dam up and compartmentalize trapped groundwater.

2. North-trending cross faults may serve as conveniently oriented planes of weakness along which the landslide margin developed and blocks within landslides slipped past each other.

3. Inferred south-dipping faults possibly originated as conjugate shears to major faults and are potential planes of weakness. Based on the dipmeter logs, they appear to be common features.

4. Nearly flat (with slight north-dipping) faults such as the Bluff and the Seacliff faults may be planes of weakness which may ramp northward if and when the support is withdrawn due to landsliding or grading.

5. The Shoreline fault of the Malibu Coast fault zone with its north-dipping breccia and gouge is both a plane of weakness and a groundwater barrier.

The Shoreline fault is part of the Malibu Coast fault system which may be active. There is no evidence, for or against, activity of the Shoreline fault at BRM because of the lack of appropriately youthful deposits. The California Division of Mines and Geology (CDMG) is currently studying the Malibu Coast fault (personal communications with J. Trieman) and it is our understanding that definitive conclusions regarding activity and ground rupture have not been reached at this time. As will be discussed in Section 4.2, BYA has analyzed past seismic events and developed relevant seismic input for stability analyses.

The steeply dipping beds of the sedimentary rocks in BRM indicate significant rotation and folding of rock layers. The northward and northeast-ward dips in the Sespe formation, for example, are vertical to overturned in the western part of BRM. The main exception to this pattern is upper Piedra Gorda Canyon, where southward dips are seen marking the north limb of a west-northwest trending syncline. The hinge of this fold lies along the crest of the ridgeline bounding the main active landslide. It lies between two north-dipping thrust faults and is oversteepened due to drag by the upper of these faults (Las Flores fault). The

general character of BRM south of the syncline is homoclinical towards the north. This reflects the general structural fabric of the surrounding portion of the Santa Monica Mountains, wherein folds have developed along northwest trends. From a geotechnical engineering viewpoint, the folds at BRM affect the groundwater infiltration path, the groundwater divide and residence time.

4.1.4 Geologic Cross Sectional Profiles

A series of geologic cross sectional profiles were developed through the BRM landslide area and the adjacent Western Extension area based on engineering interpretation and evaluation of the following data:

- Data used in generating the geologic map shown in Figure 4-1.2,
- Borehole/Well Logs Data,
- Gamma and Dipmeter Logs,
- Inclinometer Data.

These data represent our best understanding at this time and form the basis from which stability calculations were made, in conjunction with groundwater conditions. These developed profiles include 5 cross sections (A-A' through E-E') across the main BYA landslide, 2 cross sections (F-F' and I-I') through the Western Extension area and 2 east-west cross sections (G-G' and H-H') through both the Western Extension and main BRM landslide area. The locations and details of these cross sections are shown in Figures 4-1.4 through 4-1.12.

Although based on substantially more comprehensive and better quality data than previously available, significant assumptions, interpretation and extrapolation were still involved in developing these geological profiles, because:

1. Available subsurface information was based on data obtained at widely spaced locations,
2. No deep subsurface information within the slope of the Bluff Region is available,
3. No borings along PCH in the western part of the mesa have been performed. This represents one of the largest gaps in evaluating the stability of the western bluff zone, and would provide a better understanding of the Western Extension, and
4. The complexity of geologic structures make extrapolation of data difficult over even short distances.

The following remarks can be made upon a close examination of the geologic profiles shown in Figures 4-1.4 through 4-1.12 in conjunction with the geologic map shown in Figure 4-1.2:

1. The subsurface conditions in the BRM area are complex reflecting the complicated geologic and tectonic environments.

2. The slide surfaces involved in the BRM landslide have moved at least several hundred feet in the past. Thus, the BRM landslide was a reactivation of an existing landslides which had moved in the past, probably through a number of episodes.

3. The identified slide surfaces for the BRM landslide are deep-seated. A relatively higher percentage of the slide surfaces cut across bedding planes (i.e., cross bedding), while only a smaller fraction appears to have occurred along planes of weakness such as bedding planes and known faults.

4. Groundwater levels at the time of the BRM landslide were high. Judging from the relatively rapid stabilization response to dewatering, high groundwater levels can be considered as the most direct cause of the BRM landslide.

5. Geologic environments significantly affect slide characteristics. Mitigation of the BRM landslide, however, requires engineering solutions. During the implementation stage of mitigation measures (such as when wells are installed) detailed logging should be done to enhance the geological understanding of the mesa, thereby optimizing the engineering solutions.

4.2 SEISMICITY

As shown in Figure 4-1.1, the BRM area is situated along the southern boundary of the Transverse Range Province. The Malibu Coast fault, Santa Monica fault and the Anacapa fault are the faults dominating the near-field shaking of the site, which is characterized by high frequency content and high peak accelerations, whereas the San Andreas and Newport-Inglewood faults are the major (but distant) faults which are capable of generating longer duration, but significantly lower peak acceleration ground shaking. Table 4-2 shows the seismic parameters of distant major faults. Both the Malibu Coast and Anacapa fault zones are north-dipping, high-angle reverse faults with probable left oblique slip movement histories. The area has been seismically active. Figure 4-2.1 shows the events between 1932 to 1990, based on records available from the California Institute of Technology (Caltech). Among the 10,945 earthquakes shown in Figure 4-2.1, those earthquakes greater than a magnitude of 3 are shown in Figure 4-2.2. The following recent events are of particular significance:

1) Sierra Madre Earthquake of June 28, 1991 (M = 5.8)

This M=5.8 earthquake occurred at about 7:40 a.m. with an epicenter located about 60 km (34.262N, 118.002W) from BRM. The estimated focal depth of this earthquake is about 11 km. According to the USGS and Caltech, the earthquake had a thrust mechanism with the San Gabriel mountains on the upthrown block (CDMG Report OSMS 91-03). Structural damage was not reported to have occurred at BRM. However, local rockfalls were noted along PCH with rocks up to 3-feet across in size falling from the bluff face. About 6 hours following the event, BYA staff monitored the producing hydraugers along PCH. The discharge of hydraugers showed an 11% increase after the earthquake compared to measurements taken about 2 weeks before. Based on this event alone, it is uncertain if the increase in hydrauger discharge was due to the pore pressure (groundwater) increase induced by the seismic shaking. But the possibility of the seismically induced pore pressure increase cannot be discounted. The nearest strong motion station with a record of this event

is about 15 km away (CSMIP Station 24436) in Tarzana, which recorded a peak acceleration of 0.09g.

The shortest epicentral distance of the station triggered by the earthquake was about 4 km at Cogswell Dam (CSMIP Station 23210). BYA has chosen the strong motion record of this dam as one of the time-history records for seismic stability analysis at BRM because: (1) the Sierra Madre earthquake's thrust mechanism is similar to the potential causative thrust faults in the BRM area, and (2) of the comparable near-field (4 km) records that are available. The seismic stability analysis is given in Section 8.0.

2) Malibu Earthquake, January 18, 1989 (M=5)

An earthquake originating from the Malibu Coast fault system, located about 27 km from BRM, occurred on January 18, 1989. Limited interviews with residents indicated that almost everyone recalled the jolt, but no structural damage was observed (by those being interviewed). BYA staff noted minor rockfall and sloughing along the bluff facing PCH. Of particular interest is an average increase of 16% in hydrauger discharge based on measurements taken 2 days after the event. When this is considered together with the Sierra Madre event of 1991, BYA believes that the seismic-induced pore (groundwater) pressure increase is a distinct possibility.

3) Whittier Earthquake, October 1, 1987 (M=5.9)

This M=5.9 earthquake had an epicentral distance about 70 km from BRM. This earthquake generated a maximum ground acceleration on the order of 0.048 g at Point Dume School in Malibu which is about 18 km to the west from BRM. BYA conducted a limited interview with BRM residents in 1991 which indicated that there were no noticeable rockfalls or structural damage.

4) Point Mugu Earthquake, February 21, 1973 (M=5.3)

A 5.3 magnitude earthquake occurred along the Anacapa fault zone with an epicenter located offshore of Point Mugu approximately 40 km to the west of the site. This tremor and its associated aftershocks resulted in a moderate level of ground shaking at the site (± 0.05 g max.) with no documented distress or slope failures.

5) San Fernando Earthquake, February 9, 1971 (M=6.6)

A 6.6 magnitude earthquake occurred along the San Fernando fault zone about 25 miles north of the site resulting in moderately intense ground shaking (± 0.1 g max.) in the BRM area. There were no slope failures or rock slides documented in the immediate vicinity as a result of this earthquake or the associated aftershocks.

A closer examination of the recorded events shown in Figure 4-2.2 indicates that most of the recent events had a focal depth between 5 to 15 km. From the perspective seismic response, it is the near-field ground motions generated from the Malibu Coast and Anacapa fault zones which are of concern. These near-field motions are characterized by higher peak acceleration, but shorter wave length and durations. These motions are more likely to induce rockfalls, slope displacement or wedge type failures along rock joint sets. Several

design seismic time histories have been chosen based on the stiff site conditions of BRM. For the more distant regional major faults, such as the San Andreas and Newport-Inglewood (Figure 4-1.1) the seismic shaking at the site is likely to be of low peak acceleration, but with longer wavelengths and durations as shown in Table 4-1.

A probabalistic seismic hazard evaluation is summarized in Figures 4-2.3 and 4-2.4. These two figures provide the probability of exceedence versus peak acceleration and the average return period versus acceleration, respectively, for the BRM area. For seismic stability evaluation purposes (see Section 8.0), a near field earthquake of magnitude 6.5 ± with a peak acceleration of about 0.7g is taken as the maximum credible earthquake associated with the Malibu Coast/Anacapa fault zones. As shown in Figure 4-2.3, this corresponds to a return period of about 10,000 years. This earthquake is utilized to evaluate the near worst case scenario (with extremely low probability of occurrence - about 1% probability of occurrence in one hundred years - Figure 4-2.4).

TABLE 4-1

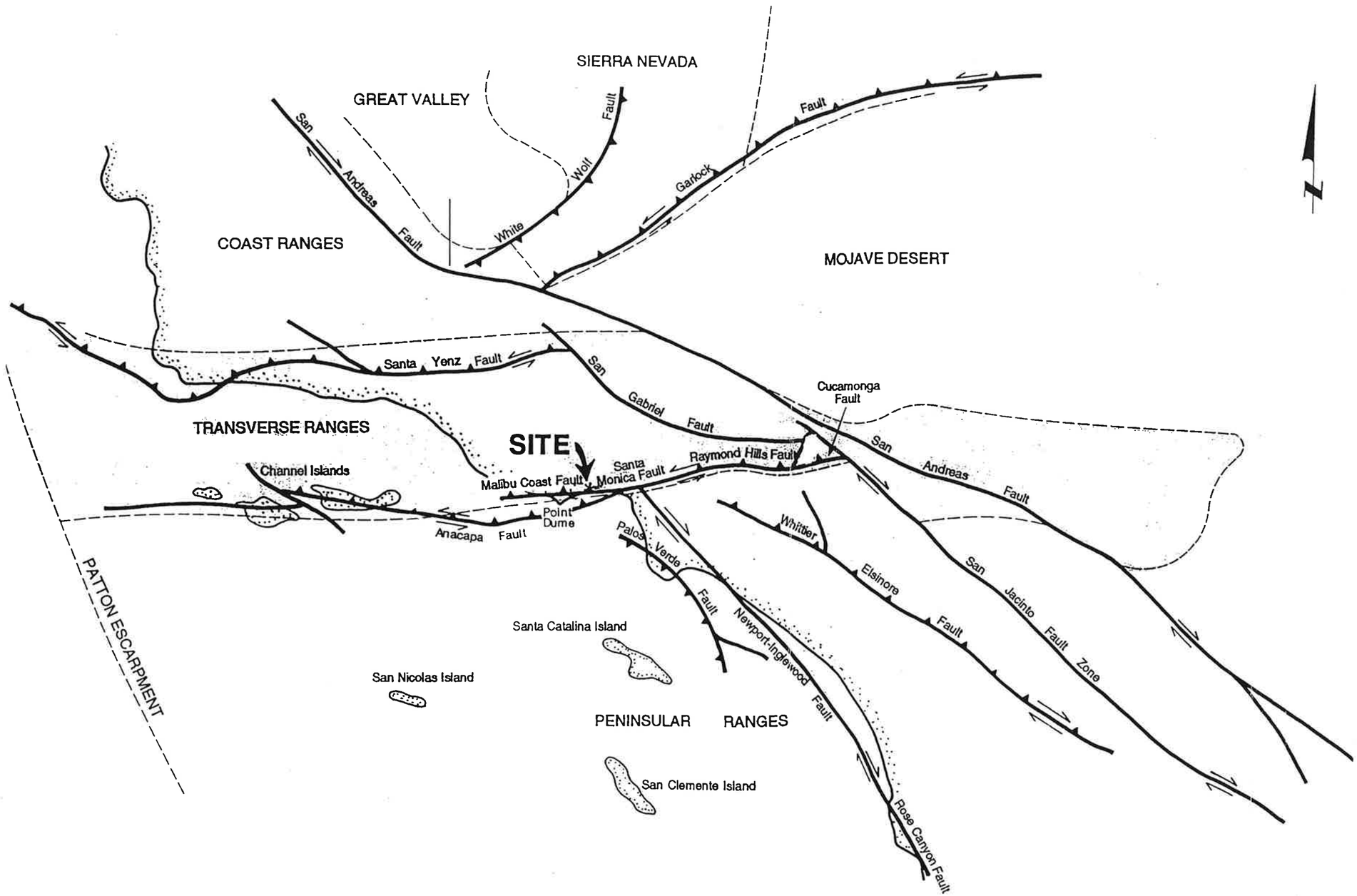
SEISMIC PARAMETERS OF REGIONAL (DISTANT) FAULTS *

POTENTIAL CAUSATIVE FAULTS	APPROX. DISTANCE TO SITE (km)	EST. MAX. PROBABLE MAGNITUDE	ESTIMATED SLIP RATE MIN./YR. AT BRM SITE **	ESTIMATED PEAK ACC.	ESTIMATED DURATION SEC.
Newport-Inglewood	14	7	0.6	0.26	25
Whittier-Elsinore	51	6.5	1.0	0.05	18
Sierra Madre - Cucamonga	34	6.5	- -	0.07	18
San Jacinto	89	7.0	0.18	0.03	25
San Andreas	68	8 +	0.23	0.07	35

NOTES:

* Other than Malibu Coast, Anacapa and Santa Monica fault systems which generate near-field strong motions.

** Based on alternative relations as proposed by Joyner and Boone (1982).



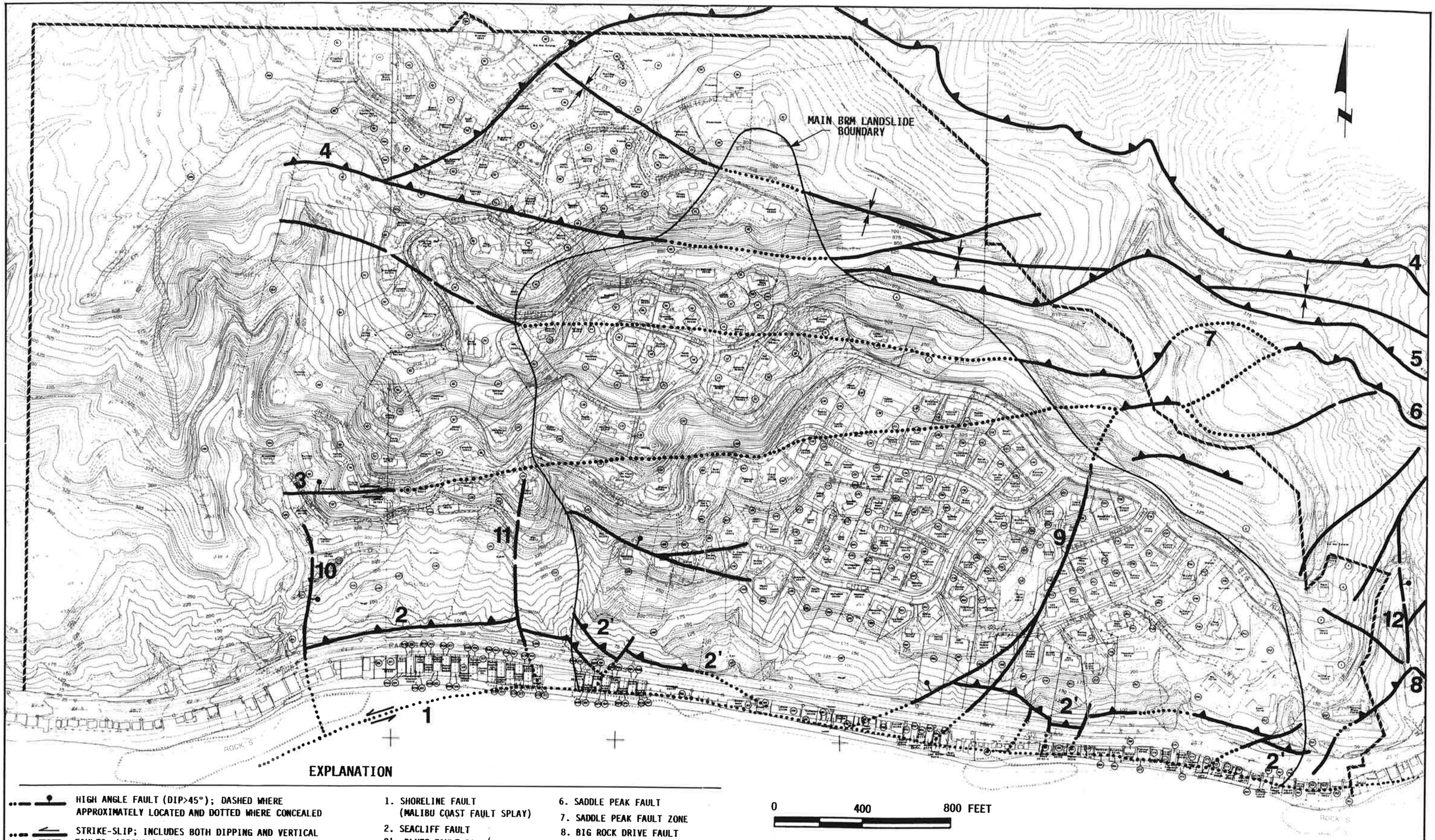
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REGIONAL GEOMORPHIC PROVINCES AND MAJOR FAULTS

FIGURE 4-1.1



EXPLANATION

HIGH ANGLE FAULT (DIP>45°); DASHED WHERE APPROXIMATELY LOCATED AND DOTTED WHERE CONCEALED

STRIKE-SLIP; INCLUDES BOTH DIPPING AND VERTICAL FAULTS; ARROWS SHOW DIRECTION OF RELATIVE MOTION

LOW-ANGLE AND REVERSE FAULT, SAWTEETH ON UPPER PLATE; DASHED WHERE APPROXIMATELY LOCATED AND DOTTED WHERE CONCEALED

FOLDS; SYNCLINE, APPROXIMATELY LOCATED SHOWING TROUGLINE AND ITS DIRECTION OF PLUNGS

1. SHORELINE FAULT (MALIBU COAST FAULT SPLAY)
2. SEACLIFF FAULT
2'. BLUFF FAULT ZONE
3. SEABOARD FAULT
4. LAS FLORES FAULT
5. NORTH FAULT
6. SADDLE PEAK FAULT
7. SADDLE PEAK FAULT ZONE
8. BIG ROCK DRIVE FAULT
9. INLAND LANE FAULT
10. ROCK POINT FAULT
11. LOVE FAULT
12. PIEDRA GORDA FAULT

0 400 800 FEET

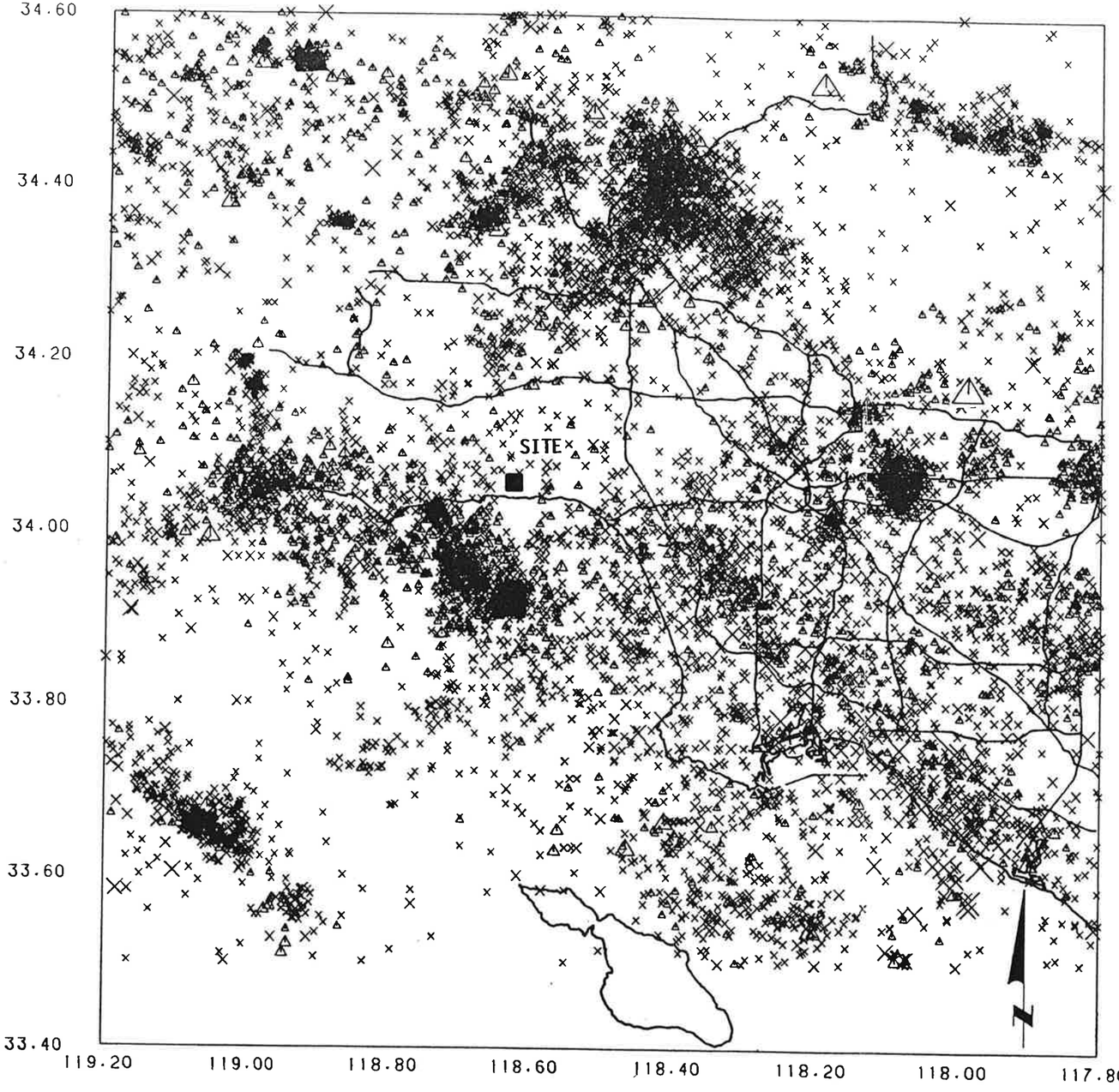
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TECTONIC MAP

FIGURE 4-1.3





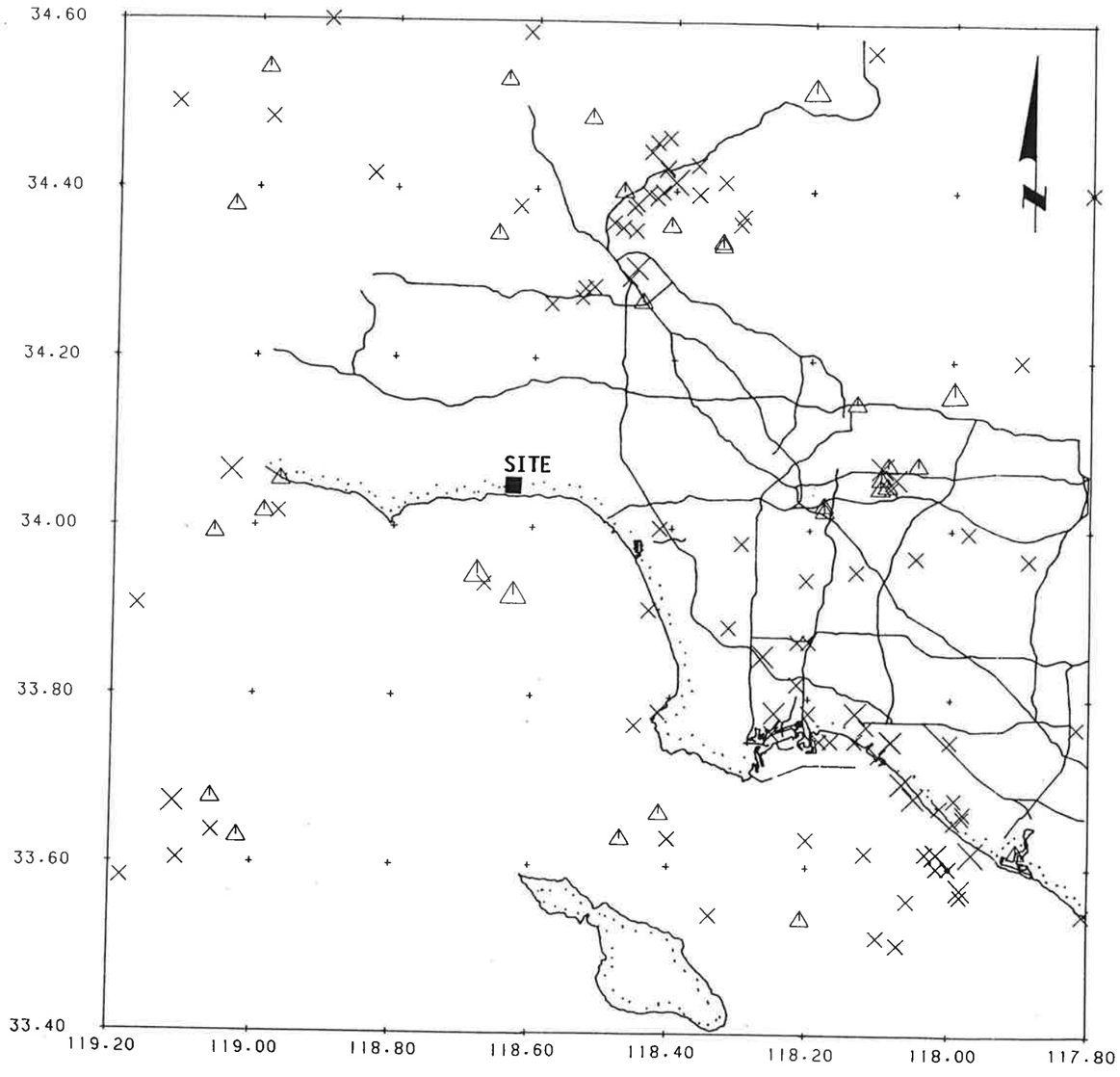
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SEISMICITY MAP-
A COMPILATION OF 10,945 EVENTS
FROM 1932 TO 1990

FIGURE 4-2.1



DEFINITIONS

MAGNITUDE	DEPTH, KM <10.0	11.0 -100.0	>101.0
M<3.0	×	△	○
3.0≤M<4.0	×	△	○
4.0≤M<5.0	×	△	○
5.0≤M<6.0	×	△	○
6.0≤M<7.0	×	△	○
7.0≤M<8.0	×	△	○
M>8.0	×	△	○

0 10 20 30 MILES

APPROXIMATE SCALE

* SIERRA MADRE ONLY, 6/28/1991

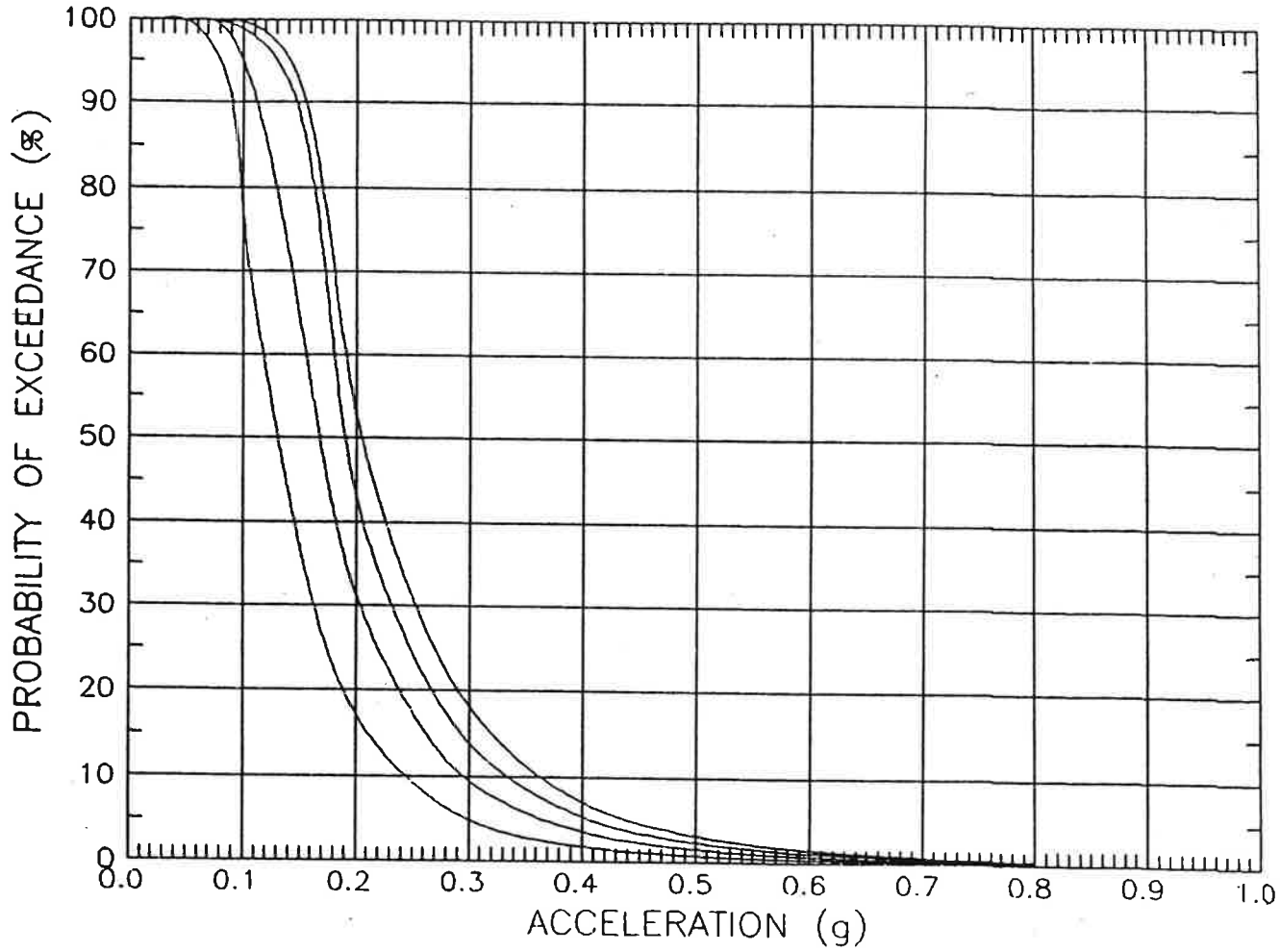
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SEISMICITY MAP OF MAGNITUDE
3 OR GREATER EVENTS; 1932 TO 1991*

FIGURE 4-2.2



EXPOSURE PERIODS:

25 YEARS	75 YEARS
50 YEARS	100 YEARS

JOYNER & BOORE (1982) LRG. SIG.

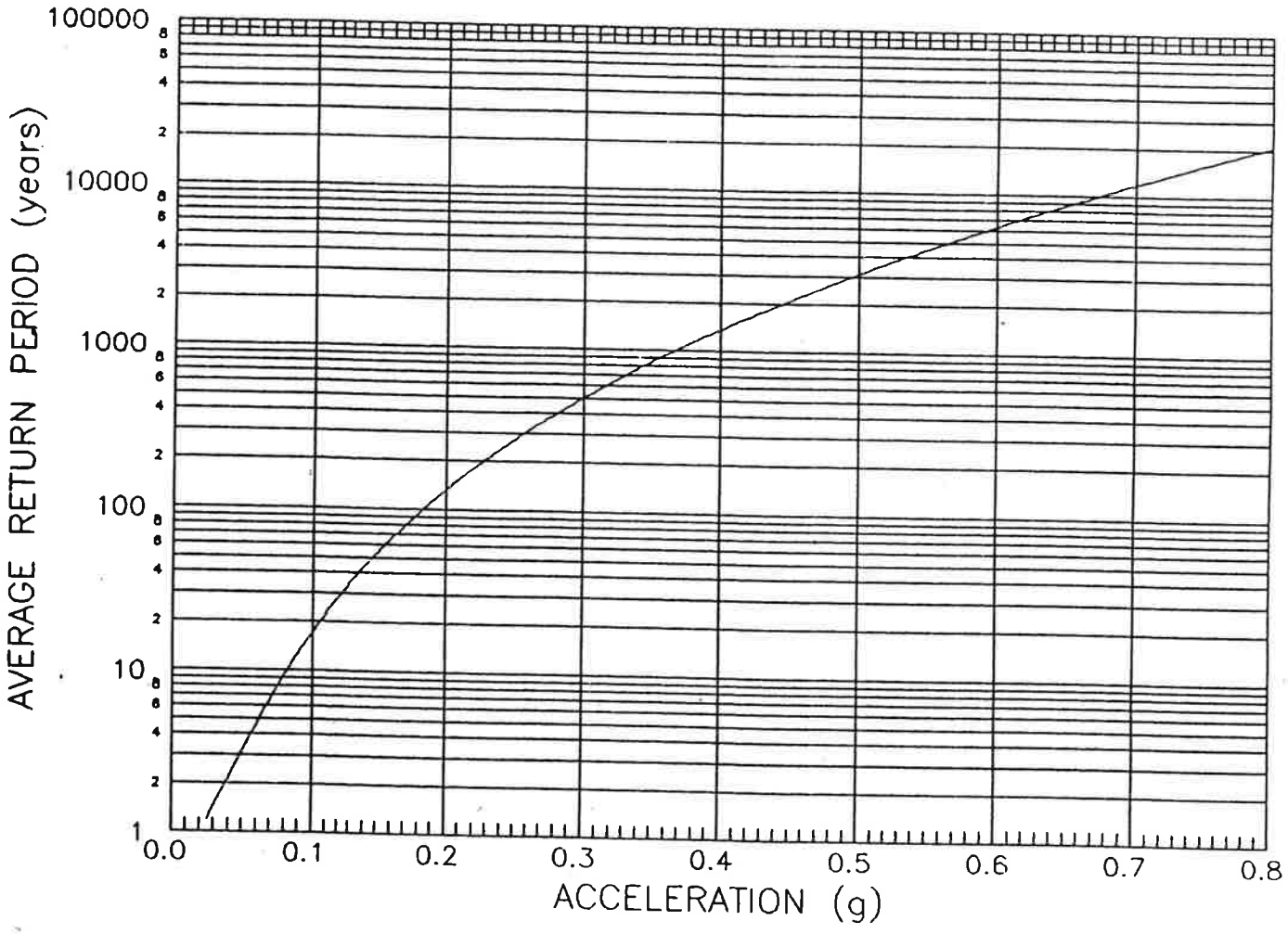
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PROBABILITY OF EXCEEDANCE VERSUS ACCELERATION

FIGURE 4-2.3



JOYNER & BOORE (1982) LRG. SIG.

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AVERAGE RETURN PERIOD VERSUS ACCELERATION

FIGURE 4-2.4

SECTION 5.0

LANDSLIDE CHARACTERISTICS

5.1 AERIAL EXTENT AND SUBSURFACE GEOMETRY

5.1.1 Aerial Extent

The surface expression or aerial extent of the Main Mesa Landslide is relatively well defined by post failure ground cracking, structure deformation and by survey data.

The main slide mass is approximately 136 acres in size. It encompasses 206 developed parcels and about 41 million cubic yards of rock. The boundary of the slide is relatively well defined by ground cracks along its eastern, northern and northwest borders (see Figure 5-1.1), and by ground deformation evidences along its southern boundary. The southern leg of the western boundary, from approximately Seaboard Road to PCH, is subtle and defined mainly by geomorphology and survey data.

To confirm the aerial extent of the Main Mesa Landslide evidenced by the ground cracks, a detailed review and analysis of the survey data provided by the Los Angeles County Survey Division was performed by Dr. Perry Ehlig. The results of this work indicate that the survey data are in good agreement with the boundaries of the Main Mesa failure as shown on Figures 2-1.4 and 4-1.2. Specifically, the survey data indicates that the eastern boundary of the landslide passes between Monuments 19C, BB and BRM-123 which have remained essentially stable through time, and Monuments 18, AA and BRM-122A which have moved. The northern boundary of the slide (northern limit of the Hansch Extension) passes between stable Monument BRM-101 and adjacent Monument BRM-102 which has moved more than 7.7 feet. The western margin of the slide passes between Monuments 2C, BRM-103 and BRM-119 which are within the landslide and Monuments 1C, BRM-129 and BRM-121 which are outside the slide boundary. The analysis of survey data is illustrated in Figures 5-2.1 and 5-2.2.

Although the survey data and ground crack trends clearly delineate the northern, western and eastern boundaries of the Main Mesa Landslide, additional evidences were needed to confirm the southern boundary. Some discussions in the past have centered around a 1983 Boomer (Acoustic Profiling) Survey performed by McClelland Engineers, Inc. which showed an offshore anomaly suspected to be a feature of the landslide toe. However, evidence constraining the toe of the slide to the shoreline, as shown in Figures 2-1.4 and 4-1.2 is relatively conclusive as summarized below:

1) Deformation of PCH in the area of the Main Mesa failure (as indicated by survey data and visual observation) consists of several feet of uplift consistent with the proximity of the area to the toe of the slide.

2) Deformation of homes along PCH indicates that the upper portions of the homes were pushed seaward indicating that a landslide toe coincident with the Shoreline fault has moved the upper home sections (see Figure 5-1.2). If the main BRM landslide toe existed seaward of the oceanfront homes, deformation patterns would be considerably different. The deformation shown by tilted pilings and crack patterns (Figure 5-1.2) was confirmed by BYA field observations. These field observations were also used to confirm the lateral extent of the southern landslide boundary.

3) No trace of the offshore anomaly was detected in a scuba diving expedition performed by BYA in 1989.

4) Photogrametric survey data of the reef rocks in the surf zone reported by Evans (1985) indicate that no movement (outside the accuracy of the survey: Horizontal = 1 foot: Vertical= .1 foot) occurred from 1971 to 1985.

5) Borings along PCH and a better understanding of the Shoreline fault suggest the toe of the Main Mesa movement is buttressed by and toes out along the steeply dipping Shoreline fault (see Appendix B).

5.1.2 Subsurface Geometry

The subsurface geometry of the basal rupture surface(s) of the main slide mass are defined by slope inclinometer deformations, deformations in well casings (or the lack of deformation in slope inclinometer and well casings), and geological and geophysical interpretation (Section 4.0 and Appendix B). As can be seen by the geologic cross sections shown in Figures 4-1.4 to 4-1.12, and by the slide plane contour map (Figure 5-1.3), the failure surface is roughly bowl shaped with its deepest portion located in the central portion of the main slide mass at an elevation of about 125 feet below sea level. From this point the primary slide surface becomes shallower in all directions towards the landslide boundaries. The general bowl shape is interrupted somewhat east of the Inland Lane fault whereby the surface becomes shallower by approximately 70 feet (see Figure 4-1.10).

The primary slide surface is confirmed in several discrete locations (see Table 5-1) by the shearing off of several slope inclinometers installed during and soon after the inception of the 1983 Main Mesa Landslide movement. Sheared inclinometers include SP-1, SP-5, SP-6, SP-7, SP-8, SP-11 and SP-12 along PCH; SP- 26, SP-18, SP-35, and SP-38 in the Hansch property area; SP-4 and SP-17 in the main slide area; and SP-3 in the main slide mass. In addition, several indicators, although not sheared off, exhibited movement signatures characteristic of deformation along a discrete slip surface at a depth consistent with the main slide surface. These include SP-27A, and SP-34 along PCH; and possibly SP-33 in the Southeast Bluff Region. SP-24 also exhibited a deformation signature characteristic of a discrete surface, but the elevation of the movement was not consistent with known control points for the basal rupture surface (see Figure 4-1.7). Consequently, the movement was interpreted to be a local shallow slide surface. Several small ($\approx$ .25 inches) recent movements recorded by BYA have also helped to further delineate the primary slide surface. These movements were recorded in the following slope inclinometers: SP-3A, SP-5A, BYA-5A, SP-8A, SP-11, SP-12, SP-26, SP-27A, SP-29, SP-30 and possibly SP-33. Movement data and locations of these slope inclinometers are summarized in Table 5-2.

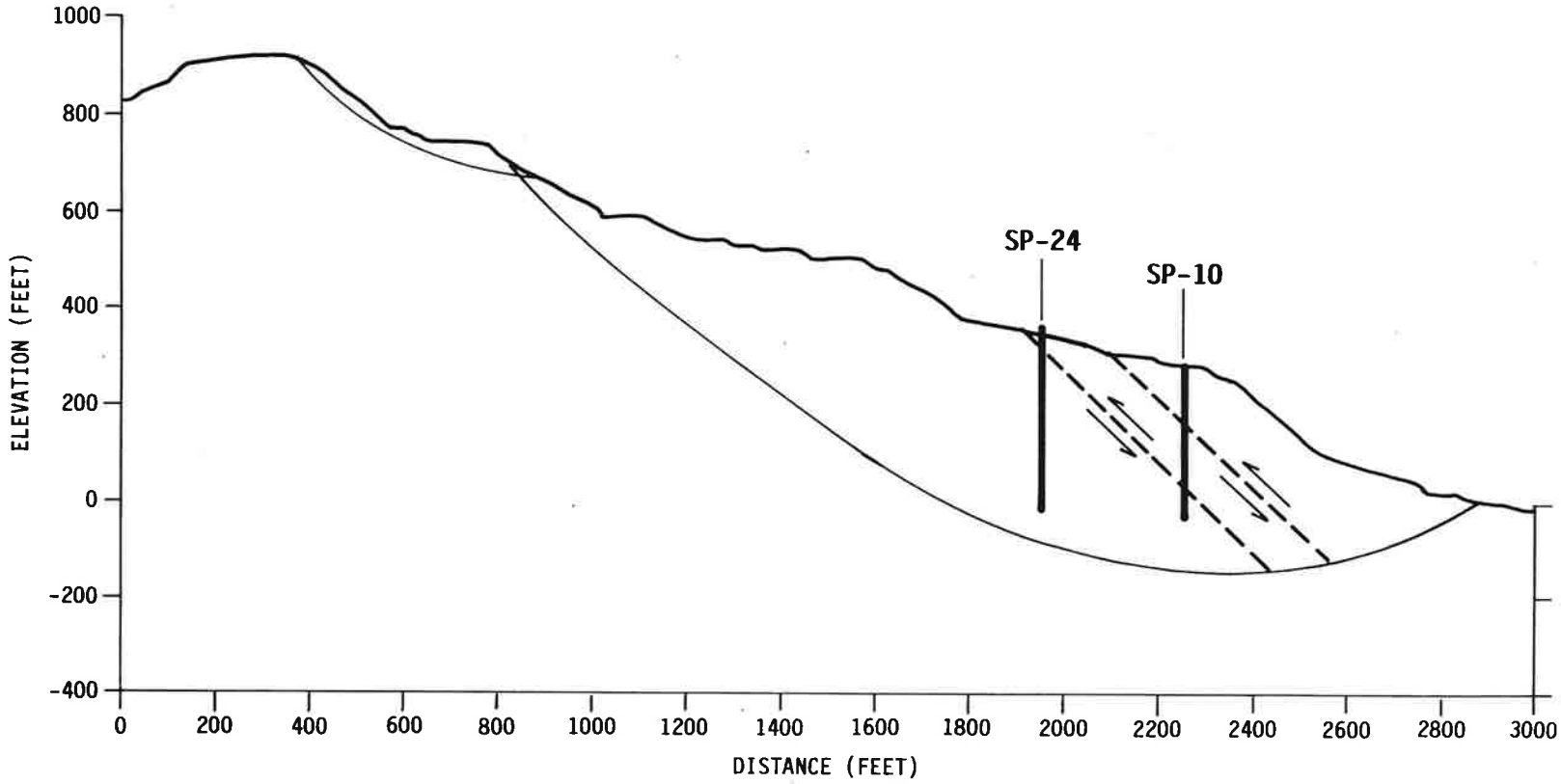
TABLE 5-1

SUMMARY OF DEPTHS TO PRIMARY SLIDE SURFACE
BASED ON SLOPE INCLINOMETER AND WELL CASING DEFORMATIONS

INCLINOMETER/ WELL NO.	INTERPRETED DEPTH TO PRIMARY SLIDE SURFACE (Ft.)	APPROX. DATE OF MOVEMENT	OBSERVATION*
SP-1	29	12/83	SI closure
SP-3	136	2/84	SI closure
SP-4	100	1/84	SI closure
SP-5	74	12/83	SI closure
SP-6	60	12/83	SI closure
SP-7	59	12/83	SI closure
SP-8	88	12/83	SI closure
SP-9A	Below SI	- -	No indication of shearing deformation
SP-10	Below SI	- -	No indication of shearing deformation
SP-11	18	12/83	Definitive shear deformation
SP-12	43	3/84	SI closure
SP-14	Below SI	- -	No indication of shearing deformation
SP-16	Below SI	- -	No indication of shearing deformation
SP-17	212	2/84	SI closure
SP-18	38	11/83	SI closure
SP-24	Below SI	- -	No indication of shearing deformation

TABLE 5-2
RECENT MOVEMENT DATA SUMMARY (1988-PRESENT)

INSTRUMENT	APPROXIMATE MOVEMENT PERIOD	LOCATION	OBSERVED MAGNITUDE (IN.)	BEARING	DEPTH OF MOVEMENT (Ft.)	NOTES
SP-3A	3/88-10/91	Southeast of 20173 Rockport Way	.3	S30°W	165	
SP-5A	11/89-11/90	Across from 20094 PCH	.08	S20°E	72	
BYA-5A	4/91-5/91	North of 20130 Rockport Way	.25	Unknown	186	Sheared prior to first reading.
SP-8A	8/89-8/91	Across from 20436 PCH	.3	S	88	
SP-11	9/88-1/90	Across from 20120 PCH	.2	S	20	
SP-12	9/88-8/89	20318 PCH	.05	S	22	
SP-15	9/88-11/89	20530 PCH	.08	S10°W	27	
SP-24	11/90-3/91	20520 W. Seaboard	.1	S20°E	100	
SP-26	11/90-7/91	20600 Rockcroft Dr.	.3	S05°E	34	
SP-29	10/88-8/91	Across from 20536 PCH	.1	S45°W	54	
SP-27A	9/88-7/89	20214 PCH	.15	S	30	
SP-30	10/88-7/91	Across from 20238 PCH	.14	S	39	
SP-33	11/81-11/90	20270 Inland Ave.	.05	S	210	
BRM-101	10/88-1/91	Above 20600 Rockcroft	1.2	S26°E	N/A	Surv. Monument
SP-18	1/89-5/91	20600 Rockcroft Dr.	2.04	S16°E	N/A	Surv. Monument
SP-26	10/88-5/91	20600 Rockcroft Dr.	1.32	S25°E	N/A	Surv. Monument



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POTENTIAL CROSS SHEARING MECHANISM IN THE VICINITY OF SP-10

FIGURE 5-2.5

Records of the slope inclinometers are included in the Data Book, an accompanying volume of technical data to this report.

In addition to the inclinometers, several dewatering wells were found to have deformed casings indicating landslide movement. The well casing deformations were found during BYA's well renovation program from pulled drop pipe, as well as utilizing a downhole video camera, e.g. ovaling of the well casing due to slide movement often prevented the video camera from advancing deeper than the location where slide movement occurred. Deformations were found in Wells, W-1, W-3 and W-12. Several hydraugers were also found to be either sheared off or blocked by excessive deformation during the hydrauger cleaning operations. However, the lengths at which the shearing and/or deformations are inferred (Figure 3-2.1) are not deep enough to suggest deformation from the primary slide surface. Alternatively, it suggests possible local deformation within the Bluff Region.

Slope inclinometers that did not exhibit landslide type deformations were also useful in estimating the landslide surface. For example, if an inclinometer casing was in place during the time when the main slide moved, and did not exhibit any deformations indicating landslide displacement, then the plane of movement (primary slide surface) must be below the instrument. To confirm this hypothesis BYA compared slope inclinometer displacements with movements recorded by nearby survey monuments. One such comparison is shown in Figure 5-1.4 for slope inclinometer SP-9. This figure clearly shows that while over 13 inches of displacement were recorded by nearby survey monuments, less than one inch of displacement was recorded by slope inclinometer SP-9. Further examination of SP-9 indicates that the one inch of movement is most likely from instrument imprecision. Consequently, it can be concluded that the primary slide surface passed below the bottom elevation of SP-9, or in other words, SP-9 was not deep enough to record the movement of the failure surface. Using this technique, similar conclusions were reached for inclinometers SP-10, SP-14, SP-16, SP-24 and SP-28.

Based on the aforementioned discussions it can be seen that although several discrete control points were identified for the primary slide surface a data gap existed in the Central Region west of the Inland Lane fault. This data gap, and the need for a better understanding of the geology and groundwater conditions, lead to the location of BYA's continuous core borings BYA-1, BYA-3 and BYA-4. One of the main tools utilized to determine the failure surface in these borings was the geophysical data, specifically the high precision gamma ray and dip meter loggings.

The usefulness of the gamma loggings became apparent to BYA when reviewing the results for corehole SP-17A which was drilled by others only several feet away from SP-17 which was sheared off due to slide movement. Since the depth to the slide plane was known from SP-17, the geophysical logs could be correlated to the primary slide surface. The results of the gamma loggings indicated that a sharp gamma low was recorded at the same elevation as where SP-17 had been sheared off (the primary slide surface). This information combined with the log of SP-17 indicated that the basal rupture surface in this area was coincident with a highly fractured intrusion of basalt. This discovery was also important from a geotechnical engineering perspective in two respects: 1) it indicated a tendency for the primary slide surface to be coincident with intrusive basaltic and diabasic rocks, and 2) the characteristic low gamma ray signatures made it possible to accurately determine the depth and thickness (both apparent and real) of the igneous intrusions. Consequently, the large

gamma ray data base compiled by BYA formed a basis for determining geologic structure and identifying the primary slide surface. Selected gamma ray plots have been superimposed on all of the geologic cross sections (Figures 4-1.4 through 4-1.12). All of the geophysical data have been included in the Data Book.

The dip meter logging results also proved valuable, not only in determining geologic structure, but also in confirming the location of the primary slide surface. In many cases, due to the general movement and rotation of the slide mass, the bedding dip and orientation would differ above and below the primary slide surface or across faults. These discordances were identified clearly in the dip meter plots and further helped to define the subsurface structure of the area. A total of approximately 15,000 feet of geophysical loggings were carried out not only in BYA borings, but at holes drilled previously by others. This resulted in substantial savings in drilling costs. However, it should be noted that gamma loggings are a qualitative type of data which are different from quantitative data (such as cored samples), which can be subjected to visual examination and testing. The gamma ray count mainly indicates the contrast of the rocks in a borehole with only broad inference to the actual rock type: basalt, sandstone and/or clay shale. Figures 4-1.4 to 4-1.12 show only a small portion of the gamma ray data base.

5.2 HISTORY AND KINEMATICS OF MOVEMENT

5.2.1 Precursor Distress

Appendix A-1 is a chronological list of documents related to BRM. Among those are several hundred documents which discuss events and observations of ground movement which occurred before the main slide movement of 1983. These movements and/or manifestations of the movements are summarized in Table 2-2 and include: several bluff failures dating back to 1972, extensive cracking throughout the Southeast Region in 1972 and 1973, ruptured water service mains along PCH in 1980, zones of bulging and uplift along PCH as early as 1980, pavement cracking in the Southeast Region which is comparable with the ground cracks which occurred in 1983, and a general increasing trend of distress investigations, foundation repair and water main breaks up until the Main Mesa failure.

5.2.2 Landslide Kinematics

Data regarding kinematics of the landslide movement was obtained from survey data, slope inclinometer data and from physical model testing performed by BYA.

An examination of the survey data provided by the County of Los Angeles Survey Division indicates that the 1983 movement: 1) involved the entire mass of the Main Slide Area, 2) exhibited overall slow rates of movement which then slowed over time, 3) occurred primarily in a southerly direction, and 4) exhibited movements in the Hansch property area that were episodal and at rates and magnitudes surpassing those recorded in the Main Slide Area.

The above observations are evident by viewing Figures 5-2.1 and 5-2.2. Figure 5-2.1 shows resultant vector movements for the time period of September 1983 to July 1984, while Figure 5-2.2 plots resultant vector movements recorded over the subsequent year.

Examination of the vector magnitudes and directions from both plots indicates that, with the exception of the Hansch property area, the landslide moved somewhat en masse and primarily in a southerly direction. Comparison of Figures 5-2.1 and 5-2.2 illustrates the decrease in movement rate with time. This is also illustrated in the following table showing movement rates for selected representative monuments and time periods.

Monument	Physiographic Region	Movement Rate 9/83-7/84	Movement Rate 7/84-7/85
102	Headscarp (Hansch)	4.27 ft./yr.	1.12 ft./yr.
103	Central Region	1.78 ft./yr.	.21 ft./yr.
108	Central Region	2.04 ft./yr.	.14 ft./yr.
110	Central Region	2.24 ft./yr.	.10 ft./yr.
114	Southeast Region	2.40 ft./yr.	.15 ft./yr.
116	Southeast Region	2.36 ft./yr.	.24 ft./yr.
119	Central Region	1.61 ft./yr.	.21 ft./yr.

The survey data indicates that after approximately December 1983, the Hansch property area began to move at rates several orders of magnitude in excess of the movement rate exhibited by the Main Mesa Slide (see Figure 5-2.3). Figure 5-2.3 also shows a surge of movement (approximately 2.2 feet) in a three month period between February and May 1986. This clearly illustrates the episodical nature of this part of the slide. This phenomenon is important in that the Headscarp area, of which the Hansch property is a part, could move independently from the rest of the Main Slide Area, i.e., the Headscarp Region, which is characterized by shallower and steeper slide surfaces, has lower subregional factors of safety than other parts of the main slide area (see also Section 7.0). It is noteworthy that all of the slope inclinometers in the Hansch property area (SP-26,SP-18 and SP-35) were sheared off at shallow depths - less than 50 feet. This indicates that in this area, a local slide plane exists above the primary slide plane of the BRM landslide (see Figure 4-1.7).

Another kinematically related phenomenon observed was the existence of conjugate shearing surfaces within the Bluff zone as a result of movement of the main slide mass. This is evidenced by field observations, mathematical (finite element) and physical model testing (BYA, 1985). For example, Figure 5-2.4 shows a slope inclinometer deformation plot for SP-10 during the time period of April 1984 until May 1985. This plot was generated from raw data obtained from monitorings by D.A. Evans which indicate two probable offsets at depths of approximately 130 and 275 feet. Although at first glance these offsets appear to be consistent with landslide type movements, the bearing of the movement is in the opposite

direction of the landslide. Specifically, the bearing of movement for the upper and lower offsets is approximately N15E and N5W respectively. This observation combined with the fact that survey monuments in the general vicinity moved approximately 4- 6 inches in a southerly direction for the same time period leads to the following conclusion:

- The primary slide surface at SP-10 lies below the bottom of the inclinometer and is therefore beneath sea level at this location (see cross section D-D' - Figure 4-1.8 and the slide plane contour map - Figure 5-1.3).

- The two northerly bearing offsets which were recorded in SP-10 are the result of a conjugate shear surface in a cliff type of slope where the toe of the slide surface emerges at a steep upward angle. This type of movement is illustrated on Figure 5-2.5.

5.2.3 Western Extension Movement

Movement of the Western Extension area has been postulated since the main landslide reactivation in 1983. Various consultants have suggested that more studies are needed in this area. The apparent increase in deformation of some individual cracks and crack areas in recent years prompted a cored boring at 20826 West Big Rock Drive (Geo-1) which indicated the presence of possible slide planes(s) and suggested the need for additional measures, such as an expanded survey network.

BYA performed the following tasks to evaluate the possibility of movement in the Western Extension:

- Reviewed and analyzed all of the slope inclinometer data obtained from the date of installation - approximately 4/84 to present - for inclinometers located in the Western Extension area (SP- 20, 21, 22 and 23);

- Conducted extensive geologic mapping by Dr. James Anderson, including field reconnaissance with Mr. Don Michael and Dr. Perry Ehlig to observe specific locations of distress. On several occasions, local residents provided input and accompanied the BYA team;

- Interviewed home owners and inspected interiors of several houses when invited;

- Analyzed all survey data compiled to date for monuments located in the Western Extension area;

- Retained the services of Mr. Richard Lownes - a consulting engineering geologist who originally mapped the crack patterns in the Western Extension area on behalf of D.A. Evans - to remap crack patterns with emphasis on any changes;

- Drilled and cored BYA-2 and installed a deep well at the cul-de-sac of Cool Oak Way;

- Installed a tiltmeter array in the vicinity of W-18; and

- Prepared several geological Cross Sections F-F, G-G', H-H' and I-I' through the Western Extension based on all available subsurface and geophysical data including BYA-2 and Geo-1.

The results of the above work include the following: 1) the slope inclinometer deformation plots do not exhibit consistent patterns of movement indicative of landsliding; 2) the zones of deformation and individual cracks exist (and in some instances are extensive) but are localized and can be attributed to fill settlement, steepened slopes, erosion, etc. In addition, they do not appear to form any consistent pattern over the Western Extension area as a whole or are comparable to those in the Main Mesa, 3) Mr. Lownes' crack survey indicates that there appears to be no recent evidence of movement in the Western Extension, 4) the geological cross sections in the Western Extension area exhibit a geological structure not conducive to deep-seated failure, which suggests the area is not a westward extension of the Main Mesa, and 5) the survey analysis performed by Dr. Ehlig indicates that any lateral movement that may have occurred was within the precision of the survey (approximately 1.2 inches).

Potential movement in the Western Extension area can best be viewed by taking a closer look at the survey data. Figures 5-2.6A and B show true scale movement plots for four survey monuments located in the Western Extension area (BRM-126,127,128 and 145). As can be seen, the plots show a random data scatter. A circle with a radius of .1 foot has been drawn around the mean location of each of the four monuments. It can be seen that more than 80% of the measured locations from each monument are within each circle. Only four measurements (Nos. 23, 25, 26 and 29) appear to be consistently outside of the circle. However, their locations indicate surveying imprecision rather than actual ground displacement. This is illustrated by the fact that position 23 is located to the northeast, positions 25 and 26 are located to the southwest and position 29 is located to the northwest. Consequently, the surveying data does not provide any evidence of movement in the Western Extension since January 1984. As to the existing ground cracks, some of them appear to be related to settlement or differential settlement of fills. In addition, local erosion and over-steepened slopes have induced local slumps and small scale slope failures which are not related to any extension of the main BRM landslide.

Although very little data exists to support an enlargement of the Main Mesa slide it still could be argued that small incipient type movements with magnitudes within the level of accuracy of the monitorings could have occurred and consequently, are precursors of pending failures. In this regard, the need for additional subsurface exploration in the Western Extension area does exist, but are beyond the scope of BYA's study. Nevertheless, based on data currently available, BYA is of the opinion that the Western Extension is not a westward extension of the Main Mesa Slide. There appears no evidence of pending massive southeastward sliding as long as the Main Mesa is stable. More discussion is contained in Appendix B and in Sections 6.0 and 7.0.

5.2.4 On-Going Movement

As summarized in section 3.0 of this report, BYA has taken readings from 33 slope inclinometers and one extensometer on a quarterly and periodic basis, respectively. To supplement the slope inclinometer and extensometer data, detailed analyses of the survey data were performed and two tiltmeter arrays were deployed.

Recent deformation recorded by the existing slope inclinometers are summarized in Table 5-2 and indicate that small discrete movements have occurred and/or have been on-going since 1988 when BYA was first retained to take readings of the instrumentation on a regular basis. Movements are generally confined to the Southeast Region along PCH, and in the Hansch property area. However, the apparent lack of movement in the Central Region may be deceiving due to the fact that only two slope inclinometers (SP-17A and SP-32) are deep enough to penetrate the primary slide surfaces. At least one deep and carefully installed slope inclinometer in the Central Region is considered essential. This benchmark inclinometer is recommended to be located at Seamoor Drive.

Recent movement in the Southeast Region was indicated in three of the four inclinometers, SP-3A, SP5-A and BYA-5A, that are present in the region. The magnitude of the movement recorded in SP-3A and SP-5A ranges from .08 to .3 inch to the southeast and southwest respectively. The magnitude of BYA-5A can only be estimated as the casing was deformed to a point that the probe could not be placed down the casing only one month after installation. Based on the inside diameter of the casing (approximately 1.50 inches) and the fact that a water level probe can still be lowered down the casing past the break to the water table, the amount of deformation is estimated to be approximately .25 inch. Possible movement in SP-33 is also indicated with a magnitude of approximately .05 inch. The movement time history suggests that the deformations occurred over roughly the same time periods, but appear to start and stop at different times, suggesting episodical movement. The depth of deformation in SP-5A and BYA-5A were recorded at almost the same elevations where SP-5 and SP-3 had been previously sheared during the main slide movement. Possible movement in SP-33 is coincident with the interpreted basal rupture surface.

These recorded recent deformations suggest that the Southeast Region may be undergoing slow creep type deformation and may be moving independently from the Main Mesa. It is also interesting to note that the multi-position extensometer did not record any deformation over the same time period as the slope inclinometers, suggesting that the movement is probably confined to a plane located further from the bluff than the length of the longest anchored extensometer rod (approximately 465 feet).

Movement was also indicated in six inclinometers existing along PCH (west of the Southeast Region) within various time periods from September 1988 until the present. These movements were small ranging from approximately .05 inch to .3 inch and suggest some low level movement of the Central Region and/or the Bluff Region has also been occurring over the last several years.

Low level movement was also indicated in the Little Rock Way tiltmeter array installed in October 1989 in the vicinity of 20415 Little Rock Way. The results of the tiltmeters suggested an extremely small and slow regional rotation to the northwest on the order of 12 to 36 microradians per day in October 1989, when the instruments were deployed. Due to the location of the tiltmeters in the upper section of the Headscarp area, slow movement of the landslide mass would result in back-rotation in this general area. These measurements underscore the sensitive nature of the Headscarp Region which is due north of the area where the tiltmeters were installed. The relatively low margin of safety of the Headscarp area is discussed in detail in Section 7.0.

Recent movement was noted both in the one slope inclinometer (SP-26) and three survey points within the Hansch property. The movement suggested by the survey monuments is summarized in Table 5-2 and suggests approximately 1 to 2 inches of movement in a south easterly direction from approximately October 1988 to May 1991. Deformation of slope inclinometer SP-26 was also recorded at a depth of approximately 34 feet over approximately the same time period.

Recent movement indicative of a shallow landslide surface was noted in SP-24 at a depth of approximately 100 feet over the time period November 1990 to March 1991. This indicator had previously exhibited deformation at a depth of 65 feet in early 1984. SP-24 is located at 20520 Seaboard road, just north of the Bluff Region.

5.3 GROUND SURFACE DEFORMATION

Movement along the primary slide surface induced a characteristic series of ground cracks. Several consultants have prepared separate ground crack maps. These consultant's include Mr. Richard Lownes (for D.A. Evans), William Cotton and Associates, The Jay Smith Company, Lockwood-Singh and Associates, and Mr. John McNamara (for The Rodine Companies). BYA took the crack map prepared by each consultant, and along with its own observations, superimposed them to construct a composite ground cracks map. As the map was generated for delineating the boundary of the main slide movement, locations of secondary slide surfaces within the landslide mass, and approximate physiographic regions which may have different factors of safety, only major ground crack trends were placed on the composite map (Figure 5-1.1). Isolated individual cracks on the consultants' individual maps were not reproduced for simplicity and due to minor discrepancies between the maps.

One of the striking features of the composite ground crack trend map is the series of ground cracks trending northwest-south east along the top of the bluff following the anticipated conjugate shear zone. These cracks forming the Bluff Region, are significant from a stability analysis perspective as they represent zones of potential planes of weakness. The composite ground crack trend map also shows a zone of cracks in the vicinity of the northern trace of the landslide. These cracks were used to aid in the delineation of the Headscarp region and also to define secondary failure surfaces in the general area.

Ground cracks were also noted in the northwest area of the main slide mass trending northeast to southwest and to a lesser degree in the north central portion of the Main Mesa. The cracks to the northwest correlate well with the survey data in that they indicate the tendency of the main slide mass in this area to move in a southeasterly direction and define several landslide blocks within the overall slide mass. Cracks in the north central portion of the mesa are not as continuous or as prominent as crack trends in other areas and may be the result of cross shearing during main slide movement.

5.4 MOVEMENT SUMMARY

Past and present movements of the Main Mesa landslide are summarized below:

- Based on available distress data, movement of the Southeast Region may have begun as early as the 1970s, and movement of the Main Mesa landslide may have occurred as early as 1980,

- As suggested by the survey data, most of the movement (except for the Hansch property area) subsided roughly after August 1984,

- Movement in the Hansch property area as evidenced by survey and slope inclinometer data moved further and at rates several orders of magnitude faster than the rest of the main slide mass,

- Small recent movements (within the last 3 years) have been observed in slope inclinometers located in the Southeast Region of the main mass, and along PCH. Movements range in magnitude from .05 to .3 inch and are indicative of a low prevailing factor of safety,

- Movement in the Hansch property area has been observed to be continuing through the present time, based on both slope inclinometer and survey data,

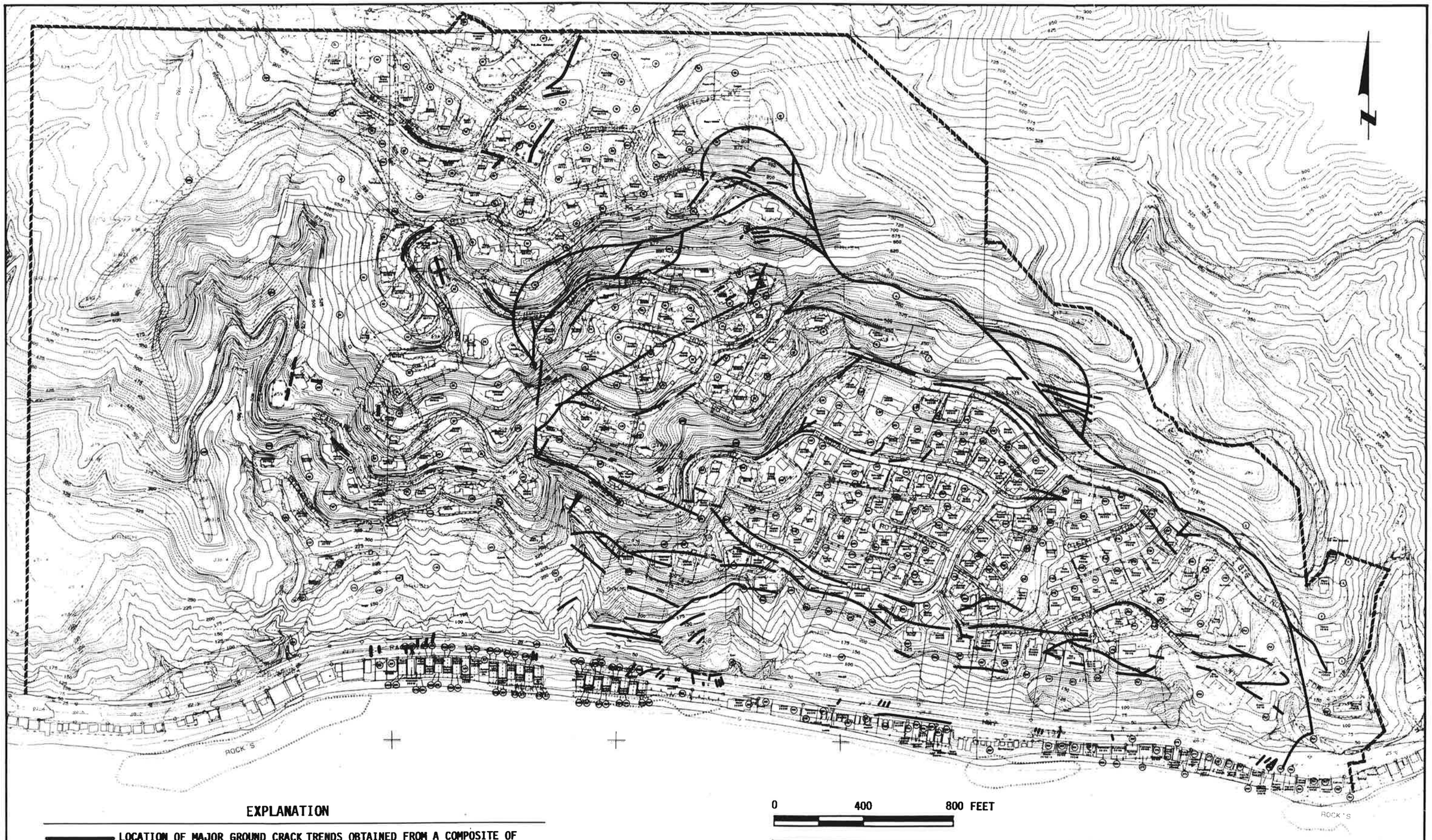
- Based on the available information, there is no conclusive evidence that the distresses observed in the Western Extension area are the direct result of the mass movement of the Main Mesa landslide, or that the Main Mesa landslide area is extending westwardly.

TABLE 5-1
(Page Two)

SUMMARY OF DEPTHS TO PRIMARY SLIDE SURFACE
BASED ON SLOPE INCLINOMETER AND WELL CASING DEFORMATIONS

INCLINOMETER/ WELL NO.	INTERPRETED DEPTH TO PRIMARY SLIDE SURFACE (Ft.)	APPROX. DATE OF MOVEMENT	OBSERVATION*
SP-26	41	7/84	SI closure
SP-27A	32	5/84	Definitive shear deformation
SP-28	Below SI	- -	No indication of shearing deformation
SP-33	210	3/85	Movement indicated
W-1	244.1	Post-1983	Well casing sheared off between 1983 and 1988
W-3	177.8	Post-1983	Well casing sheared off between 1983 and 1988
W-12	266	Post-1983	Well casing sheared off between 1983 and 1988
SP-35	33	1988 +	Large movement indicated
SP-34	33	4/85	Large movement indicated
SP-38	34	1987 +	SI closure

NOTE: * SI closure means the Slope Inclinometer has been sheared off at primary slide surface due to landslide movement.



EXPLANATION

LOCATION OF MAJOR GROUND CRACK TRENDS OBTAINED FROM A COMPOSITE OF CRACK MAPS PREPARED BY LOCKWOOD SINGH AND ASSOCAITES, WILLIAM COTTON AND ASSOCIATES, JAY SMITH COMPANY, D.A. EVANS, INC., JOHN MCNAMARA AND OBSERVATIONS FROM BING YEN & ASSOCIATES.

0 400 800 FEET

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

COMPOSITE GROUND CRACK TRENDS

FIGURE 5-1.1





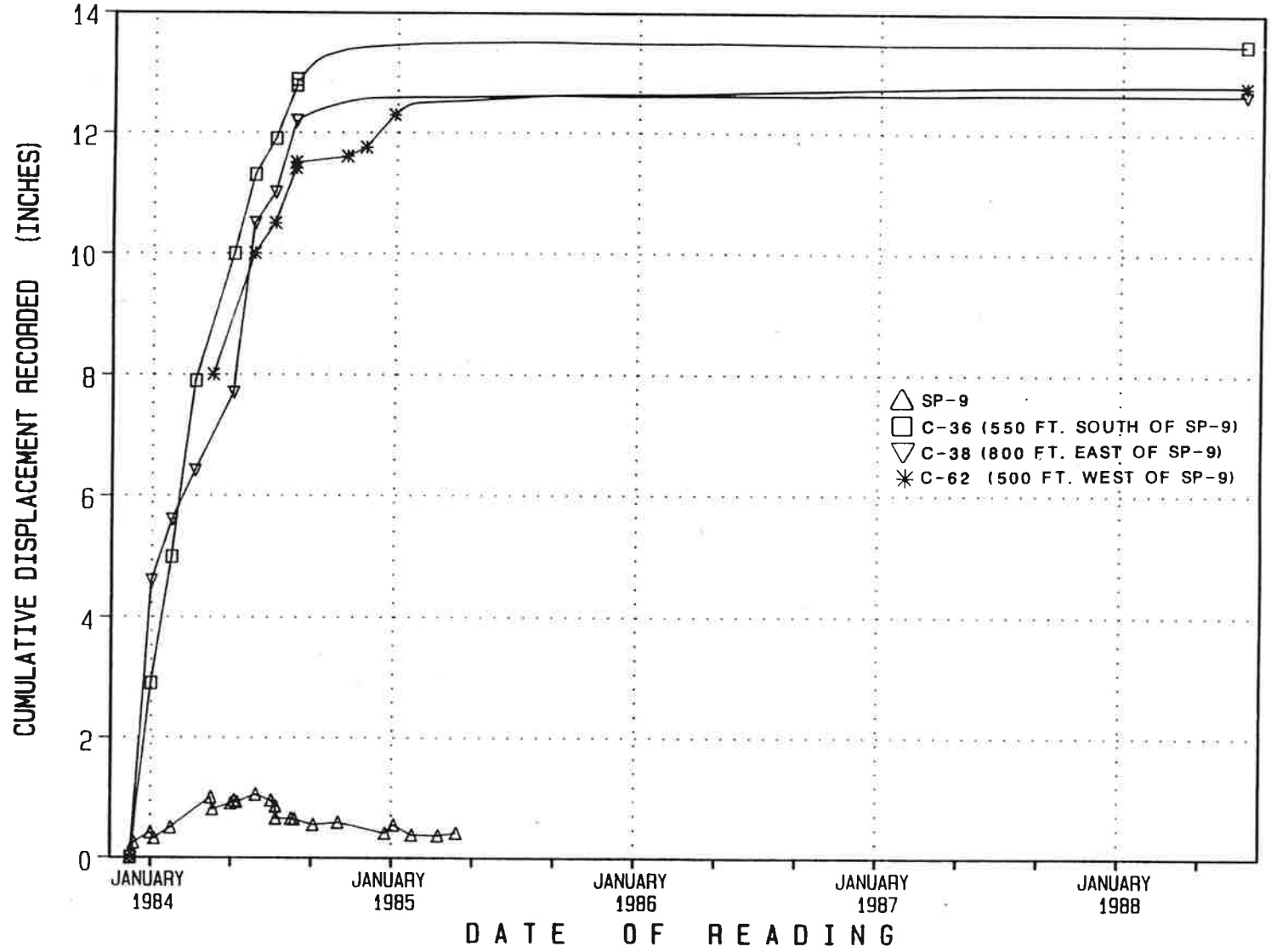
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TYPICAL DEFORMATION SEEN FROM SOUTH SIDE OF HOMES ALONG PCH WITHIN MAIN MESA LANDSLIDE

FIGURE 5-1.2



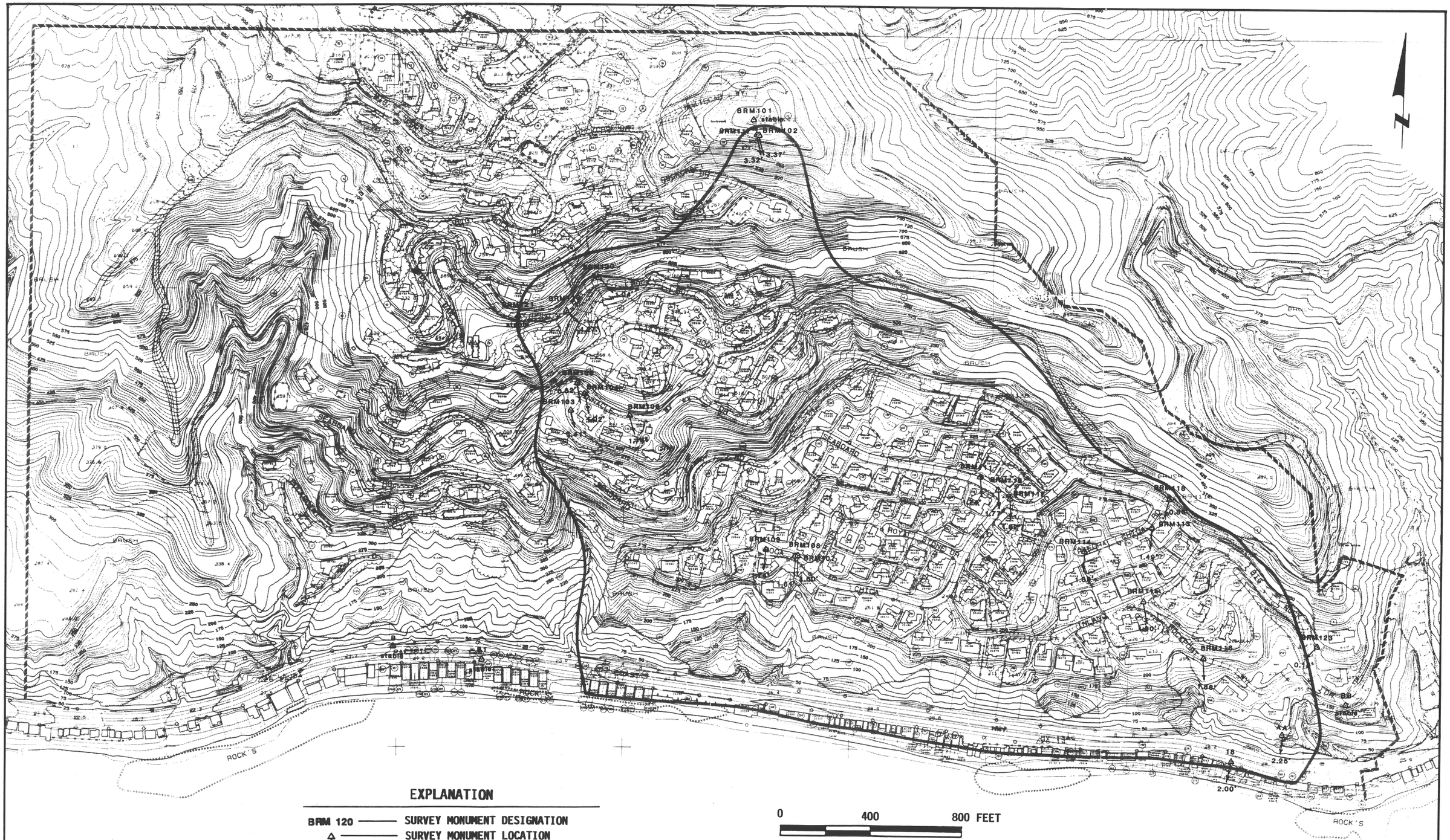
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COMPARISON OF SLOPE INCLINOMETER DISPLACEMENT FOR SP-9 AND CLOSEST SURVEY MONUMENTS

FIGURE 5-1.4



EXPLANATION

- BRM 120 — SURVEY MONUMENT DESIGNATION
- △ — SURVEY MONUMENT LOCATION
- ↕ — HORIZONTAL MOVEMENT DIRECTION
- 1.04' — HORIZONTAL MOVEMENT DISTANCE IN FEET

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SURVEY MONUMENT VECTOR MAP
SEPTEMBER 1983 TO JULY 1984

FIGURE 5-2.1

EXPLANATION

BRM 120 — SURVEY MONUMENT DESIGNATION

△ — SURVEY MONUMENT LOCATION

↓ — HORIZONTAL MOVEMENT DIRECTION

0.16' — HORIZONTAL MOVEMENT DISTANCE IN FEET

0 400 800 FEET

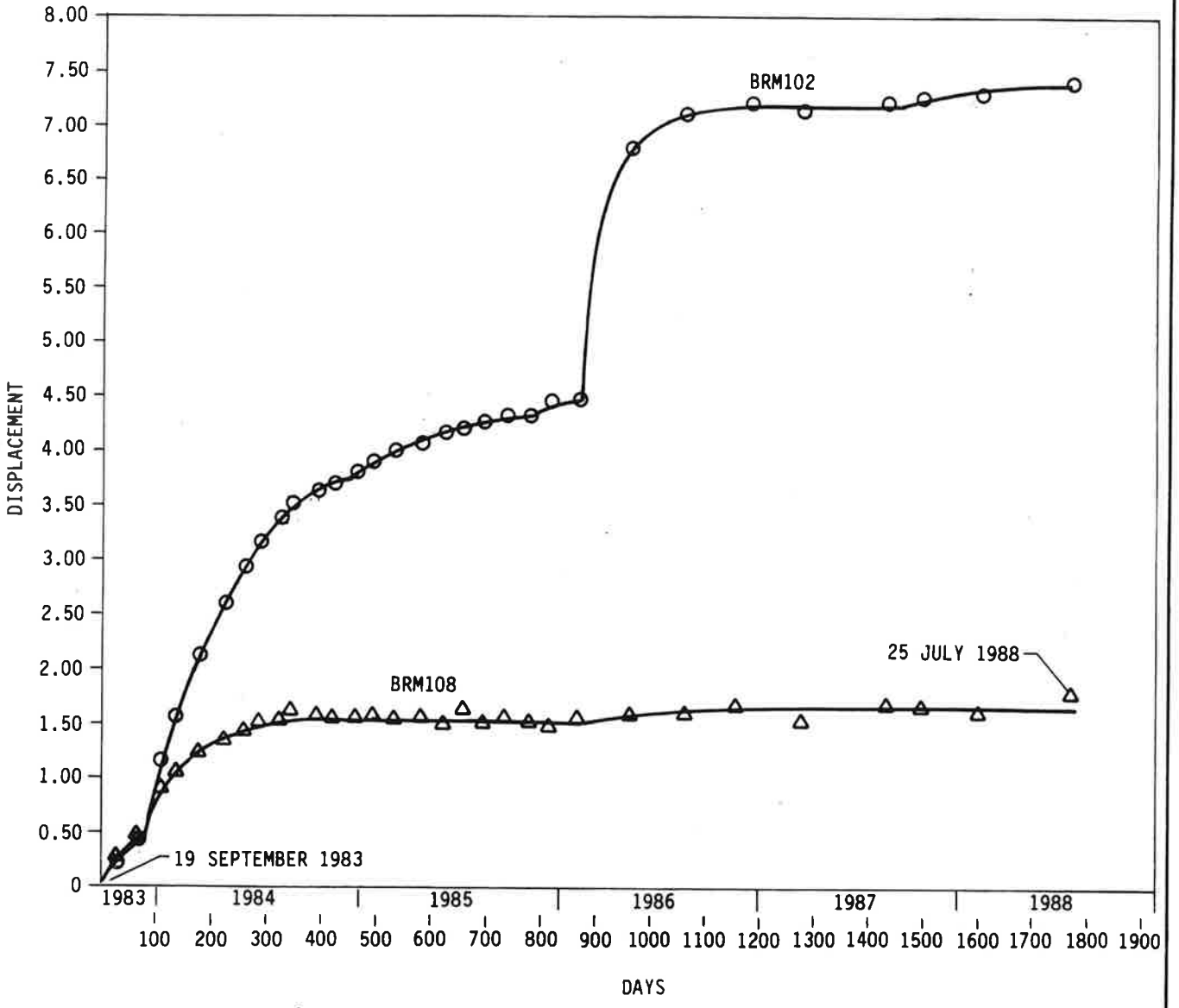
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PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SURVEY MONUMENT VECTOR MAP
JULY 1984 TO JULY 1985

FIGURE 5-2.2



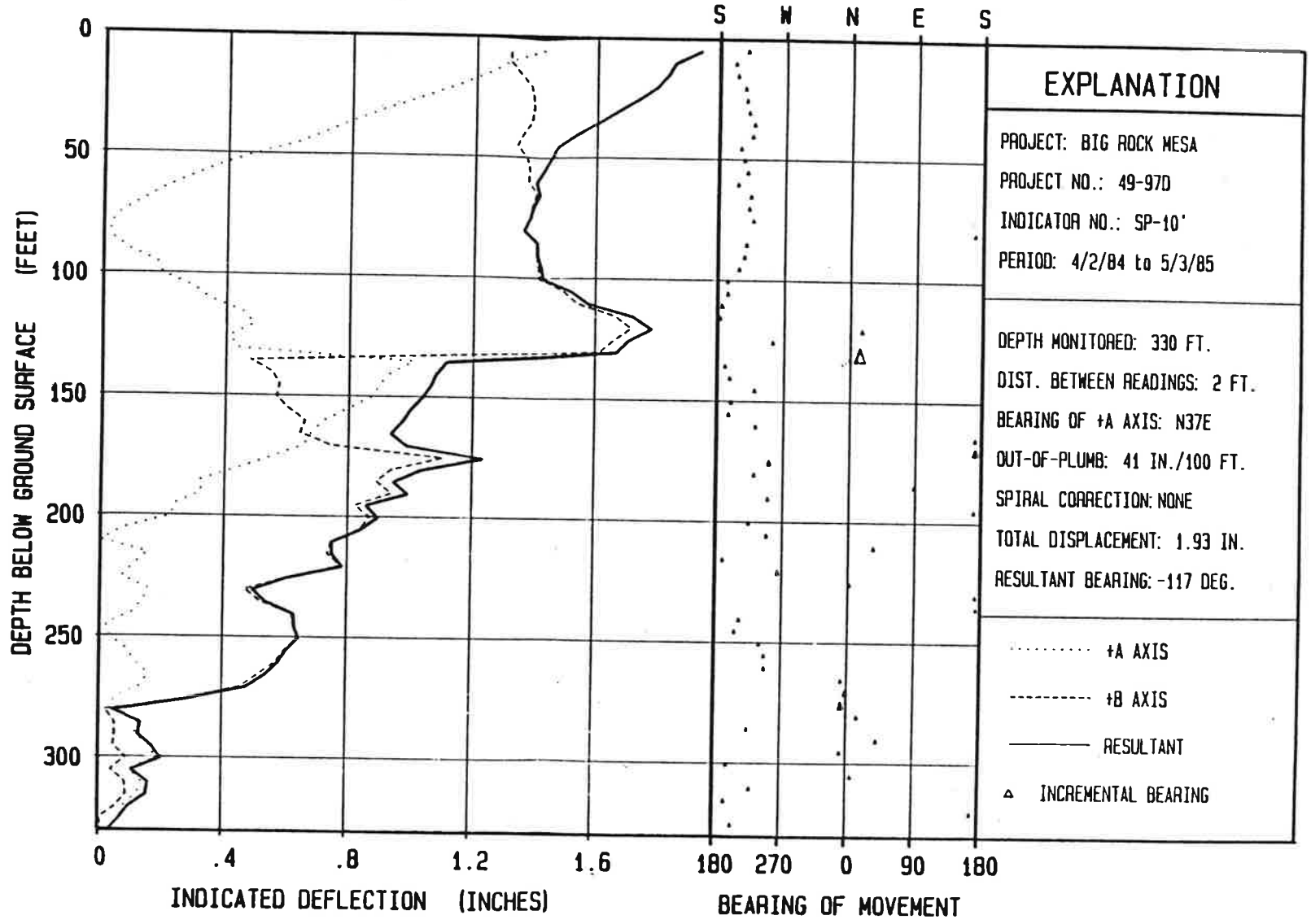
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COMPARISON OF CENTRAL MESA AND HANSCH MOVEMENT RECORDS

FIGURE 5-2.3



BING YEN & ASSOCIATES

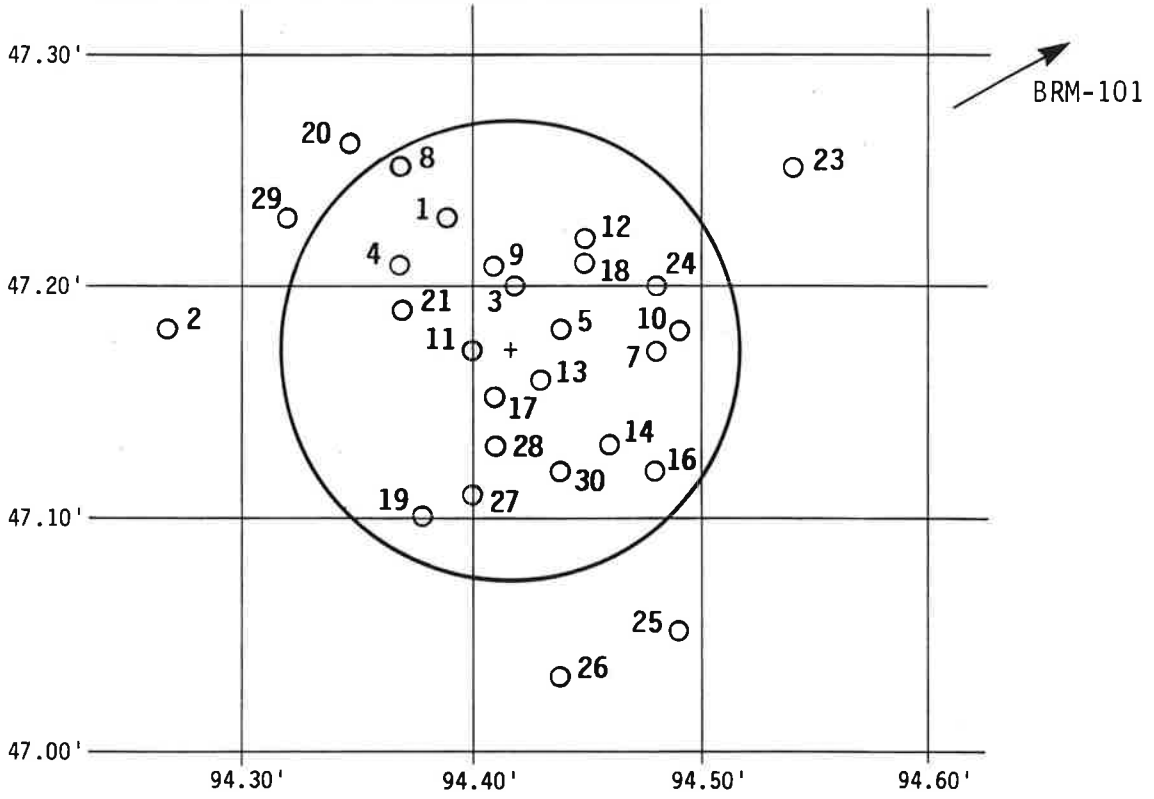
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

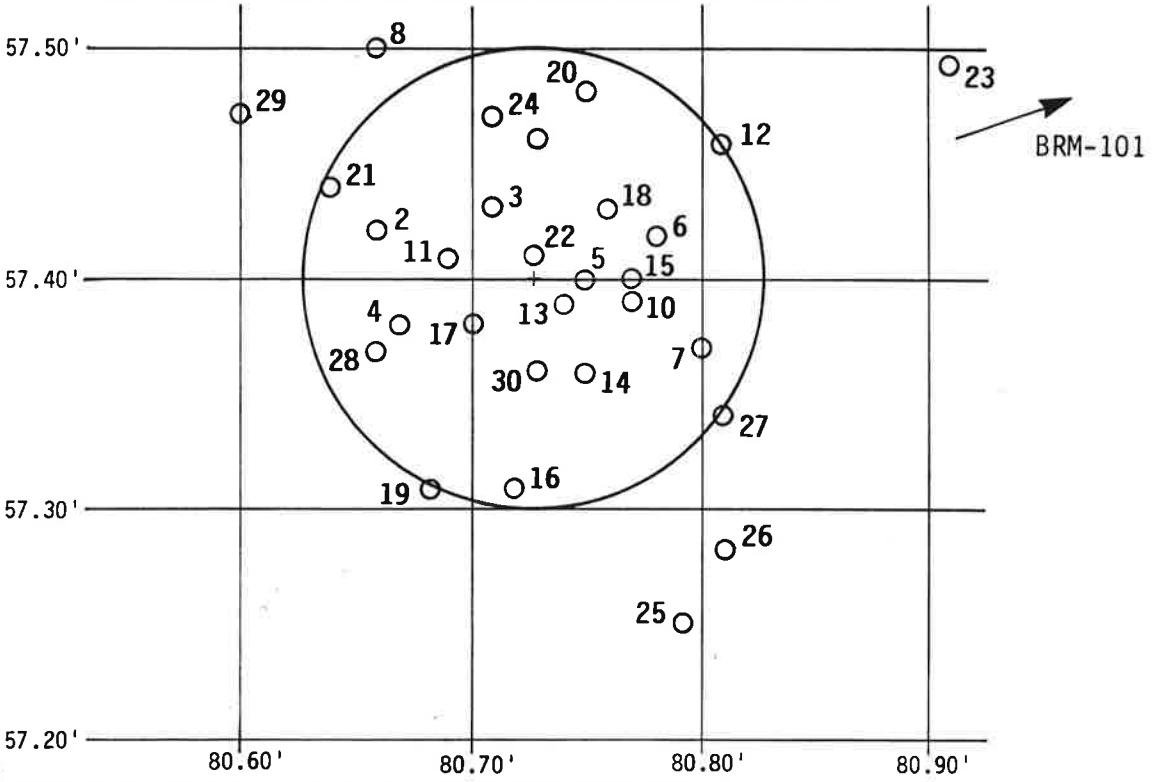
REDUCTION OF SLOPE INCLINOMETER DATA FOR SP-10 DURING MAIN MESA MOVEMENT: APRIL 1984 TO MAY 1985

FIGURE 5-2.4

TRUE SCALE PLOT OF MEASURED LOCATIONS OF BRM-126 *



TRUE SCALE PLOT OF MEASURED LOCATIONS OF BRM-127 *



*NUMBERS NEXT TO CIRCLES REPRESENT SURVEY NUMBER; GRID SHOWS LAST FOUR DIGITS OF NORTHING AND EASTING COORDINATES IN FEET.

BING YEN & ASSOCIATES

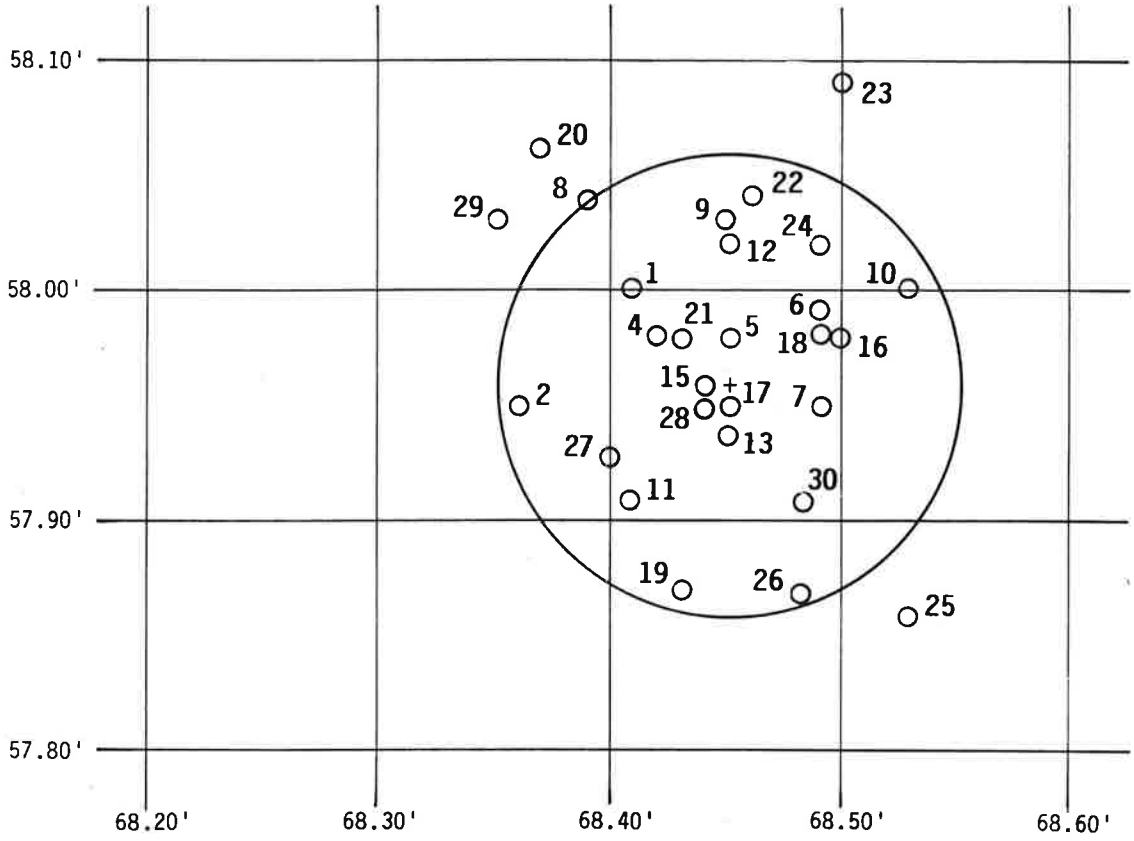
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

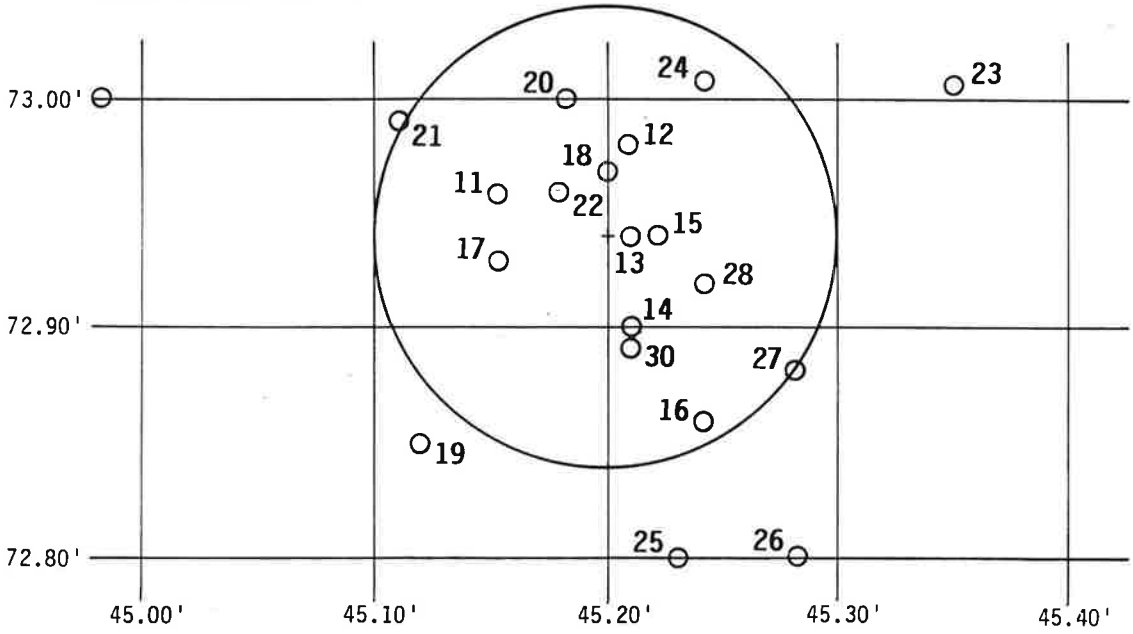
TRUE SCALE SURVEY PLOTS FOR SELECTED SURVEY POINTS WITHIN THE WESTERN EXTENSION: 1984 TO 1989

FIGURE 5-2.6(A)

TRUE SCALE PLOT OF MEASURED LOCATIONS OF BRM-128 *



TRUE SCALE PLOT OF MEASURED LOCATIONS OF BRM-145 *



*NUMBERS NEXT TO CIRCLES REPRESENT SURVEY NUMBER; GRID SHOWS LAST FOUR DIGITS OF NORTHING AND EASTING COORDINATES IN FEET.

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TRUE SCALE SURVEY PLOTS FOR SELECTED SURVEY POINTS WITHIN THE WESTERN EXTENSION: 1984 TO 1989

FIGURE 5-2.6(B)

SECTION 6.0

DEWATERING & GROUNDWATER RESPONSE

6.1 HYDROGEOLOGICAL SETTING & FORMATIONAL PROPERTIES

The BRM area constitutes a well-defined bowl-shaped groundwater basin. As described in Section 4.0 and depicted in the geologic map (Figure 4-1.2), the BRM area is bounded by the Las Flores fault system to the north, the Shoreline fault and the Pacific Ocean to the south, the Piedra Gorda Canyon to the east, and the Rockpoint Canyon to the west. These features define the boundary and/or inhibit the flow of groundwater into and out of the BRM area. Within the basin are fractured sedimentary rocks (Sespe, Vaqueros and Topanga formations), intrusive basalt, slide debris filled drainage channels, aquifers and aquacludes of varying hydrological properties. The boundaries between these aquifers and aquacludes are modified by faults (see Tectonic Map, Figure 4-1.3) in the following manner:

- The east-west trending, north-dipping faults such as the North and Saddle Peak fault zones retard the groundwater flow which would otherwise flow in a direction parallel to the surface gradient in a subdued manner. These fault zones act as groundwater barriers which compartmentalize the aquifers. The north-trending left-lateral faults such as the Inland and Rockpoint faults have the same effect. In the case of the Inland fault, it serves not only as a potential groundwater barrier between the Southeast Region and the rest of the mesa, but also represents a zone of weakness. The compartmentalization of the basin complicates efforts to dewater the area. The compartmentalization must be recognized and accounted for when designing and implementing dewatering measures.

- The seaward outflow of the groundwater is inhibited by the north-dipping Shoreline fault of the Malibu Coast fault system. The gouge materials of the fault are relatively impermeable and, of course, the sea level is the ultimate equipotential surface of the groundwater basin.

- The intrusive basalt and diabase, in the form of dikes and sills ranging from a few feet to tens of feet in thickness, cut through the older sedimentary rocks of the Sespe, Vaqueros and Topanga formations. Seeking the path of least resistance, these intrusions are also found in the fault zones. These intrusive basalts are fractured and brecciated within the fault zones, thereby being more permeable than the adjacent rocks. From a geotechnical engineering perspective, the intrusive and fractured basalts are good dewatering passages. They also serve as conduits which convey groundwater to confined areas, thereby causing artesian pressure as well as channels for surface water and sewage effluent to recharge the groundwater.

- Generally speaking, the intrusive diabase is more extensively weathered and altered to the clay and chlorite group of minerals than the basalt. The clayey minerals are less permeable and of lower strength than the brecciated basaltic rocks. The low permeability across the intrusive diabase and the low strength along the weathered clay seams must be recognized in groundwater compartmentalization interpretation and stability analysis.

The Topanga formation consists predominantly of sandstones and pebbly conglomerates. It has a lesser shale/siltstone component, and a higher permeability and specific yield than those of the Sespe and Vaqueros formations. The younger (Lower Miocene), maroon-colored Sespe formation, which consists of finer-grained sandstone, conglomerate, siltstone, and claystone is located primarily in the eastern part of BRM. The older (Upper Eocene) and paler-colored Sespe formation is coarser grained and distributed mostly in the western portion of BRM. All of these formations have been fractured by both faulting and pre-historic and recent landsliding. Generally speaking, the more permeable Topanga formation is located inland from the Bluff Region. The less permeable Sespe formation is located primarily along the bluff with a contact between the two dipping steeply northward (see Figure 4-1.2 and geotechnical cross sections shown in Figures 4-1.4 to 4-1.9). This general condition tends to trap groundwater within the main slide area.

The Headscarp Region is characterized by shallow existing or potential slide surfaces and steep topography. Being bounded by both ancient and recent landslide scarps and fractured and fissured near-surface materials, the natural slope of the Headscarp Region is relatively porous. Infiltrating water (rainfall, irrigation and septic tank effluent) will pass through the more porous surface materials and reach the relatively less permeable bedrock, resulting in the formation of perched water zones with steep gradients. These perched water zones are critical to the stability of the Headscarp Region. If sufficient subsurface water accumulates in these zones, the steep Headscarp slopes are likely to fail. Dewatering wells may not be as effective or efficient in the Headscarp Region as in other regions, because of the shallow and steep gradient of the perched water. Improvement of surface drainage, crack filling and continuous maintenance are a must. A sewage collector system which would prevent the infiltration of septic tank effluent would be very beneficial in the Headscarp Region, especially in light of the ineffectiveness of dewatering wells in this region. The same hydrogeological setting found in the Headscarp Region also exists to the South-Facing Slope Region of the Western Extension (see Physiographic Map, Figure 2-1.4 and Cross Section F-F', Figure 4-1.9). In this area, a steep perched groundwater condition is also likely to develop within the comparatively shallow landslide debris overlying the less permeable bedrock. Consequently, the elimination of sewage infiltration by a sewage collector system, good surface drainage, crack-filling and continuous maintenance is essential.

The Bluff Region is located primarily in the less permeable Sespe formation, and is an erosion-induced seacliff. The seacliff is transected by a number of north-south oriented drainage channels. Some of these channels are partially filled with alluvial and colluvial deposits. One of these channels, located about 500 feet west of Piedra Gorda Canyon in the Southeast Region is filled with slide debris and artificial fill extending beyond the bluff area. In recent years, this water-bearing, filled-in channel has been the source of seeps frequently observed along the eastern bluff. Bounded by the Shoreline fault and the Pacific Ocean to the south and the northwest-southeast crack zones which run approximately parallel to Roca Chica Drive, the Sespe rock in the Bluff Region was dilated and probably sheared (conjugate

shear planes) as a result of the 1983 main mass movement. Infiltrating water tends to saturate the rock joints and the dilated fissures on the steep bluff. The northerly dipping of the formation provides a mixed blessing for the Bluff Region in that:

1. The northern dip on the south-facing bluff face is favorable, because it decreases the probability of a bedding plane type of instability, but

2. The northern dip of the bedding also tends to direct infiltrated water back into the Main Mesa landslide area causing a rise of groundwater level which has a destabilizing effect to the bluff.

As described in Section 4.2, BYA noted pore pressure increases induced by the two seismic events (the Malibu Earthquake of 1989 and the Sierra Madre Earthquake of 1991). As will be discussed in Section 8.0, increased pore pressure within the bluff or the main slide area will reduce their stability. From a hydrogeological viewpoint, it is desirable therefore to keep the rock joints and fissures from becoming saturated. A number of positive actions can be undertaken by the citizens of BRM in general and those who dwell within the Bluff Region in particular. These include installing gutters, maintaining positive surface drainage to the street, and maintaining and re-sealing cracks in the streets. In this regard, a survey of BRM residences with and without rain gutters is shown in Figure 6-1.1. The survey was completed by BYA staff during field reconnaissance in the summer of 1991 by observation from the street. Therefore, it may not be complete, nor does it depict the conditions of the gutter (e.g., with or without down-spouts, filled with debris, etc.).

The eastern boundary of the Western Extension is a crack zone resulting from the 1983 Main Mesa landslide movement. The western boundary of the Western Extension essentially follows the flowline of Rockpoint Canyon and veers towards the eastern wall of the canyon to follow the Rockpoint fault (see Figure 4-1.3). The steeply north-dipping Las Flores, North and Saddle Peak fault systems form a series of barriers (see Cross Section I-I', Figure 4-1.12) which compartmentalize the groundwater in a step-wise manner. This can also be seen from Cross Section F-F' (Figure 4-1.9). South of these faults, and as depicted in Cross Sections G-G' and H-H' (Figures 4-1.10 and 4-1.11), the south-easterly dipping component of the Sespe formation exists, but is buttressed by the main mass and does not daylight. Deep wells (BYA-2 and -3 with pumps at depths 422 ft. and 483 ft., respectively) have resulted in an additional decrease of the water level in the Western Extension.

The crack zone which forms the boundary between the 1983 Main Mesa landslide and the Western Extension, is a major zone of infiltration. Surface drainage improvements implemented by the CI have significantly reduced the infiltration of surface water in this zone. The most noteworthy improvement eliminated the infiltration of the discharge from Well W-18. Well W-18 has been one of the highest producing wells in the BRM area. Before the surface drainage improvements, the water pumped out by Well W-18 was released onto the surface, where a significant portion of the discharge infiltrated back into the ground within several hundred feet of the well. The crack zones will need maintenance. Some cracks will reopen and some will close as subsurface soil and rock continue to adjust and readjust themselves. This phenomenon will be more evident during wet years and in the western end of the Headscarp Region where the Western Extension and the Headscarp merge (see Physiographic Map, Figure 2-1.4). Cleaning existing hydraugers (HD-17, 18 and 19), and installing additional hydraugers in this area are recommended.

BYA conducted pumping tests and well recovery tests for a number of wells, including : BYA-1, -2, -3, -4, -5 and W-1, -2, -3, -8, -15, -16, -17 and 18 during the period of this investigation. The hydraulic properties of the formational materials are summarized in Table 6-1. These values were estimated from calculations based on the following assumptions:

1. If the well penetrates more than one geologic unit, the hydraulic properties are identified as a composite of the units;

2. Because of the highly fractured and broken nature of the rocks, the horizontal and vertical permeabilities (hydraulic conductivities) are assumed to be the same;

3. Head loss across well casing perforation is negligible; and

4. The radius of influence for each well is assumed to be 500 ft. (note that the permeability is insensitive to the radius of influence, e.g., the radii can vary from 200 ft. to 1,000 ft. with less than 10% variation in the calculated hydraulic conductivity).

6.2 ANALYSIS

Groundwater inflow (groundwater recharge), I_f, is evaluated in accordance with the following formula:

I_f = Rainfall Recharge (Rainfall - Runoff - Evapotranspiration) + Irrigation/Sewer Recharge (Imported Water - Irrigation Runoff - Evapotranspiration) + Underground Inflow into the Basin

Groundwater outflow (O_f) is the amount of water extracted by the dewatering system (dewatering wells and hydraugers), plus the underground outflow out of the basin. If $I_f > O_f$, groundwater will be accumulated within the subsurface formations, resulting in a rise of groundwater levels, or an increase in the piezometric heads. If $I_f < O_f$, groundwater levels or piezometric heads will be decreased. Thus, groundwater analysis consists of evaluating I_f and O_f as well as their balance in terms of the rise or fall of groundwater levels. Details of this analysis are presented in this section.

6.2.1 Rainfall

Rainfall is a major source of groundwater. In order to mitigate the BRM landslide, it is necessary to understand how rainfall varies over time. Figure 2-4.1 is a plot of annual rainfall between 1877 and 1991. This figure was compiled from the sources shown in Table 2-3. The mean annual rainfall during this 114-year period is 15.4 inches. Perhaps more significant is the fact that the 4-year period between 1979 and 1983 is one of the two wettest periods during those 114 years (Figure 6-2.1). The accumulative rainfall during those 4 years was 90-inches. In this regard, the period ending 1983 was also the wettest 6-year and 8-year periods of the BRM region as well.

For purposes of this investigation, it is judged to be more representative for BRM to use the coastal rain gages located at Las Flores Canyon, Carbon Canyon and Station 1239 whose combined records span a 51-year period between 1939 and 1991 (Figure 6-2.2). Based on

these records, the average annual rainfall is 16-inches. This is about 0.6 inches higher than the 114-year average annual rainfall which is based, in part, on rainfall records from a downtown Los Angeles station. Figure 6-2.3 depicts an annual rainfall probability distribution based on the 51 years of coastal records. For example, using Figure 6-2.3, the probability is 10% for any given year that the annual rainfall will exceed 24-inches. In other words, it is probable that once in every 10 years, annual rainfall can be expected to be in excess of 24-inches. According to Figure 6-2.3, it is probable that once in every 20 years (5% probability) the annual rainfall may exceed 30-inches. There are certainly limitations for using Figure 6-2.3 because of the relatively short (51 years) rainfall records available for BRM. But it provides a rational basis of using the available data to evaluate the relative risks associated with the selection of consecutive wet seasons to assess their impact on groundwater recharge.

The residence time of the groundwater in the mesa from the beginning of infiltration to its removal by the existing dewatering system and underground outflow depends on too many factors to be precisely determined. These factors include surface drainage and runoff characteristics, geological structures, hydraulic properties as well as the location and gradient of the groundwater levels during the period when the recharging occurs. An attempt was made during this investigation to evaluate the transient state of recharging and other dewatering alternatives using the U.S.G.S. Modular Flow Model (MODFLOW-1990). Assuming the vertical and horizontal hydraulic conductivities being the same, the time required for recharging water to reach the current water table varies considerably. However, it is clear that 3 to 5 consecutive wet seasons will most likely cause severe groundwater problems from the viewpoint of residence time for BRM.

Not all precipitation becomes groundwater. Runoff, interception and evapotranspiration (ET) all reduce the amount of rainfall, which can recharge the groundwater. Runoff coefficients vary. For a typical single family residential area, the percentage of rain that appears as direct runoff is in the range of 40 to 50% (Merritt, 1983). In the BRM area, about 50% of the area is covered by non-irrigated ground covers of indigenous shrubs or in steep slope areas with sparse vegetation (see Figure 2-4.5). About 90% of the residences have gutters as shown in Figure 6-1.1 and about 30 acres can be interpreted as interceptors (e.g., roofs, roads and driveways, etc.). Weighing all the factors, including the physiography described in Section 2.0, 80% of total rainfall is assumed to be lost through a combination of surface runoff and ET. This means that about 20% of the total rainfall is estimated to recharge the groundwater. Consequently, the recharge to the groundwater due to rain (Rr) is equivalent to 33 acre-ft. per year for BRM, assuming an average rain year of 16.0 inches.

6.2.2 Imported Water and Sewage Recharge

Figure 6-2.4 summarizes the master water meter reading data of the imported water to the mesa. Other than seasonal fluctuation, water consumption averaged approximately 132,000 gallons per day (gpd) from 1988 through 1991. For a total of 270 dwellings on the Mesa, it represents an average water consumption of about 490 gpd per dwelling. In a 1984 statistical study (Winneberger, 1984) of septic tanks in Novato, California, the mean wastewater flows to the septic tanks were 233 gpd per dwelling, with a standard deviation of 84 gpd per dwelling. The surveyed data base had a mean of 3.8 bedrooms and 3.8 persons per dwelling. Lacking detailed census of BRM residences and considering the possibility that BRM may be a more affluent neighborhood (i.e., more water consumption),

we have assumed that the average wastewater flows to BRM septic tanks is 245 gpd per dwelling (in comparison with 233 gpd at Novato). For BRM, this represents a 50/50 distribution of the total imported water (490/2 = 245 gpd per dwelling) between flows to septic tanks and other usage. It has been assumed that the flows to the septic tank (50% of the total consumption) eventually become recharge to the groundwater, whereas the other 50% is lost through irrigation runoff and evapotranspiration. This assumption is considered reasonable because of the compensating effect between the irrigation water and sewage discharge. For example, about 10% of septic tank effluent is lost via capillary action to vegetation, and about 10% of irrigation water may infiltrate beyond the root zone and eventually reach the groundwater below. For a 50/50 distribution between flows into septic tanks and other usage, the 10% described above is mutually compensating. The precise quantity may never be known short of a series of expensive on-site long-term pilot studies. For purposes of this study and based on the BRM master meter reading and the Winneberger study, it is assumed that 50% (or 66,000 gpd) of the total imported water of 132,000 gpd recharges to the groundwater. This amounts to about 73.9 acre-feet per year.

6.2.3 Dewatering

This section presents an analysis of the groundwater response to dewatering, past and present. Analysis of the groundwater responses to dewatering serves as a prognostic tool to evaluate the impact of future consecutive wet seasons on groundwater conditions. The results of groundwater contours (or piezometric heads in the mesa) at different times will be used for slope stability analysis (Section 7.0).

With respect to dewatering efforts since 1983, Figures 6-2.5, 6-2.6 and 6-2.7 show the historic total hydrauger production, well production and total dewatering in the BRM area, respectively. The location of dewatering wells are shown in Figure 6-2.8. Figure 6-2.8 summarizes the dewatering wells installed at various periods since the 1950's. Tables 6-3 through 6-7 list all dewatering wells and their pertinent information, including installation history, pump size, and current pump elevations. Groundwater contours are plotted based on observations from all available instruments (piezometers, wells, slope inclinometers) whose locations are shown in Figure 3-8.1. Table 6-2 provides a reference summarizing a series of figures (Figures 6-2.9 to 6-2.16) depicting the groundwater response to dewatering at different time periods and contains remarks as to their engineering significance. Figure 6-2.17 shows the October 1991 piezometric elevation above the basal rupture surface which is used to calculate the prevailing factors of safety in Section 7.0.

It should be noted that there are locations where zones of confined aquifers exist because of the overlying relative impermeable stratum (see Section 4.0). The standpipe type of piezometer, which is most prevalent in BRM, can only measure the average piezometric head. Efforts were made during pumping tests from observation wells to identify zones of confined aquifers as well as during the BYA deep borings. Nonetheless, the groundwater contours depicted in Figure 6-2.17 should be considered as piezometric heads where confined waterbearing zones exist.

6.2.4 Groundwater Budget and Evaluation of Average Groundwater Level

It is believed that, in general, after nearly 5 years of drought and after bringing 5 new deep wells on-line, the current BRM groundwater basin has reached a steady state with respect

to the current dewatering system and the existing groundwater levels. Being in a steady state means the net inflow into the groundwater basin (I_f) is equal to the net outflow (O_f) from the basin, i.e., $(I_f)-(O_f) = 0$.

The following observations support the steady state hypothesis:

- For the past 3 years (during which more systematic and frequent monitorings have taken place), the daily dewatering rate has averaged approximately 72,000 gpd (Figure 6-2.7). On an annual basis, this dewatering (Dw) withdraws about 80.7 acre-feet of groundwater from the basin.

- Imported water, while fluctuating with the winter and summer seasons (Figure 6-2.4), has averaged about 132,000 gpd. On an annual basis, this is equivalent to about 73.9 acre-feet of groundwater recharge (R_i) from imported water as described in Section 6.2.2.

- The groundwater levels in the BRM area in the past 3 years, except for those in the immediate vicinity of the new wells, have remained relatively constant.

The following assumptions have been made to evaluate the effects of wet years as well as changes in effluent recharge on the average groundwater level of the BRM basin:

1. The current BRM groundwater basin is in steady state;

2. The current average dewatering rate will be maintained in the future (this assumes the dewatering system is properly operated and maintained);

3. Any future changes in rainfall recharge (Δ Rr) and/or changes in effluent (imported water) recharge (Δ Ri) will be reflected by changes in Storage Capacity (Δ S) which, in turn, dictate the change of groundwater levels; and

4. The prevailing groundwater levels cannot be further lowered with the existing dewatering system, because of limitations in the existing well penetration depths, the large spacings between wells, and the configuration of the BRM basin.

In essence, the above assumptions lead to the following equation:

$$\Delta R_i + \Delta R_r = \Delta S \qquad (1)$$

It should also be noted that the changes in storage capacity and groundwater levels (ΔH) can be expressed as:

$$\Delta S = Sy \cdot \Delta H \cdot A \qquad (2)$$

$$\Delta H = \frac{\Delta Ri + \Delta Rr}{Sy \cdot A} \qquad (3)$$

Equation (3) enables the prediction of groundwater level changes as a function of changes in rainfall and groundwater recharge in which,

ΔS = Changes in Storage Capacity in Acre-Ft; S can be depletion due to dewatering or replenishment due to excessive recharge to groundwater from rainfall or effluent discharge.

S_y = Specific yield of rock formations; S_y varies, S_y = 5% is adopted for estimation purposes (also see Table 6-1).

ΔH = Increase in groundwater levels over the prevailing conditions (October 1991).

A = Area (in acre); see Figure 6-2.17 for the area covered by the prevailing groundwater level.

Table 6-8 shows the estimated increase in average groundwater levels in the entire basin (without a sewer system) due to differing annual amounts of rainfall. One can choose to combine any number and/or sequences of wet seasons to estimate the corresponding maximum groundwater rise. Different combinations of wet seasons represent different levels of groundwater. Different groundwater levels, as will be presented in Section 7.0, represent different factors of safety. As an illustration, Table 6-8 shows that an estimated average rise in the groundwater level of up to 14.3 feet is possible for a series of 3 wet seasons with return periods of 2 years (average rainfall 16 in./yr.), 10 years (24 in./yr.), and 20 years (30 in./yr.). For an average rainfall year (return period of 2 years), the groundwater level increase is estimated to be about 2.3 feet per year.

It is essential to recognize the assumptions used to derive equation (3) and Table 6-8. The following is a discussion on some of the salient points regarding the limitations of their applications:

1. Equation (3) and Table 6.8 are based on the assumption that the dewatering rate is constant. But, in fact, the dewatering rate increases as the groundwater rises, i.e., pumping rates of the existing dewatering system will increase as groundwater levels rise. Hence, the estimated increase of water level due to consecutive wet seasons represents a theoretical upper bound as long as the existing dewatering system is maintained properly and retains its efficiency comparable to the present (December 1991) level.

2. As shown in Figures 6-2.13 through 6-2.16, the existing dewatering system is more effective in certain areas than others. Local groundwater compartmentalization has been discussed earlier. One must be cautious in any attempt to extrapolate an average groundwater rise for the BRM area as a whole to use in local or subregional slope stability calculations.

3. As will be discussed in Section 7.0, if the average groundwater level changes, the gross stability of the main mass will change. To highlight the inter-relationship between the factor of safety (stability) of the area and groundwater levels, the following example is given for illustration:

- As shown in Table 6-8, the calculated groundwater increase is about 2.3 feet for a normal rainfall year (return period of 2 years). This means that groundwater levels will increase about 23 and 46 feet over 10 and 20 year periods of normal rainfall, respectively - even without any consecutive wetter years. These conditions respectively correspond to overall decreases of factor of safety of about 0.05 and 0.1, for the main BRM landslide (see Section 7.0) i.e., reducing the prevailing factor of safety of 1.25 or less to about 1.2 and 1.15 or less, respectively.

6.2.5 Effluent Recharge and Average Groundwater Levels

The effects of the elimination of effluent recharge (due to a new sewage collector system) on the average groundwater level of the entire basin can be evaluated for varying combinations of rainfall years. For the case of consecutive wet years with a new sewer system (i.e., $\Delta R_i = -73.9$ acre-feet in Equation (3)), groundwater level increase (ΔH) can be expressed as:

$$\Delta H = \frac{\Delta R_r - 73.9}{10.95}, \geq 0$$

Table 6-9 shows the effects of various consecutive wet years on the average groundwater level of the entire basin. This table assumes that a new sewage collector system has eliminated all present day effluent recharge to the groundwater. As can be seen from this table, the implementation of a new sewage collector system will negate the effects of any wet years with return periods of less than 20 years. For return periods of 20 years or more, the increase in groundwater levels are minimal (about 2.3 feet for a return period of 50 years) and can be practically alleviated in subsequent years of lesser rainfall magnitudes. Thus, the implementation of a new sewer system is likely to have the following beneficial effects:

1. Eliminate the cones of infiltration emanating from individual septic systems, thus increasing local stability, especially in areas where perched groundwater conditions are likely to develop (e.g., Headscarp and the South-facing Slope Regions of the Western Extension) and the Bluff Region.

2. Negate the potential groundwater level increases due to wet years, as illustrated in Table 6-9.

For the purposes of comparison, Table 6-8 and Figure 6-2.18 represent estimated basin-wide average groundwater conditions without a sewage collector system. The methodology and results presented in this section provide a rational technical basis upon which the effect of a sewage collector system on the average groundwater level of the entire basin can be quantified.

TABLE 6-1

AQUIFER PROPERTY RANGES

AQUIFER FORMATION & DESCRIPTION	HYDRAULIC CONDUCTIVITY Ft./Day (cm/sec)	ESTIMATED SPECIFIC CAPACITY GPM/Ft.	ESTIMATED SPECIFIC YIELD (%)	ESTIMATED TRANSMIS-SIVITY GPD/Ft.
Intrusive Basalt and Diabase: Sheared & altered	2.5 +/- (1×10^{-3} +)	0.1 +	10 +	- -
Topanga Formation: Fractured and contain some sheared intrusives	0.25 to 1 (1 to 4×10^{-4})	0.05 to 0.1	5 to 10	100 ±
Topanga/Seape: Contact Zone; Fractured	0.1 to 0.25 (0.4 to 1×10^{-4})	0.02 to 0.05	3 to 8	- -
Sespe Formation: Fractured and contain some sheared intrusives	0.05 to 0.1 (0.2 to 0.4×10^{-4})	0.01 to 0.02	2 to 5	20 to 40 ±

TABLE 6-2

SUMMARY OF GROUNDWATER RESPONSES TO DEWATERING

FIGURE NUMBER	DESCRIPTION	REMARKS
6.10	Estimated Groundwater Contour as of September 1983	Groundwater contours, period of mass movement
6.11	Estimated Groundwater Contour as of September 1988	Groundwater contours before BYA well renovation
6.12	Estimated Groundwater Contour as of January 1989	Groundwater contours after BYA well renovation and County hydrauger cleaning
6.13	Estimated Groundwater Contour and/or Piezometric Head as of October 1991	Groundwater contours of the existing system
6.14	Change of Groundwater Levels; Sept. 1983 to Sept. 1988	Change of groundwater regime prior to this investigation
6.15	Change of Groundwater Levels; Sept. 1983 to Jan. 1989	Response of groundwater regime to well renovation and hydrauger cleaning
6.16	Change of Groundwater Levels; Sept. 1983 to Oct. 1991	Summary of groundwater changes near the end of this investigation
6.17	Change of Groundwater Levels; Sept. 1988 to Oct. 1991	Period approaching steady state of BRM groundwater sub-basin

TABLE 6-3

INFORMATION ON DEWATERING WELL SYSTEM PRIOR TO SEPTEMBER 1983

WELL NAME	STATUS AS OF 10-91	INSTALLATION* DATE	BY	PUMPING START DATE	TOP ELEV. (FT.)	BOTTOM ELEV. (FT.)	PUMP ELEV. (FT.)	INITIAL H2O EL. (FT.)	PRODUCTION START (GPM)	PRODUCTION STEADY RATE @ TIME **	CASING DIAM/MATL. PERF. TYPE	COMMENTS
W-1	PROD.	7-73	MMDC*	11-73	210.5	-72	60.5	UNK.	50	8 GPM @ 2 WEEKS	6/STEEL IN SITU	PUMPING SUSPENDED ON 8-6-75 DUE TO LACK OF MMDC FUNDING.
W-2	PROD.	1955	BRBC*	1-72	219	UNKNOWN	119	UNK.	40	17 GPM @ 11 MONTHS	6/STEEL UNK.	PUMPING SUSPENDED IN EARLY '75 DUE TO LACK OF MMDC FUNDING. PRODUCTION REDUCED TO 2 GPM IN LATE 1974. POSSIBLY PUMPED PERIDICALLY BY PROPERTY OWNER TO 9-83.
W-3	PROD.	11-73	MMDC*	7-74	243.5	61	138.5	UNK.	38	20 GPM @ 6 MONTHS	6/STEEL IN SITU	PUMPING SUSPENDED ON 8-6-75 DUE TO LACK OF MMDC FUNDING. RECORDS INDICATE PERIODIC PUMPING BY PROPERTY OWNER TO '81 AND CCWC TO 9-83.
W-4	NON-PROD.	11-73	MMDC*	NOT DEVELPD	248	-2	-	UNK.	-	-	6/STEEL IN SITU	WELL NOT DEVELOPED DUE TO LACK OF MMDC FUNDING. CAPPED WITH DRILLING MUD LEFT IN CASING.

NOTES:

* MMDC = MALIBU MUTUAL DRAINAGE COMPANY.

** BBRC (PRODUCTION STEADY STATE @ TIME) REFERS TO RATE OF PRODUCTION AT STEADY STATE CONDITIONS AND TIME AFTER PUMPING INITIATION NECESSARY TO REACH THIS CONDITION.

TABLE 6-4

INFORMATION ON DEWATERING WELL SYSTEM DEVELOPED AS A RESULT OF 1983 MAIN BRM LANDSLIDE MOVEMENT

WELL NAME	STATUS AS OF 10-91	INSTALLATION* DATE	BY	PUMPING START DATE	TOP ELEV. (FT.)	BOTTOM ELEV. (FT.)	PUMP ELEV. (FT.)	PUMP SIZE (HP)	INITIAL H2O EL. (FT.)	PRODUCTION START (GPM)	PRODUCTION STEADY RATE @ TIME **	CASING DIAM/MATRL PERF. TYPE	COMMENTS
W-1	PROD.	7-73	MMDC	9-30-83	210.5	-72	75	1	147.5	25	<1 GPM @ 4 MONTHS	6/STEEL IN SITU	WELL REDEVELOPED BY CCWC. PUMPING SUSPENDED ON 9-18-74 DUE TO LOW PRODUCTION.
W-2	PROD.	1955	BRBC	10-12-83	219	39	51	3	162	60	4 GPM @ 6 MONTHS	6/STEEL UNK.	WELL REDEVELOPED BY CCWC.
W-3	PROD.	11-73	MMDC	10-11-83	243.5	61	98.5	1.5	230.5	55	45 GPM @ 6 MONTHS	6/STEEL IN SITU	WELL REDEVELOPED BY CCWC. PUMPING SUSPENDED IN EARLY '75 DUE TO LOW PRODUCTION.
W-4	NON-PROD.	11-73	MMDC	11-4-83	248	-4	58	1	151	3	<1 GPM @ 2 MONTHS	6/STEEL IN SITU	WELL REDEVELOPED BY CCWC. PUMPING SUSPENDED IN 6-16-84 DUE TO LOW PRODUCTION.
W-5	NON-PROD.	11-83	CCWC	11-9-83	280	190	UNK.	1.5	243	70	30 GPM @ 1 MONTH	6/PVC UNK.	PUMPING SUSPENDED ABOUT 1-84 DUE TO STATIC WATER LEVEL DROPPING BELOW CASING.
W-6	NON-PROD.	11-83	CCWC	4-4-84	174	77	104	1.5	113	23	UNK.	6/PVC .01" SLOTS	PUMPING SUSPENDED 7-10-84 DUE TO LOW PRODUCTION.
W-7	NON-PROD.	11-83	CCWC	12-13-83	257	-43	174	1.5	217	UNK.	6 GPM @ 5 MONTHS	6/PVC .04" SLOTS	PUMPING WAS CONTINUOUS UNTIL 10-84. THEREAFTER PUMPING WAS INTERMITTENT WELL DRILLED BY L.A. COUNTY FLOOD CONTROL FOR CCWC.
W-8	PROD.	11-83	DAE	12-24-83	287	87	119	5	232	64	34 GPM @ 6 MONTHS	6/PVC .01" SLOTS	PUMPING CONTINUED ON TIMED INTERVALS TO 11-88.
W-9	NON-PROD.	12-83	CCWC	12-16-83	282	87	110	1.5	189	2	1 GPM @ 6 MONTHS	6/PVC .04" SLOTS	PUMPING SUSPENDED 10-1-84 DUE TO STATIC WATER LEVEL DROPPING BELOW CASING. WELL DRILLED BY L.A. COUNTY FLOOD CONTROL FOR CCWC.

TABLE 6-4 (Page Two)

INFORMATION ON DEWATERING WELL SYSTEM DEVELOPED AS A RESULT OF 1983 MAIN BRM LANDSLIDE MOVEMENT

WELL NAME	STATUS AS OF 10-91	INSTALLATION* DATE	BY	PUMPING START DATE	TOP ELEV. (FT.)	BOTTOM ELEV. (FT.)	PUMP ELEV. (FT.)	PUMP SIZE (HP)	INITIAL H2O EL. (FT.)	PRODUCTION START (GPM)	PRODUCTION STEADY RATE @ TIME **	CASING DIAM/MATRL PERF. TYPE	COMMENTS
W-10	PROD.	12-83	LACRD	1-5-84	432	189	204	3	270	38	24 GPM @ 6 MONTHS	8/PVC .03" STOTS	PUMPING SUSPENDED 9-1-84 DUE TO LOW PRODUCTION.
W-11	PROD.	12-83	DAE	12-8-83	507	284	289	3	337	UNK.	5 GPM @ 1 MONTH	6/PVC .01" SLOTS	PUMPING STOPED BETWEEN 10-28-84 AND 2-85. PUMPING SUSPENDED IN MAY '86 DUE TO LOW PRODUCTION.
W-12	NON-PROD.	12-83	LACRD	1-7-84	375	85	122	5	233	14	<1 GPM @ 6 MONTHS	8/PVC .03" STOTS	PUMPING SUSPENDED 12-9-84 DUE TO LOW PRODUCTION.
W-13	PROD.	12-83	DAE	12-28-83	361	164	193	3	266	62	5 GPM @ 3 MONTHS	6/PVC .04" SLOTS	PUMPING CONTINUED @ 4 GPM TO 9-88. CASING DEFORMED @ ELEVATION 188, PREVENTING LOWERING OF THE PUMP.
W-14	NON-PROD.	5-84	DAE	5-15-84	283	128.5	132	0.75	218	12	5 GPM @ 1 MONTH	6/PVC .01" SLOTS	PUMPING SUSPENDED 8-12-84 DUE TO STATIC WATER LEVEL DROPPING BELOW CASING.
W-15	PROD.	6-84	DAE	6-29-84	295	166.5	123	1.5	UNK.	34	5 GPM @ 4 MONTHS	6/PVC .01" SLOTS	PUMPING CONTINUED @ 4 GPM TO 9-88.
W-16	PROD.	6-84	DAE	6-27-84	325	88	114	1.5	UNK.	UNK.	12 GPM @ 1 MONTH	10/PVC .01" SLOTS	PUMPING CONTINUED @ 7 TO 10 GPM TO 9-88.
W-17	PROD.	6-84	DAE	7-10-84	270	30	34	3	205.5	54	6 GPM @ 5 MONTHS	10/PVC .01" SLOTS	PUMPING CONTINUED @ 3 TO 4 GPM TO 9-88.
W-18	PROD.	6-84	DAE	8-19-84	750	179	194	7.5	663	58	13 GPM @ 12 MONTHS	8/PVC .01" SLOTS	PUMPING CONTINUED @ 10 TO 12 GPM TO 9-88.

NOTES:

MMDC = MALIBU MUTUAL DRAINAGE COMPANY

BRBC = BIG ROCK BEACH WATER COMPANY

CCWC = CONCERNED CITIZENS FOR WATER CONSERVATION

DAE = D.A. EVANS

LACRD = L.A. COUNTY ROAD DEPARTMENT

STEADY RATE @ TIME REFERS TO RATE OF WELL PRODUCTION AT STEADY STATE CONDITIONS AND TIME SINCE PUMPING INITIATION NECCESSARY TO REACH THIS CONDITION.

TABLE 6-5

INFORMATION ON DEWATERING WELL SYSTEM PRIOR TO AND IMMEDIATELY AFTER BYA DEVELOPMENT OF 11-88

WELL NAME	TOP ELEV. (FT.)	BOTTOM ELEV. (FT.)	PUMP ELEV. (FT.)	PUMP SIZE (HP)	INITIAL H2O EL. (FT.)	PRODUCTION BEFORE (GPM)	PRODUCTION AFTER (GPM)	COMMENTS
W-1	210.5	-33.6	-22.5	0.5	65.4	0 *	3.3	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-2	219	41.6	42	0.5	146	2	5	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-3	243.5	65.7	70.5	0.75	67.5	0 *	5	NEW PUMP CONTROLLED BY TIMER.
W-4	248	-9	-	-	93.2	0 *	0	WELL NON-PRODUCTIVE DUE TO SUSPENDED SOLIDS, CLOGGING PUMP.
W-5	280	190	-	-	-	0 *	0	NON-PRODUCTIVE DUE TO LACK OF DEPTH.
W-6	174	80	-	-	85	0 *	0	NON-PRODUCTIVE DUE TO LACK OF DEPTH.
W-7	257	171	-	-	177	0 *	0	NON-PRODUCTIVE DUE TO LACK OF DEPTH.
W-8	287	93	100	1	138	5.5	12.5	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-9	282	87	-	-	125	0 *	0	NON-PRODUCTIVE DUE TO LACK OF DEPTH.
W-10	432	192	194	0.75	207	0 *	1	NEW PUMP CONTROLLED BY TIMER.
W-11	507	286.6	285	0.75	312	0 *	3.8	NEW PUMP CONTROLLED BY TIMER.
W-12	375	105.5	-	-	188	0 *	0	OFFSET @ ELEV. 185 PREVENTING PUMP LOWERING.
W-13	361	184	189	1	234	2	7	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-14	283	131.5	-	-	DRY	0 *	0	NON-PRODUCTIVE DUE TO LACK OF DEPTH.
W-15	295	120.2	131	1	158	3	9	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.

TABLE 6-5 (Page Two)

INFORMATION ON DEWATERING WELL SYSTEM PRIOR TO AND IMMEDIATELY AFTER BYA DEVELOPMENT OF 11-88

WELL NAME	TOP ELEV. (FT.)	BOTTOM ELEV. (FT.)	PUMP ELEV. (FT.)	PUMP SIZE (HP)	INITIAL H2O EL. (FT.)	PRODUCTION BEFORE (GPM)	PRODUCTION AFTER (GPM)	COMMENTS
W-16	325	107	112	0.75	161	5	10	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-17	270	41	50	0.75	98	3	5	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
W-18	750	179	225	3	360.4	7	15	NEW PUMP CONTROLLED BY RECIRCULATION UNIT.
TOTAL:						27.5	76.5	

NOTES:

* WELL WAS NON-FUNCTIONING PRIOR TO BYA DEVELOPMENT.

1) WELL BOTTOM ELEVATION DETERMINED BY DOWN HOLE CAMERA LOGGING, IF PERFORMED ON WELL, OR BY SOUNDING.

2) INITIAL WATER ELEVATIONS DETERMINED AT STATIC CONDITIONS AND AFTER RECOVERY, WHEN APPLICABLE.

TABLE 6-6
INFORMATION FOR DEWATERING WELLS INSTALLED BY BYA (1989-1991)

WELL DESIGNATION	COMPLETION DATE	PUMPING START DATE	INITIAL WATER ELEV.	INITIAL PROD. (GPM)	CURRENT WATER ELEV.	CURRENT PROD. (GPM)
BYA-1	6-90	6-22-90	146	25	10	3.6
BYA-2	7-90	3-4-91	395	12	350	1.1
BYA-3	9-90	3-4-91	340	10	200	4.5
BYA-4	1-91	3-4-91	230	8	0	4.5
BYA-5	2-91	*	65	*	65	*

NOTES:

* STATISTICS OF WELL BYA-5 (BROUGHT ON-LINE JANUARY 1992) ARE NOT INCLUDED.

1) ALL OTHER WELL STATICS ARE SHOWN ON TYPICAL WELL DRAWINGS AND TABLE 6-7.

2) CURRENT DATA RETRIEVED IN OCTOBER 1991.

TABLE 6-7

BIG ROCK MESA DEWATERING WELL STATUS AS OF OCTOBER 1991 *

WELL	NON-PRODUCING	TOP ELEVATION FEET	BOTTOM ELEV. (Ft.)	PUMP ELEV. (Ft.)	STATIC WATER ELEV. (Ft.)	DRAWDOWN (Ft.)	PUMP SIZE (HP)	PUMPING RATE (GPM)	WELL YIELD (GPM/FT. OF DRAWDOWN)	REASON FOR BEING NON-FUNCTIONAL
BYA-1	PRODUCING	283	-162	-126	-0-	126	3	3.6	.3	N/A
BYA-2	PRODUCING	665	215	243	324	81	1.5	1.1	-.1	N/A
BYA-3	PRODUCING	510	- 40	27	200	173	3	4.5	.3	N/A
BYA-4	PRODUCING	360	- 80	- 40	-10	30	1.5	4.5	1.5	N/A
1	PRODUCING	210.5	- 30	14.5	27	41.5	1.5	.9	.2	N/A
2	PRODUCING	219	41	44	27	41.5	1.5	1.3	7.2	N/A
3	PRODUCING	243.5	65.5	70.5	79.5	9	3/4	1.9	1.0	N/A
4	NON-PRODUCING	248	-10	N/A	N/A	N/A	N/A	N/A	N/A	CASING PERFORATIONS CLOSED DUE TO SILTATION
5	NON-PRODUCING	280	252	N/A	N/A	N/A	N/A	N/A	N/A	CAPPED 4/4/84
6	NON-PRODUCING	174	80	N/A	N/A	N/A	N/A	N/A	N/A	STATIC WATER LEVEL AT BOTTOM OF CASING
7	NON-PRODUCING	257	171	N/A	N/A	N/A	N/A	N/A	N/A	STATIC WATER LEVEL AT BOTTOM OF CASING
8	NON-PRODUCING	287	93	98	130	32	1	4.0	1.3	N/A
9	NON-PRODUCING	282	87	N/A	N/A	N/A	N/A	N/A	N/A	

TABLE 6-7 (Page Two)

BIG ROCK MESA DEWATERING WELL STATUS AS OF OCTOBER 1991 *

WELL	NON-PRODUCING	TOP ELEVATION FEET	BOTTOM ELEV. (Ft.)	PUMP ELEV. (Ft.)	STATIC WATER ELEV. (Ft.)	DRAWDOWN (Ft.)	PUMP SIZE (HP)	PUMPING RATE (GPM)	WELL YIELD (GPM/FT. OF DRAWDOWN)	REASON FOR BEING NON-FUNCTIONAL
10	PRODUCING	432	192	194	208	14	3/4	0	0	PUMP PRODUCING 30 GALLONS PER DAY
11	PRODUCING	507	285	292	296	4	3/4	.1	.3	N/A
12	NON-PRODUCING	375	195	N/A	N/A	N/A	N/A	N/A	N/A	CASING SHEARED @ STATIC WATER LEVEL (EL.=185)
13	PRODUCING	361	184	193	191	0	1.0	.7	0	N/A
14	NON-PRODUCING	283	131	N/A	N/A	N/A	N/A	N/A	N/A	STATIC WATER LEVEL BELOW BOTTOM OF CASING
15	PRODUCING	295	121	130	137	0	3/4	0	0	PUMP PERIODICALLY PRODUCES
16	PRODUCING	325	107	113	150	37	3/4	5.1	1.4	N/A
17	PRODUCING	270	41	50	89	39	3/4	3.6	3.9	N/A
18	PRODUCING	750	179	225	237	12	3	8.7	7.3	N/A

NOTE:

* STATISTICS OF WELL BYA-5 (BROUGHT ON-LINE IN JANUARY 1992) ARE NOT INCLUDED.

TABLE 6-8

CALCULATED INCREASE IN THE AVERAGE GROUNDWATER LEVEL OF THE ENTIRE BASIN DUE TO CONSECUTIVE RAINFALL YEARS OF DIFFERING RETURN PERIODS WITHOUT A NEW SEWER SYSTEM

Return Period	Rainfall (In./Yr.)	Δ Rr (Acre/Ft.)	Δ H (Ft.)	Three Consecutive Rainfall Years	
				Δ H* (Ft.)	Δ H** (Ft.)
2	16	25.6	2.3	2.3	
5	21	43.8	4.0		
10	24	54.8	5	5	5
15	27	65.7	6		
20	30	76.65	7	7	
25	32	84	8		7.7
50	36	98.6	9		9
			TOTAL:	14.3	21.7

* 3 consecutive rainfall years with return periods of 2, 10 and 20 years.

** 3 consecutive rainfall years with return periods of 10, 25 and 50 years.

NOTE: This table applies to the estimated increases in the average groundwater level of the entire basin. It is not applicable to the subregions.

TABLE 6-9

CALCULATED INCREASE IN THE AVERAGE GROUNDWATER LEVEL OF THE ENTIRE BASIN DUE TO CONSECUTIVE RAINFALL YEARS WITH A NEW SEWER SYSTEM

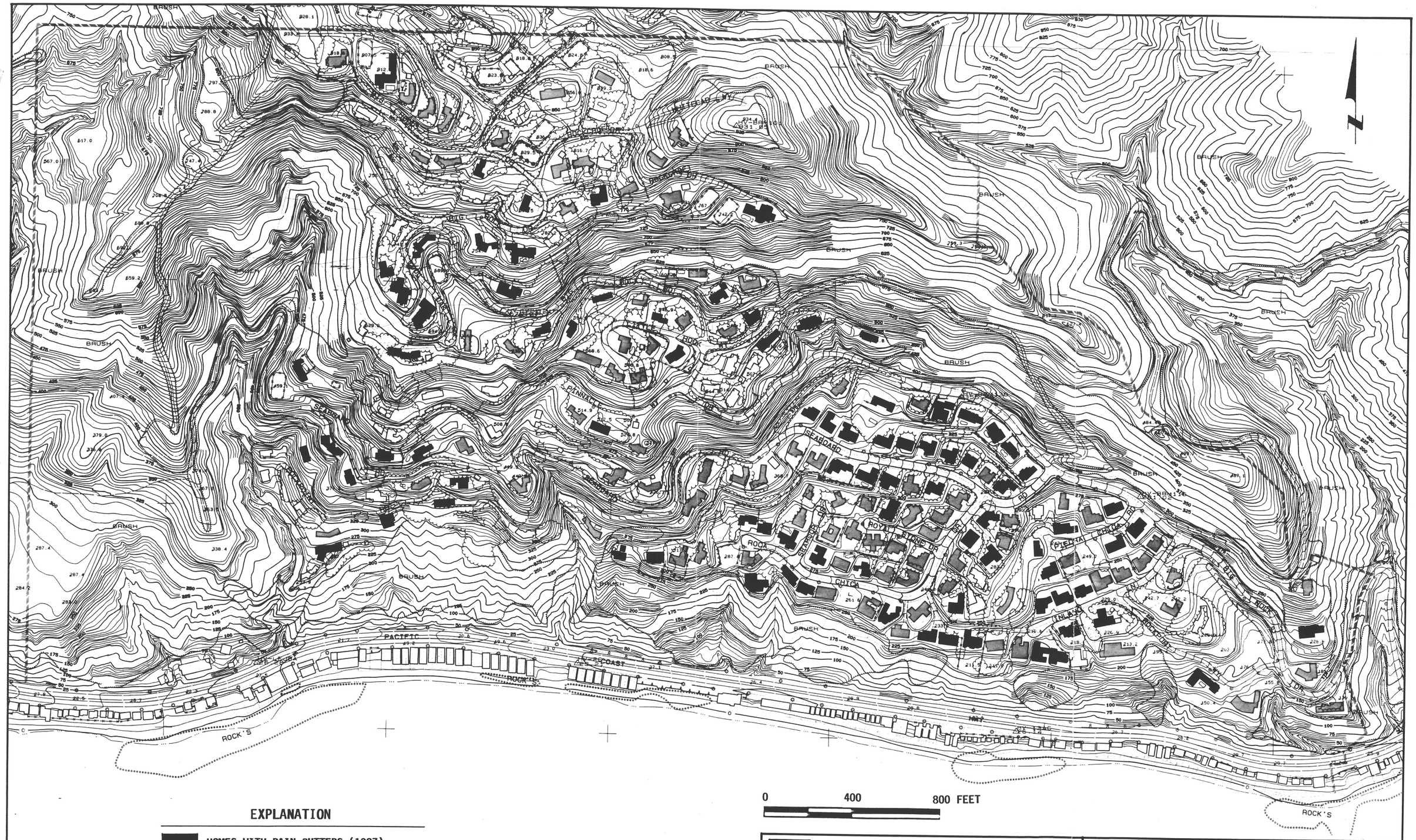
Return Period	Rainfall (In./Yr.)	Δ Rr (Acre/Ft.)	Δ H (Ft.)	Three Consecutive Rainfall Years	
				Δ H* (Ft.)	Δ H** (Ft.)
2	16	25.6	0	0	
5	21	43.8	0		
10	24	54.8	0	0	0
15	27	65.7	0		
20	30	76.7	0.3	0.3	
25	32	84.0	0.9		0.9
50	36	98.6	2.3		2.3
			TOTAL:	H = 0.3*	H = 3.2**

* 3 consecutive rainfall years with return periods of 2, 10 and 20 years.

** 3 consecutive rainfall years with return periods of 10, 25 and 50 years.

NOTE:

This table applies to the estimated increases in the average groundwater level of the entire basin. It is not applicable to the subregions.



EXPLANATION

- HOMES WITH RAIN GUTTERS (1987)
- HOMES WITHOUT RAIN GUTTERS (1990)

TOTAL HOMES SURVEYED: 177 HOMES

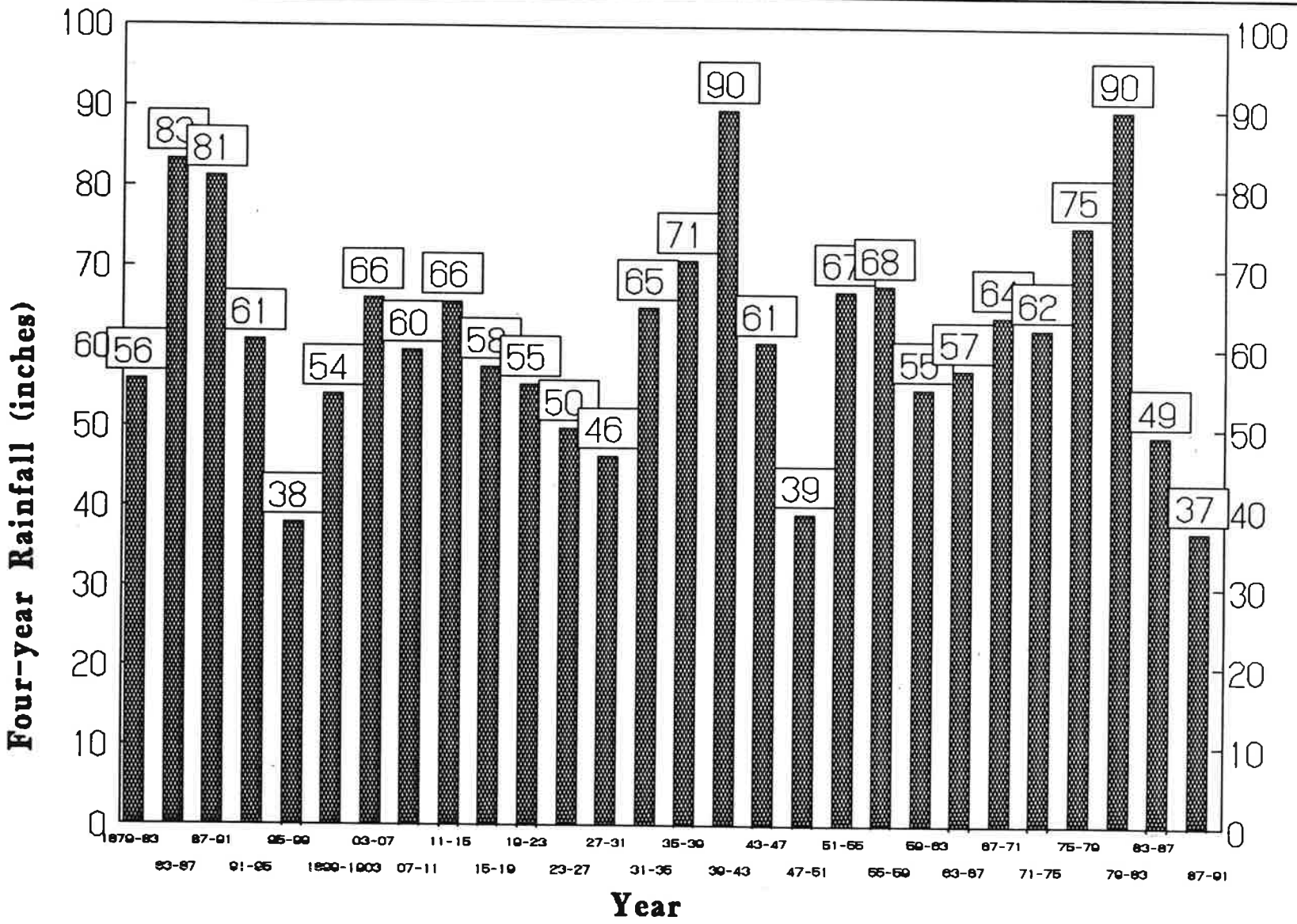
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

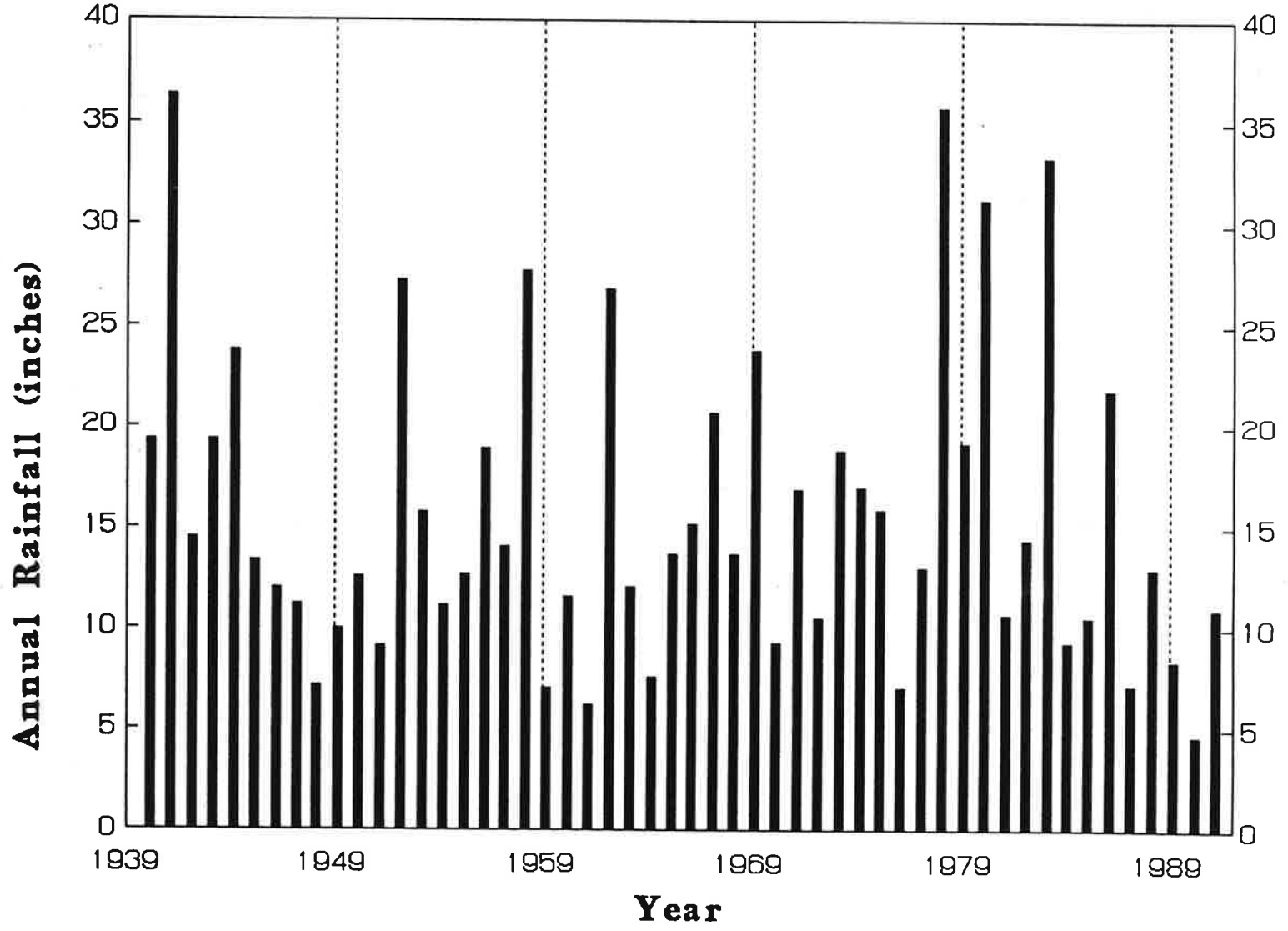
PROJECT NO.: 49-97D | DATE: DECEMBER 1991

RAIN GUTTER SURVEY

FIGURE 6-1.1



BING YEN & ASSOCIATES		REGIONAL RAINFALL FOR 4-YEAR INTERVALS
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION		
PROJECT NO.: 49-97D	DATE: DECEMBER 1991	FIGURE 6-2.1



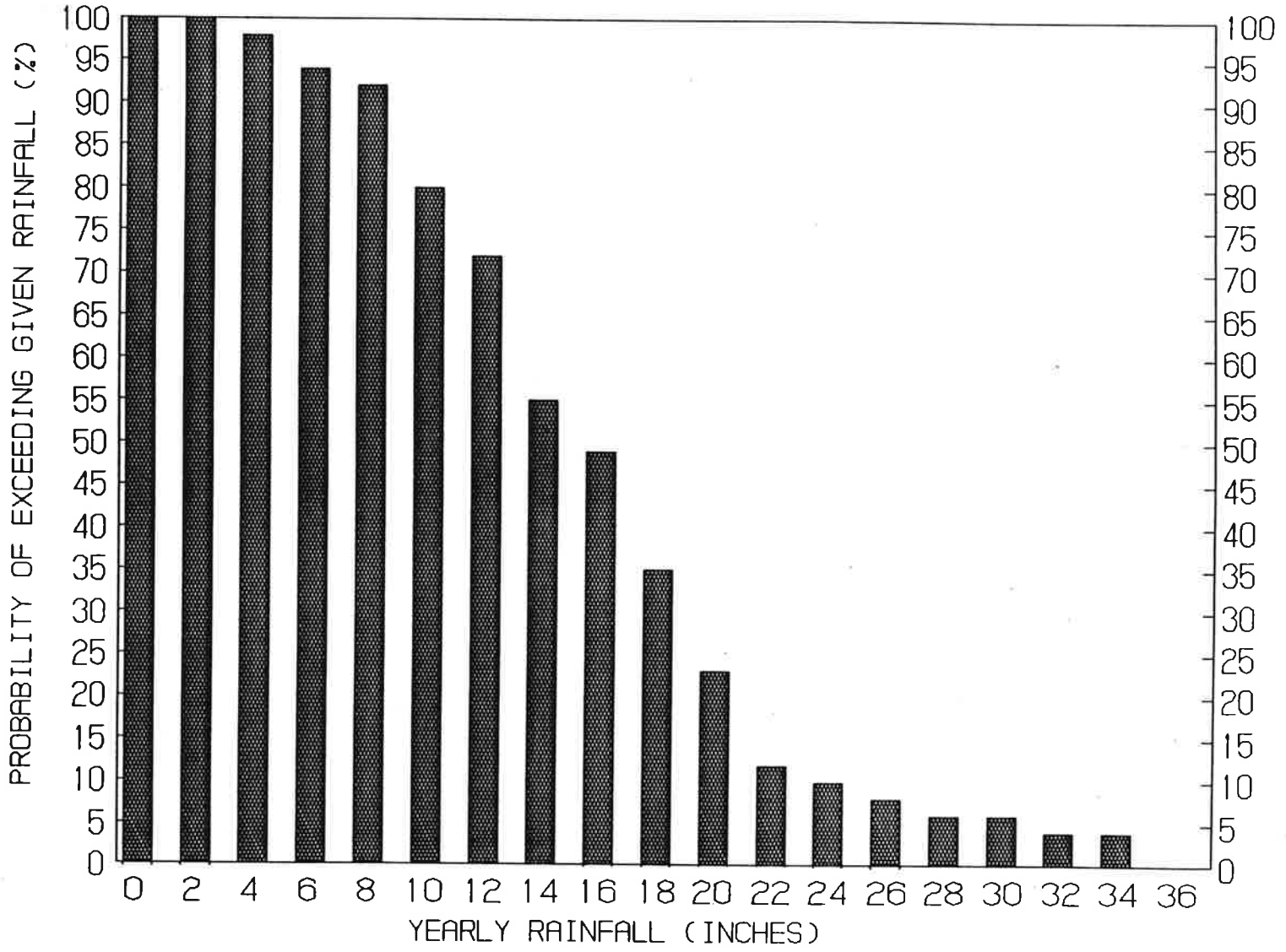
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

51-YEAR RAINFALL RECORDS OF THE COASTAL AREA NEAR BRM (STA. 447A.C., 1239)

FIGURE 6-2.2



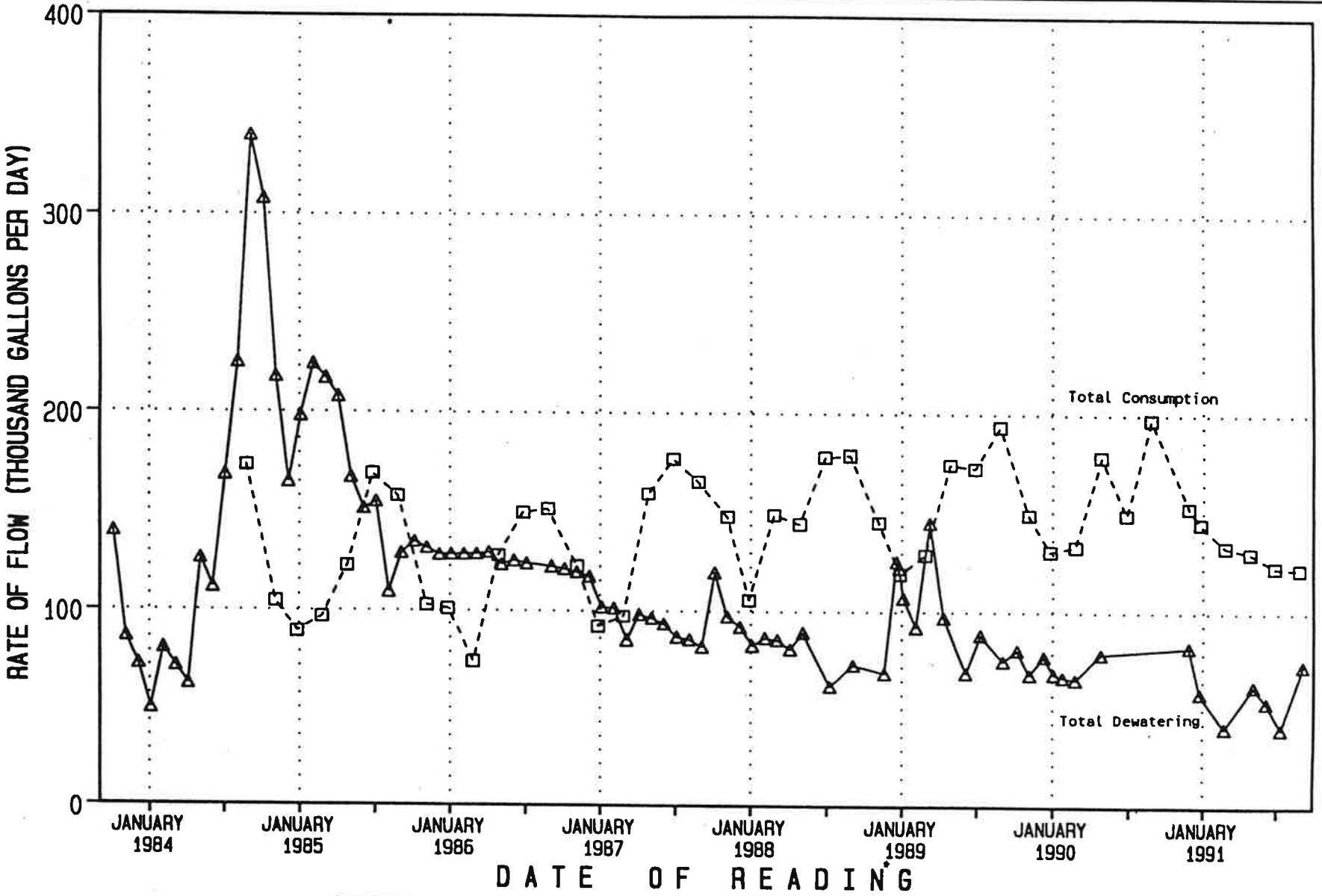
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

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RAINFALL PROBABILITY DISTRIBUTION FOR BIG ROCK MESA

FIGURE 6-2.3



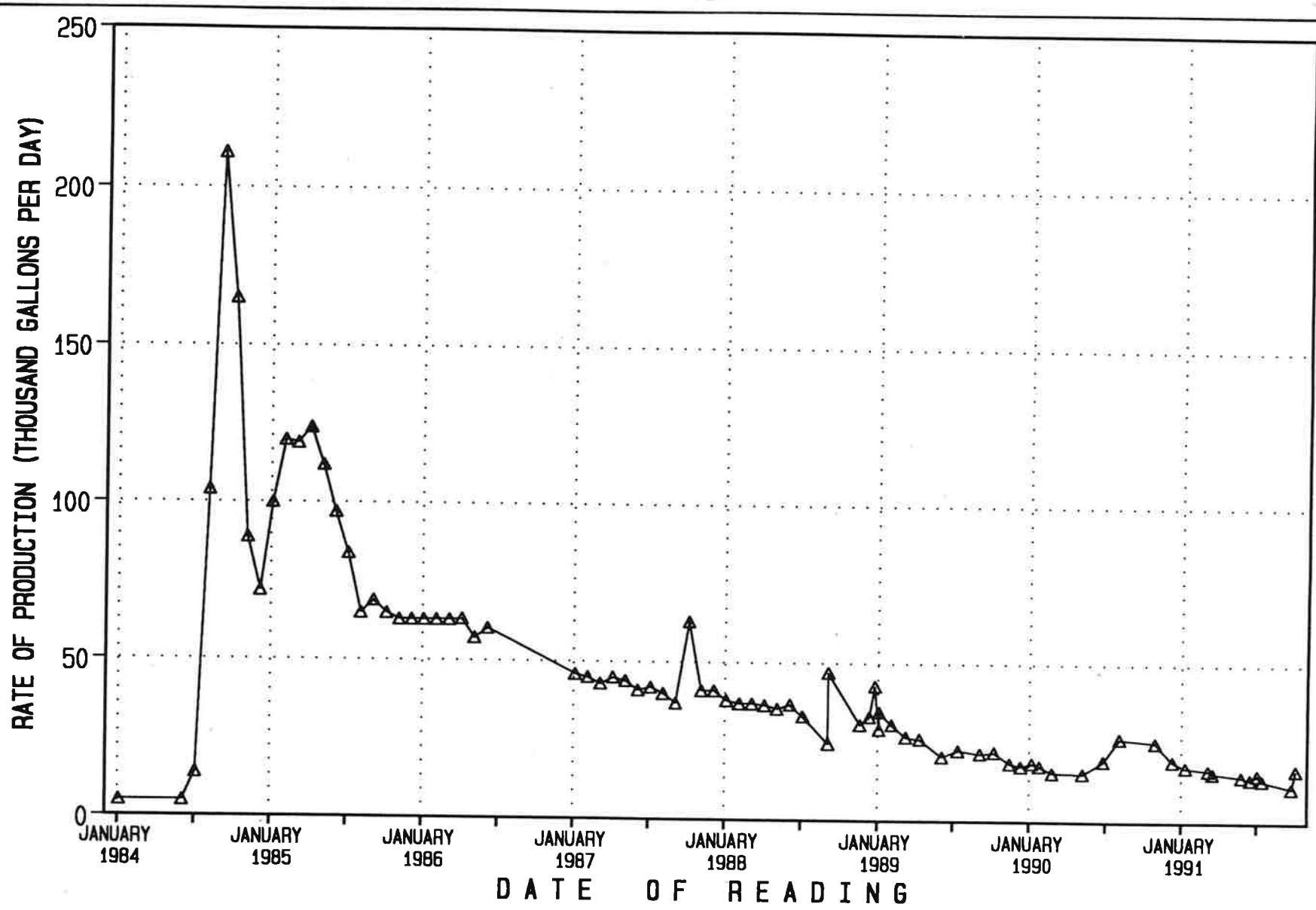
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TOTAL DEWATERING PRODUCTION VERSUS TOTAL WATER CONSUMPTION

FIGURE 6-2.4



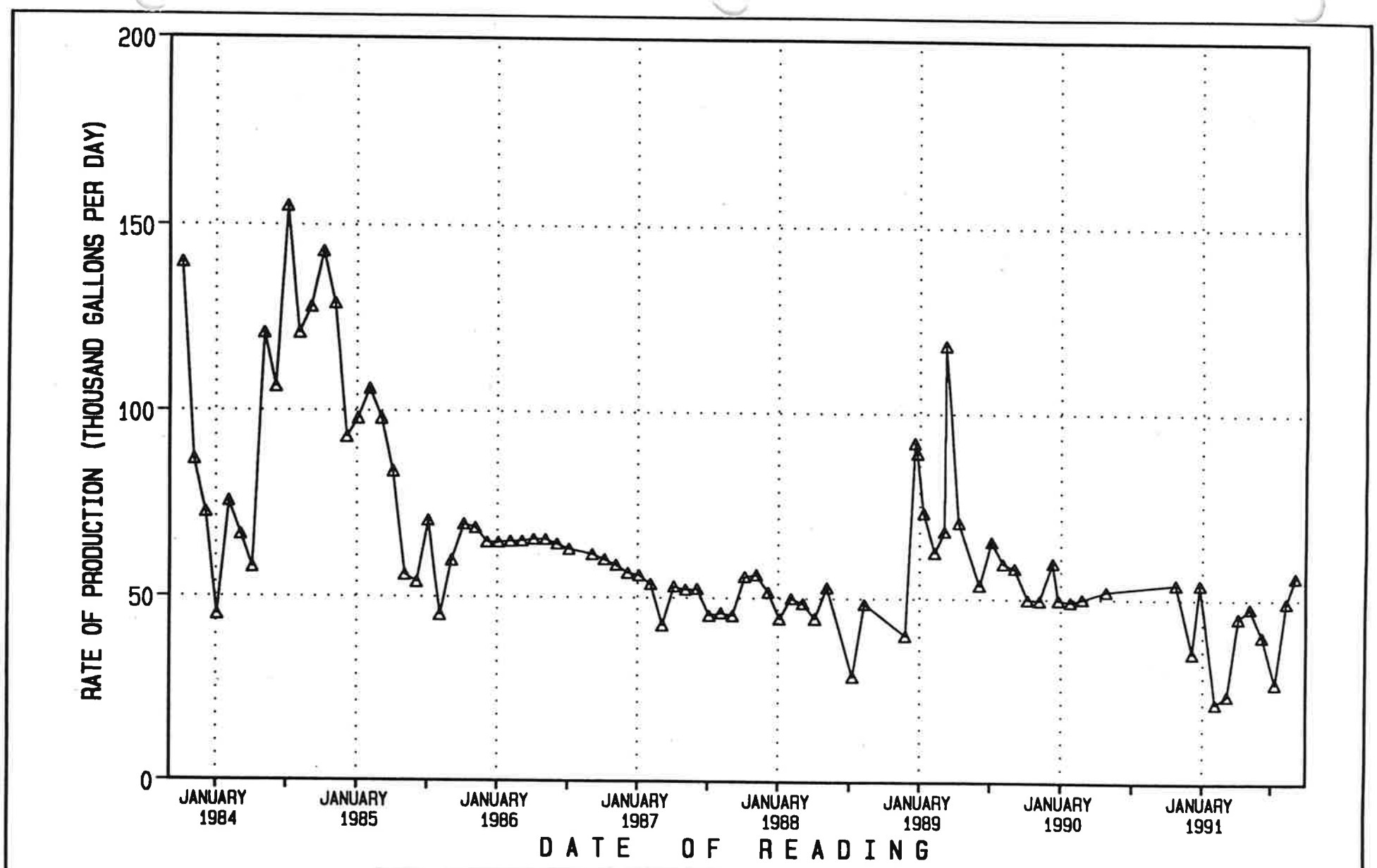
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TOTAL HYDRAUGER PRODUCTION HISTORY

FIGURE 6-2.5



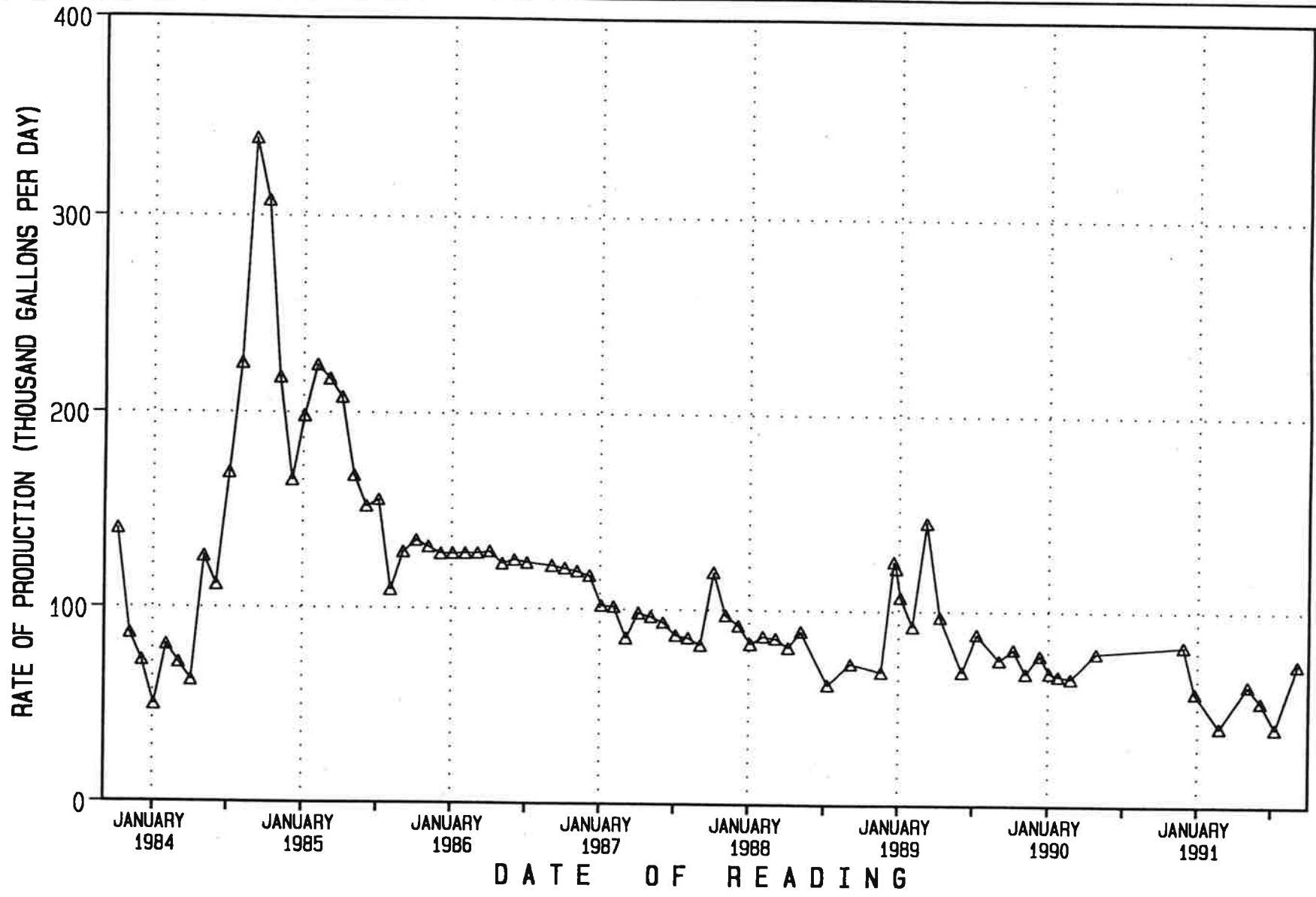
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TOTAL DEWATERING WELL PRODUCTION HISTORY

FIGURE 6-2.6



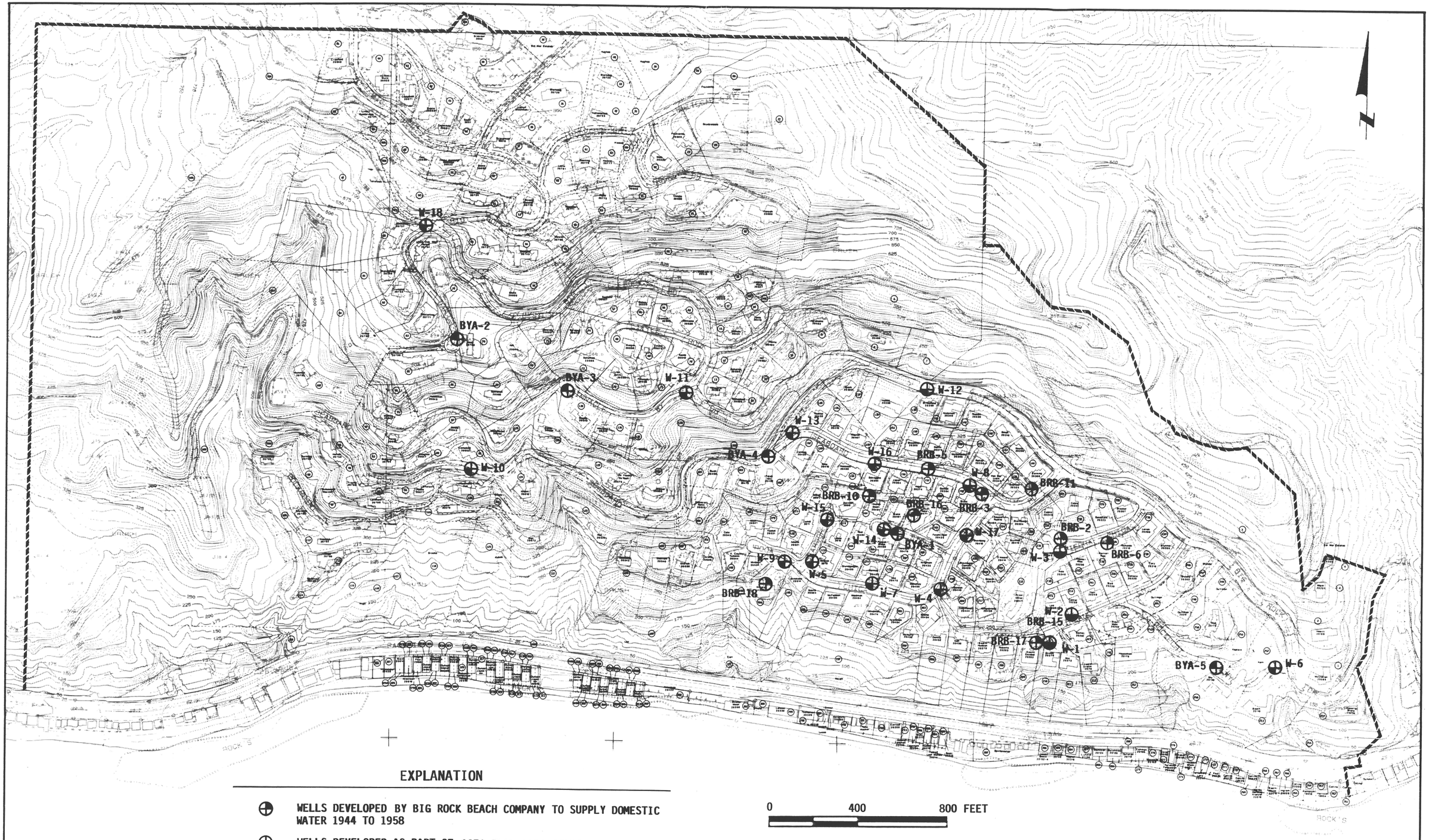
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

TOTAL DEWATERING PRODUCTION HISTORY
(WELLS AND HYDRAUGERS)

FIGURE 6-2.7



EXPLANATION

- WELLS DEVELOPED BY BIG ROCK BEACH COMPANY TO SUPPLY DOMESTIC WATER 1944 TO 1958
- WELLS DEVELOPED AS PART OF 1971 THRU 1974 DEWATERING EFFORT
- WELLS DEVELOPED AS PART OF 1983 DEWATERING EFFORT
- WELLS DEVELOPED POST SEPTEMBER 1988 BY BYA

0 400 800 FEET

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

APPROXIMATE HISTORIC WELL LOCATIONS

FIGURE 6-2.8

650
600
550
500
450
400
350
300
250
200
150
100
50

EXPLANATION

- ● PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◐ NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◕ MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- ○ STAND PIPE PIEZOMETER
- ——— ESTIMATED EQUAL GROUNDWATER CONTOUR ELEVATION (MSL) IN FEET, DASHED WHERE APPROXIMATE

NOTE: 1. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

0 400 800 FEET

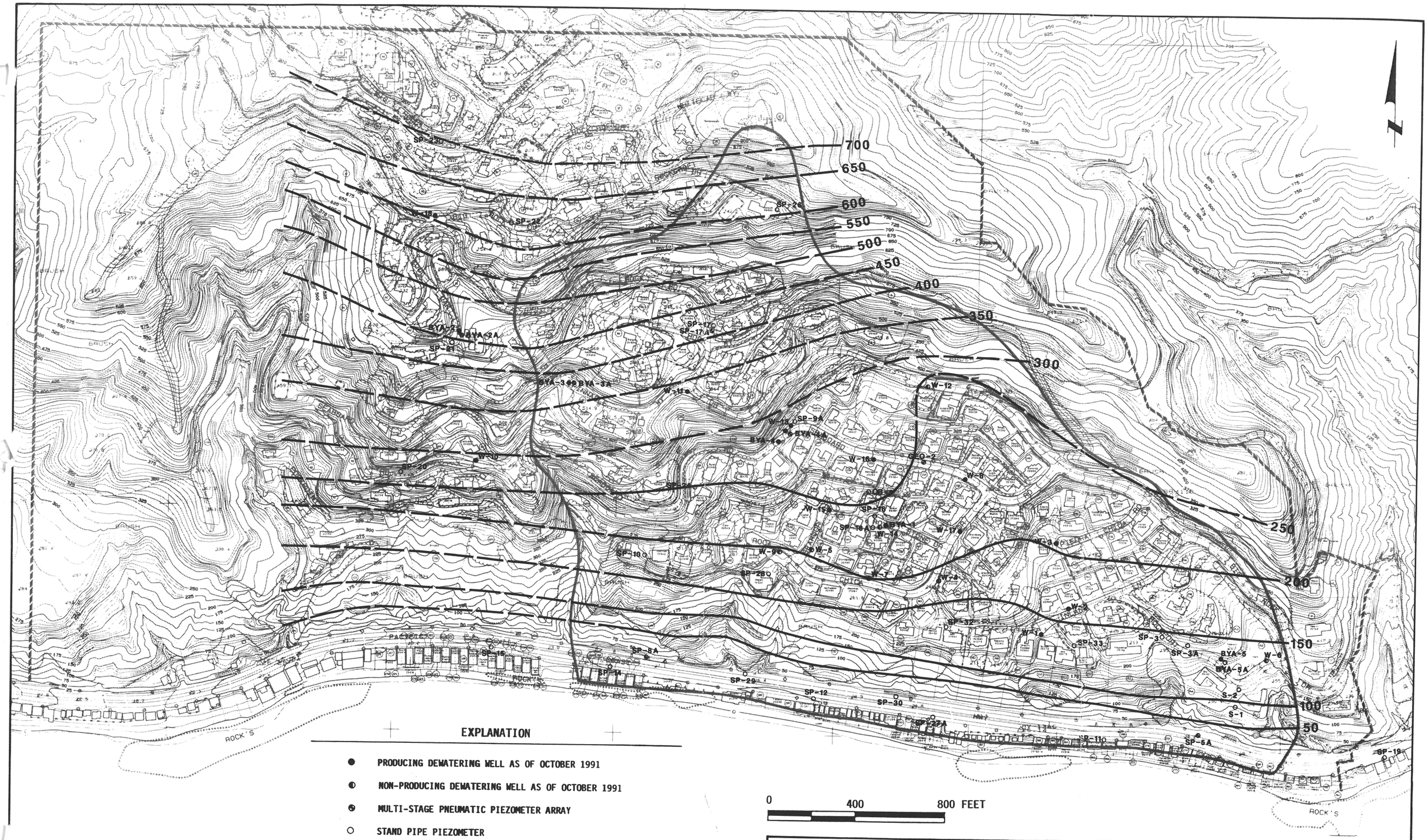
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ESTIMATED GROUNDWATER CONTOURS AS OF OCTOBER 1991

FIGURE 6-2.12



EXPLANATION

- ● PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◐ NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◉ MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- ○ STAND PIPE PIEZOMETER
- ——— ESTIMATED EQUAL GROUNDWATER CONTOUR ELEVATION (MSL) IN FEET, DASHED WHERE APPROXIMATE

NOTE: 1. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

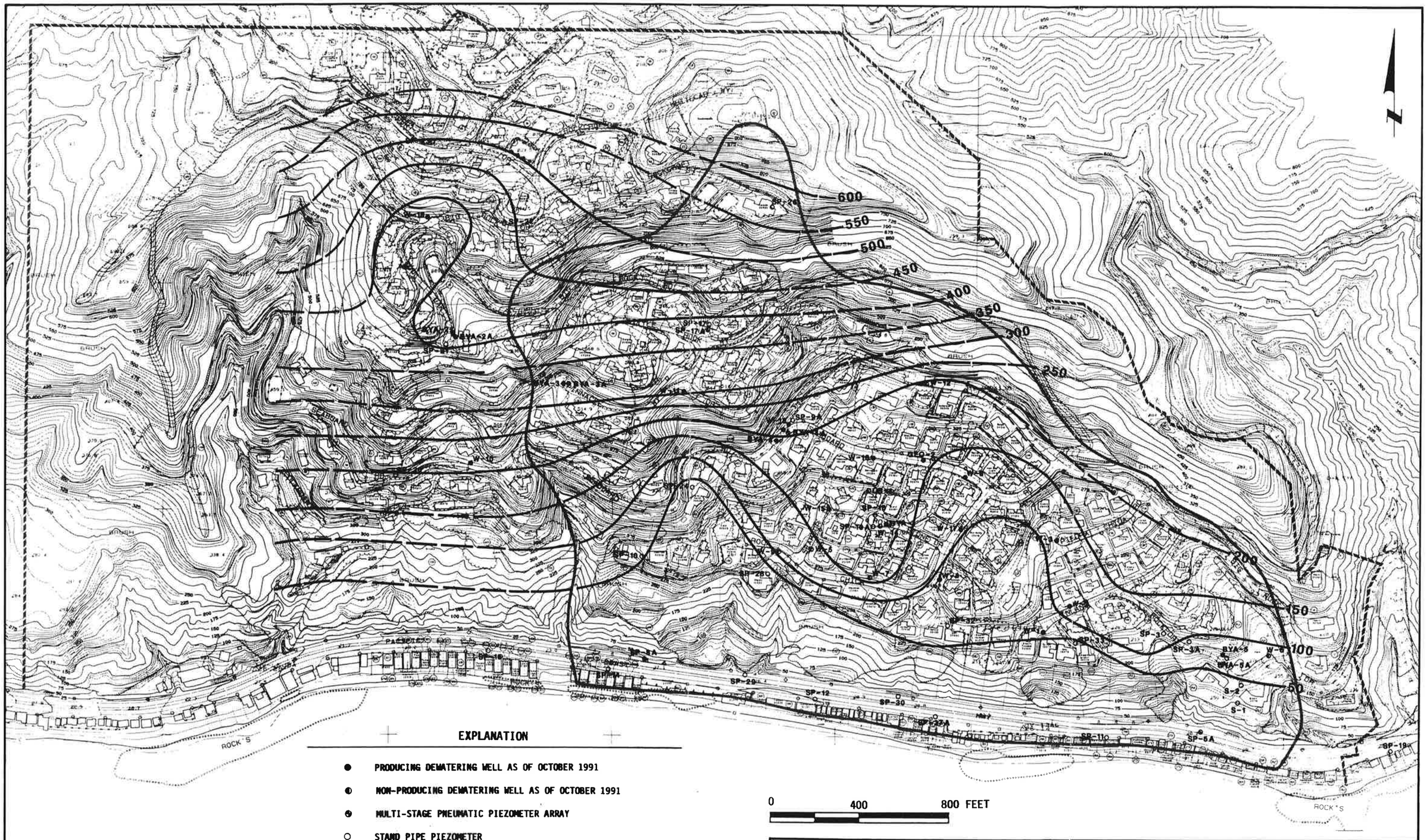
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ESTIMATED GROUNDWATER CONTOURS AS OF SEPTEMBER 1983

FIGURE 6-2.9


N
600
550
500
450
400
350
300
250
200
150
100
50
EXPLANATION
PRODUCING DEWATERING WELL AS OF OCTOBER 1991
NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
STAND PIPE PIEZOMETER
ESTIMATED EQUAL GROUNDWATER CONTOUR ELEVATION (MSL) IN FEET, DASHED WHERE APPROXIMATE
NOTE: 1. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS
0
400
800 FEET
BING YEN & ASSOCIATES
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION
PROJECT NO.: 49-97D
DATE: DECEMBER 1991
ESTIMATED GROUNDWATER CONTOURS AS OF SEPTEMBER 1988
FIGURE 6-2.10

EXPLANATION

- PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- STAND PIPE PIEZOMETER
- INTERPRETED EQUAL FEET OF CHANGE CONTOUR, DASHED WHERE APPROXIMATE

NOTE: 1. GROUNDWATER LEVEL CHANGE INTERPRETED FROM ESTIMATED GROUNDWATER CONTOURS
2. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

0 400 800 FEET

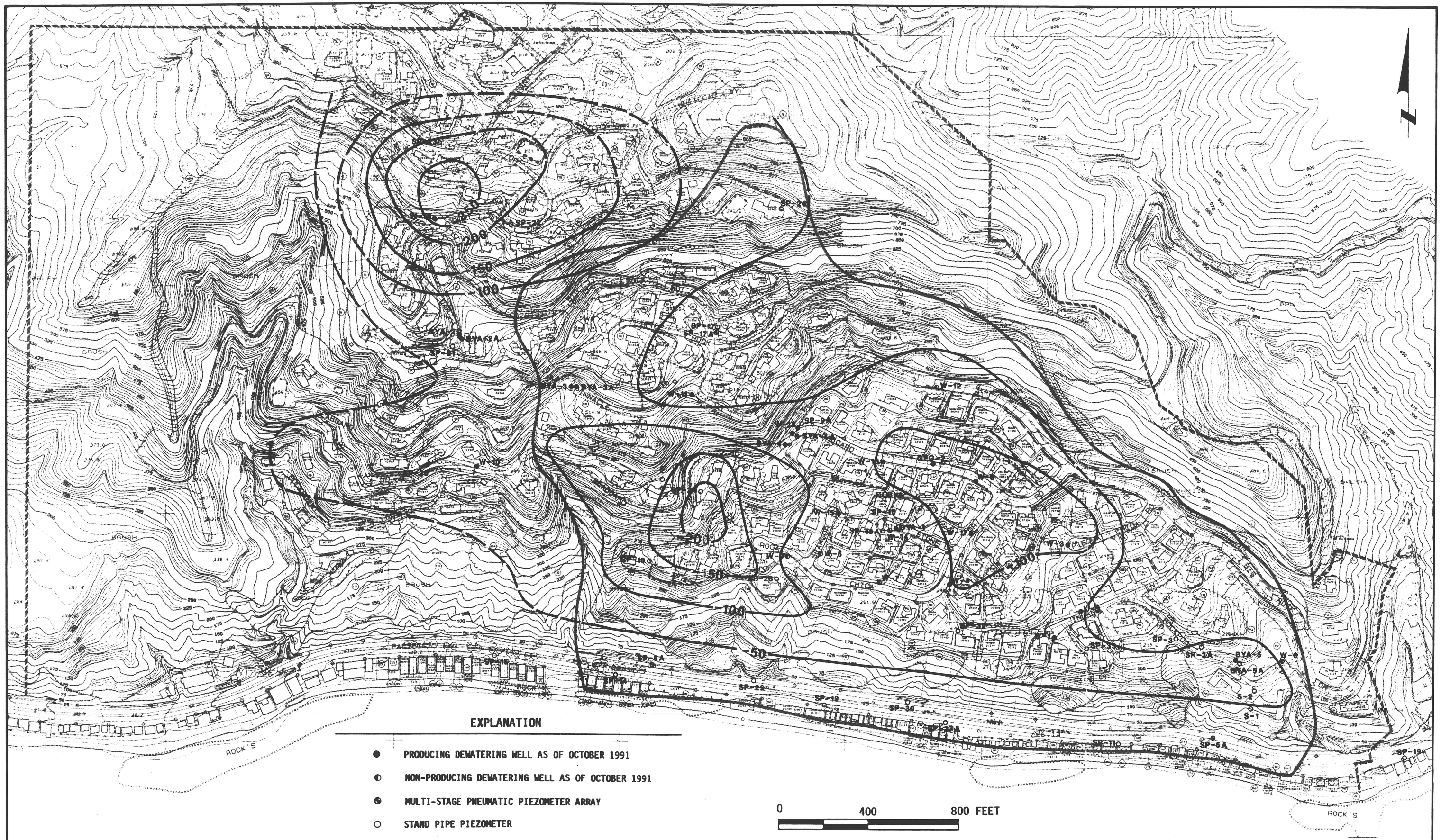
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

CHANGE IN GROUNDWATER LEVELS;
SEPTEMBER 1988 TO OCTOBER 1991

FIGURE 6-2.16



EXPLANATION

- ● PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◐ NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◉ MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- ○ STAND PIPE PIEZOMETER
- ——— INTERPRETED EQUAL FEET OF CHANGE CONTOUR, DASHED WHERE APPROXIMATE

NOTE: 1. GROUNDWATER LEVEL CHANGE INTERPRETED FROM ESTIMATED GROUNDWATER CONTOURS
2. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

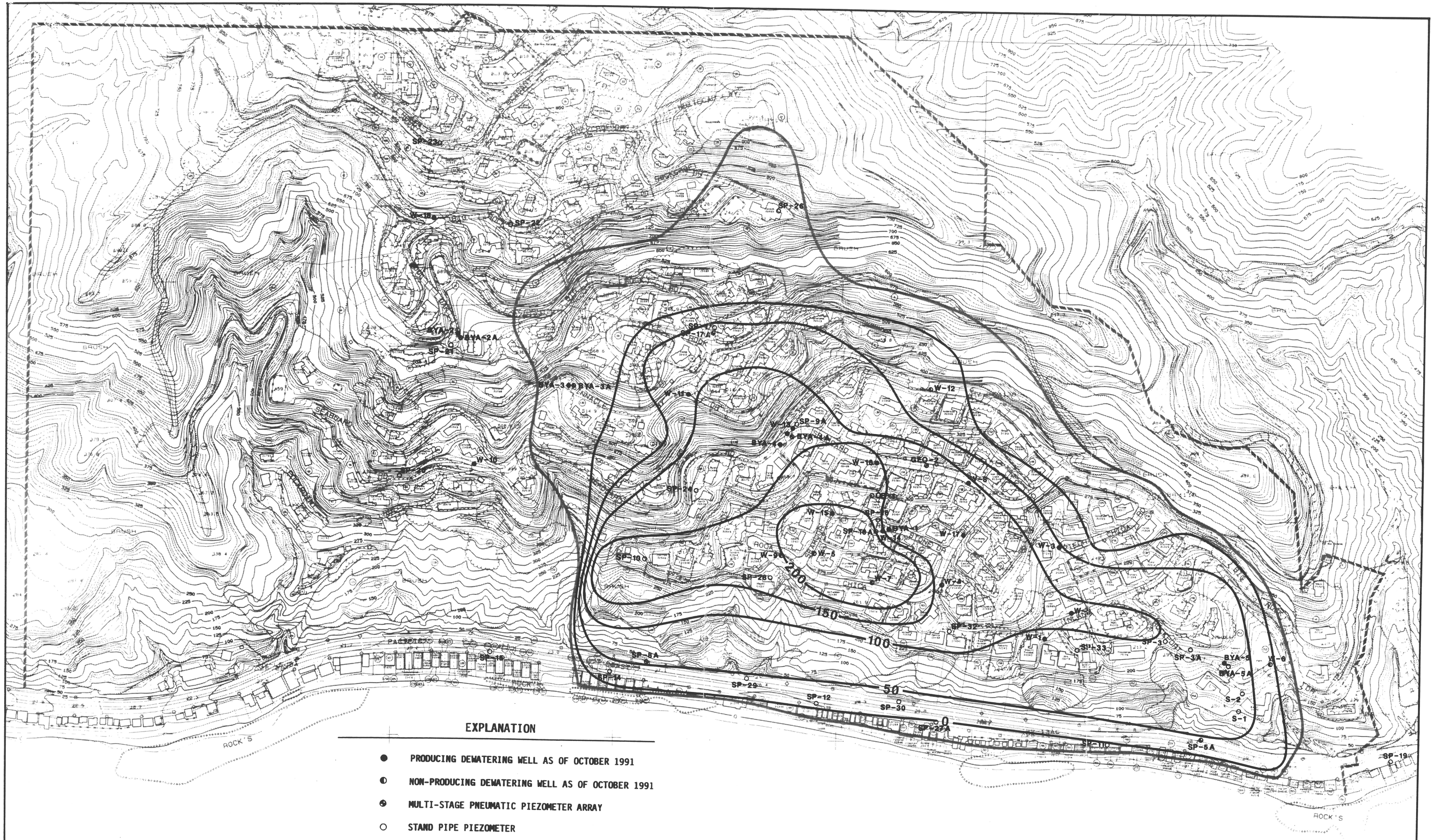
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

CHANGE IN GROUNDWATER LEVELS; SEPTEMBER 1983 TO JANUARY 1989

FIGURE 6-2.14



EXPLANATION

- ● PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◐ NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ⊕ MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- ○ STAND PIPE PIEZOMETER
- ——— INTERPRETED EQUAL PIEZOMETRIC HEAD LINE

NOTE: 1. PIEZOMETRIC ELEVATIONS INTERPRETED FROM ESTIMATED GROUNDWATER CONTOUR
2. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

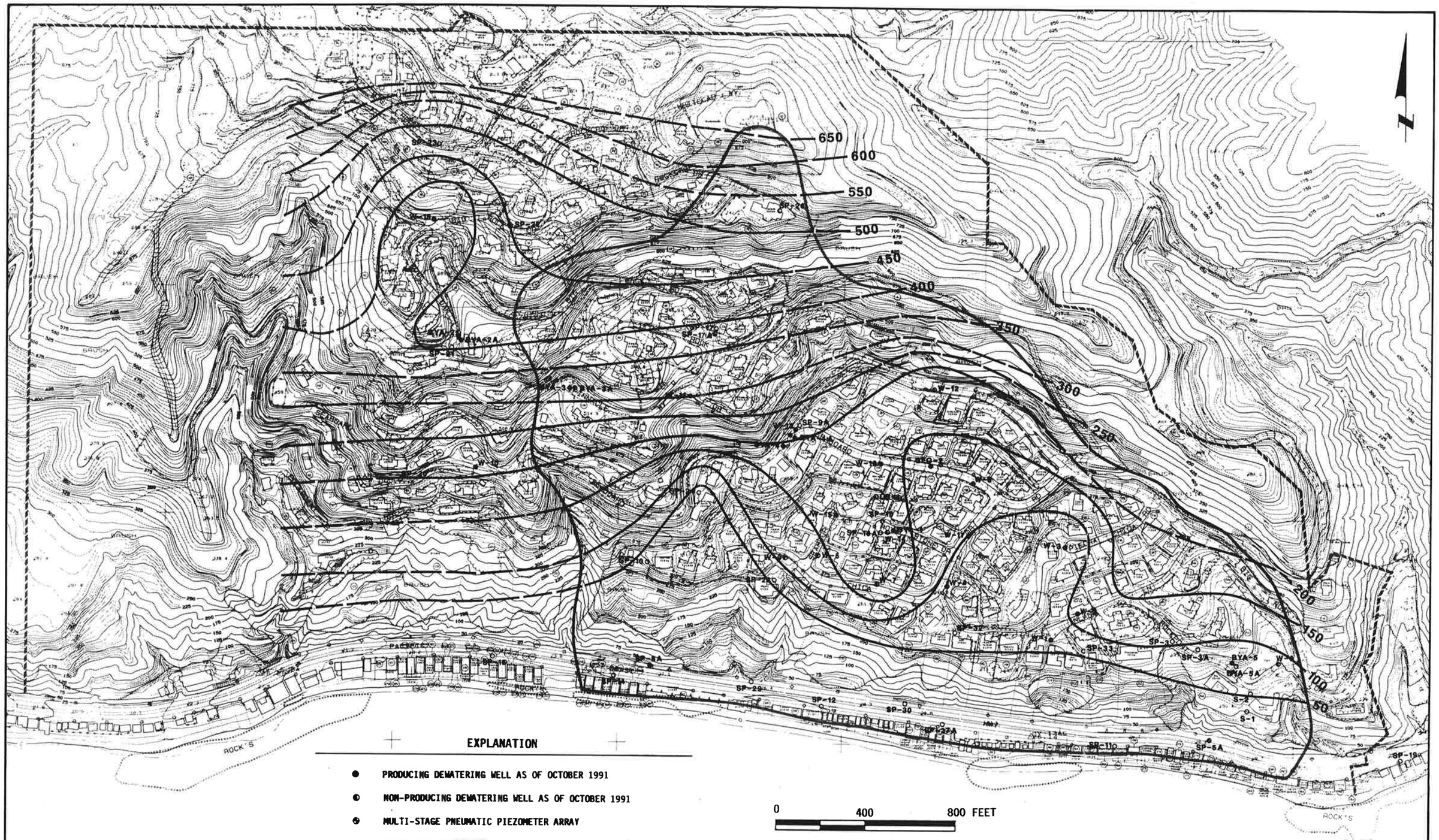
BING YEN & ASSOCIATES

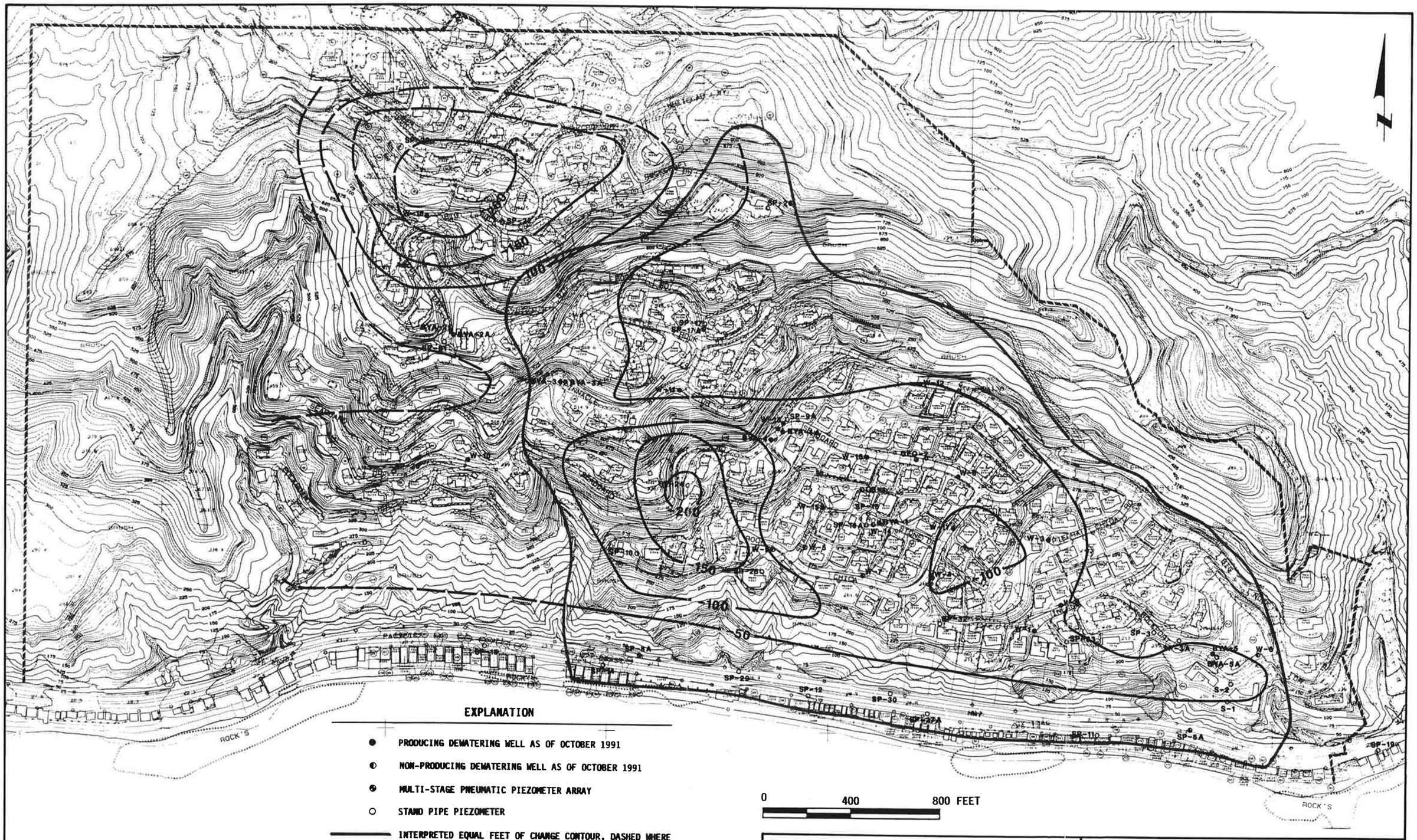
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ESTIMATED PIEZOMETRIC HEAD ACTING ON INTERPRETED 1983 PRIMARY SLIDE SURFACE AS OF OCTOBER 1991

FIGURE 6-2.17


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EXPLANATION

- ● PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ◐ NON-PRODUCING DEWATERING WELL AS OF OCTOBER 1991
- ⊛ MULTI-STAGE PNEUMATIC PIEZOMETER ARRAY
- ○ STAND PIPE PIEZOMETER
- —— INTERPRETED EQUAL FEET OF CHANGE CONTOUR, DASHED WHERE APPROXIMATE

NOTE: 1. GROUNDWATER LEVEL CHANGE INTERPRETED FROM ESTIMATED GROUNDWATER CONTOURS
2. GROUNDWATER MONITORING INSTRUMENTATIONS SHOWN AS EXISTING OCTOBER 1991 IN APPROXIMATE LOCATIONS

0 400 800 FEET

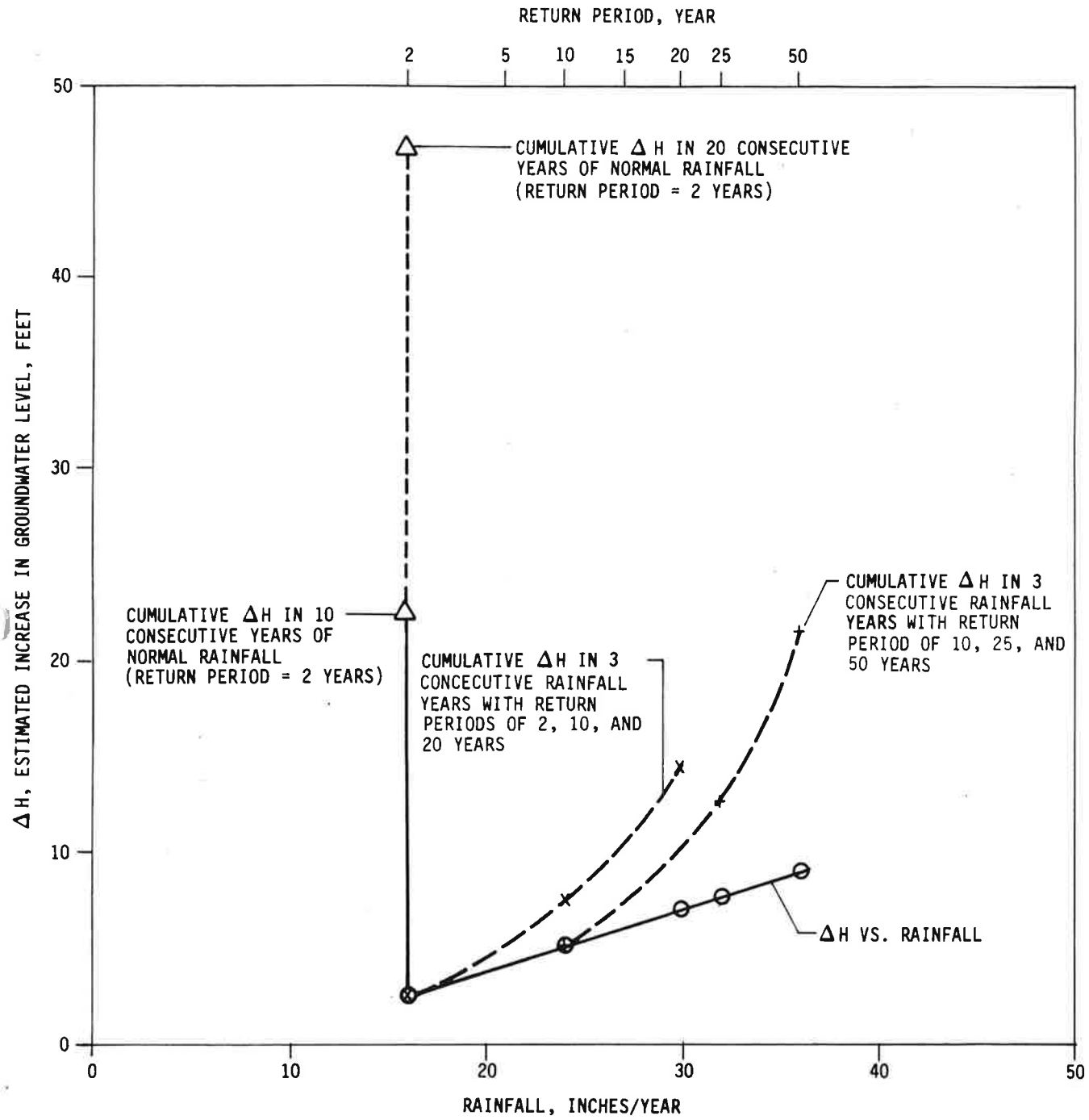
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

CHANGE IN GROUNDWATER LEVELS;
SEPTEMBER 1983 TO OCTOBER 1991

FIGURE 6-2.15



BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ESTIMATED AVERAGE GROUNDWATER LEVEL INCREASES IN THE MAIN BIG ROCK MESA GROUNDWATER BASIN DUE TO CONSECUTIVE WET YEARS WITHOUT A NEW SEWER SYSTEM

FIGURE 6-2.18

SECTION 7.0

STATIC STABILITY

7.1 GENERAL

This section presents the results of an engineering evaluation of the current prevailing (December 1991) gross factor of safety of the main BRM landslide mass. Stability analyses have also been performed for a number of subregions in the study area based on observed geotechnical features described in Sections 4.0, 5.0 and 6.0. In addition, this section analyzes the theoretical maximum factors of safety attainable by additional dewatering of the main BRM landslide area. The "maximum attainable condition" is an idealized state in which all of the rocks or aquifers above the deepest critical slide surface have been drained to their specific retention, i.e. a condition where there is no free water surface above the basal slide surface. This condition may require extensive deep dewatering and installation of a sewer system. In other words, this is the condition representing the maximum factor of safety attainable without grading, buttressing or implementation of an active retaining system.

Stability analyses have been performed for the following regions (see Figure 2-1.4 for the map locations of the regions):

- Southeast Region : This region is part of the main BRM landslide mass. It is located east of the Inland Lane fault. This region underwent substantial cracking in 1971-1973, fully 10 years before the 1983 episode of movement. Some localized areas within the region are subject to recent small, but perceptible ground movement.

- Bluff Region: This region forms the southern part of the main BRM landslide mass, including the bluff portion within the Southeast Region. It underwent substantial cracking during the 1983 main BRM landslide. The eastern portion of the Bluff Region within the mass of the Southeast Region was also extensively cracked during the 1971-1973 period.

- Headscarp Region: This region includes the headscarp of the main BRM landslide and upslope areas. This region generally perches above Big Rock Drive and extends northwesterly following the crack zone of the 1983 episode of movement.

- South-Facing Slope Region within the Western Extension area: This region consists of a large landslide complex encompassing smaller landslides, including the "Love Landslide" which was activated in 1975.

It should be noted the boundaries of the above regions shown in Figure 2-1.4 are intended to accentuate their gross physiographic, geomorphological and geotechnical environments for stability analysis and illustration purposes. In reality, the boundaries are transitional zones rather than individual lines.

combination of loadings due to gravity, groundwater and seepage, structure/facilities surcharge or earthquakes. Thus, the accuracy and confidence level of a stability evaluation will depend on the accuracy and credibility of the various input data that affect the estimate of the magnitudes of the driving and resisting forces. These data include:

- Ground surface geometry and topography;
- Configuration and geometry of landslide surfaces;
- Magnitude and distribution of groundwater pressure and seepage forces acting on the slide surface;
- Shear strength (shear resistance) characteristics of the materials along the landslide/failure surfaces as a function of deformation (past or future);
- The weight and distribution of mass above the landslide surface which can be determined by the knowledge of unit weights of the subsurface materials and which, together with water pressure, determines the gravity driving force as well as the magnitude of frictional resistance of the materials along the landslide surface; and
- External sources and magnitudes of driving and resisting forces.

The topographic base map used by BYA during this investigation is based on high resolution stereographic aerial photographs (1989) of the site area. This map reflects ground surface information and is considered sufficiently accurate for the purposes of stability analysis. The density/unit weight values of different rock units in the study area were obtained based on laboratory determination. The laboratory rock samples used for density determination are cored and do not contain the fractures and fissures of the rock mass in the field. Therefore, the laboratory density tends to be higher than what actually exists in the field. Since there is no reliable and economical way to determine the field rock mass density, which also varies in the field from location to location, an average total wet unit weight of 140 pounds per cubic foot (pcf) was chosen for use in the analysis. Variations from this value will result in little or no sacrifice in accuracy. External sources of driving or resisting forces are considered in seismic stability analyses (Section 8.0) and in the development of mitigation options (Section 9.0).

The remaining factors (landslide surface, groundwater and strength characteristics) are addressed in subsequent subsections.

7.2.2 Landslide Configurations

Subsurface information collected prior to the initiation of this work was rather limited for various reasons. Many borings were too shallow or insufficient in detail to delineate the BRM landslide configurations. The usable information consisted primarily of data from a number of slope inclinometers near the bluff top and the toe of the landslide along the PCH, two slope inclinometers (SP-3 and SP-4) in the eastern mesa, three slope inclinometers (SP-26, SP-35 and SP-38) near the headscarp area in the Hansch property (20600 Rockcroft Drive), and one slope inclinometer (SP-17) near the intersection of Big Rock Drive and Little Rock Way in the upper/central mesa that were deep enough to intercept primary

(basal) slide surfaces for landslide delineation purposes. In other words, little or no control on the depth or configuration of landslide surfaces in the Central Region, western portion of the main slide area and the Western Extension area existed at the start of this work. Thus, the landslide surfaces developed and evaluated previously involved a relatively high degree of uncertainty.

Through the current effort (including five deep borings, dip meter logging, high resolution gamma logging, video logging of dewatering wells, continued monitoring of a net work of new and existing inclinometers, and more detailed field mapping), a considerably improved picture of the 1983 BRM landslide surfaces was developed. However, the current work has its constraints as well. As will be discussed later, further subsurface information in certain areas such as the Western Extension area, the Shoreline fault, certain bluff zones and the Southeast Region are needed.

For stability analysis purposes, five cross sectional profiles through the main BRM landslide area and one cross sectional profile through the South-Facing Slope Region in the Western Extension area were developed by superimposing groundwater levels and deeper potential slide surfaces upon the geotechnical cross sections shown in Section 4.0. These cross sections are shown in Figures 7-2.1 to 7-2.6. The locations of these cross sectional profiles are shown in Figure 4-1.2. In general, Cross Section A-A' was developed to represent the conditions for the Southeast Region and Cross Sections B-B' through E-E' were developed to represent the conditions throughout the rest of the main slide. Cross Section F-F' was developed for the South-Facing Slope Region in the Western Extension area. In addition to delineating the 1983 landslide surfaces, these cross sections also depict deeper fractured rock zones which may be relics of ancient slides or tectonic activities. These deeper potential slide surfaces are evidenced by the presence of extremely poor quality rock mass (with an RQD value near zero - i.e., a highly-fractured rock mass) or by the presence of deeper gouge materials or planes of weakness (shears, bedding, etc.). Two east-west oriented cross sections (G-G' and H-H') were also developed (Figures 4-1.10 and 4-1.11) in order to provide a better overall perspective of the subsurface conditions of the main BRM landslide area and the adjacent Western Extension. A computer generated 3-dimensional drawing of the BRM area (Figure 2-1.3) and the slide surface configuration of the main slide mass (Figure 2-1.5) are also included. These figures were used in the 3-dimensional slope stability analysis which is discussed below.

7.2.3 Groundwater Levels

Groundwater levels can be monitored through measurements taken in wells, pneumatic piezometers or standpipes within inclinometers. Shortly after the 1983 BRM landslide, a series of wells and inclinometers were installed for dewatering and movement monitoring purposes. Since this initial effort, a series of 7 multi-stage piezometers at 3 inclinometer locations (SP-5A, SP-8A and SP-17A) have been installed along with the 5 BYA deep wells to supplement the groundwater observation array. Information regarding groundwater levels at the time of main BRM landslide in 1983 is based on data from the initial monitoring network while the prevailing groundwater level information is based on measurements taken from the current instrumentation array (Figure 3-8.1). Both 1983 and current groundwater levels are noted in the cross sectional profiles shown in Figures 7-2.1 to 7-2.6.

Given that the current groundwater observation array is more extensive, and that the data suggests steady state conditions (see Section 6.0), the prevailing groundwater levels depicted in Figures 7-2.1 to 7-2.6 are believed to involve a higher degree of certainty than the extrapolated 1983 values. It should also be noted that, because of the relatively low permeability of the in situ rock masses, especially the Sespe and Vaqueros formations, and the presence of groundwater barriers (faults and gouge materials along some of the landslide surfaces), there can be areas of localized perched groundwater with water levels higher than the groundwater levels indicated. This is because the present groundwater levels shown are interpolated and extrapolated from locations which are still too far apart relative to the complex geological conditions of the site.

7.2.4 Shear Strength Characteristics

Of all the influencing factors, the shear strength characteristics of the materials along existing and potential slide surfaces are probably the most important and most difficult to determine. In general, strength properties are determined by performing in situ shear testing at representative locations or by laboratory testing on representative samples. Statistically, the higher the number of tests on samples from more representative locations and the broader the coverage in geologic material types, the more certainty there is in determining the strength magnitudes and distribution.

In general, determining strength by the appropriate extent of geotechnical investigation and testing is only economically feasible for a small area. For the BRM landslide area, extensive testing to eliminate uncertainties in the determination of shear strength characteristics is neither possible nor practical since the landslide involves a large, geotechnically complex area spanning 136 acres and 41 million cubic yards of slide mass. The cost of obtaining a sufficient number of representative samples for statistical or probabilistic shear strength characterization purposes would be prohibitively high since it would involve the drilling and coring of numerous deep, close-spaced borings through the basal rupture surfaces and deeper potential sliding zones. Moreover, such an expensive field and laboratory program would still not eliminate all uncertainties, since it is difficult to obtain representative, good quality failure surface samples (gouge and/or highly fractured materials) even with state-of-the-art drilling procedures.

For the BRM landslide area, reasonable assumptions can be made with respect to the state of stability at the onset of the main slide movement. It can be confidently assumed with a high degree of certainty that a factor of safety of about unity existed at the time when the landslide was observed to be in progress in 1983. This allows for the analytical determination of the average shear strength characteristics of the materials along the landslide surfaces through back-calculation. The shear strength of a material includes a friction component expressed in terms of angle of internal friction (ϕ) and a cohesion component (C). A back-calculated shear strength value will not be unique and will involve an infinite number of potential combinations of C and ϕ values. However, the 1983 landslide involved activation of slides which, based on available geological data, had been tectonically disturbed and had moved tens to several hundreds of feet prior to the 1983 episode. Under such conditions, the shear strength of the slide surface material most likely will have approached its residual value (i.e., residual shear strength) which generally involves little or no cohesion component. Thus, it is reasonable to assume that the shear strengths

7.2.5 Analytical Methodology

A three-dimensional computer plot of the delineated primary slide surface of the main BRM landslide is shown in Figure 2-1.5. The three-dimensional plot represents a composite of various delineated cross sectional profiles (A-A' to E-E' shown in Figures 7-2.1 to 7-2.5) through the landslide area. As can be seen from this figure, the three-dimensional slide surface approximates a bowl with its downslope length similar in magnitude to its width. The stability of this three-dimensional failure surface can best be represented by a three-dimensional analysis to more realistically simulate its true three-dimensional configurations than the conventional examination of a series of two-dimensional profiles along the down-slope direction. The slide surface in the Southeast Region is also bowl-shaped (Figure 2-1.6) and, like the primary slide surface of the main BRM landslide, is three-dimensional in nature.

A series of two- and three-dimensional stability analyses were performed. Three-dimensional analyses were performed for the main BRM landslide area and the Southeast Region within the main landslide area. Two-dimensional analyses were performed for five two-dimensional profiles (Figures 7-2.1 to 7-2.5) through the main slide to evaluate the reasonableness of the backfitted shear strength values and to analyze the relative stability of various locations within the main landslide. Two-dimensional analyses were also utilized to evaluate the stability of the Bluff and Headscarp Regions, which are elongated in areal extent and can be reasonably simulated by a two-dimensional approximation. The stability evaluation for the South-Facing Slope Region in the Western Extension area is based on two-dimensional approximation, since available data are not sufficient to accurately delineate the three-dimensional limits of potential failure surfaces in these areas.

7.2.6 Additional Uncertainties

Although the current efforts have resulted in a significant improvement in the project data in terms of quality and quantity, various uncertainties still exist for stability evaluation purposes. Some of these uncertainties with respect to groundwater level, landslide surfaces and strength characteristics have been described in previous sections. Additional uncertainties include the following:

1. A major focus in BYA's efforts-to-date has been the dewatering and delineation of the primary slide surfaces in the main BRM landslide area. Available data are insufficient to delineate with as high a level of accuracy and confidence as in the main slide area, the potential landslide surfaces and groundwater conditions in various regions, especially in the Bluff Region and in the Western Extension area. For example, in the 79-acre Western Extension area, there exist only two wells (W-10 and W-18) and four inclinometers (SP-20 through 23) and two deep borings (BYA-2 and GEO-1). Also, in the Bluff Region it appears that, based on the observed crack patterns and limited inclinometer data, subsidiary (conjugated) slide surfaces developed during the movement of the main landslide, but no downhole observation data is currently available to confirm such failure surfaces in the Bluff Region.

2. For areas where mass movement did not occur, engineering backfit analysis could not be performed to enable detailed assessment of prevailing and future stability with a desirable high degree of certainty. These areas include the Bluff Region, the South-Facing Slope Region in the Western Extension and part of the Headscarp Region.

All of the limitations and uncertainties inherent in the stability analyses presented in this report must be recognized and understood before one can accurately evaluate the present and future gross stability of the BRM area and the various regions and before one can intelligently evaluate future mitigation measures.

7.3 STABILITY EVALUATION & RESULTS

7.3.1 Foreword

The engineering evaluation in this section assesses the gross stability of the primary slide surface of the BRM landslide and the gross stability of various regions in the BRM area. No stability evaluation has been made of any specific lots or parcels. Lot-specific stability is heavily dependent on site-specific geologic and groundwater conditions, and is not within the scope of this study. As explained in the next paragraph, individual lots can be considerably less stable than the gross stability of the region in which the lots are located.

Gross stability is a stability assessment of a relatively large region based on generalized conditions prevalent throughout the region. Such conditions include the gross behavior and characteristics of soils and rocks in the region, average groundwater levels, etc. For example, the groundwater levels used in the gross stability analysis are based on engineering interpretation and extrapolation of monitored groundwater levels at widely-spaced well and inclinometer locations. The interpreted average groundwater levels do not reflect potential localized perched groundwater conditions or the inevitable cones of infiltration emanating from individual seepage pits and/or leach fields which recharge the groundwater. Localized conditions such as these can be critical to the stability of an individual lot or group of lots. Such conditions were neither monitored nor are they predictable due to complexity of the subsurface in terms of geologic units, extent of fracturing, alteration, faulting (groundwater barriers) and permeability characteristics. Thus, it is entirely possible that a localized area can be much less stable than the gross stability of the region in which it is located.

Another caveat concerns the properties located near the boundaries of various regions. If a property in a region with a higher factor of safety is adjacent to an area with a lower factor of safety, the failure of that neighboring area could definitely negatively impact the stability of the property. For example, if the Hansch slide failed, the properties downslope of it could be seriously impacted.

7.3.2 Primary Slide Surface of the Main BRM Landslide and the Central Region

7.3.2.1 Primary Slide Surface

Figure 2-1.4 shows the boundaries of the main BRM landslide. The configuration of the primary or basal slide surface of the main landslide can best be seen by a 3-dimensional plot as shown on Figure 2-1.5. This figure was based on a composite of the two-dimensional

cross sectional profiles (A-A' through E-E' shown in Figures 7-2.1 to 7-2.5 and 3 other cross sections in the Southeast Region that are not included in this report).

Several assumptions were used in evaluating the stability of the primary slide surface. These include:

1. The factor of safety was 1.0+ during the period of late 1983 to mid-1984 when the emergency dewatering program was being implemented. In other words, the average groundwater level measured after this period represented a condition under which the main slide movement had slowed down significantly but still, at least locally, exhibited creep-like movements.

2. The average groundwater levels for the late 1983 to mid-1984 period are those shown in Figures 7-2.1 to 7-2.5, which were interpolated or extrapolated based on groundwater level data obtained from wells, inclinometers and piezometers.

3. The slide surface at the time when the main slide movement occurred is the same as that delineated in Figures 7-2.1 through 7-2.5.

4. The sliding resistance is best approximated by utilizing residual shear strength which consists of a frictional component (i.e., internal frictional angle, ϕ) and a negligibly small cohesion component (i.e., assumed C = O in this study).

Both two-dimensional and three-dimensional analyses were performed. The results of these analyses for the primary slide surface are summarized in Table 7-1.

Stability of deeper potential slide surfaces was also evaluated by two- and three-dimensional analyses and the results are summarized in Table 7-2.

Based on the results shown in Tables 7-1 and 7-2, the following observations can be made:

1. The prevailing factor of safety of the primary slide surface of the main BRM landslide is 1.25. This factor of safety will decrease if groundwater levels are allowed to rise due to part or all of the existing dewatering system becoming inoperative, or increased recharge as a result of successive wet years or increases in irrigation/sewage effluent infiltration.

2. Even though there are fractured and sheared rocks below the slide surface of the 1983 main slide movement, failure through these deeper zones is unlikely based on the results of the analysis (i.e., higher factor of safety, Table 7-2). Similar maximum attainable factors of safety of 1.4+ were obtained for both the deeper and primary slide surface when and if the groundwater is lowered near or below the 1983 basal rupture surface. Thus, 1.4+ is the maximum factor of safety against activation of mass movement theoretically attainable.

3. Within the main slide area, the portions near the mid-eastern third of the mesa (Cross Section B-B') and near the western boundary of the BRM landslide area (Cross Section E-E') appear to be slightly less stable than the remaining portion. This appears to coincide with the observations that the more pronounced cracks were observed in these less stable portions of the main slide area (Figure 5-1.1).

4. The back-calculated shear strength values are reasonably compatible with the laboratory test data. For example, an average back-calculated friction angle of 19° for the primary BRM slide surface of the main slide area compares very well with the lower bound residual shear strengths obtained from direct shear and triaxial tests on Sespe gouge material (approximately 17° to 18° as described in Section 3.4.1.1). As stated previously, and as can be seen in the geotechnical cross sections, a majority of the slide plane passes through the Sespe formation.

5. Back-calculated shear strengths for Cross Sections D-D' and E-E' (where slide surfaces consisted of partly in Topanga formation and partly in Sespe formation) are higher than those calculated for Cross Sections A-A', B-B' and C-C' (where slide surfaces are primarily within the Sespe and Vaqueros formations). This is consistent with the laboratory test data showing that Topanga formation is, in general, stronger than brecciated basaltic rock which, in turn, is strong than the Sespe formation.

7.3.2.2 Parametric Verification

As illustrated by the five cross sections through the main BRM landslide area, the primary slide surfaces pass through a number of geologic units and are frequently located at the interface of two different formation materials. The residual strength parameters (in terms of residual friction angles) include:

ϕ_s: Residual friction angle for Sespe formation (T_s)

ϕ_t: Residual friction angle for Topanga formation (T_t)

ϕ_{bs}: Residual friction angle for the intrusive basalt

ϕ_v: Residual friction angle for the Vaqueros formation

As shown in the five cross sections through the main BRM landslide, the Vaqueros formation constitutes less than 10% of the landslide mass and, similarly, less than 10% of the primary slide surfaces pass through the Vaqueros formation. Because of composition similarity between the Vaqueros and Sespe formations, and because the minor percentage of the Vaqueros formation along the slide surfaces, it is assumed in this study, with little or no sacrifice in the accuracy of stability assessment, that $\phi_v = \phi_s$.

Laboratory tests (Section 3.0) have shown a range of residual ϕ values for these formations. Selecting the appropriate ϕ value for stability analysis has been a challenge to geotechnical engineers, in general, and for the BYA team, in particular, because the bowl shaped BRM slide is clearly a 3-dimensional problem. To reconcile the potential differences between laboratory tests and the slide geometry, a methodology was developed, as illustrated in Figure 7-2.7. This figure is a flow chart illustrating the back-calculation and iteration process

from which the gross average values of ϕ were chosen for stability analysis. Briefly, Figure 7-2.7 utilizes the fact that the main BRM mass failed in 1983 (factor of safety = 1), both 2-dimensionally (2-D along each cross section) and 3-dimensionally (3-D). In the 2-D analysis, the strength range of limited test results of Sespe (T_s), Topanga (T_t) and the intrusive basalt (Bs), as well as their respective lengths or areal extents along the slide surfaces in each cross section (A-A' through E-E') are selected for analysis. For a factor of safety equal to 1, each cross section defines a unique relationship between the ϕ values of these units. For example, the slide surface in Cross Section A-A' for the Southeast Region, involves primarily T_s - whereas Cross Section D-D' involves T_s, T_t and Bs. The results of these analyses are plotted in Figure 7-2.8. It can be seen from this figure that the strength parameters of ϕ_s, ϕ_t, ϕ_{bs} converge into a fairly small zone. A 3-D slope stability analysis is then performed using the same iteration process . The results of calculated ϕ_s and ϕ_t as a function of ϕ_{bs} are plotted in Figure 7-2.9. The significance of Figure 7-2.9 can best be illustrated by first listing some salient features of the geologic cross sections and laboratory test results, from an engineering point of view, as follows:

1. The primary slide surfaces pass mostly through Ts and Tt material.

2. The primary slide surfaces only shear through basalt on a limited basis.

3. In those cases where the primary slide surface is along the interface between basalt and Ts or Tt, it is the weaker material controlling the failure.

As described in Section 4.0 and Appendix B, the presence of intrusive basalt helped to better understand the geologic structure. However, as illustrated in Figure 7-2.9, its presence has only a limited effect on stability.

Based on the above, a line of equal T_s and T_t strength was then plotted on Figure 7-2.9. The intersection of the line of equal T_s and T_t strength with the ϕ_{bs} lines defines a small zone (with an average $\phi \approx 19°$) which represents the gross average residual strength parameters for the BRM slide Note that for a $\phi \approx 19°$ shown in Figure 7-2.9 is consistent with the weighted average values based on laboratory test results and areal extents of the Sespe and Topanga formations. The results of this parametric study verify the validity of the shear strength values and the methodology utilized in the stability analysis.

7.3.2.3 Central Region

As described in Section 2.0, the main slide area encompasses the Central, Southeast, Bluff and Headscarp Regions. All regions, except the Central Region, can move by themselves, or together as part of the main slide movement. The Central Region can move as part of the main slide movement or move together with the Bluff Region. The results of stability analysis indicates that the gross factors of safety for the combined Central and Bluff Regions are greater than those for the reactivation of the main BRM landslide under either prevailing or maximum attainable conditions. Thus, the stability (factor of safety) of the Central Region should be considered to be the same as that of the primary slide surface of the main BRM landslide described above.

7.3.3 Southeast Region

As described previously, this region (see Figures 2-1.4 and 2-1.6) is located within the boundaries of the main BRM landslide. The Southeast Region experienced extensive cracking between 1971-1973, and moved as part of the main BRM landslide. Small but perceptible ground movements are still being observed at inclinometer SP-3A, SP-5A, BYA-5A and possibly SP-33. Thus, stability of this region is considered precarious and is evaluated in this study.

In evaluating the stability of this region, assumptions similar to those assumed for the main slide mass (Section 7.3.2) were also made. Several composite three-dimensional slide surfaces for this region, including the 1983 slide surface and deeper potential failure surfaces were developed for three-dimensional slope stability analysis purposes. The results are tabulated in Table 7-3. The results indicate that the prevailing factor of safety is about 1.2, which is less than that of the overall main slide area. The seeps frequently observed near PCH and the water-bearing channel fill are all of concern.

7.3.4 Bluff Region

The boundaries of the Bluff Region are depicted in Figure 2-1.4. The relevant slide surface configurations are represented by five cross sectional profiles, as shown in Figures 7-2.1 to 7-2.5. There exist a number of uncertainties in the stability evaluation of the Bluff Region. The most notable one is that there are few borehole or instrumentation data to delineate the mechanics of the Bluff Region movement during the 1983 landslide. It is known, however, that the top of the bluff was extensively cracked (Figure 5-1.1). Subsidiary sliding probably developed at that time, but it is not known whether a continuous slide surface(s) was fully developed. Such a slide surface would facilitate future downslope movement of the southern portions of the bluff. Due to the lack of verifiable subsurface data, the following assumptions have been made:

1. All potential slide surfaces in the Bluff Region initiated at the locations of the cracks.

2. Existing slide surfaces and faults (Seacliff fault) are weak and highly likely to be part of the potential slide surfaces in the Bluff Region.

3. All potential slide surfaces can be postulated by connecting the locations of observed cracks and existing slide surfaces or faults as shown in Figures 7-2.1 to 7-2.5.

4. The shear strength characteristics of the existing slide surfaces and faults are assumed to have the same values as those obtained by the back-calculated shear strength values for the primary slide surfaces of the main landslide mass (Section 7.3.2). The factor of safety for the Bluff Region at the time of the main slide movement was 1.0.

Another uncertainty also involves a general lack of information with respect to how far below-ground the cracks propagated and the configurations of these cracks (i.e., depth and shape). The existence of deep cracks reduces stability. Cracks contribute no resistance to sliding and they may trap groundwater which exerts hydraulic forces on the sliding mass. For this study, it is assumed that the depths of existing cracks were negligibly shallow (i.e., zero depth) and that no water was trapped in the cracks. These assumptions may cause the

factor of safety of this region to be overestimated. It should be noted that a number of cracks still remain open in the Bluff Region near Cross Section E-E' and possibly other areas. Consequently, it is strongly recommended that they be located and sealed off as soon as possible to minimize the possibility of trapping-water and the consequent reduction of stability in the Bluff Region.

Based on the above assumptions, a series of potential slide surfaces through the Bluff Region were developed and are shown in Figures 7-2.1 to 7-2.5. A series of two-dimensional stability analyses were performed utilizing these potential surfaces and the groundwater conditions as shown in Figures 7-2.1 to 7-2.5. Figure 7-3.1 shows the back-calculated shear strength envelope (C and ϕ) for the portion of the slide surfaces between the observed cracks and existing slide surfaces or faults in the five cross sectional profiles. As can be seen from this figure, the strength envelopes are relatively similar for the five cross sectional profiles evaluated. They also compare reasonably well with the available test data on non-gouge samples of Sespe Formation (Figure 3-4.2) which is also shown in Figure 7-3.1.

The calculated factors of safety for the five cross sectional profiles with respect to the prevailing conditions and the maximum attainable by additional dewatering are summarized in Table 7-4. As can be seen from this table, current prevailing factors of safety for the central and central western bluff ranges from 1.1 to 1.3 with an average of about 1.2. The stability of the Bluff Region between the central portion of the Bluff and the Southeast Region (i.e., the area represented by cross sectional profiles B-B' and C-C') appears to be most precarious. In addition, further dewatering measures would appear to be less effective in this area. This finding appears to be consistent with the observation that inclinometer SP-30 located near the toe of the bluff between Cross Sections B-B' and C-C' shows signs of recent perceptible movement. Judging from the observation of movement at inclinometer SP-30 and the calculated prevailing factors of safety, the Bluff Region remains one of the most critical areas in the main BRM landslide area. Its stability is marginal. It should also be noted that the calculated factor of safety of 1.22 for the western Bluff area (Cross Section E-E') was obtained assuming the open cracks in the vicinity have been infilled. The actual factor of safety could be less than calculated since open cracks still exist in the area. This is evidenced by the data from slope inclinometer SP-8A which still exhibits small but perceptible movement.

The above stability analyses do not include evaluations of various existing small landslide debris masses (Figures 7-2.1 to 7-2.5) which are remnants of past surficial instability episodes. These extremely heterogenous debris masses are located on the slopes of the bluff where no geotechnical investigations in the form of either borings or wells/inclinometers have been performed to delineate their configurations. Although no stability evaluation was performed for these bluff slope debris masses, the following two points are noted:

1. Available information in the BRM area and in the general coastal region indicates that these bluff slope debris masses were primarily generated due to excessive high groundwater tables. Documented surficial slope failures due to high groundwater levels included those which failed in 1964 near cross section E-E' and in 1971-1973 near Cross Sections A-A', B-B' and C-C' (see Section 5.0).

2. At the time of the main BRM landslide, these landslide debris masses appeared to be stable primarily because they were either fully or partly above the level of the groundwater table.

Thus, it is important for the stability of the debris masses on the bluff slope would be to minimize infiltration and the accumulation of groundwater in the debris by maintaining proper surface drainage and eliminating effluent recharge.

7.3.5 Headscarp Region

The boundaries and slide surface configurations of the Headscarp Region are shown in Figure 2-1.4 and in Cross Sections A-A' through E-E' (Figures 7-2.1 to 7-2.5). In this region, the potential slide surfaces include those of 1983.

In the Headscarp Region, stability analyses were performed based on the following assumptions:

1. Shear strengths of the existing slide surfaces are residual in nature and consist primarily of a frictional component (i.e., in terms of angle of internal friction, ϕ) with zero cohesion component.

2. The shear strength characteristics of slide surfaces within the five representative cross sectional profiles (A-A' through E-E') are the same.

3. The Hansch Slide is within the Headscarp Region (Cross Section D-D'). Since it was involved in the main BRM landslide, it can be prudently assumed that the critical factor of safety of the Headscarp Region in the vicinity of the Hansch property was about 1.0 to 1.05.

Based on these assumptions, various slide surfaces in the Headscarp Region (see Figures 7-2.1 to 7-2.5) were evaluated. The calculated factors of safety of various critical slide surfaces are summarized in Table 7-5.

The calculated factors of safety in the Headscarp Region range from 1.0 to 1.2 with an average of about 1.1. These factors of safety are precariously low. They indicate that the Region will likely experience intermittent movement, especially in areas near Cross Sections A-A', B-B' and D-D' (Figures 7-2.1, 7-2.2, and 7-2.4). The stability of the Headscarp Region will be further reduced by infiltration and accumulation of groundwater due to irrigation/sewage effluent recharge, and exacerbated by periods of heavy rainfall. These adverse conditions can be alleviated by eliminating septic tank effluent and improving surface drainage to minimize rain water infiltration. It should also be noted that, in the Headscarp Region, there exist numerous cracks that should be filled.

7.3.6 Western Extension

The site characteristics of the Western Extension are presented in Section 5.0. The term Western Extension is adopted because of the familiarity of the term to the citizens, even though the term itself is, in retrospect, a misnomer. The term implies that the area is an extension of the main BRM landslide. BYA believes that it is not. Although localized

distresses exist from differential settlement of past engineered or non-engineered fills or movements of locally steep slopes or due to the readjustment of subsurface materials subsequent to these localized movements, it does not appear that the Western Extension will by itself have a mass movement similar to or as a result of the 1983 BRM landslide. The potential settlement of fills can be inferred from Section 2.2 (site development history). The manifestation of distresses are shown in the major crack trends map (Figure 5-1.1) compiled from various investigators.

An examination of the available cross sections (F-F', G-G', H-H' and I-I' shown in Figures 7-2.6 and 4-1.10 through 4-1.12) through the Western Extension area indicates that potential gross movements, if any, in the Western Extension area may be along either a southeasterly direction toward the main BRM landslide's western boundary, or a southerly direction within the South-Facing Slope Region (Figure 2-1.4). The gross stability of the Western Extension is dependent on the stability of the main BRM landslide which provides a buttressing effect against the southeasterly movement. As long as there is not mass movement of the main BRM landslide, the Western Extension should be stable and is unlikely to develop gross movement. Thus, available information indicates that the overall gross stability of the general Western Extension area is equal to or greater than stability of the main BRM landslide mass along its basal slide surface, except the South-Facing Slope Region which is described below.

7.3.6.1 South-Facing Slope Region

The approximate boundaries of this region and potential slide surfaces are shown in Figures 2-1.4 and 7-2.6, respectively. As shown in Figure 2-1.4, the estimated mass above the major slide surface consists of a large landslide complex which includes several smaller slides. The slide mass is mostly composed of landslide debris.

Many recent relatively shallow failures have occurred in this region. For example, a small portion of the area (known as the "Love Landslide" below 20676 Rockpoint Way) failed in 1975 and an adjacent landslide in the seacliff of 20674 Rockpoint Way failed during heavy rains in 1978. There are numerous cracks within the landslide debris found throughout this region. Many of these cracks remain open at the time of this report.

Based on available information, the landslide debris found in this region was not reactivated at the time of the main mass movement of 1983 BRM landslide. Available groundwater level data at Well W-10 and Inclinometer SP-20 also indicate that the landslide debris in the South-Facing Slope Region was likely to be fully or partly above the groundwater levels at the time of the BRM landslide and has since remained above groundwater levels.

Sufficient subsurface information specific to this region is not available at this time. However, past failure history suggests that failure is likely to occur if the landslide complex is saturated. As shown in Figure 7-2.6, the landslide complex in this region consists of about 20% Topanga and 80% Sespe Formations whose angles of internal friction (ϕ) have been documented previously to be 19° and 31.5°, respectively. Using a distributed ϕ of 21.5° (0.8 x 19° + 0.2 x 31.5°) and assuming the slope is not saturated (i.e., the prevailing condition), the calculated factor of safety is 1.1. Drilling and sampling in this region are necessary if the level of confidence and accuracy in the calculated factor of safety is to be increased.

The calculated factor of safety is marginal. However, more importantly, if the slope becomes saturated, it will most probably fail. This means that preventing groundwater recharge and perched water conditions is of vital importance to the stability of this region. Cracks should be infilled, septic tank effluent recharge eliminated, and surface drainage improved.

7.3.7 Oceanfront Homes

As shown in Figures 2-1.4 and 4-1.4, a large number of oceanfront homes on PCH are located either on or adjacent to the Shoreline fault which forms the southern boundaries of the main BRM landslide area, the Southeast Region and the Bluff Region. Failure of one or more of these areas will cause damage to these homes. Thus, the stability of these oceanfront homes should be considered the same as that of the least stable area among these areas. In other words, the prevailing factor of safety for these oceanfront homes within the main BRM landslide boundaries (Figure 2-1.4) should be considered as being about 1.2, which represents the prevailing factor of safety for both the Southeast Region (Table 7-3) and the Central Bluff Region (7-4) and which is less than the prevailing factor of safety of 1.25 for the Main Mesa landslide area (Table 7-1).

7.4 SUMMARY

The calculated prevailing gross factors of safety and the maximum attainable values for the main slide area, its various subregions, the Western Extension area and the South-Facing Slope Region are summarized in Table 7-6. As can be seen from this figure, the calculated average prevailing factor of safety for the primary slide surface of the main BRM landslide is 1.25. The (average) prevailing factors of safety for the Southeast, Bluff, Headscarp and South-Facing Slope Regions are all less than 1.25. A factor of safety of less than 1.5 is substandard. 1.5 is the minimum factor of safety generally required for residential construction. Some jurisdictions allow construction when the factor of safety is between 1.25 and 1.50, but place special restrictions on such construction. Factors of safety of 1.2 or less are marginal. They do not provide a sufficient stability reserve against potential adverse conditions and developments such as unknown adverse subsurface conditions and consecutive heavy rain years. Slow creep movement can and does occur in areas with a factor of safety of 1.2 or less. The stability of an area with a factor of safety approximately 1.1 is especially precarious. Future movement is most likely to (first) occur in such areas. The factors of safety listed in Table 7-6 are gross factors of safety. They apply through a region and are not lot-specific. It is entirely possible that due to localized conditions, a lot or lots can be much less stable than the gross stability of the region in which it is located. Generally speaking, it is unlikely that the factor of safety of an individual lot will be greater than the factor of safety of the region in which it is located.

TABLE 7-1

STABILITY ANALYSIS RESULTS
BASAL SLIDE SURFACE OF MAIN BRM LANDSLIDE

AREA/PROFILE	CALCULATED ANGLE OF INTERNAL FRICTION, Φ, DEG.	PREVAILING GROSS FACTOR OF SAFETY	MAXIMUM ATTAINABLE** FACTOR OF SAFETY
I. THREE-DIMENSIONAL ANALYSIS			
Main BRM Landslide Area	19	1.25	1.4+
II. TWO-DIMENSIONAL ANALYSIS*			
Cross Section:			
A-A'	18	1.29	1.43
B-B'	16	1.23	1.3
C-C'	16	1.26	1.50
D-D'	23	1.30	1.43
E-E'	25	1.24	1.40

NOTES:

* Two-Dimensional analyses were made for the purpose of strength characterization of different formational material, assuming the factor of safety equals to one in 1983.

** See text (Section 7.1) for a discussion of maximum attainable factor of safety.

TABLE 7-2

STABILITY ANALYSIS RESULTS
MAIN MESA & DEEPER POTENTIAL SLIDING SURFACES
MAIN BRM LANDSLIDE

PROFILE	PREVAILING GROSS FACTOR OF SAFETY	MAXIMUM ATTAINABLE FACTOR OF SAFETY**
I. OVERALL THREE-DIMENSIONAL		
Main BRM Landslide Area	1.33	1.45+
II. TWO-DIMENSIONAL*		
Cross Section:		
A-A'	1.30	1.53
B-B'	1.30	1.44
C-C'	1.31	1.49
D-D'	1.33	1.47
E-E'	1.28	1.48

NOTES:

* Two-Dimensional analyses were made for the purpose of strength characterization of different formational material, assuming the factor of safety equals to to one in 1983.

** See text (Section 7.1) for a discussion of maximum attainable factor of safety.

TABLE 7-3

3-DIMENSIONAL STABILITY ANALYSIS RESULTS

SOUTHEAST REGION

AREA/ PROFILE	PREVAILING GROSS FACTOR OF SAFETY	MAXIMUM ATTAINABLE FACTOR OF SAFETY*
Reactivated Sliding Surface in BRM Landslide	1.2	1.4
Deeper Failure Surfaces	1.27	1.43

NOTE:

* See text (Section 7.1) for a discussion of maximum attainable factor of safety.

TABLE 7-4

STABILITY ANALYSIS RESULTS
BLUFF REGION

BLUFF AREA WITHIN CROSS SECTION PROFILE/ CRITICAL FAILURE SURFACE	PREVAILING GROSS FACTOR OF SAFETY	MAXIMUM ADDITIONAL FACTOR OF SAFETY ****
Eastern Bluff A-A'/BF3 (Figure 7-2.1)	1.20*	1.4***
Central Bluff B-B'/BF2 (Figure 7-2.2)	1.10**	1.28
Central Bluff C-C'/BF2 (Figure 7-2.3)	1.13**	1.26
Central Bluff D-D'/BF1 (Figure 7-2.4)	1.27**	1.52
Central Western E-E'/BF2 (Figure 7-2.5)	1.22	1.47

NOTES:

* Note that the entire Southeast Region has a factor of safety of 1.2 (Table 7-2). Hence, the factor of safety of 1.2 controls the eastern Bluff Region (Cross Section A-A') instead of the 1.35 calculated herein.

** The average factor of safety of the Central Bluff is about 1.17 1.2

*** 1.4 controls as shown in Table 7-3.

**** See text (Section 7.1) for a discussion of maximum attainable factor of safety.

TABLE 7-5

STABILITY ANALYSIS RESULTS

HEADSCARP REGION

CRITICAL SLIDING SURFACE	CROSS-SECTION/ FIGURE	BACKFITTED ANGLE OF INTERNAL FRICTIONS (Deg.)	CALCULATED PREVAILING GROSS FACTOR OF SAFETY *
AA-SC1	A-A'/Figure 7-1	31.5	1.03
BB-SC3	B-B'/Figure 7-2	31.5	1.11
CC-SC2	C-C'/Figure 7-3	31.5	1.24
DD-SC2	D-D'/Figure 7-4	31.5	1.00
EE-SC1	E-E'/Figure 7-5	31.5	1.20

NOTE:

* Because groundwater levels in the Headscarp Region are below the critical sliding surfaces, the maximum attainable factor of safety by dewatering/sewering is the same as the calculated prevailing factor of safety. See text (Section 7.1) for a discussion of maximum attainable factor of safety.

TABLE 7-6

SUMMARY OF AVERAGE PREVAILING AND MAXIMUM ATTAINABLE GROSS FACTORS OF SAFETY

REGION	PREVAILING GROSS FACTOR OF SAFETY	MAXIMUM ATTAINABLE FACTOR OF SAFETY*
BRM LANDSLIDE AREA:		
* Basal Slide Surface of Main Slide Mass	1.25	1.4 +
* Central Region	1.25	1.4 +
* Southeastern Zone	1.2	1.4
* Eastern Bluff	1.2	1.4
* Central Bluff	1.2	1.3
* Western Bluff	1.2	1.4
* Headscarp Area	1.0+ to 1.2	Site Specific
WESTERN EXTENSION:	1.25 +	1.4 +
* South-Facing Slope	1.1	Site Specific

NOTE:

* See text (Section 7.1) for a discussion of maximum attainable factor of safety.

SECTION 8.0

SEISMIC STABILITY

8.1 GENERAL

Seismicity of the BRM area has been described in Section 4.2. In general, the magnitude of the maximum credible earthquake associated with the Malibu Coast/Anacapa fault zones will likely be 6.5±. This near-field earthquake is characterized to consist of high frequency (relatively short seismic wavelengths) and high peak ground acceleration. Other major but more distant faults may generate higher magnitude maximum credible earthquakes, but because of attenuation effects, will result in lower ground acceleration in BRM (see Table 4-1). With respect to the seismic stability of BRM, the near field maximum credible earthquake associated with the Malibu Coast/Anacapa fault zones will be more critical than those associated with distant causative faults. Thus, only the near field maximum credible earthquake is considered for seismic stability evaluation in this study.

8.2 METHODOLOGY AND ANALYSIS

Traditional seismic stability by pseudo-static methods using a seismic force equivalent to a seismic coefficient times the weight of sliding mass, represents a less than realistic over-simplification of the actual seismic stability of the mass. If the size and length of a potential slide surface is small compared to the wavelengths of the earthquake, a pseudo-static factor of safety less than unity means that the slope mass may have a temporary (transient) tendency to move corresponding to the transient and cyclic nature of earthquake ground motions, instead of the sustained force as assumed in a pseudo-static stability analysis. However, if the potential slide surface is comparably long with respect to the wavelengths of the earthquake, pseudo-static analysis is not appropriate, since earthquake ground motions within the potential slide mass will consist of both pushing (downslope driving forces) and pulling (upslope resisting force) against each other so that the net effects of an earthquake on the potential landslide surface will be relatively small (in terms of forces and displacement) at a given time during the earthquake loading. While seismic displacement is usually not a concern for a relatively large (longer than predominant wave lengths), landslide mass there still exists an earthquake-related concern relating to potential seismic-induced pore pressure increases within the slide mass which decreases the resistance to sliding. The seismically induced pore pressure increase at BRM was documented twice during this investigation as described in Section 4.0.

The method to rectify the shortcoming of pseudo-static analyses was first developed by Newmark (1965) and subsequently modified by others. This method evaluates permanent slope displacement by assuming that the potential landslide mass can be modeled as a rigid sliding block. As an extension to Newmark's original concept, various investigations (e.g., Makdisi and Seed, 1978; Franklin and Chang, 1977; and Chang et al, 1984) have proposed modifications as well as empirical design charts based on various engineering assumptions and seismic response analyses using synthetic or real earthquake time histories. The use of such empirical relations does not consider potential effects of site-specific characteristics which may significantly modify ground motion.

In this study, site-specific responses with the Newmark type of analysis are followed to evaluate seismic-induced permanent displacement. Site-specific response analysis using seismic input from a number of actual near-field earthquake records of similar magnitudes, were modified to reflect the anticipated maximum credible earthquake at the site area (Magnitude of about 6.5).

Basically, the analyses involves the following steps:

1. Calculate the yield acceleration.

2. Determine the earthquake time histories for input in the seismic analysis.

3. Determine the seismic responses in the potential sliding masses.

4. Calculate the permanent displacement based on double integration of the portion of the acceleration response time history that exceeds the yield acceleration.

8.2.1 Yield Acceleration

Pseudo-static analyses were performed for prevailing site stability conditions as well as hypothetical conditions reflecting the maximum stability attainable by dewatering/sewering for the various regions in the BRM area. The results are summarized in Table 8-1.

8.2.2 Earthquake Time History

Four actual near field earthquake records with similar magnitudes and similar site conditions were normalized to 0.7g, corresponding to the estimated peak acceleration level of the maximum credible earthquakes associated with the Malibu Coast/Anacapa fault zones. These earthquake records are summarized in Table 8-2 and their corresponding normalized time histories are shown in Figure 8-2.1. These earthquake time histories were utilized to ensure that all potential variations and ranges of frequency and duration characteristics of near field earthquakes generated by active thrust faults with similar earthquake magnitudes were considered and reflected in the analysis.

8.2.3 Seismic Response Analysis

A series of engineering analyses were performed using the computer program SHAKE to evaluate the potential ranges of seismic response in various regions within the BRM area. The four normalized earthquake time histories were utilized as input. To account for the potential amplification effects due to variation in site characteristics, the seismic response analyses were performed by varying and accounting for the anticipated ranges of stiffness of subsurface materials and the thickness of various sliding masses within the BRM area. Selected typical maximum seismic responses within the potential sliding masses in terms of acceleration time histories are shown in Figure 8-2.2.

8.2.4 Seismic-Induced Permanent Displacement

Once the seismic response time histories have been established and the values of yield acceleration have been calculated, double integration of the seismic acceleration to obtain the permanent displacement that may be induced by earthquake motions can be carried out. Table 8-3 summarizes the calculated range of seismic-induced permanent displacement in terms of earthquake time history input and yield acceleration levels.

8.3 SEISMIC-INDUCED PERMANENT DISPLACEMENT

The methodology and analysis presented in Section 8.2 are applicable for relatively small slopes such as those in the Bluff and Headscarp Regions where sliding surfaces are short as compared with the wavelengths produced by the earthquake. For the slide surfaces of the main BRM landslide, the Southeast Region, and the South-Facing Slope Region in the Western Extension area, where the potential sliding surfaces are relatively long with respect to the predominant wavelengths of near-field earthquakes, this analysis overestimates the permanent displacement. Thus, the seismic-induced permanent displacement in this case should be a fraction of that calculated by the methodology described in Section 8.2.

It is estimated that the near field earthquakes from the Malibu Coast/Anacapa fault zones will exert seismic waves to the BRM area at an incident angle of about 45°. The projected lengths (along the incident wave direction) of potential sliding surfaces are about 400 to 1200 feet (with an average of about 800 feet) in the main BRM landslide. For the Southeast Region and the South-Facing Slope Region, the projected sliding surfaces are 400 and 550 feet, respectively. Due to the fractured nature of the subsurface materials we assumed that the predominant shear wave velocity of such materials is on the order of 1,000 feet per second. Taking into consideration the high frequency nature of the near-field earthquakes, we have estimated the predominant wavelengths of the near-field maximum credible earthquake for the site area to be on the order of 250 to 750 feet.

Based on a comparison of the projected lengths of potential failure surfaces with the predominant wavelengths of a near field earthquake, it can reasonably be assumed that the ratio of the realistic permanent displacements to the corresponding calculated values (based on the methodology and analysis described in Section 8.2) should be about 20% for the main slide mass, 50% for the South-Facing Slope Region; 60% for the Southeast Region and 100% for the steepest slope areas (Bluff and Headscarp Regions). The estimated seismic induced permanent displacement ranges based on this assumption are shown in Table 8-4.

The upper bound estimates for the various regions are summarized as follows:

Area/Region	Estimated Maximum Seismic Induced Displacement (Ft.)	
	Prevailing Stability Conditions	Maximum Condition Attainable by Dewatering/Sewering
Central Region	0.2	0.1
Southeast Region	0.7	0.4
Bluff Region	1.1	0.6
Headscarp Region	2.3	2.3
South-Facing Slope Region in Western Extension	0.6	0.6

8.4 OTHER POTENTIAL CONCERNS

One of the major earthquake-related concerns is the potential of seismic-induced excess pore pressure within the landslide mass, which will reduce stability of the slide mass until such excess pore pressure is dissipated over time. Such a possibility is evidenced by the hydrauger production increases which followed the January 18, 1989 Malibu Earthquake (Magnitude = 5) and the June 28, 1991 Sierra Madre Earthquake (Magnitude = 5.8) as described in Section 4.2.

The extent of seismic-induced excess pore pressure cannot be predicted with any reasonable degree of certainty, based on current state-of-the-art knowledge and available site-specific data. Since the prevailing factors of safety in many regions are low to begin with, any substantial pore-pressure increase will reduce their stability even further. The concern is that the seismic-induced excess pore pressure may reduce the stability to such an extent as to cause reactivation of landslides. Thus, it is imperative that the following measures be adopted both to evaluate and to minimize the risk of seismical-induced pore pressure increases:

1. Implement mitigation options (Section 9.0) to increase the margin of safety over the prevailing conditions so that a sufficient stability reserve is available to accommodate the adverse stability effects of the potential of pore-pressure increases in future earthquake events.

2. Observe/monitor the groundwater levels in the wells, inclinometers and multi-stage pneumatic piezometers, as well as the production rates of the wells and hydraugers immediately after any future earthquake events so that a site-specific database can be established to enable a better prediction of the potential maximum increase of pore pressures associated with a design earthquake (such as the maximum credible earthquake associated with Malibu Coast/Anacapa fault zones) as well as a close assessment of their effects on the stability of the site area.

TABLE 8-1

CALCULATED YIELD ACCELERATION

REGION/AREA	CALCULATED YIELD ACCELERATION (g)	
	PREVAILING CONDITIONS	ATTAINABLE CONDITION BY DEWATERING
Central Region	0.05	0.1
Southeast Region	0.05	0.1
Bluff Region:		
Cross Section A-A'	0.13	0.2
Cross Sections B-B' and C-C'	0.05	0.1 to 0.14
Cross Sections D-D' and F-F'	0.1 to 0.12	0.2 to 0.24
Headscarp Region:		
Cross Sections A-A' and D-D'	0 to 0.2	0 to 0.2
Cross Section B-B'	0.05	0.05
Cross Sections C-C' and E-E'	0.08 to 0.1	0.08 to 0.1
South Facing Slope Region in Western Extension *	0.05	0.05

NOTE:

* Within the Western Extension area, only the South-Facing Slope Region is considered in the seismic analysis. Because of the buttressing effect of the main BRM landslide area, the remaining portion of the Western Extension is expected to be at least as stable as the Central Region.

TABLE 8-2

ACTUAL NEAR FIELD EARTHQUAKE
RECORDS UTILIZED IN SEISMIC-INDUCED
PERMANENT DISPLACEMENT EVALUATION

EARTHQUAKE EVENT	MAGNITUDE	RECORD STATION	COMPO-NENT (Deg.)	EPICENTER DISTANCE (Km)	PEAK ACCELER-ATION (g)
1979 Imperial Valley	6.6	Array 7	230	< 5	0.46
1983 Coalinga	6.5	Switchyard	45	12	0.6
1991 Sierra Madre	5.9	Cogwell Dam	155	5	0.3
1971 San Fernando	6.6	Pacoima Dam	- -	5	1.17

TABLE 8-3

CALCULATED SEISMIC-INDUCED PERMANENT DISPLACEMENT

NORMALIZED EARTHQUAKE TIME HISTORY*	CALCULATED PERMANENT DISPLACEMENT (Ft.) YIELD ACCEL. = 0g	0.1g	0.2g	0.3g
1979 Imperial Valley - Array 7	2.07 to 2.27	0.51 to 0.58	0.27 to 0.29	0.14 to 0.16
1983 Coalinga Switch Yard	1.75 to 1.93	0.44 to 0.62	0.21 to 0.26	0.12 to 0.14
1991 Sierra Madre - Cogwell Dam	0.59 to 0.61	0.19 to 0.21	0.09 to 0.11	0.04 to 0.06
1973 San Fernando - Pacoima Dam	1.13 to 1.22	0.28 to 0.31	0.06 to 0.12	0.02 to 0.05
Overall	0.59 to 2.27	0.19 to 0.62	0.06 to 0.29	0.02 to 0.16

NOTE:

* Normalized to a peak acceleration of 0.7g to represent near-field credible maximum earthquake from Malibu Coast/ Anacapa fault zones.

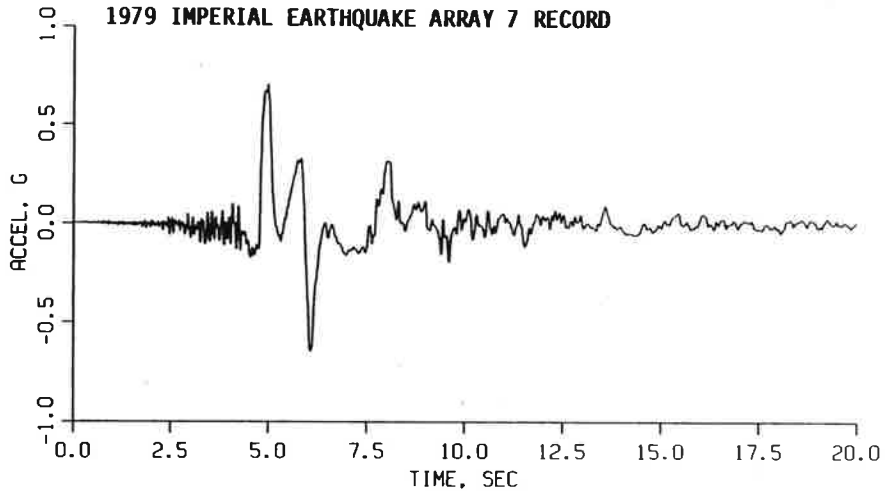
TABLE 8-4

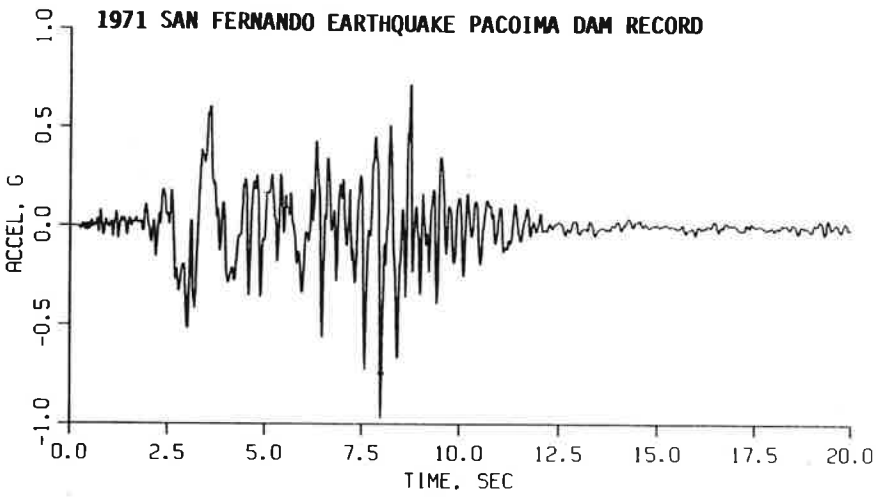
ESTIMATED RANGES OF SEISMIC-INDUCED PERMANENT DISPLACEMENT

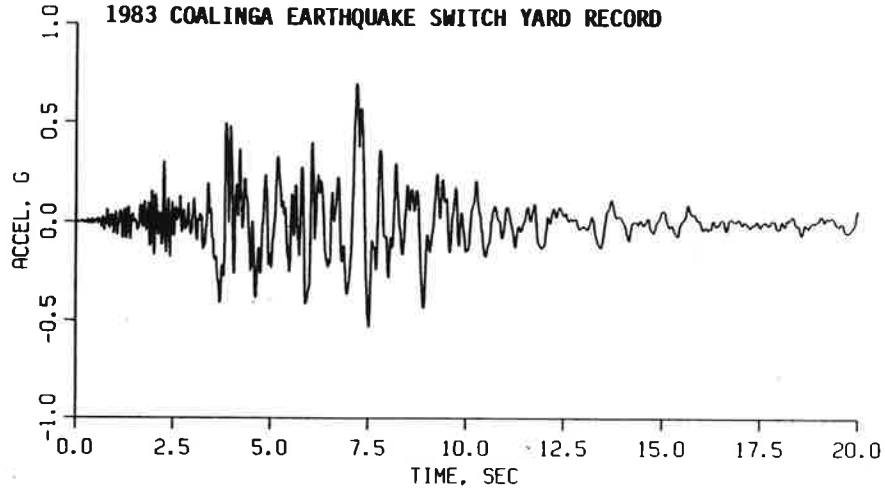
REGION / AREA	EST. PERMANENT DISPLACEMENT (Ft.) PREVAILING STABILITY CONDITIONS	EST. PERMANENT DISPLACEMENT (Ft.) MAXIMUM STABILITY CONDITION ATTAINABLE BY DEWATERING/SEWERING	NOTES:
Central Region	0.07 to 0.2	0.04 to 0.1	Anticipated to be very small because of extraordinary length of the sliding surface.
Southeast Region	0.2 to 0.7	0.1 to 0.4	Assumed to be about 60% of calculated values because of large lengths of sliding surface.
Bluff Region:			
Cross Section A-A'	0.15 to 0.5	0.06 to 0.29	
Cross Sections B-B' and C-C'	0.35 to 1.1	0.13 to 0.62	
Cross Sections D-D' and F-F'	0.15 to 0.62	0.03 to 0.3	
Headscarp Region:			
Cross Sections A-A' and D-D'	0.6 to 2.3	0.6 to 2.3	
Cross Section B-B'	0.35 to 1.1	0.35 to 1.1	
Cross Sections C-C' and E-E'	0.19 to 0.75	0.19 to 0.75	
South Facing Slope Region in Western Extension *	0.2 to 0.6	0.2 to 0.6	Assumed to be about 50% of calculated values because of large lengths of sliding surface.

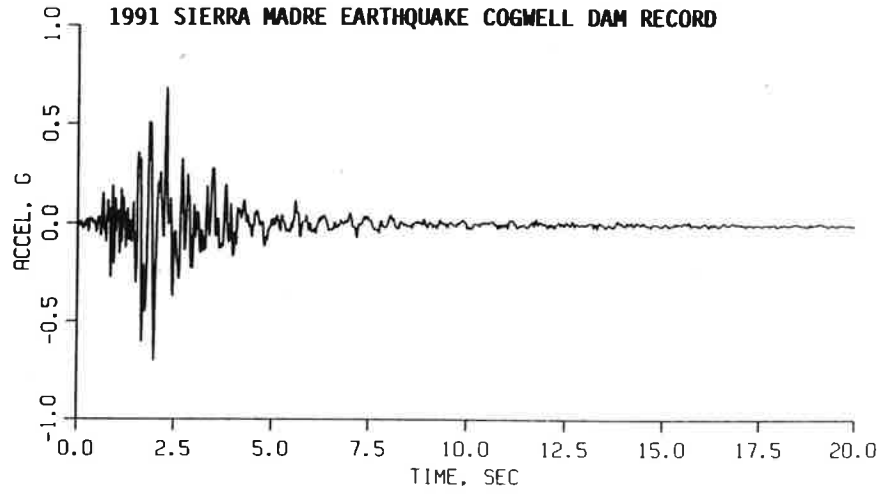
NOTE:

* Within the Western Extension area, only the South-Facing Slope Region considered in assessing the seismic-induced permanent displacement. Because of the buttressing effects by the main BRM landslide area and the significant lengths of potential sliding surfaces (as compared with the predominant earthquake wavelengths), the magnitudes of potential seismimc-induced permanent displacement in the remaining portion of the Western Extension area are expected to be less than those estimated for the Central Region.









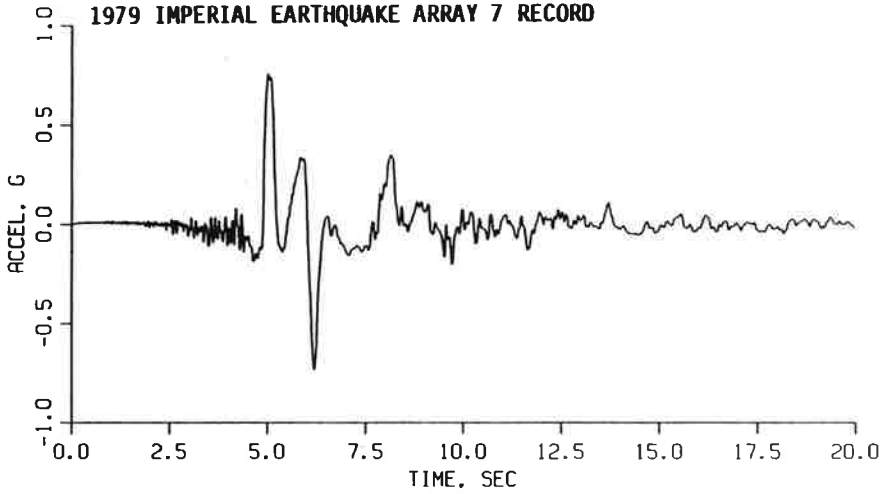
BING YEN & ASSOCIATES

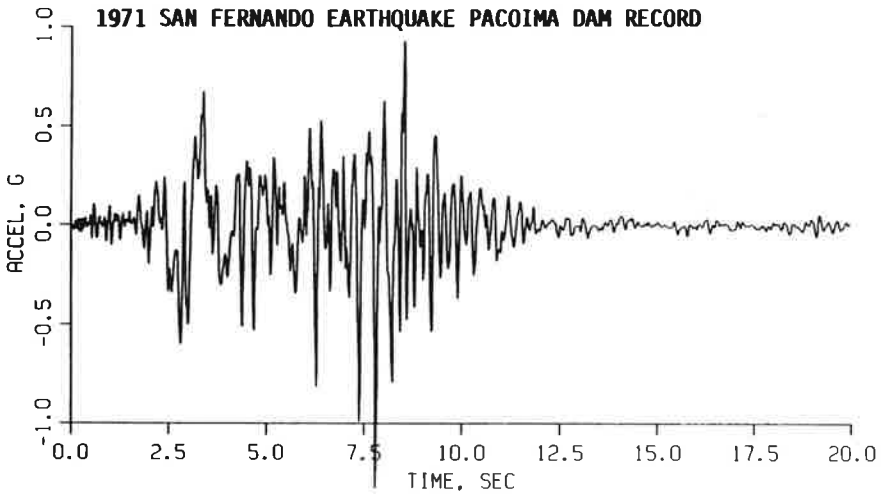
BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

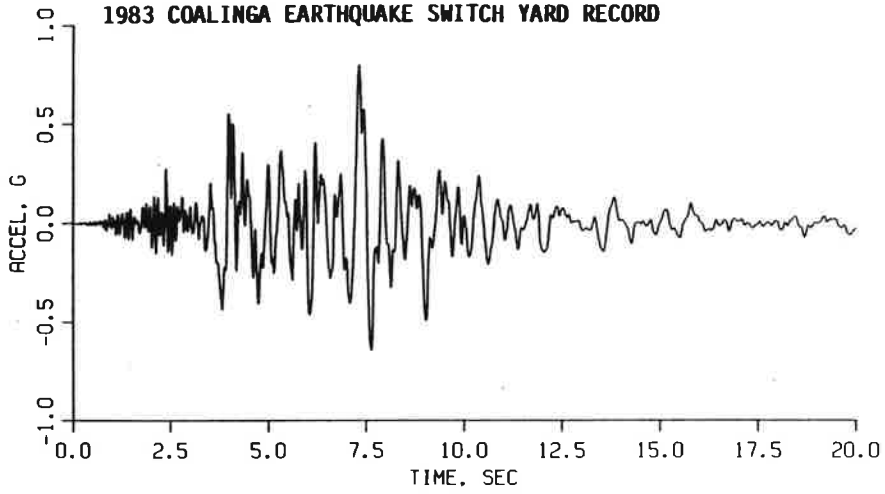
PROJECT NO.: 49-97D | DATE: DECEMBER 1991

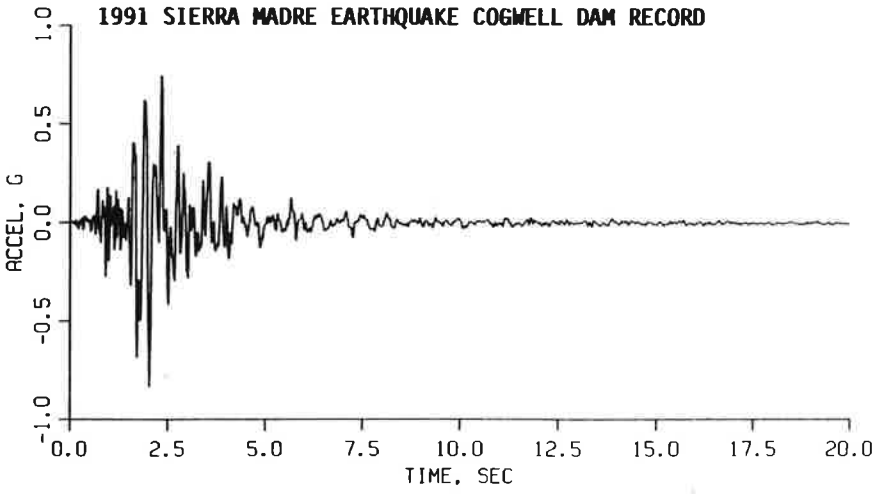
CALCULATED MAXIMUM SEISMIC RESPONSE TIME HISTORIES WITHIN THE MAIN BRM LANDSLIDE MASS

FIGURE 8-2.2









BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EARTHQUAKE TIME HISTORY INPUT-
NORMALIZED TO 0.7g

FIGURE 8-2.1

SECTION 9.0

MITIGATION OPTIONS

9.1 GENERAL

The current (December 1991) state of stability of the main BRM landslide mass has apparently reached a transient equilibrium primarily because of the dewatering system, the drought, and stabilized domestic water usage. As described in Section 7.0, the calculated average prevailing factor of safety for the primary slide surface of the main BRM landslide is 1.25. The (average) prevailing factors of safety for the Southeast, Bluff, Headscarp and South-Facing Slope Regions are all less than 1.25. These currently prevailing factors of safety are likely to be the maximum factors of safety which can be achieved with the existing dewatering system. This is evidenced by the currently existing steady state groundwater condition. Since factors of safety are transient in nature, the factor of safety will decrease if the driving forces causing instability are allowed to increase or if the resisting forces are reduced. Driving forces will be increased if groundwater levels increase as a result of prolonged wet seasons, increase in domestic water usage, an increase of surface water infiltration, accumulation of groundwater in existing cracks, or the lack of maintenance on the existing wells and hydraugers. Resisting forces can be reduced due to further degradation of the shear resistance characteristics as a result of physical or chemical alteration or other factors. Since the prevailing factors of safety for the main BRM landslide area and some of its regions are low to begin with, any further increase in driving forces or reduction in resisting forces may exacerbate the state of stability and reactivate landslide movement. As shown in Figure 9-1.1, the results of a sensitivity analysis for the main slide mass indicate that a uniform 60 feet increase of groundwater levels above present levels will decrease the factor of safety of the main slide mass by about 0.15 (i.e., decrease the prevailing factor of safety of 1.25 to 1.10). Similarly, a reduction of the average composite angle of internal friction (ϕ) by about 2 degrees (i.e., reducing from the current 19° to 17°) will also result in reducing the factor of safety of the main BRM landslide by about 0.15. The probable error of the above estimation is estimated at 0.05 in terms of factor of safety.

The low currently prevailing factors of safety in the BRM area, the above described potential effects of rising groundwater levels and the potential accumulation of groundwater within existing cracks are a constant reminder to the citizens of the BRM area of the shared responsibility to minimize groundwater recharge by reducing effluent recharge, filling in cracks, improving surface drainage to reduce surface water infiltration and diligently maintaining the existing wells and hydraugers.

Such precautionary measures are prudent in minimizing adverse factors that exacerbate instability. However, they are not sufficient to prevent future potential reactivation. Additional mitigation efforts will be needed if the citizens choose to increase the margin of safety against the potential reactivation of landsliding in the area. It is necessary, and indeed essential, to recognize that the stability of the various regions in the BRM area are interdependent. For example:

- Failure of the Bluff Region will result in lessening the support of the Central Region, thus reducing its stability;

- Movement of the main BRM landslide mass will reduce its buttressing effect on the Western Extension area as well as decreasing the support at the toe of certain slopes within the Headscarp Region;

- Failure of the Bluff Region will cause damage to the oceanfront homes on PCH, and decrease the passive resistance of the remaining regions within the main slide area;

- Failure of the Headscarp Region will put additional load on the Central Region, increasing the driving forces and reducing the stability of the main slide mass; and

- Failure of the Southeast Region or the Central Region will cause distress and damage to the oceanfront homes on PCH, and can decrease passive resistance to the Headscarp Region.

Similarly, stability improvements in one region will also likely benefit the other regions. In this regard, it should be noted that regions or areas identified in this report are defined by their geomorphological and tectonic evidences to the level of our understanding, based on the available information. Their boundaries are zones which cannot be defined by lines as shown in Figure 2-1.4. The inter-dependency of these regions should be recognized as a given condition. Thus, mitigation efforts for the main slide and the various regions are also mutually dependent.

Because of the complexity of the BRM area (Section 6.0), no single mitigation option is a panacea. The CI has taken the essential first step to significantly lower groundwater levels on an area-wide basis. However, the existing dewatering system cannot achieve much more than it already has. If the stability of the BRM area is to be maintained and improved, additional mitigation measures are required. Some of these mitigation measures can be area-wide. Others must be tailored to the specific characteristics of a given region. Because of the inter-dependency of the various regions, stability improvements in one region will benefit other regions. The extent to which the stability of the area should be improved is a collective decision for the CI property owners. It is one which involves a balancing of the risks the owners are willing to bear, versus the costs of the various potential mitigation measures.

9.2 MITIGATION OPTIONS

Any viable mitigation option should consider the costs associated with its installation, operation and maintenance, and the regional characteristics of the BRM area. In general, methods of increasing stability involve the principles of increasing resisting forces or decreasing driving forces, or both. Various potential mitigation options based on these principles were investigated. These options include the following:

- Chemical stabilization (increasing shear resistance by chemical additives),

- Reducing groundwater recharge from septic tank effluent (by a sewage collector system),

- Additional dewatering (active dewatering by wells or passive underground dewatering galleries consisting of shafts, tunnels and hydraugers),

- Active restraints (retaining structures and tieback anchors), and

- Other preventative measures.

Conventional buttressing (earthen-embankment) or massive grading types of stabilization options to improve the gross stability of the various BRM regions do not appear to be feasible since the various regions are too large, and too many homes would have to be removed to make such measures effective. The costs would be prohibitive. Other potential options, such as intrusion grouting proposed for the Bluff Region by earlier investigators (Evans; 1985) were ruled out because of the potential of creating additional groundwater barriers, which would further trap groundwater in the Mesa and result in reduced stability.

9.2.1 Chemical Stabilization

The principles of increasing soil strength by mixing the soil with chemicals or cementation agents is well known. It is theoretically feasible to increase the shear resistance of slide plane gouge materials by adding chemical additives to the septic tank effluent which would then infiltrate down to the slide surface. Such a plan is innovative, but we could not find any documented case histories in the literature. We are reluctant to pursue such an option. The potential strengthening effects of mixing various chemical additives with soil is well known (e.g., Borchardt, 1984). Conceptually, the ion exchange between a chemical additive and clay (gouge) materials will result in strength increases over time. The slow but nonetheless steady percolation of recharging waste water or rain water should carry the dissolved chemicals to the deep seated slide surfaces to react with clay gouge along the slide surfaces.

For this project, three selected chemicals, including Aluminum Nitrate "Al $(NO_3)_3$" Sodium Metasilicate (Na_2SiO_3) and Potassium Fluoride (KF), were added to clay gouge samples from the Sespe formation. The resistance properties of the samples showed a marked improvement over those of an untreated clay gouge sample. The results shown in Figure 3-4.5 indicate the potential usefulness of chemical additives. It should be noted that, in addition to increasing the shear strength, these chemicals were chosen because they are also capable of reducing clay plasticity, thereby increasing its permeability. However, several practical constraints may limit the potential applicability of this chemical treatment method to the BRM area. These constraints include:

1. These chemicals are generally toxic in nature, although the degree of toxicity and threshold limits can be evaluated (e.g., diffusivity groundwater flows) and soil chemistry. Such an analysis is beyond the scope of the present study.

2. Without further study, there exist no practical means of assuring and/or verifying the areal extent and the degree of strength improvement of the slide plane materials as a function of time after chemical treatment.

3. Before this concept can be implemented, it is anticipated that there would have to be a considerable amount of research and interaction with regulatory agencies such as the Regional Water Quality Control Board (RWQCB), the State Health Agency, the Coastal Commission, etc.

Thus, after considering the above, chemical stabilization methods were excluded from further consideration as a viable mitigation option from environmental and regulatory points of view.

9.2.2 Recharge Reduction

9.2.2.1 General

The more the groundwater recharge, the more likely it is for groundwater to rise above the present level (i.e., the more the chance for the prevailing factors of safety which are marginal to begin with, to decrease). All of the following measures will reduce groundwater recharge:

1. Minimize domestic water usage.

2. Improve surface drainage.

3. Install a sewage collector system to eliminate septic tank effluent recharge into the subsurface.

It is the shared responsibility of the residents of the BRM area to minimize domestic water usage and thereby reduce the rate of groundwater recharge. It is also the responsibility of each individual lot owner to improve the surface drainage of his or her individual lot. The sealing off of existing cracks is especially important in areas where numerous open cracks still exist. These areas include the Headscarp Region, the western boundary of the BRM landslide in the vicinity of the western Bluff area (see Cross Section E-E') and the Bluff area below 20676 Rockpoint Drive in the South-Facing Slope Region of the Western Extension among others.

9.2.2.2 Sewage Collector System

a sewage collector system will provide the following benefits:

rise in the groundwater table which will occur during successive normal normal rainy seasons.

saturation of subsurface materials, thus increasing their storage capacity odate increased recharge from successive wet years.

ne cones of infiltration emanating from individual septic tank and leaching ot be eliminated by a dewatering system.

ne potential of seismic-induced excess pore pressure and the associated stability.

The installation of

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As indicated previously, current area-wide groundwater levels are estimated to be in an approximate steady state condition. This means that, after five years of drought, the current dewatering system has essentially lowered the groundwater levels as much as the system can. The existing dewatering system cannot significantly further reduce existing groundwater levels because the wells and hydraugers are widely spaced. The current groundwater steady state condition also means that when normal rainfall levels return to the area, groundwater levels will rise. The rise in groundwater levels will be even greater during consecutive above-average rain years (Table 6-8). As can be seen from an examination of Table 6-9, a sewage collector system will significantly reduce further increases in the groundwater table due to average and above average rainfall. This will benefit the entire BRM area and be especially beneficial to the Headscarp Bluff and the South-Facing Slope Region, as will be discussed below.

The benefit of eliminating cones of effluent infiltration is particularly important in areas where perched groundwater conditions prevail or could develop. The development of perched groundwater is critical in areas such as the Headscarp Region, the South-Facing Slope Region, and the Bluff Region in the vicinity of Cross Sections B-B' and C-C'. In all of these areas, the prevailing factors of safety are low, and any additional accumulation of locally perched groundwater due to the presence of cones of effluent infiltration can reduce their stability even further. Besides these specific regions, a sewer system would also significantly benefit any other areas where the groundwater is usually too shallow and localized to be efficiently mitigated by wells. If an area-wide sewer system is not implemented, it is strongly recommended that a local pre-packaged on-site treatment/storage facility with off-site disposal be implemented by the residents in these areas to avoid the adverse affects of septic-effluent-induced perched groundwater conditions in the regions or neighborhoods described above.

In summary, a sewage collector system will have definite beneficial results. Such a system will not solve all of the area's stability problems. As indicated earlier, no single mitigation measure, whether it be wells, hydraugers or sewers, can.

9.2.3 Active Dewatering System

The gross stability of the Central Region, the Southeast Region, and the eastern and western portions of the Bluff Region can be substantially improved by additional active dewatering to significantly lower the overall groundwater levels currently existing above the basal rupture surfaces of the main slide mass. For a discussion of the maximum attainable factor of safety for the main BRM landslide and the various regions, see Section 7.0. Additional active dewatering will not directly address the specific mitigation needs of the Headscarp Region, the South-Facing Slope Region or the central portion of the Bluff Region. Perched groundwater conditions either exist or are likely to develop in these areas. In addition, in most of the Headscarp Region, the overall groundwater table is already below the critical slide surfaces of the main BRM landslide.

In addition to substantially improving the stability of the Central Region, the Southeast Region and the eastern and western portions of the Bluff Region, additional active dewatering also provides the following benefits:

- Significantly lowering the groundwater table will increase the storage capacity reserve of the subsurface materials to receive additional recharge due to successive wet years and/or unexpected increase in domestic water usage, thus, minimizing the potential of future rises in groundwater levels and the risk of reactivating the landslide.

- For obvious economical and practical reasons, the additional dewatering system cannot be so closely-spaced as to eliminate the potential recharge cones of septic effluent infiltration from individual lots. However, the implementation of such a system for the intended purpose of lowering area-wide groundwater levels will reduce the risk of instability for those lots adjacent to and downstream from the new dewatering locations.

- The reduced groundwater levels from the additional dewatering system will reduce seismic-induced permanent displacements (refer to Section 8.0).

- The increase in gross stability from active dewatering also provides a margin of stability reserve to compensate for the potential stability degradation due to seismic-induced excess pore pressure within the slide mass (Section 8.0).

Significantly lowering the groundwater levels which currently exist above the basal rupture surfaces of the main slide mass can be accomplished by additional deep wells or by a system of underground galleries consisting of vertical shafts (i.e., large diameter wells) to which tunnels and/or hydraugers are connected, or by a combination of both. In this study, preliminary consideration was given to the following two dewatering options:

1. A centrally-located large-diameter vertical shaft with a network of radially extended multi-level hydraugers supplemented by a series of deep wells in the Southeast Region.

2. Additional deeper dewatering wells.

The pros and cons of each of these two potential options are described below:

9.2.3.1 Shaft, Hydraugers & Wells

In this option, a large-diameter reinforced vertical shaft can be designed to collect groundwater from hydraugers which extend radially from the shaft. The collected groundwater can then be pumped out of the shaft to the existing storm drain system. This shaft-hydrauger system will be effective for most of the main slide area, except the Southeast Region which is likely to be too far away from the dewatering shaft. Therefore, the Southeast Region would require supplementary deep wells for dewatering purposes. Based on the prevailing groundwater levels, physiographical characteristics, traffic patterns and the need for a staging area for construction, the most suitable location for the shaft would be in the vicinity of the cul-de-sac at Seamoor Drive, which is located at the approximate geographical center of the main slide area. Although the final configuration of this system will require further engineering evaluation and design in the future, a conceptual configuration of the required system based on preliminary engineering evaluation and judgement was developed and is shown in Figure 9-2.1. The system consists of:

- A shaft of approximately 10 to 12 feet in diameter and about 475 feet deep in the cul-de-sac area of Seamoor Drive;

- A network of about 40 to 50 radially-arranged hydraugers with an average 4% gradient into the shaft so that the shaft can collect groundwater from the hydraugers by gravity flow. The hydraugers would be about 3 inches in diameter and have estimated total lengths of about 25,000 and 30,000 feet.

- A series of deep dewatering wells in the Southeast Region.

The estimated construction cost for the shaft/hydrauger/well option is about $4,000,000 (1991 Dollars).

In addition to being more expensive than the wells-only option (to be described below), this option also has the following concerns:

1. The construction of this option may cause significant noise, dust and traffic problems to the neighborhood in general, and in particular for the residents of 4 specific houses (3800, 3801, 3810 and 3811 Seamoor Drive) for up to 1-1/2 years.

2. The past performance of the existing hydraugers in the area has been relatively poor, as evidenced by the decrease in their production rate over time. Also, hydrauger production can be significantly reduced by being sheared off by landslide movement or by collapse as well as by being blocked due to clogging calcium carbonate deposits as described in Section 5.0.

3. There exists a possibility that these hydraugers could be sheared-off due to seismic movement during a near field maximum credible earthquake.

9.2.3.2 Vertical and Inclined Wells

This option considers additional dewatering by a number of more appropriately spaced, deep vertical and inclined wells to lower the overall groundwater table to down towards the basal rupture surfaces of the main slide mass (i.e., improving the stability of the Central Region, the Southeast Region and the eastern and western portions of the Bluff Region. A close examination of the prevailing groundwater table indicates that the existing wells, especially those located within the Sespe formation, are generally too far apart. With the exception of the 5 deep wells installed by BYA and W-18, the remaining wells are too shallow to be able to lower the prevailing groundwater levels further. Thus, any active dewatering option using deep wells for the BRM area should include new wells as well as deepening some of the existing wells so as to achieve the intended purpose at the least cost.

Based on available subsurface information and prevailing groundwater table conditions, a preliminary engineering analysis was performed to evaluate this well option. Our best estimate of required locations of these wells are shown in Figure 9-2.2 and the anticipated penetration depths of these wells are summarized in Table 9-1. In general, the required wells can be divided into the following categories:

- New vertical wells,

- New inclined, angled wells (which can be installed from public streets to penetrate through various hydrological barriers),

- Deepened existing wells.

As can be seen from Figure 9-2.2, most of the proposed wells are located within the main BRM landslide area, except two proposed wells within the Western Extension. The two wells in the Western Extension are strategically located to help keep groundwater levels in the Western Extension area lower than the identifiable potential slide surfaces based on the data available. Additional wells do not appear to be needed in the Western Extension as much as the main slide area because, in general, observed groundwater levels are lower in the Western Extension, and there is no apparent failure surface underlying the entire Western Extension area (as is the case in the main slide area).

It should be noted that the number and location of the wells required by this option are preliminary in nature and will require further refinement. There exist some uncertainties in the hydrogeological parameters of the Sespe formation where most of the new wells are located. The actual required number of wells will depend on hydrologic characteristics and potential variation patterns which will require additional investigation to provide sufficient refinement. The cost of additional investigations can be minimized by converting the borings into future wells in a phased approach. As shown in Table 9-1, the deep well option can be divided into two phases. Phase I wells are those strategically-located wells that are deemed most needed and likely to achieve the intended dewatering purposes, as well as to provide needed hydrological characterization (by performing pump and recovery tests on these wells). Phase II wells are the remaining wells, the location and number of which are to be optimized based on refined hydrological data after the Phase I program. The deep well program provides flexibility and cost optimization that are not possible by the shaft/hydrauger option which has a high start-up cost and little flexibility. The estimated total cost for this option (Phase I and II) is about $2.5 Million.

9.2.4 Active Restraints

Active restraints, such as structural retaining walls or preloaded tieback anchors, are intended to increase resistive forces and thereby to enhance the stability of a slope. These systems were evaluated for use as a supplement to the dewatering options for the high risk central portion (approximately 1,300 feet long, as represented by Cross Sections B-B' and C-C') of the Bluff Region. Two active restraint options were considered. These include a retaining wall option and a tieback option for the central Bluff Region.

The conceptual retaining wall option considered in this study is shown in Figure 9-2.3. This option includes a 20-foot high retaining wall backfilled with suitable material to form a backfill slope of about 1½ to 1-3/4 (horizontal): 1 (vertical) on top of the retaining wall. Space limitations on PCH (at the foot of the bluff) dictate that the vertical retaining wall should be at most 10 feet from the existing toe of the bluff. The height of 20 feet was subjectively selected to minimize its potential visual impact to the general area. The results indicate that an increase of 0.05 in the factor of safety for the central bluff area is possible.

TABLE 9-1

DEEP WELL REMEDIATION OPTION

A. PHASE I - ESTIMATED WELLS FOR WELLS-ONLY OPTION

WELL #	TYPE	ESTIMATED PENETRATION DEPTH (Ft.)	ANTICIPATED LOCATION	APPROXIMATE INCLINATION (Degrees)
I-1	Vertical	350	Rockport, near SP-3	0
I-2	Vertical	350	Near Inland cul-de-sac	0
I-3	Inclined	250	Opposite 20152 PCH	45
I-4	Inclined	250	Opposite 20218 PCH	45
I-5	Vertical	450	Roca Chica, near W-4	0
I-6	Inclined	450	Roca Chica, near W-7	20
I-7	Inclined	250	Opposite 20330 PCH	45
I-8	Vertical	450	Roca Chica, near W-5	0
I-9	Deepen W-15	450	Seamoor cul-de-sac	0
I-10	Deepen W-16	425	Seaboard Road	0
I-11	Inclined	550	20544 Roca Chica	20
I-12	Vertical	450	Near SP-10	0
I-13	Vertical	425	Big Rock Drive, near W-11	0
I-14	Inclined	500	Near 20771 Big Rock Drive	35

TABLE 9-1: DEEP WELL REMEDIATION OPTION (Page Two)

B. PHASE II - WELLS FOR BEST ESTIMATED CASE

WELL #	TYPE	ESTIMATED PENETRATION DEPTH (Ft.)	LOCATION	APPROXIMATE INCLINATION (Degrees)
II-1	Inclined	250	Opposite 20062 PCH	45
II-2	Vertical	350	Near 20219 Inland, 200' West of Big Rock	0
II-3	Deepen W-8	390	20405 Seaboard	0
II-4	Deepen W-17	350	20418 Roca Chica	0
II-5	Inclined	450	Near SP-32	30
II-6	Inclined	250	50' East of SP-8A	45
II-7	Vertical	450	300' ± East of SP-10	0
II-8	Vertical	450	Between 20470 and 20490 Seaboard	0
II-9	Inclined	450	20418 Seaboard	25
II-10	Vertical	400	Little Rock Way, about 150' East of SP-17	0
II-11	Inclined	500	20494 Roca Chica	30
II-12	Inclined	500	Roca Chica, 100' ± East of W-7	30
II-13	Inclined	400	Inland & Rockport	35
II-14	Vertical	300	20677 Seaboard	0

9.3 DISCUSSIONS & SUMMARY

The prevailing factors of safety for most of the study area and its subregions are 1.25 or less. The margin of safety represented by these factors of safety is considered too slim. Failures can and will occur at some future time. To mitigate this risk, additional mitigation measures are needed.

Various mitigation options are evaluated in Section 9.2. As previously discussed, the complexity of the BRM area limits the number of potentially viable mitigation options. Such options are further constrained by cost and the practical concern of being able to reach a community consensus.

Considering all of the potential constraints, the most viable mitigation options for consideration by the residents in the BRM area are summarized as follows:

1. An additional dewatering system (best estimate cost of about $2.5 Million) consisting of new wells and the deepening of some existing wells is capable of improving the gross factors of safety of the Central and Southeast Regions, and a major portion of the Bluff Region. Because of the interdependency of the various regions, the stability benefits offered by this option benefit most of the BRM area, including the Western Extension and the Southeast Region. This option will not improve the current stability of the Headscarp Region, the South-Facing Slope Region, nor the Central Bluff. Neither will it eliminate septic effluent-induced cones of infiltration (which can reduce lot-specific stability and can jeopardize stability of areas in the Headscarp, Bluff and South-Facing Slope Regions). Proper maintenance of the existing dewatering system and monitoring must be continued.

2. A new area-wide sewage collector system would eliminate about 60% of groundwater recharge in a year of average rainfall (16-inches). The new sewer system would especially benefit those areas where perched groundwater and shallower slide surfaces exist. A sewage collector system would eliminate cones or infiltration emanating from individual septic tanks which cannot be eliminated by a dewatering system. The elimination of these cones will also have the beneficial effect of improving the local stability of individual lots, especially in the Headscarp, Bluff and South-facing Slope Regions. A sewage collector system will also prevent or reduce rising groundwater caused by successive wet years, but will not substantially reduce current basin-wide groundwater levels, only additional dewatering can do that. If an area-wide sewage collector system is not built, then packaged on-site treatment and offsite disposal systems should be used in those regions where septic effluent recharge may further deteriorate the already precarious stability conditions. These regions include the Headscarp Region, the Bluff Region and the South-Facing Slope Region in the Western Extension area.

3. Crack filling throughout the BRM area, especially in the Headscarp Region (everywhere), Bluff Region (especially in the vicinity of Cross Section E-E') and the South-Facing Slope Region in the Western Extension, including collaboration among neighbors to implement a continuing crack filling/surface drainage improvement and maintenance program.

4. Maintain and improve surface drainage of individual lots.

5. It should again be emphasized that there exists a potential of earthquake-induced excess pore pressure which can significantly reduce stability in general and the stability of the Bluff Region and the Southeast Region in particular. It is important that the groundwater levels in wells, inclinometers and multi-staged pneumatic piezometers in the BRM area be observed immediately after any future earthquake events so that a site-specific database can be established to enable a better prediction of the potential magnitudes of seismic-induced excess pore pressures and their potential adverse effects on the stability of the BRM area.

6. The use of rock-nets to restrain debris and/or debris fences to divert the impact of debris flows with respect to potential rockfalls in the steeped slope areas, especially in the Headscarp and Bluff Regions should be considered.

7. Improve potential rainfall-induced perched groundwater conditions within the Headscarp Region and the South-Facing Slope Region by the proper design and placement of hydraugers. Maintenance should be routinely performed to minimize potential blockage or clogging of the hydraugers.

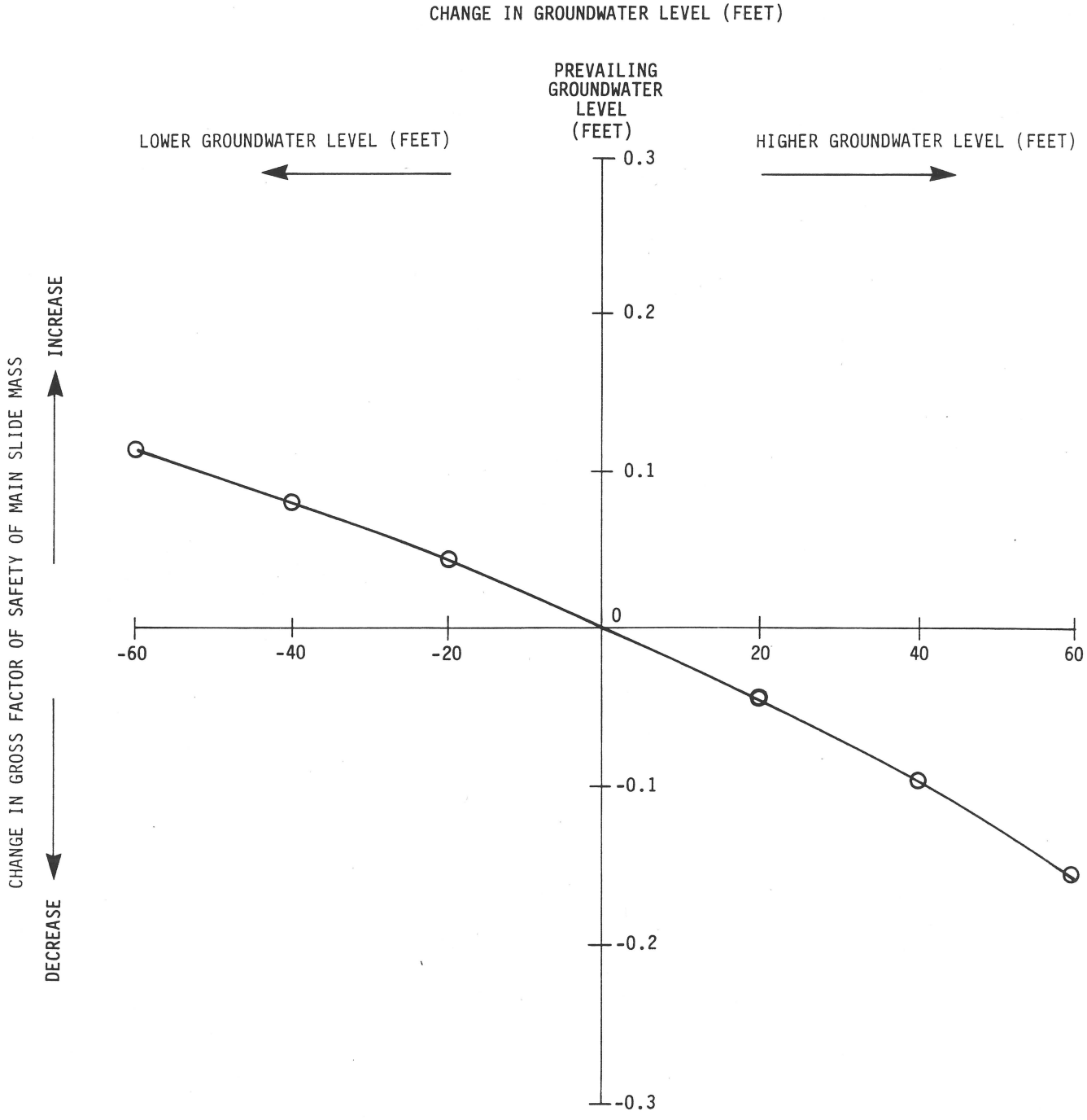
Although our understanding of the BRM has been substantially improved as a result of this investigation, many uncertainties still remain. In light of these uncertainties, it is especially important for the community to pursue a conservative course of action in evaluating and implementing future mitigation measures.

BYA is pleased to have had the opportunity to conduct this investigation and to present this report to the citizens of the Improvement District.

Prepared by the Project Team of:
BING YEN & ASSOCIATES, INC.



Bing C. Yen, Ph.D., RGE #917
President



NOTE: SEE TEXT FOR USES AND LIMITATIONS OF THIS FIGURE

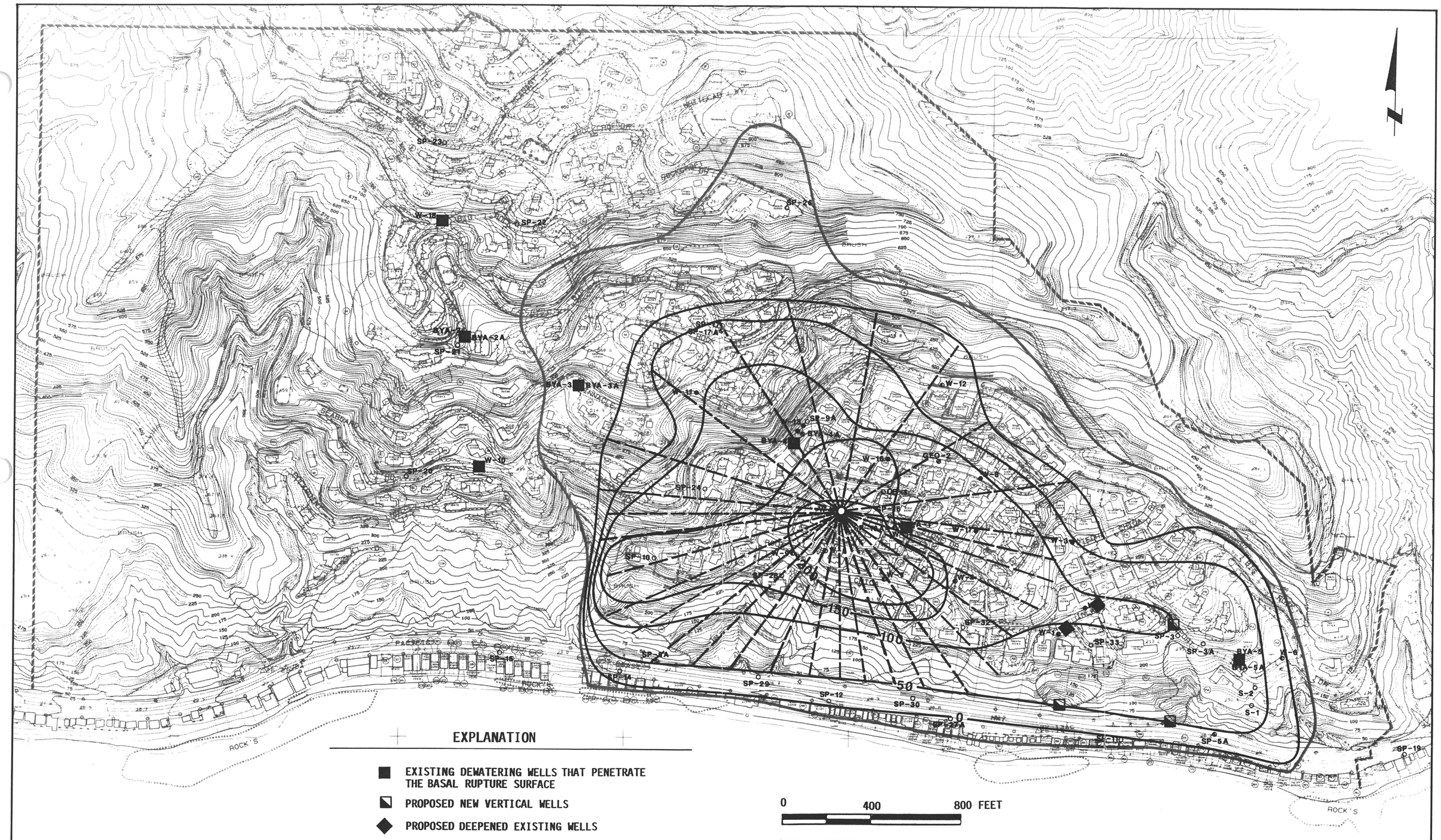
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EFFECT OF CHANGING GROUNDWATER LEVELS ON THE FACTOR OF SAFETY OF THE MAIN BRM LANDSLIDE MASS

FIGURE 9-1.1


SP-23
W-15
SP-22
SP-21
SP-26
SVA-1
SVA-2A
SP-27
SVA-3
SVA-3A
SP-17A
W-11
W-12
SP-9A
SVA-4A
SVA-4
W-13A
GEO-2
W-8
W-10
SP-24
W-17
W-14
SP-10
W-9
W-7
SP-32
W-16
SP-33
SP-30
SP-3A
SVA-5
SVA-5A
W-6
S-2
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SP-5A
SP-19
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EXPLANATION

- EXISTING DEWATERING WELLS THAT PENETRATE BELOW THE BASAL RUPTURE SURFACE
- DESIGNATED PHASE I DEWATERING WELL LOCATION
- DESIGNATED PHASE II DEWATERING WELL LOCATIONS
- DIRECTION OF INCLINATION
- ESTIMATED PIEZOMETRIC HEAD ON BASAL SURFACE AS OF OCTOBER 1991

0 400 800 FEET

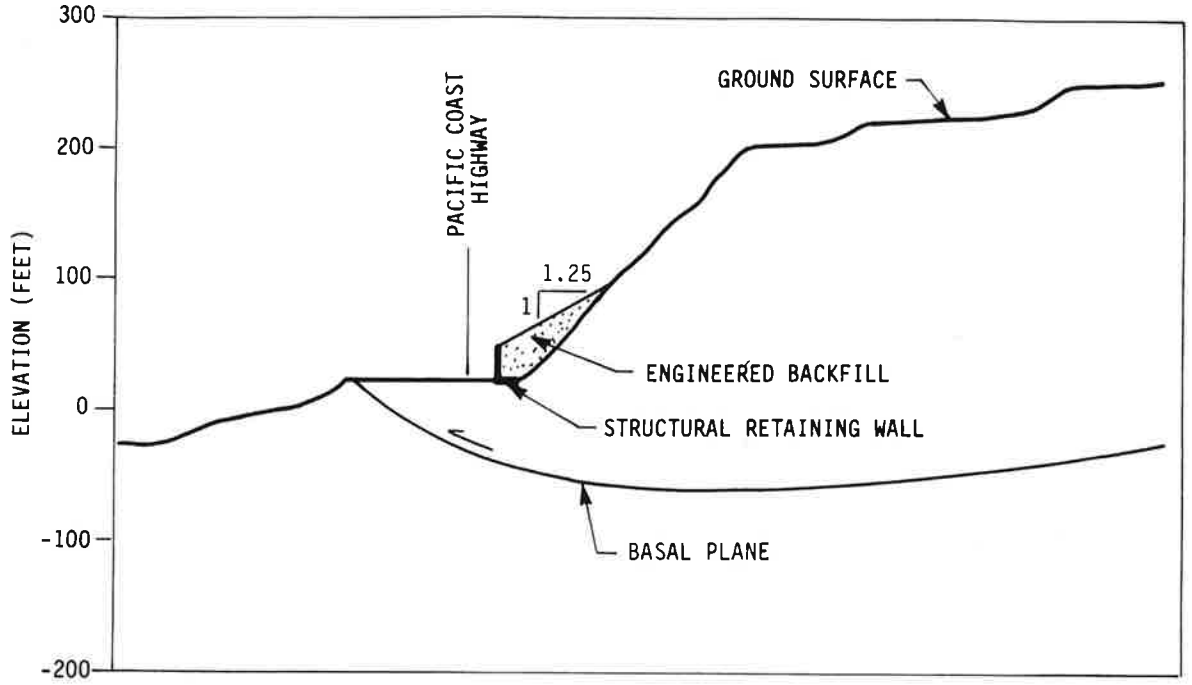
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

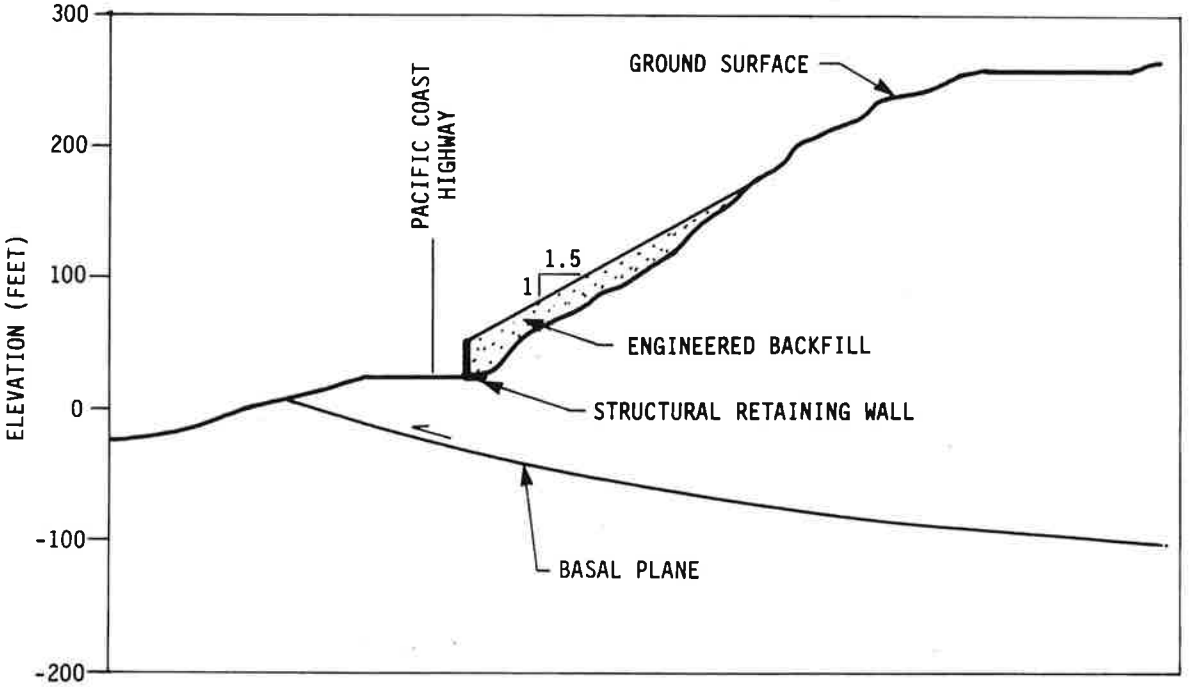
PROJECT NO.: 49-97D | DATE: DECEMBER 1991

DEEP DEWATERING WELL MITIGATION SCHEME

FIGURE 9-2.2



A. CROSS SECTION B-B'



B. CROSS SECTION C-C'

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EXAMPLE OF RETAINING WALL OPTION FOR INCREASING STABILITY OF BLUFF REGION

FIGURE 9-2.3

APPENDIX A

LIST OF DOCUMENTS REVIEWED

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Correspondence from Donald R. Warren Co. to Mr. John M Drury, Re: Fill Investigation Opposite 20358 Big Rock Drive. Nov. 27, 1959

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Engineering Geology Report - Tract 26263 Malibu, Ca . By: Eugene D. Michael - Engineering Geology. Feb. 23, 1961.

Supplement to Engineering Geology Report, Tract 26263. By: Eugene D. Michael Engineering Geology. Feb. 23, 1961.

Stability Investigation - Tentative Tract 26263, Malibu, CA By: Moore & Taber - Engineering Geologists. July 24, 1961.

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Correspondence from Moore & Taber to Roberts Enterprises. Re: Stability of Tentative Tract 26263. Oct. 26, 1961.

Technical Correspondence from United States Geological Survey, to Mr. John A. Lombie, L.A. County Engineer. Re: Preliminary Geologic Map of the Big Rock Mesa Area. Nov. 1, 1961.

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Correspondence from Dr. James E. Slosson to Pierie Sherman Co. Re: Addendum to the Geologic Report dated July 12, 1961 of Tract 26766, L.A. County (Big Rock Mesa, Malibu, CA.). Feb.6, 1962.

Correspondence from Moore & Taber to Mr. Luis Monzano - AMCO Engineers, Re: Revised Tentative Map of Tract 26263. Apr. 18, 1962.

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Los Angeles County Document Re: Stability of Tract 26263. May 21, 1962.

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Correspondence from Moore & Taber to AMCO Engineers. Re: Grading Plan Review, Tract 26263 and 27463. Oct. 9, 1962.

Los Angeles County Document Re: Maintenance of Horizontal Drains, Tentative Tract No. 26263. Jan. 4, 1963.

Correspondence from Attorney Richard L. Kite to Mr. Frederick J. Barlow. Re: Deposit on Maintenance of Subsurface Drainage Pipes. Dec. 27, 1962.

Los Angeles County Document Re: Modification to Tentative Conditions of Tracts 26263 and 27463. Jan. 2, 1963.

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Correspondence from Moore & Taber to AMCO Engineers Re: Location and Depth of Seepage Pits on Tracts 26263 and 27463. Apr. 8, 1963.

Correspondence from John D. Merrill, Engineering Geologists to Dr. Berry Richman. Re: Engineering Geologic Reconnaissance, Approximately 3 Acre Parcel, West End of Seaboard Drive, Big Rock Mesa Area, Malibu, California. May 16, 1963.

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Correspondence from AMCO Engineers to L.A. County Dept. of Building and Safety; Re: Rough Grading Certification, Lots 16, 17, and 18, Tract No. 26263. Aug. 26, 1963.

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Correspondence from Moore & Taber to Mr. Chet Mason Re: Final geologic inspection, Lots 16, 17, and 19, Tract 26263, Big Rock Mesa. Dec 16, 1963.

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APPENDIX B

APPENDIX B

GEOLOGIC DESCRIPTIONS, INTERPRETATIONS AND ANALYSES

B.1 GEOLOGIC SETTING

B.1.1 Geologic Setting and History

B.1.1.1 Depositional History

This part of the Santa Monica Mountains contains sedimentary rock formations that represent the displaced northern end of the Los Angeles basin. One can think of the area as having been cut off from the rest of the basin by the fault system bounding the southern edge of the Transverse Ranges tectonic province (e.g. the Cucamonga-Santa Monica-Malibu Coast fault system). It has been suggested that the rocks of the Santa Monica Mountains have been shifted many kilometers westward (left-laterally) with respect to the original axis of the Los Angeles Basin. The evidence for this interpreted displacement is similarity of stratigraphic sequence north and south of the fault. Specifically, the strata of the main part of the Santa Monica Mountains correlates with that of the eastern part of the Los Angeles basin.

Part of this basin fill sequence is seen in the BRM area. Most of these rocks are Tertiary age (e.g. Paleocene to Miocene) units that include the Coal Canyon, Sespe, and Vaqueros formations as well as members of the Topanga Group. The oldest rock formation, exposed north of BRM, is the Tuna Canyon Formation of late Mesozoic (Cretaceous) age. The base of the sedimentary section, marked by metamorphic basement, is exposed in the eastern Santa Monica Mountains but is not seen in the BRM area and, presumably, lies at depth.

The two oldest formations, the Tuna Canyon and Coal Canyon, are not seen in depositional contact with the younger main sequence of the BRM area or with each other. Both are separated by faults from the main part of the mesa (re. geologic map) and from the younger rocks located there.

Regionally within the Santa Monica Mountains, the Paleocene Coal Canyon Formation contains a shoreline sequence located a few kilometers east of Topanga Canyon. The section in that area thickens rapidly westward, from about 300 to 5000 feet according to Yerkes and others (1965) with fossil-bearing marine deposits extending westward to and beyond the BRM area. Coarse conglomerates together with shale in the BRM area, however, suggest fluctuation from near-shore to offshore environments of deposition.

Sespe Formation in the BRM area and regionally marks a period of terrestrial red bed deposition during which fluctuating shorelines transgressed and regressed periodically across the area. The deposits seaward of the shorelines are called Vaqueros Formation. At BRM, one of these marine transgressions (lower Miocene) is recorded by an eastward-thinning succession of fossil-bearing Vaqueros beds. Sespe below the marine beds contains coarse

sandstones and conglomeratic sandstones that grade abruptly upward into finer-grained redbeds that mark the transition to marine Vaqueros sandstone and shale. This sequence records an eastward shift of the shoreline across BRM. The end of this short-lived episode of marine deposition is marked by another gradational transition back to redbed deposition, wherein marine sandstones and shales grade upward into predominantly fine-grained redbeds of the Sespe. This upper succession of the Sespe probably records a period of nearshore deposition by relatively low-energy currents as suggested by a lack of conglomeratic beds. Sources of Sespe sediment appear to have been located in the northeastern quadrant (Yerkes and others, 1965).

Due to faulting, Topanga Group rocks have not been seen in unambiguous depositional contact with underlying Sespe at BRM, thus obscuring the nature of the contact locally. Regionally, however, a "significant period of uplift and erosion" followed deposition of the Sespe and Vaqueros according to Yerkes and others (1965) so that a regional unconformity generally marks the beginning of post-Sespe deposition. It follows that at BRM the beginning of Topanga deposition was probably marked by transgressive onlap of lower middle Miocene (middle Miocene: 11.2-16.6 Ma) marine sediment onto this unconformity as the shoreline shifted from west to east across the area. By this time the Los Angeles basin was a well-developed northwest trending low within which these shallow marine deposits accumulated. BRM was located near the eastern edge of the basin.

The Topanga section at BRM is from the lower Topanga Group. Upper Topanga Group units occur in adjacent areas including volcanic rocks of the Conejo Volcanic Series and younger units. The roots of the Conejo volcanoes are present at BRM in the form of intrusive basaltic and diabasic dikes and sills that cut upward through all of the units described thus far. This intrusive activity apparently occurred in upper Miocene time and affected all units younger than late middle Miocene (middle Miocene: 16.6-11.2 Ma). The coarse diabasic textures of most intrusions at BRM indicate relatively deep burial (e.g. greater than approximately 1 km) at the time of intrusion.

Although the local depositional history at BRM ends after lower middle Miocene, it is important to note that middle Miocene units elsewhere are unconformably overlain by upper Miocene (11.2-5.3 Ma) sedimentary units of the Modello/Monterey formations. This unconformity marks a period of time during which the Santa Monica Mountains were uplifted and deeply eroded. The eastern Santa Monica Mountains were locally eroded to basement so that when marine sedimentary deposition resumed, the resulting upper Miocene sequence was deposited unconformably on those basement rocks. In general, the upper Miocene sequence is separated from underlying older formations by a pronounced unconformity representing a period of significant deformation of importance to the BRM area.

All deposition in the Santa Monica Mountains apparently ceased in early Pliocene (5.3-3.4 Ma) time, apparently marking the beginning of uplift of the present range. However, the Santa Monica Mountains were not high enough by late Pliocene (3.4-1.6 Ma) to constitute a significant sediment source that shed distinctive and recognizable sediment into adjacent basins. By the end of Pliocene time large parts of the Santa Monica Mountains stood high above sea level as did other areas located adjacent to the Los Angeles Basin.

Continued uplift of the Santa Monica Mountains affected the BRM area to the present time. Quaternary uplift is indicated by elevated marine terraces that have been documented along the coast, in the vicinity of the site and elsewhere. These terraces formed near or below present sea level and have been elevated tectonically, in the BRM area, to elevations of 50 to 225 feet.

The terraces appear to date from the period 80,000 to 125,000 years ago during which sea level was at a relatively high level similar to that seen today (Shackleton and Matthews, 1977; Birkeland, 1972). During low stands, sea level dropped by as much as 300 feet below present and remained there for periods of several centuries to several millennia. The last low stand ended about 10,000 years ago. When sea level was low, the coastline was located well offshore from where it is today.

The highest marine terrace in the BRM area is marked by the fossil locality 300 feet northeast of the intersection of Big Rock Drive and Pacific Coast Highway (see geologic map) at an elevation of approximately 200 feet. This terrace is at the same elevation as the "Coral" terrace of Birkeland (1972) which corresponds globally to the last interglacial sea level maximum of oxygen isotopic stage 5e dated at 120,000-125,000 years ago (Chappell, 1974; Shackleton and Matthews, 1977). Sea level at that time was of the order of 10 to 15 feet higher than present which implies uplift at BRM of approximately 1.5 feet per thousand years since the terrace was formed.

B.1.1.2 SUMMARY TECTONIC HISTORY

The regional tectonics of the western Transverse Ranges is complicated and subject to varied interpretations. Recent attempts, for example, to interpret the deep geologic structure (Namson and Davis, 1988) using retrodeformable cross-sections have met with considerable debate (Hill, 1989; Yeats and Huftile, 1989; Weldon and Humphries, 1989). This does not reflect negatively on the ability of the researchers involved but rather highlights the complexity of the geology. This complexity has been brought about by multiple deformations under stresses that appear to have varied through time. A generalized sequence of events is as follows:

1. Development of the Los Angeles Basin containing sedimentary sequences that currently extend northward into the area now occupied by the Transverse Ranges to the approximate position of the Oak Ridge thrust (Campbell and Yerkes, 1976); although described as a northwest-trending syncline by Yerkes and Campbell (1965), more current interpretation suggests a basin bounded by normal faults later rotated into present position (Davis, Namson, and Yerkes, 1989; Luyendyck and others, 1980);

2. Broad uplift and erosion of Sespe prior to deposition of the Topanga; possible beginning of left-lateral slip along the Santa Monica Fault; possible inception of clockwise rotation;

3. Extensional deformation, after deposition of the Topanga, in the form of either low-angle detachment faulting (Yerkes and Campbell, 1966) or high-angle normal faulting associated with basin development (Davis, Namson, and Yerkes, 1989); concurrent volcanism including intrusion of diabasic and basaltic dikes and sills; clockwise rotation of entire area of the Transverse Ranges (Luyendyck and others, 1980);

4. Imbricate thrust faulting and concurrent folding of entire sequence along east-west trends associated with left-oblique displacement; latest Miocene to early Pliocene (perhaps Pliocene-Pleistocene according to Campbell and Yerkes, 1976); left-lateral component of displacement variously estimated at 6-13 km by some researchers (Lamar, 1961; Wright, 1973; Truex, 1976) and 60-90 km by Campbell and Yerkes (1976; also Yerkes and Lee, 1987); Concurrent with later stages of regional clockwise rotation (Luyendyck and others, 1980); Miocene age intruded normal faults possibly folded into reverse-fault geometry by compressional deformation (Davis, Namson, and Yerkes, 1989; Davis and Namson, 1989; Jacobson and Lindblom, 1987);

5. Continued movement along faults during uplift or Santa Monica Mountains related to left-oblique transgression along the Malibu Coast/Santa Monica fault system; mobilized by stresses at plate margin at present position of San Andreas Fault; uplift rate at BRM of 1.5 feet per thousand years, during the past 125,000 years, indicated by elevated marine terraces (Birkeland, 1972; Shackleton and Matthews, 1977; Chappell, 1974).

6. Main body landsliding and satellitic sliding (probably second).

Of importance to Big Rock Mesa are 1) the idea that extension occurred early in the deformational history and that volcanism accompanied that extension or occurred very shortly thereafter, 2) the idea that following this extension, during late middle Miocene time (Campbell and Yerkes, 1976; Yerkes and Lee, 1987), the Los Angeles Basin sedimentary sequence was truncated and uplifted as it was displaced left-laterally by the Santa Monica/Malibu Coast fault system concurrently with major clockwise rotation of 70-80 degrees; and 3) the idea that north-northeast/south-southwest horizontally-directed compressive stress and resultant left-oblique transgression (dominantly dip-slip reverse at BRM) has dominated since then to the present. At currently interpreted rates of uplift, the Santa Monica Mountains in the vicinity of BRM could have been elevated entirely during the Pleistocene (e.g. the last 2 Ma).

The geology of the BRM area, as described in subsequent sections bears the clear imprint of the complex tectonic history of the Transverse Ranges summarized above. The structural features documented on the geologic map and interpreted in the geologic cross-sections are the product of polygenetic (multiple episodes of) deformation resulting from at least two distinctly different stress regimes; the first of these was extensional and the second was compressive as per items 1) and 2) of the foregoing paragraph. A third stress regime (item 3; also compressive) can be inferred to have coincided with the transition from the dominantly strike-slip deformation of item 2 to the dominantly dip-slip (left-oblique) reverse faulting of item 3.

Understanding the details of the stress regimes that have affected BRM through time is important in two fundamental ways to both the remediation of existing landslide conditions and the mitigation of future landslide hazards. First, the current stress regime controls the type and distribution of earthquakes discussed in Section 4.2 of this report. Second, current and past stress regimes have produced structural patterns that are to some extent predictable from the standpoint of empirical experiments and studies of similar structures elsewhere. This second factor makes it possible to predict, within limits, the orientations of structures that might adversely impact the stability of BRM.

There is general agreement that the regional stress field has been controlled through time by tectonic interaction of the North American and Pacific plates. Beyond that, there is no consensus regarding details of this interaction. No completely satisfactory model has yet been proposed and a comprehensive summary of existing models will not be attempted here. A selective treatment of the two existing models, however, will be undertaken as examples of reasonable, if not complete, explanations of how some of the important structural geologic aspects of BRM could have developed. The first of these deals with the large 70-80 degree clockwise rotation of the Transverse Ranges mainly during the Miocene (Luyendyck and others, 1980); the second addresses compressional shortening of the Transverse Ranges from Pliocene to present (Davis, Namson, and Yerkes, 1989; Namson and Davis, 1988).

Paleomagnetic data suggesting clockwise rotations of 70-80 degrees for rocks of the Transverse Ranges are summarized in Luyendyck and others, 1980, including Kamerling and Luyendyck, 1977 and 1979. These rotations affected primarily rocks of Miocene age and older.

The Luyendyck and others (1980) model employs rigid body rotation of multiple blocks (microplates) about vertical axes (Figure B-1.1) starting in Oligocene and ending in Pliocene with most motion during the Miocene. Rotation is related to the early stages of growth of the San Andreas Fault at its current position within the Transverse Ranges tectonic province. The model permits major clockwise rotation of the Transverse Ranges with little or no rotation of areas to the south.

As with any model, this one has strengths and weaknesses. The strengths include: 1) it provides a mechanism for substantial left-lateral shear along the frontal faults of the Transverse Ranges; 2) it provides a mechanism for extension and associated subsidence of the Los Angeles Basin; and 3) as explained above, it does not require major rotation of areas south of the Transverse Ranges where right-lateral strike-slip is dominant. Item 1) also provides a mechanism for folding and thrusting the Santa Monica Mountains at BRM if transpression is invoked due to convergence along the left-lateral strike slip faults.

A significant weakness of the Luyendyck and others (1980) model is that it doe not address non-rigid body deformation, an important aspect of the regional tectonics.

The Davis and others (1989; and Namson and Davis, 1988) model is based upon north to south deep cross-sectional analysis through both the Transverse Ranges and the Los Angeles Basin to the south. In terms of geologic time, it takes up where Luyendyck and others (1980) model ends. The cross-sections produced during this analysis were retrodeformable or "balanced" as per Dahlstrom (1970) and Suppe (1985), meaning that they are restorable to their initial "undeformed" state. In the case of the Transverse Ranges and adjacent Los

Angeles Basin, "undeformed" means the structural state existing when the deformation began in the Pliocene. The solutions derived from this analysis, as stated by the authors, are nonunique. However, there are useful insights to be gained.

The Davis and others (1989; and Namson and Davis, 1988) model is based upon the idea that the thrusts and associated folds in the Transverse Ranges and Los Angeles Basin are linked to a regional mid-crustal detachment at a depth of 10-15 km. This structure is theoretically seismogenic, thereby, posing a significant problem for seismic risk analysis tied to the mapped surface traces of faults. Simply stated, earthquakes with foci of 10-15 km can occur anywhere in the region.

Of more local interest to BRM, is the idea that basin bounding normal faults are rotated, in the modelled deformation, into reverse fault orientations. This idea is compatible with the results of field studies of certain faults at BRM, the details of which are discussed in subsequent sections. These can be thought of, if the Luyendyck and others (1980) model is also considered, as basin bounding normal faults that originally had northerly trends that were rotated clockwise into east-west orientations and then were compressed and folded as part of the Santa Monica Mountains uplift from Pliocene to present.

B.1.2 Faults and Other Geologic Structures

The two most authoritative geologic maps containing compilations of new and preexisting data for BRM and surrounding areas are Yerkes and Campbell (1980) and Dibblee (in press). Both have a final scale of 1:24000.

In addition to reviewing the above maps, field orthophotographic annotations by Yerkes and Campbell at 1:2400 scale were examined for the immediate area of the BRM investigation. These notes included data not published in the final U.S. Geological Survey map (Yerkes and Campbell, 1980).

Also, a one-day field conference was held with T. Dibblee, on July 24, 1990, for the purpose of discussing his preliminary mapping of BRM and surrounding area (Dibble, in press). A preliminary copy of this map was obtained and considered in the compilation.

The geologic map (Figure 4-1.2 contained in Section 4.0 of the main report) includes raw data compiled from 22 different sources in addition to substantial new mapping. The data incorporated into the compilation consisted of outcrop identifications, bedding attitudes, and fault/fracture attitudes. Interpretive data was considered but not included directly. The 22 sources are as follows:

Humphrey and Maynard (1947)
Slosson (1961)
Slosson (1962)
Michael (1961)
Moore and Tabor (1963)
Yerkes and Campbell (undated, field data)
Merril (1972a)
Merril (1972b)
Lockwood-Singh (1973)

Lockwood-Singh (1974)
Stone and Associates (?)
Kovacs-Byer (1976)
Kovacs-Byer (1977)
Kovacs-Byer (undated)
Soils International (1977)
Merril (1977)
Michael (1979)
Yerkes and Campbell (1980)
Cotton (1988-1989, field data)
Macnamara (1986-1987, field data)
Evans (1986)
Dibblee (in press)

Aerial photography was utilized extensively with particular emphasis on the period predating development. Fourteen generations of vertical aerial photography from various sources were used. The dates of the photography are as follows:

1928, 1931, 1933, 1938, 1946,
1948, 1949, 1950, 1967, 1968,
1983, 1984, 1986, 1990

Four generations of oblique aerial photography flown in the years 1973, 1978, 1982, 1983 were also utilized.

Field mapping, sample collection, and checking were conducted from 1990-1991 using large-scale base maps ranging from 1:480 (1 inch = 40 feet) to 1:1200 (1 inch = 100 feet); the final compilation was done at 1:1200 scale on a scale-stable mylar base.

The area mapped is extensively vegetated except where topography is particularly steep and superficial mass wasting is active. Developed areas are largely covered by landscaping. Mapping compiled from sources before or during development was particularly useful in such landscaped areas. New mapping concentrated on areas bordering the developed portions of BRM and included Piedra Gorda Canyon, Rockpoint Canyon, the seacliff adjacent to Pacific Coast Highway, and the ridgeline bounding the active landslide. This mapping, together with deep core drilling within BRM, made it possible to trace geologic structures throughout the area.

B.1.2.1 Folds

Steep dips across the BRM area indicate significant rotation and bending of rock layers. Dips in the Sespe formation, for example, are vertical to overturned in the western part of the map area and commonly dip steeply northward or northeastward elsewhere. The main exception to this pattern is upper Piedra Gorda Canyon where southward dips are seen marking the north limb of a west-northwest trending syncline. The hinge of this fold lies along the crest of the ridgeline bounding the main active landslide. It lies between two north-dipping thrust faults and is oversteepened due to drag by the upper of these (Las Flores Fault).

There is no evidence for the presence of an anticline anywhere in the map area except possibly north of Piedra Gorda Canyon. Dibble (in press) has reinterpreted the area north of Piedra Gorda Canyon (north of the Las Flores Fault) to be an overturned anticline cored by Cretaceous sedimentary rocks; under this interpretation, the northward-dipping units in that area are overturned to the south. Yerkes and Campbell (1980) imply the existence of such a structure on their cross-section DD' but do not show a fold on their map. The Geologic map (Figure 4-1.2), pending verification of the overturned geometry proposed by Dibblee (in press), shows the geology as per Yerkes and Campbell (1980).

The general character of BRM south of the syncline is homoclinal toward the north. This reflects the general structural fabric of the surrounding portion of the Santa Monica Mountains wherein folds have developed along northwest trends.

B.1.2.2 Faults

All major faults trend generally east-west and are predominantly north-dipping as shown in Figures 4-1.2 and 4-1.3 of the main report. Numerous cross-faults occur in the BRM area with mainly north-northeast trends and variable dips. The generally east-west faults form an imbricate zone of stacked fault slices; the individual faults, however, probably represent at least three generations of deformation. The oldest of these are folded faults formed under extensional stresses with younger rocks overlying older across the fault planes; post-dating these are thrust faults of the Las Flores fault zone with associated folding along nearly parallel trends; the third are left-oblique slip faults of the Malibu Coast fault system with dominantly reverse dip-slip motion.

Major faults with generally east-west trends are typically intruded by basalt or diabase. Cross-faults are less commonly intruded, particularly within the active landslide.

I. THRUST/REVERSE FAULTS

This category of faults is defined in the usual geometric sense to include faults that have hanging walls displaced upward with respect to footwalls. By this definition, rotated normal faults with appropriate orientations are also included.

A general characteristic of thrust/reverse faults is that older rocks are usually but not always thrust over the top of younger rocks. Another way of looking at this is to say that fault planes of thrusts tend to cut through successively higher parts of the section in the up-dip direction. A second general characteristic of thrusts is that they tend to be closely associated with folding either from fault propagation or fault bending. This causes hanging wall rocks to often be strongly rotated. A typical pattern is for steeply-dipping rocks to be thrust over shallowly dipping rocks. Some of the faults at BRM (e.g. the Seacliff fault) are clearly incompatible with these general characteristics of thrusts.

A. SADDLE FAULT:

Where it is exposed in the east wall of Piedra Gorda Canyon, this fault dips 11 degrees northeast with younger rocks (Saddle Peak Member, Topanga) above and older (basal Topanga in contact with Sespe) below as shown in Figure B-1.2. Rocks above the fault are rotated up to 83 degrees clockwise in the horizontal and are steeper in dip by 27-47 degrees compared to rocks below. In general rocks above the fault dip northeastward whereas those below dip northwestward.

The basal Topanga exposed beneath the fault contains abundant fossil mollusks including the pelecypods Vertipecten Nevadanus, Lyropecten, and Cardium (rare). Most occur within sandy intervals but one was found in shale containing fish scales.

The stratigraphic separation across the fault at the above locality would appear to be less than 350 feet based upon observed thickness data for the Saddle Peak Member. However, this estimate has only local applicability because of the sharp angular discordance between the rock units on opposite sides of the fault.

The Sespe and Topanga below the fault are discordant with respect to each other by an amount nearly equal to that produced by the fault above. Discordancy is characteristic of this important contact throughout BRM.

B. LAS FLORES FAULT:

Dips of 10-15 degrees north were obtained at exposures east and west of BRM where older rocks (Cretaceous and Paleocene) occur above the fault and younger rocks (Sespe) below. Where it is exposed in the north wall of Piedra Gorda Canyon, this fault separates rocks that dip northward above it and southward below. The reinterpretation of this area by Dibblee (in press) requires that the northward dipping rocks are overturned as explained previously. The strike of adjacent bedding is generally parallel to the fault as is the syncline located to the south suggesting that the folding developed concurrently with the faulting.

The stratigraphic separation is more than 1200 feet based upon the cross-sections of Yerkes and Campbell (1980). Rocks south of the fault are Sespe Formation in most areas. However, Topanga Formation is present south of the fault in some localities.

C. NORTH FAULT:

A possible splay of the Las Flores Fault, this fault dips 35-68 degrees north in exposures in Piedra Gorda Canyon and in upper BRM. Rocks north of this fault are synclinally folded; the fold overlies homoclinally north dipping beds beneath the fault.

Stratigraphic separation is shown to be more than 300 feet by Yerkes and Campbell (1980). Sespe is typically displaced over Topanga but locally the fault separates lower Topanga (Saddle Peak Member) above from upper Topanga (Cold Creek Member) below.

D. BIG ROCK DRIVE FAULT:

In various exposures along Pacific Coast Highway, this fault dips 30-80 degrees north with younger rocks (Piuma Member of the Sespe) above and older rocks (Vaqueros) below. Rocks above the fault dip homoclinally northward while those in the underlying Vaqueros dip discordantly northwestward or northeastward.

Very little dip-slip stratigraphic separation is evident. The section exposed east of Big Rock Drive along Pacific Coast Highway is nearly identical to that seen in the west wall of Rockpoint Canyon of the western extension.

E. SEA CLIFF FAULT:

Nearly continuous exposures of this fault can be seen in the sea cliff above Pacific Coast Highway in the area between Rockpoint Canyon on the west and the western margin of the active BRM landslide to the east. Dips in this interval are 9-31 degrees north with dips as low as 5 degrees north observed on small displacement subsidiary splays of the fault. Homoclinally north-dipping Sespe occurs both above and below the fault with steep dips greater than 70 degrees common. Rocks immediately adjacent to the fault are near vertical to overturned southward in some areas.

Although the magnitude of stratigraphic displacement is uncertain, the sense of displacement is clearly evident. Figure B-1.3 shows small displacements on fault splays wherein younger layers of the Sespe above are shifted southward relative to those below. Kinematic analysis of fractures within the main fault zone indicate a younger over older displacement history as shown in Figure B-1.4A and B-1.4B. The direction of motion indicated by striae on slickensides is generally south (up fault dip).

The fault appears to be folded near Rockpoint Canyon where it steepens in dip and changes strike abruptly as it nears the Rockpoint Fault, a north-trending cross fault described below.

F. BLUFF FAULTS:

At least two low-angle faults are present within the seacliff portion of the active landslide that do not correlate with either the Seacliff or the Big Rock Drive faults. The faults cut through rotated Sespe beds and are identifiable by the resultant discordancy of bedding.

Both magnitude and sense of displacement are uncertain because of similarity of Sespe adjacent to both sides of the faults. Near the western edge of the active BRM landslide two faults are marked by red clay gouge (no intrusions). These faults are displaced by north-trending cross faults at numerous points within the landslide.

II. FAULTS WITH STRIKE-SLIP COMPONENTS

This category of faults, as applied here, includes those with lateral slip components of motion based either on regional or site specific evidence. Faults of this type in the BRM area strike generally east-west and have relatively steep dips.

A. SHORELINE FAULT:

A major north-dipping fault zone lies closely adjacent to Pacific Coast Highway and appears to be part of the Malibu Coast Fault system. Although no surface exposures exist at BRM, the fault zone has been penetrated by borings along Pacific Coast Highway. Core recovered from boring SP-37 (BRM-6 in Figure B-1.5), for example, contained a thick breccia/gouge zone separating Sespe north of Pacific Coast Highway from presumed Zuma Volcanics and underlying faulted petroliferrous Monterey (?) shale on the south (Anderson and Keesey, 1986). This is the same stratigraphic relationship that is shown by Yerkes and Campbell (1980; re. their cross-section BB') north and south of the Malibu Coast Fault west of BRM.

A large left-lateral component of slip would be inferred on the basis of identifying the volcanics as Zuma as per Yerkes and Campbell (1980). An alternative and more conservative interpretation is that the volcanics are from the chemically and lithologically similar Conejo Volcanics of the Topanga Group. If correct, the vertical component of stratigraphic separation, based upon cross-section DD' of Yerkes and Campbell (1980), is approximately 4100 feet. Either way this fault is easily the largest in terms of displacement in the BRM area and is, therefore, minimally a frontal fault of the Santa Monica Mountains subject to the same stress regime as the Malibu Coast Fault or other similar faults in the Transverse Ranges.

B. SEABOARD FAULT:

Although not well exposed, this fault has a well-defined straight trace on pre-development vertical aerial photography. This together with mapped distribution of adjacent rock units indicates a near vertical angle of dip. The trace of this fault is most evident in Rockpoint Canyon/Drive area. It extends eastward, from that area, to the margin of the active BRM landslide where it abruptly ends due to truncation by sliding.

Left-lateral displacement of approximately 400 feet is suggested by the relative position of the Sespe/Vaqueros contact north and south of the fault. However, 280 feet of vertical (normal fault, north side down) displacement could have produced the same apparent horizontal separation. Both factors are probably involved whereby the net movement was left-oblique slip. A left-lateral component of displacement is supported by a series of drainage steps, most notably at Rockpoint Canyon and at the west edge of the active landslide mass.

The clear topographic expression of this fault together with the drainage shifts suggests relative youth with respect to other faults in the area.

III. NORTH-TRENDING CROSS FAULTS

North-trending faults of relatively short length occur throughout the BRM area. Typically they are high-angle faults with predominantly northeast trends. They are relatively more numerous within the active BRM landslide where they are either primary tears within the landslide mass or remobilized bedrock faults that act as accommodation structures between blocks.

A. ROCKPOINT FAULT:

A north-northeast trending high-angle fault displaces Sespe sandstone and conglomerate near the mouth of Rockpoint canyon at Pacific Coast Highway.

Stratigraphic displacement for this fault can be discussed in terms of possible vertical and horizontal components. Purely vertical displacement of 100 feet down to the north or purely right-lateral motion of 57 feet would produce the observed separation.

Rotation of bedding documented closely adjacent to the fault suggests that motion has been largely right-lateral. Rotation of bedding strike is approximately 20 degrees clockwise while dip shallows by 33-43 degrees from west to east across the fault. Clockwise rotation is compatible with simple shear (drag) associated with right-lateral slip (seaward) of rocks east of the fault. A similar rotation occurs across the western boundary of the active BRM landslide.

B. LOVE FAULT:

A north-northeast striking vertical fault, the Love Fault is well-exposed in the sea cliff downslope from the western edge of the Love landslide complex approximately 120 feet west of the active BRM landslide as previously mapped (Figure B-1.6A). This fault may have originated entirely as the result of landslide movement. Active landslide motion has been accommodated by this structure producing a net displacement down to the east with a pronounced clockwise rotation of Sespe east of the fault.

Sespe east of the fault is competent conglomeratic sandstone in contrast to the 50-80 foot wide chaotic, sheared and rotated, softer red sandstone on the west. The fault is marked by a seam of soft clay gouge up to 1 inch thick containing nearly horizontal slickensides striae (plunging 10 degrees north) on parting surfaces (Figure B-1.6B). The sandstone adjacent to the gouge zone has been tectonically softened.

The Seacliff fault (described previously) is displaced and rotated downward by 50 feet (vertical component) from west to east across the Love Fault. If all of this displacement was assumed to be horizontally seaward, 137 feet of motion would be required to produce the observed offset.

Rotation within the block east of the fault is approximately 40 degrees clockwise. This causes the trace of the Seacliff to plunge sharply downward to highway level over a distance of a little more than 100 feet.

The kinematic data including subhorizontal striae, apparent normal displacement down to the east, and clockwise rotation all point to a style of deformation that would be anticipated to exist at the margin of a landslide.

C. INLAND FAULTS:

These faults include two or more northeast-trending faults that separate the lower BRM into eastern and western blocks. Both are northwestward dipping normal faults that displace the stratigraphic section downward in that direction. As in the case of the Love Fault,

these faults could have originated entirely as accommodation structures associated with landsliding but also could have originated as bedrock faults. Faults of this type usually form as the result of shear within a landslide caused by differing rates of motion.

D. PIEDRA GORDA FAULT: (not exposed)

This fault is interpreted on the basis of juxtaposition of lower Sespe west of the fault against Piuma Member of the Sespe to the east, and by the absence of Vaqueros within Piedra Gorda Canyon.

III. SESPE/TOPANGA CONTACT - UNCONFORMITY OR FAULT?

The Sespe/Topanga contact has been demonstrated to be unconformable regionally. At BRM the contact was mapped as a detachment fault, called the Malibu Bowl fault by Yerkes and Campbell (1980), separating Vaqueros (actually Piuma Member of the Sespe), from Topanga. The position of their Malibu Bowl fault agrees with the Sespe/Topanga "contact" recognized by subsequent larger-scale mapping including that done in support of this project.

Our findings have determined the following about this important horizon: 1) it is marked by an abrupt angular discordance throughout the BRM area; 2) it is ubiquitously intruded by sheared and brecciated diabase with thicknesses as great as 80 feet; 3) it is commonly not parallel to rocks either above or below it (e.g. it cannot be projected successfully using surface bedding dips); 4) basal Topanga containing distinctive fauna (e.g. Ostrea titan or pectens including Vertipecten Nevadanus) is found in a number of localities adjacent to the fault but is absent elsewhere, and 5) a range of facies are present at the base of Topanga that change abruptly over short distances including concretionary shale in some areas and coarse pebbly sandstone in others. The contacts between the Sespe, Piuma Member, and Vaqueros are not similarly intruded at BRM.

These factors are supportive of the interpretation that the "contact" is actually a low-angle fault geometrically similar to the detachments described and mapped by Yerkes and Campbell (1980); moreover, the position of this fault coincides approximately with the "Malibu Bowl Fault" of their map. However, large displacements are not suggested by available data at BRM.

B.1.3 EXISTING LANDSLIDE FEATURES

The BRM landslide consists of at least seven discrete deep-seated blocks, a satellitic landslide complex along its northern margin, and a complex of relatively shallow landslides along its southern edge (Figure 4-1.2 in the main report).

Differential translation and rotation of the deep-seated blocks has been accommodated by bounding shear zones. This has minimized internal deformation within the blocks, preserving to some extent their original tectonically deformed state. The geology of the blocks, where exposed, is mappable. Many block boundaries are divergent, resulting in infilling of the area between blocks with debris.

Differential movement of the blocks is what gives BRM its stepped topography. Relatively greater prehistoric movement of the blocks of the lower mesa, for example, has resulted in their relatively lower topographic position. All of the deep-seated blocks are included in the active landslide.

The Satellitic landslide complex includes both source/scarp areas and deposits along the north edge of the BRM area. These failures are comparatively shallow and overlap the larger blocks to the south. For the most part only the lower part of this complex has been reactivated. The main exception to this is the northernmost and highest of the landslides in the northeastern part of the overall landslide.

Shallow landslides along the southern (leading edge) of the deep-seated landslide are numerous. For the most part they affect the topographically steep sea cliff area and toe up at and near sea level or, less commonly, higher up on the sea cliff. An additional landslide of this category extends across the topographically steep boundary between blocks of the upper and lower mesa, from Pinnacle Way to Seamoor Drive.

Outside the main active landslide and adjacent to it is a complex of relatively shallow landslides that includes the Love slide. It toes up in part at the north-dipping Seacliff fault well above Pacific Coast Highway.

B.1.4 STRATIGRAPHY

The Stratigraphy of the BRM area is summarized in the units description portion of the geologic map legend. Additional detailed lithologic descriptions are documented in the logs for the BYA-series borings (Appendix C).

Stratigraphic nomenclature is consistent with that of Yerkes and Campbell (1979, 1980). Other work reviewed that contained useful local stratigraphic details included those by McGill (1948), Traxler (1948), Brady (1951), Suzuki (1951), Pelline (1952), Carter (1958), Hardey (1958), Newton (1958), and Roohi (1968). In addition, Loel and Corey (1932), Moore and others (1952), Cox (1960) provided applicable regional details on fossil mollusks.

B.1.4.1 Fossil Bearing Formations

Fossil mollusks were useful in positively identifying various units in both surface outcrops and in the subsurface in core. The Vaqueros formation represents a marine transgression within the terrestrial Sespe formation. It contains at least two horizons within which fossil concentrations of the gastropod Turritella inezana are found. Pelecypod fragments of unknown genus also occur within this unit. Fossil localities of both types are shown on the geologic map (Figure 4-1.2).

The Topanga Formation is relatively rich in fossils at BRM. These occur in two distinct groupings of mollusk species that occur in the Saddle Peak Member and the Cold Creek Member, respectively.

Saddle Peak fauna at BRM consist of concentrations of either Pecten genera or Ostrea. Carter (1958, pg. 36), in describing the area directly north of BRM, mentions "a persistent fossil reef, typically containing the mollusks Vertipecten nevadanus Ostrea titan, and other

species" approximately 50 feet (70 feet according to Suzuki (1951) above the Sespe-Topanga contact. He further states (Carter, 1958, pg. 37) that the Vertipecten nevadanus occurs with Ostrea titan in some localities. These observations are consistent with what is seen along Piuma Road north of BRM near the summit of the Santa Monica Mountains. BRM differs only in the respect that more than one genus of Pecten is seem and that Pecten and Ostrea genera have yet to be seen together.

Where Pecten have been observed, Lyropecten and Vertipecten nevadanus (Figure B-1.7) are usually present. In addition, the genus Cardium (rare) is also sometimes seen. Where Ostrea titan is present it is the dominant species. Although Ostrea occurs relatively high in the Saddle Peak south of Pinnacle Way, it is seen and Pecten concentrations otherwise faithfully mark the position of the base of the Topanga Formation. The lone Ostrea occurrence higher in the section could be from the Cold Creek Member, as seen in the "second fossiliferous horizon" of Suzuki (1951, pg. 11) where it occurs with numerous other species.

Cold Creek fauna at BRM are distinctive because of the variety of species that are usually present and because of the absence of Ostrea and Pecten. Cool Oak cul-de-sac is an excellent place to see typical Cold Creek fauna. However, there are numerous other outcrops containing these fossils (Figure 4-1.2; geologic map). Fossil mollusks identified so far include: gastropod genera, Polinices and Turritella (species uncertain); and pelecypod genera Mytilus Macoma and Phacoides.

The pattern of faunal variation from the Saddle Peak to Cold Creek at BRM is similar to that from the first and second fossil horizons of Suzuki (1951) documented immediately north of BRM. The gastropod genera in particular are lacking in the first fossil horizon compared to the second. Significantly, the two horizons are more than 1200 feet apart stratigraphically in Suzuki's study area north of the crest of the Santa Monica Mountains compared to approximately 350 feet at BRM. The missing section could be attributed to several causes, including: 1) an unconformity within the Topanga, 2) thinning of the intervening Topanga southward, or 3) fault truncation.

B.1.4.2 Intrusions

Intrusions were traced with confidence in the subsurface on the basis of gamma-log signature. Initial confirmation of gamma log characteristics was obtained by comparison with core of the BYA-series borings and then applied to other borings without core. Reliable attitudes for intrusions were obtained by calculating tilt solutions using three-borings where close spacing of holes and gamma log records permitted.

Intrusions at BRM contain basalt and its more slowly cooled variety diabase, in some cases together in the same body. Basalt seen in gradational contact with diabasic intrusions is commonly the result of more rapid cooling of the portion of the diabasic intrusion adjacent to cool surrounding country rock. This relationship has been observed in both core and surface outcrops at BRM and in adjacent areas (Brady, 1957). There are, however, bodies of basalt that are independent of diabase and with compositions that are distinct.

Porphyritic intrusive basalt, separate from diabasic intrusions, has been observed at the Sea Cliff Fault and beneath the landslide in BYA-5. Although Traxler (1948, pg. 4) refers to

extrusive basalt in the lower Topanga, there is no extrusive basalt that was observed at BRM. Photomicrographs of thin sections of this basalt are shown in Figures B-1.9A and B-1.9B. Plagioclase phenocrysts are abundant in these rocks within a fine groundmass of interlocked plagioclase, clinopyroxene, and magnetite. The degree of alteration is generally less than that seen in diabases (Figures B-19.C and B-1.9D). Shattering of phenocrysts with resultant visible displacements of albite twin lamellae (Figure B-1.9A) is common. This is further evidence of continued deformation through time of the BRM area.

The presence of diabase and separate basalt bodies indicates at least two episodes of intrusive activity at BRM. Brady (1957) suggests the possibility of two episodes of intrusion corresponding to basalt and diabase, respectively, wherein the basalt was the younger of the two. The relative age relationships of the two are unclear at BRM where both intrude faults.

Magnetic susceptibility determinations were made on both basalt and diabase using a portable fluxgate magnetometer. Some samples were found to be ferromagnetic and others had little or no detectable ferromagnetism. These observations are consistent with the pervasive but variable alteration seen in both surface and subsurface samples. Where magnetite is still present, ferromagnetism is detectable.

B.1.5 STRUCTURAL GEOLOGIC INTERPRETATION

Most of the mapped structures at BRM can be explained as having formed initially under horizontally directed north-northeast to south-southwest compressive stress or as having been remobilized by that stress. Favorably oriented planes of weakness inherited from previous deformational episodes have played an active role.

The map pattern at BRM is that of south-directed imbricate thrust belt. Most notably, the Las Flores, North, and Shoreline (Malibu Coast) faults displace older rocks southward over younger and sandwich a west-northwest trending syncline between them. This fold and the general northeastward homoclinal dip of bedding in rest of the BRM area, together with the thrusts, are physical manifestations of north-northeast south-southwest compression.

BRM lies at the leading edge of the thrust belt where stress is most concentrated within the Santa Monica Mountains uplift. The Shoreline fault under Pacific Coast Highway is the frontal fault of the range (Malibu Coast Fault). Deformation is, therefore, most concentrated adjacent this fault and attenuates rapidly northward. The north side of the range in contrast shows comparatively little of the effect seen along the coast to the south. The coastal area of the Santa Monica Mountains has been tectonically softened by its complex deformational history and can be thought of as a megashear zone.

Yerkes and Campbell (1980) assign an early large left-lateral component of displacement to the Malibu Coast fault. However, reverse oblique slip has probably dominated its more recent history.

The north dip and oblique-slip character of the Malibu Coast Fault is analogous to empirical clay model studies involving transpression under strongly convergent conditions; such experiments produce thrust-faulted anticlinal uplifts closely adjacent to the dipping oblique-

slip faults. The uplifts are the result of local rotation of the regional stress field under simple shear. The frontal fault, in such models, is a stress concentrator wherein the deformation (shortening) is concentrated along the edge of the block.

North-northeast to south-southwest compression in theory will produce conjugate shears dipping approximately +/- 30 degrees above and below the compressive stress couple; this means that for a thrust fault dipping 35 degrees northward such as the North Fault in Piedra Gorda Canyon, the conjugate thrust fault should dip approximately 25 degrees seaward, a relatively common value for southward dip meter solutions seen in the BYA-series borings.

Upward ramping of south-directed thrusts can also produce south-dipping subsidiary fractures as the result of fault-bend folding wherein rock is abruptly rotated within a thrust slice as it passes through a bend in the fault plane. Fracturing can occur throughout but is concentrated near the top and bottom of a thrust sheet.

Although no anticline is evident in the BRM area, the axial plane of such a fold could easily have been thrust seaward in the hanging wall of the Shoreline fault and then erosionally removed. This, in fact, is the interpretation of Yerkes and Campbell (1980) for the hanging wall of the Las Flores Fault. The steep northward dipping beds at BRM are, under this interpretation, the north limb of an anticline.

Extensional structures formed during earlier deformational episodes would have been severely affected. Normal faults formed under extensional stresses, for example, would have been rotated and resheared during later compressional folding and thrusting. These faults would appear to be low-angle faults with younger over older displacements (Figure B-1.8A). There is, however, an alternative explanation for such faults.

Faults where younger rocks are displaced over older could also be explained by a compressive model if one invokes folding prior to thrusting. Under this model, the displaced limb of a syncline could be thrust over rocks deeper within the limb of the same fold. If the folding was relatively steep before faulting, a configuration similar to that seen at the Sea Cliff Fault could be generated as shown in Figure B-1.8B.

North-trending cross faults under the compressional model can form in two ways; first by east west extension where the intermediate and least principal stresses are nearly equal or, second, as right-stepping echelon tension cracks or riedel shears under left-lateral shear.

B.2 SUMMARY OF SIGNIFICANT GEOLOGIC FEATURES AFFECTING LANDSLIDE CHARACTERISTICS

The geologic features summarized here fall into the general categories of 1) rock strength characteristics, and 2) structures. Both are fundamentally important to the stability of the coastal portion of the Santa Monica Mountains in general and the BRM area specifically. As mentioned in the preceding section, the site lies at the leading edge of an imbricate thrust belt bounded by the Malibu Coast fault. This has caused stress concentration and resultant strain that has affected the entire area. The first order geologic feature, therefore, that has affected landslide characteristics is this frontal fault zone of the Santa Monica Mountains. Included in this broad frame of reference are the many structures documented

here. The net affect of this feature has been to weaken the south edge of the range so that mechanical strength essentially decreases seaward and increases northward. From this overall perspective the tendency of slopes to fail counter to the structural fabric (e.g. across dip) can be better understood.

B.2.1 Rock Strength Characteristics

Mechanically weak silty/shaley sequences occur locally in Sespe, Vaqueros, and Topanga formations as layers interbedded within much thicker and mechanically stronger sandstone and conglomeratic sequences. These are planes of relative weakness within the section. This is particularly evident in borings where such layers were often observed to be penetratively sheared (Appendix C). Surface outcrops of these materials were also noted to be friable due to brecciation and shear. The weak layers dip generally northward but in some areas, components dip in a seaward direction; the western margin of the main active landslide, for example, is manifested in outcrop by a series of strike-parallel shear zones in redbeds of this type. Also, red beds in some areas mark the position of the Bluff faults where red sediment has been spread along the faults by shearing.

Mechanically weak basalt/diabase cross-cuts sedimentary layering; shearing and brecciation of intrusions is common at BRM, weakening what might otherwise have been relatively competent rock; this material is further weakened by alteration to clays, chlorite, and serpentine minerals. Many unoxidized samples from borings have a green coloration due to alteration; oxidized samples contain pervasively altered ferromagnesian minerals with alteration of plagioclase feldspar significant but less extreme; resultant alteration products are somewhat expansive and produce clayey gouge. Although shattering and brecciation of this material enhances secondary permeability, clayey gouge inhibits it and contributes to the development of perched ground water bodies.

Chaotic deposits of landslide debris fill depressions within the ancient landslide deposits. In many areas these have been subsequently graded and are difficult to delineate accurately on the geologic map (Figure 4-1.2). They are, however, important from the standpoint of dewatering efforts. The existence of such deposits is likely along the upslope margins of blocks within the landslide. Sedimentary breccia, for example, logged near the tops of BYA-3 and BYA-4 (Appendix C) is probably such material; possible graben fill material has also been observed along the upper margin of the lower BRM along Big Rock Drive.

Superficial deposits of landslide debris in some areas overlie deep-seated blocks. Landslide deposits originating at the eastern edge of the upper BRM, for example, may have encompassed a large area extending southeastward from Pinnacle Way to beyond Seamoor Drive. Pre-development vertical aerial photography shows large blocks of rock that originated from the edge of the upper mesa and slid southeastward onto the lower BRM. Relatively shallow landsliding of the satellitic complex at north edge of the BRM landslide have similarly encroached onto the deep-seated blocks to the south. These materials are considerably more dilated, rotated, and chaotic than the blocks beneath them. They are, areas of locally higher permeability and lower material strength.

B.2.2 STRUCTURAL FEATURES

North-dipping faults dominate the structure of the area. They form an imbricated thrust belt consisting of a series of stacked fault slices. The faults that bound these slices are commonly intruded with basalt or diabase that is typically sheared and largely altered to clay and chlorite group minerals. Shearing and brecciation of basalt within fault zones increases its secondary permeability. In contrast, gouge zones, either within or at the margins of intrusions, are barriers to ground water flow. The net result is that the combined effect of gouge and displacement of permeable zones by faults is to increase the tendency for perched water bodies above faults. The faults have the effect of compartmentalizing rock bodies.

The Shoreline Fault (Malibu Coast Fault) with its thick north-dipping breccia and impermeable gouge zone, is a significant plane of weakness along which upward ramping can take place at the toe of the BRM landslide. Because it truncates the stratigraphic section across the entire width of the landslide, it is an important consideration in any model dealing with groundwater flow in that it forms a groundwater barrier.

North-dipping low-angle faults within the seacliff portion of the BRM landslide provide ready-made slip surfaces at higher levels within the landslide mass that could potentially affect bluff stability. This includes the bluff faults and other similarly oriented nearly flat faults. In the western part of the landslide, they are marked by red clay gouge zones in contrast to the intrusive basalt seen in the Sea Cliff Fault across the lateral margin of the landslide to the west. The gouge zones again have the potential to compartmentalize groundwater and cause perched water bodies. In addition, these zones are mechanically weak.

North-trending cross-faults provided conveniently-oriented planes of weakness along which landslide margins developed and blocks within landslides slipped past each other. The Inland Fault, for example, is an accommodation structure that permits different rates of movement within blocks of the eastern and western lower BRM. Because there are more of these faults within the landslide than in areas to the east or west, it is probable that many of them formed as accommodation structures (tears) local to the landslide mass. They are, however, present throughout the BRM area and in effect form partitions within the stacked thrust fault-bounded slices.

Prehistoric landslide block boundaries (Figure 4-1.2) have not all been remobilized by renewed historic movement. This is because of the limited amount of movement that has occurred to date. The positions of active block boundaries are apparent by their surface crack patterns.

Ground shaking or uplift that might result from activity of the Malibu Coast Fault or fault splays in the general vicinity of the site are factors that could have a profound effect on the BRM landslide. Regional data, although not conclusive, suggest that the Santa Monica-Malibu Coast fault system may be active and may, therefore, be a potential source of earthquake shaking or possible uplift. There is no evidence at present for or against activity of the Shoreline Fault at BRM because of the lack of appropriately youthful and datable deposits. The Seaboard Fault, however, shows some youthful characteristics. First, it coincides with several left shifts of drainages in the area. Second, one of these is at the western edge of the main active landslide, opening up the possibility that the ancient

landslide margin has been displaced left-laterally. Third, a lineament can be seen on pre-development vertical aerial photography in landslide and terrace deposits west of Rockpoint Canyon along the trend of the Seaboard Fault; these observations, although inconclusive without further investigation, are suggestive of a relatively youthful motion history compatible with that of the Malibu Coast Fault.

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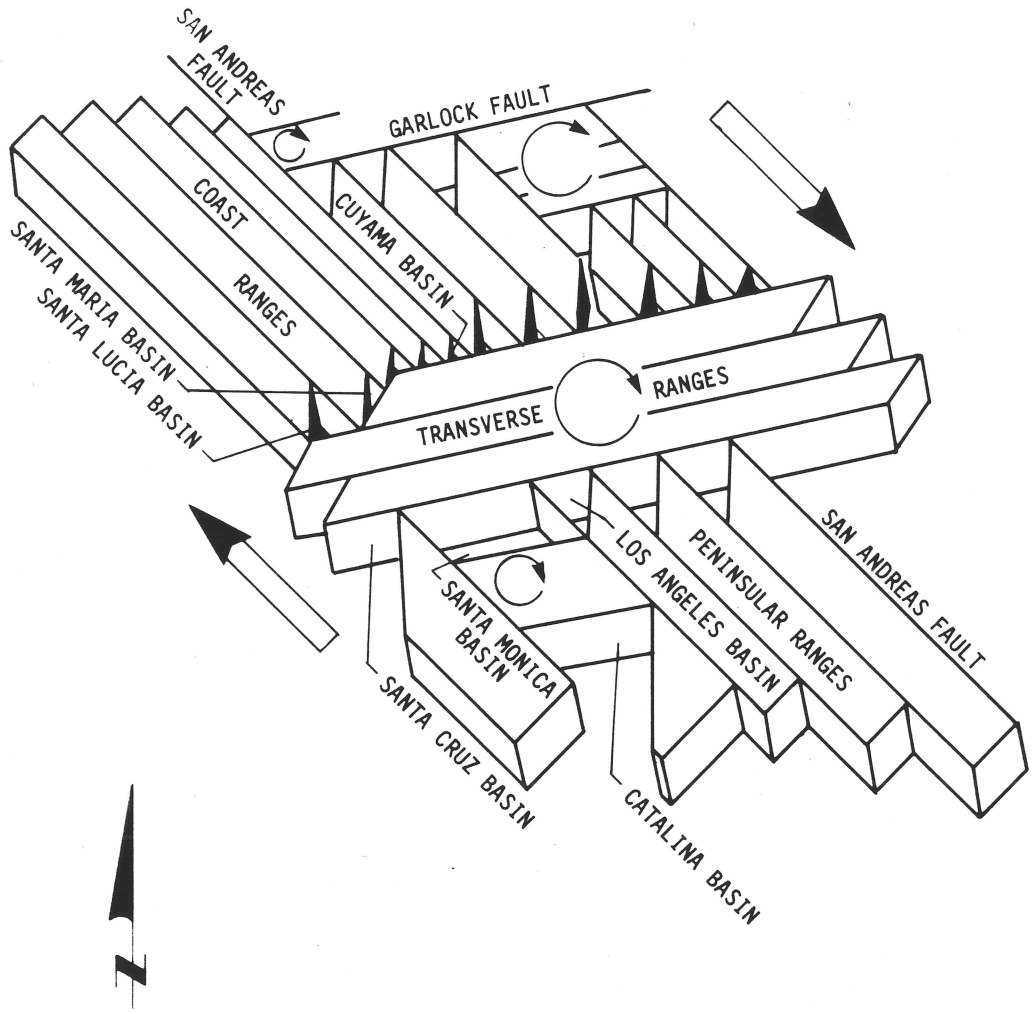
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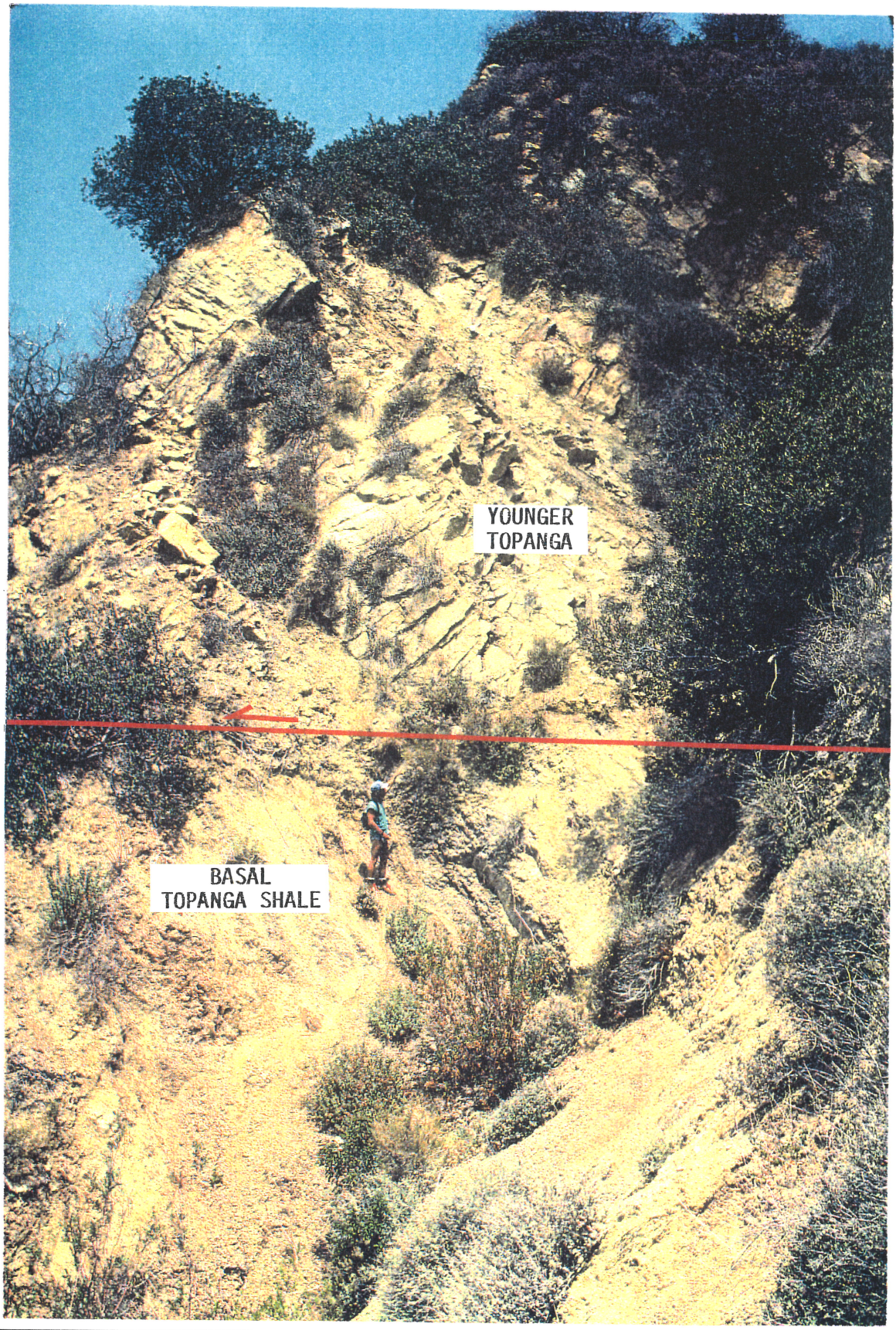
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

A RIGID BODY MULTIPLE BLOCK MODEL FOR SOUTHERN CALIFORNIA TECTONIC HISTORY

FIGURE B-1.1



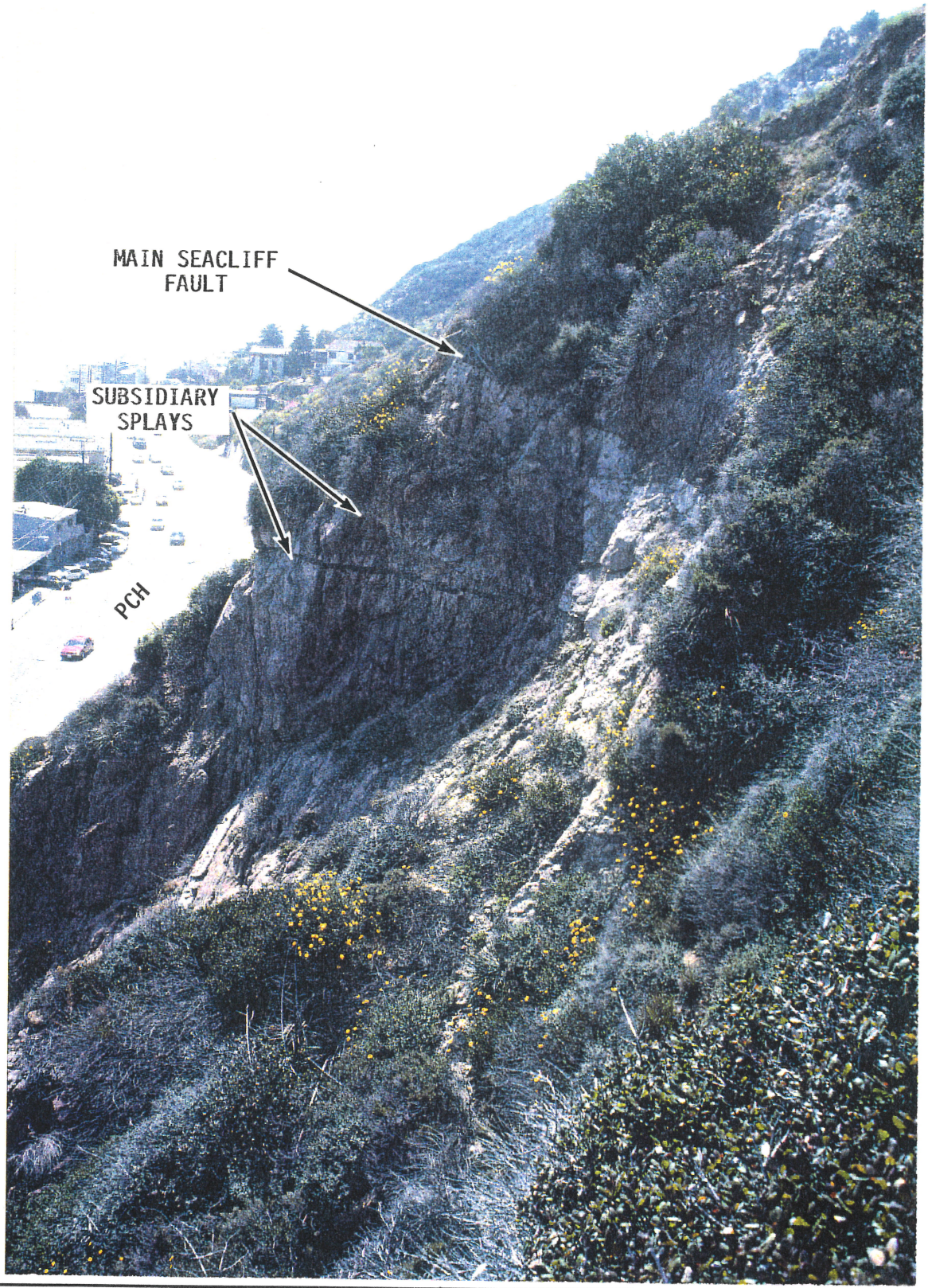
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EXPOSURE OF SADDLE FAULT IN EAST WALL OF PIEDRA GORDA CANYON VIEWED LOOKING NORTH

FIGURE B-1.2



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PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EXPOSURE OF SEA CLIFF FAULT ABOVE PACIFIC COAST HIGHWAY IN WESTERN PART OF MAP AREA LOOKING WEST

FIGURE B-1.3



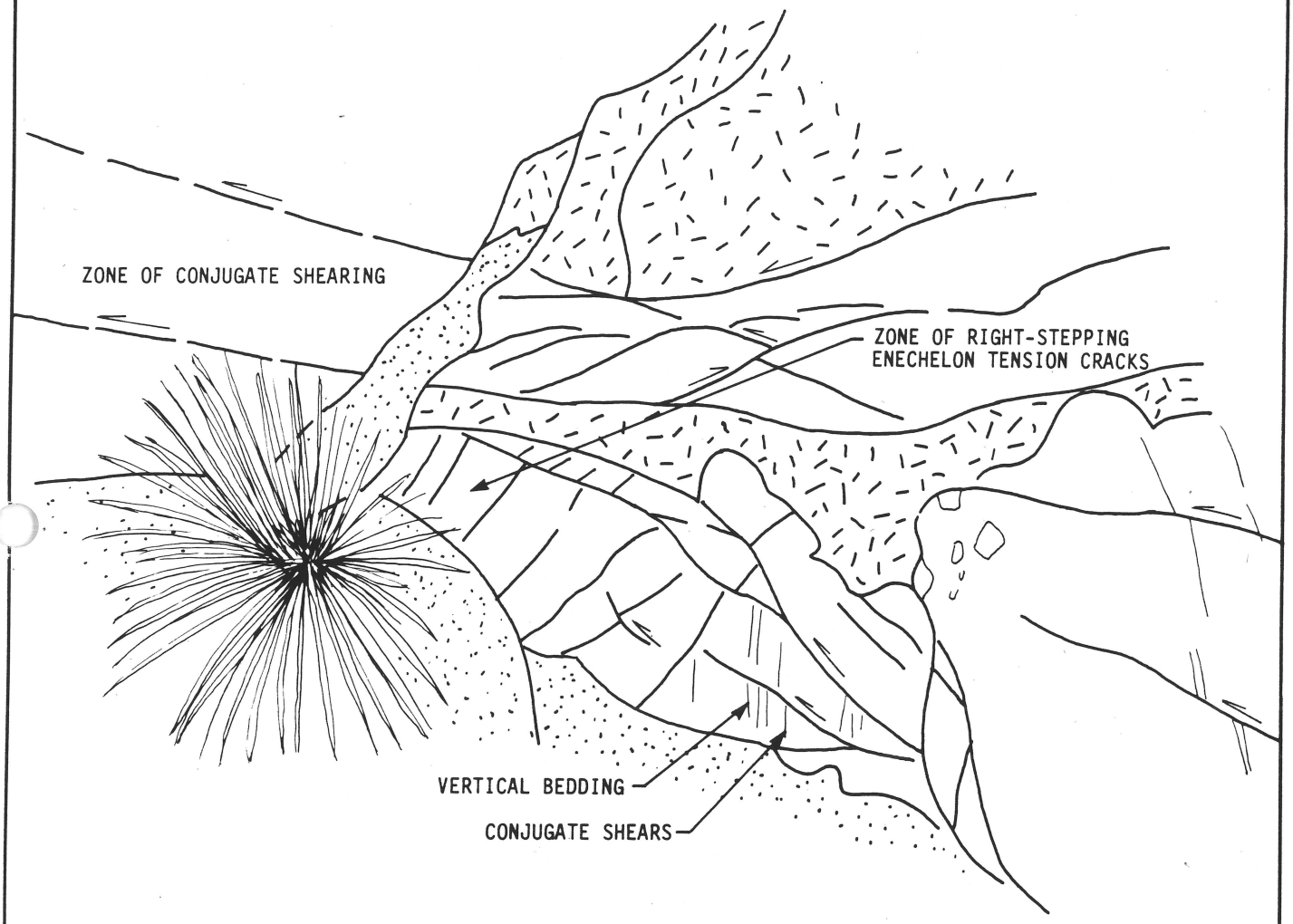
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

EXPOSURE OF SEA CLIFF FAULT AND ASSOCIATED SHEAR ZONE AND BASALTIC INTRUSIONS LOOKING WEST. (DEATILED KINEMATIC FEATURES SHOWN ON FIGURE B-1.4(B)

FIGURE B-1.4(A)



BASALT

SLOPE WASH AND SAND

SESPE

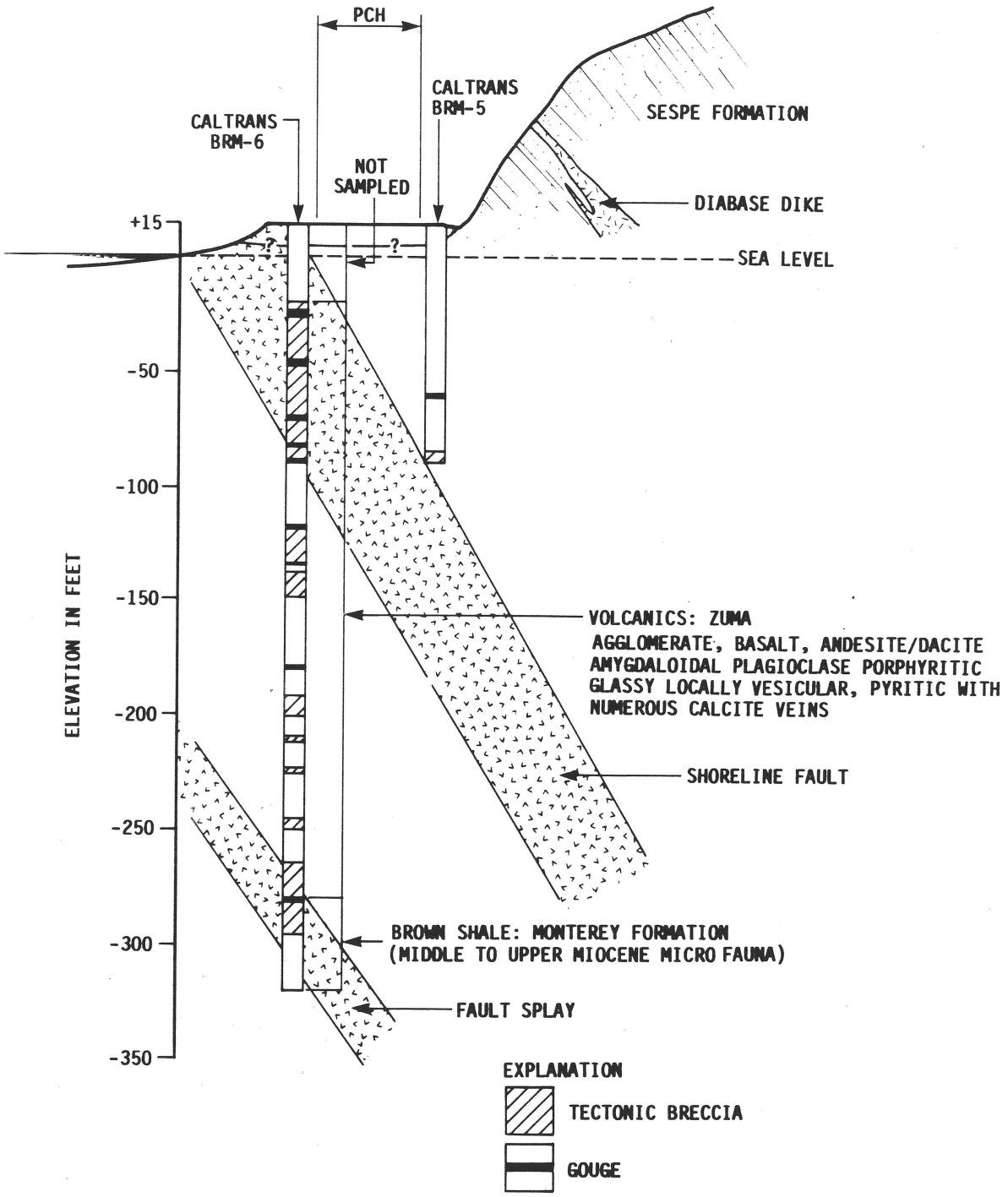
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KINEMATIC DATA INCLUDING RIGHT-STEPPING ENECHELON TENSION CRACKS, CONJUGATE SHEARS, AND DRAG OF BEDDING IN FOOTWALL INDICATE MOTION OF MAIN FAULT AS SHOWN

FIGURE B-1.4(B)



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SUBSURFACE GEOLOGIC INTERPRETATION OF THE AREA BENEATH PACIFIC COAST HIGHWAY

FIGURE B-1.5



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EXPOSURE OF LOVE FAULT IN SEA CLIFF AT PACIFIC COAST HIGHWAY LOOKING NORTH

FIGURE B-1.6(A)



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CLOSE UP OF LOVE FAULT EXPOSURE SHOWING NEAR HORIZONTAL STRIAE IN CLAY GOUGE

FIGURE B-1.6(B)



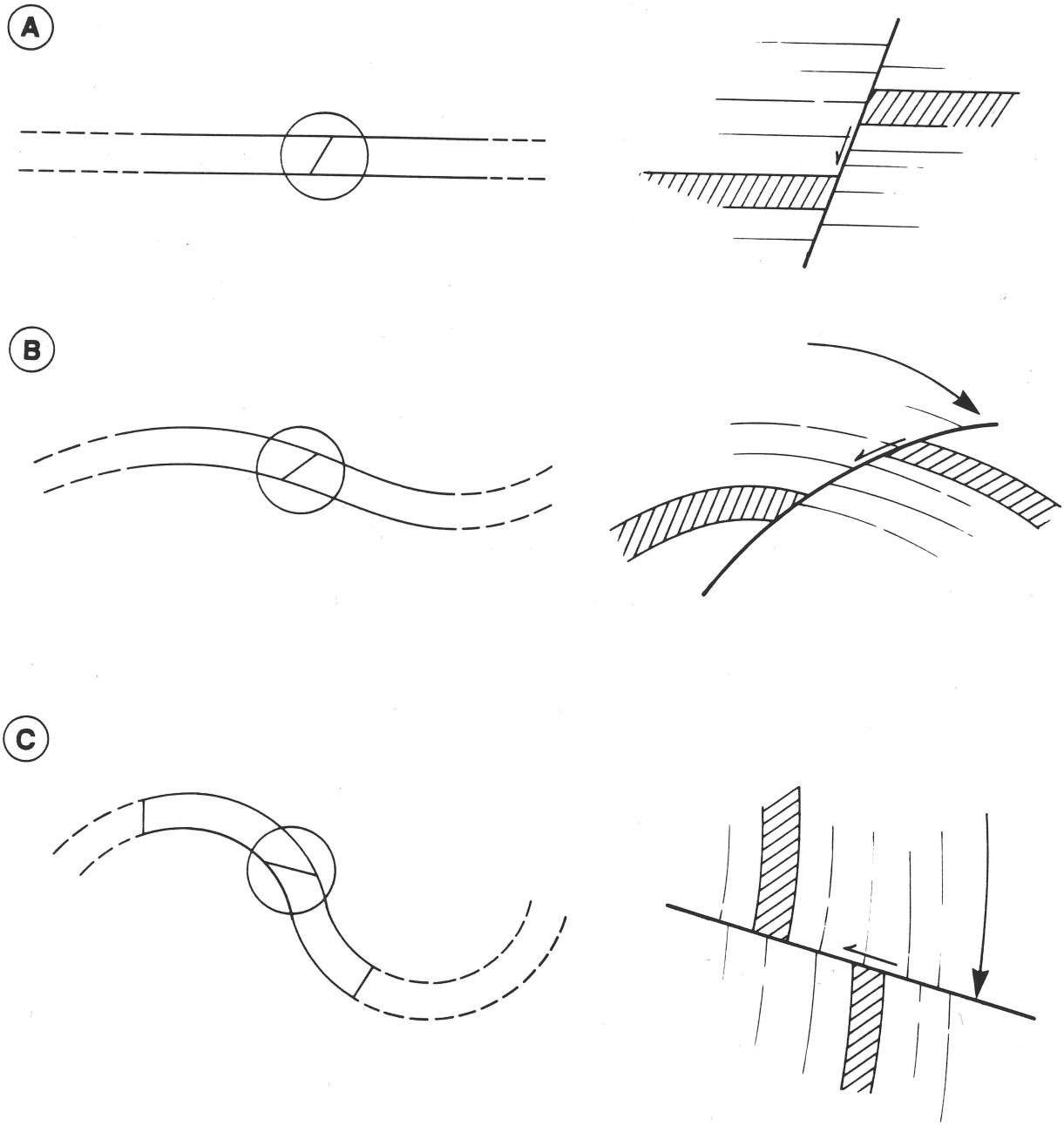
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PROJECT NO.: 49-97D | DATE: DECEMBER 1991

FOSSILS OF VERTIPECTEN NEVADANUS FROM THE SADDLE PEAK MEMBER OF THE TOPANGA FORMATION AT BIG ROCK MESA

FIGURE B-1.7



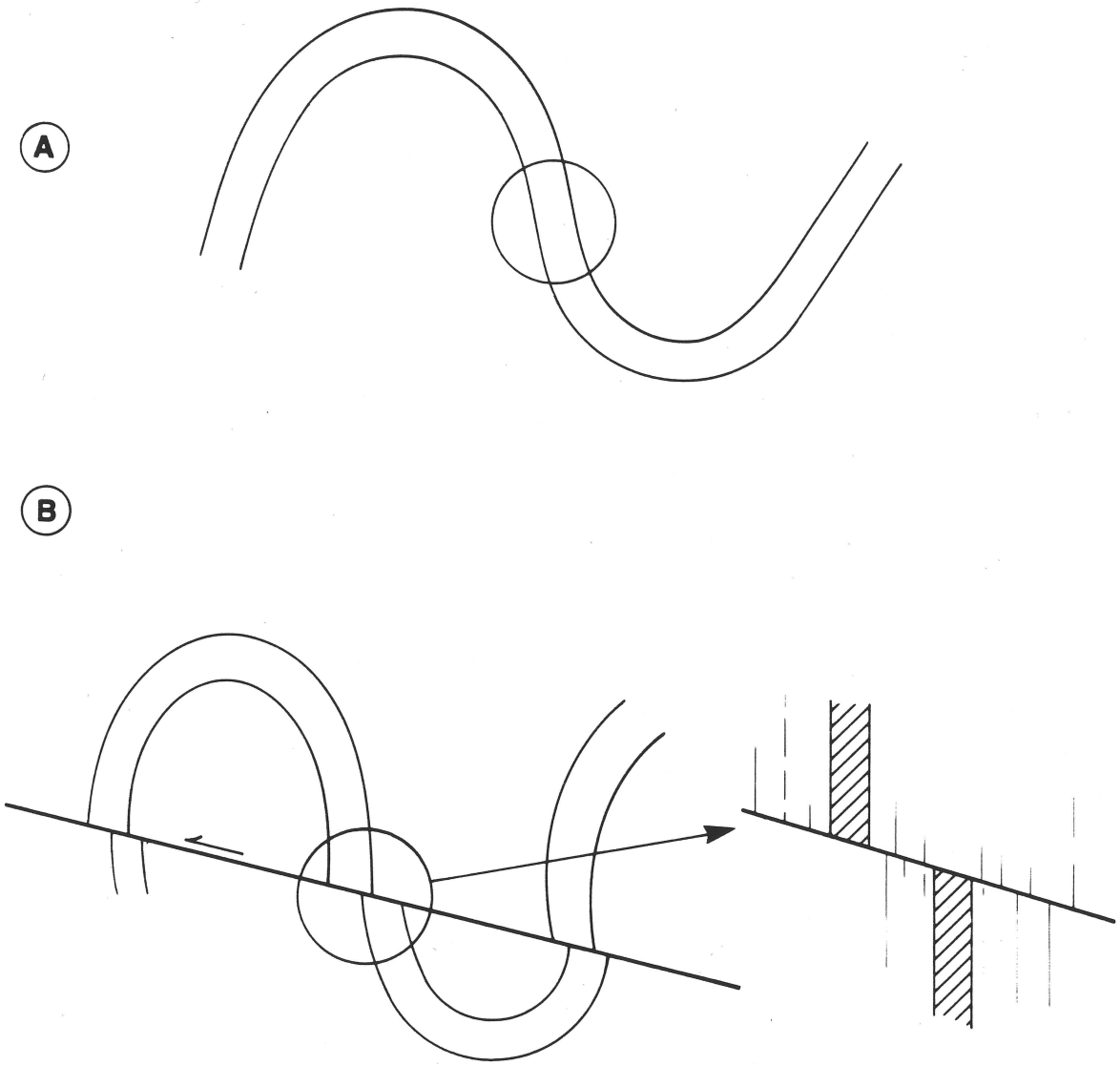
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

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ONE OF TWO MODELS FOR ORIGIN OF LOW ANGLE FAULTS - NORMAL FAULT FORMED DURING REGIONAL EXTENSION AS ROTATED DURING LATER COMPRESSION

FIGURE B-1.8(A)



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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

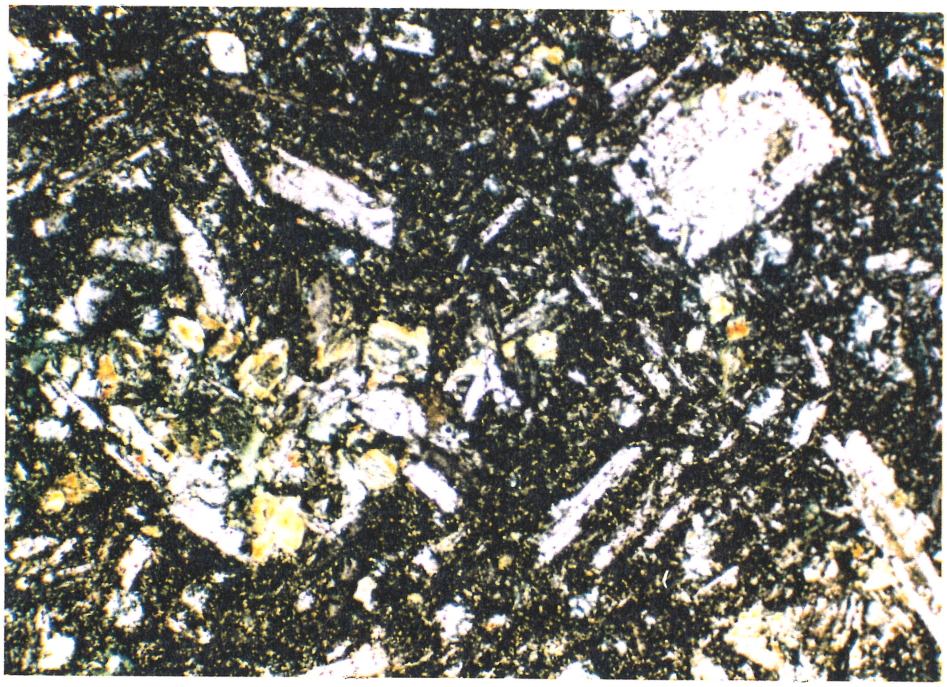
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SECOND OF TWO MODELS FOR ORIGIN OF LOW ANGLE FAULTS - FOLDING OCCURS BEFORE THRUST FAULTING SO THAT YOUNGER ROCKS IN SYNCLINE ARE DISPLACED OVER OLDER ROCKS

FIGURE B-1.8(B)



A. RELATIVELY UNALTERED PLAGIOCLASE PORPHYRITIC BASALT WITH SHATTERED AND DISPLACED PHENOCRYSTS



B. SOMEWHAT ALTERED PLAGIOCLASE PORPHYRITIC BASALT

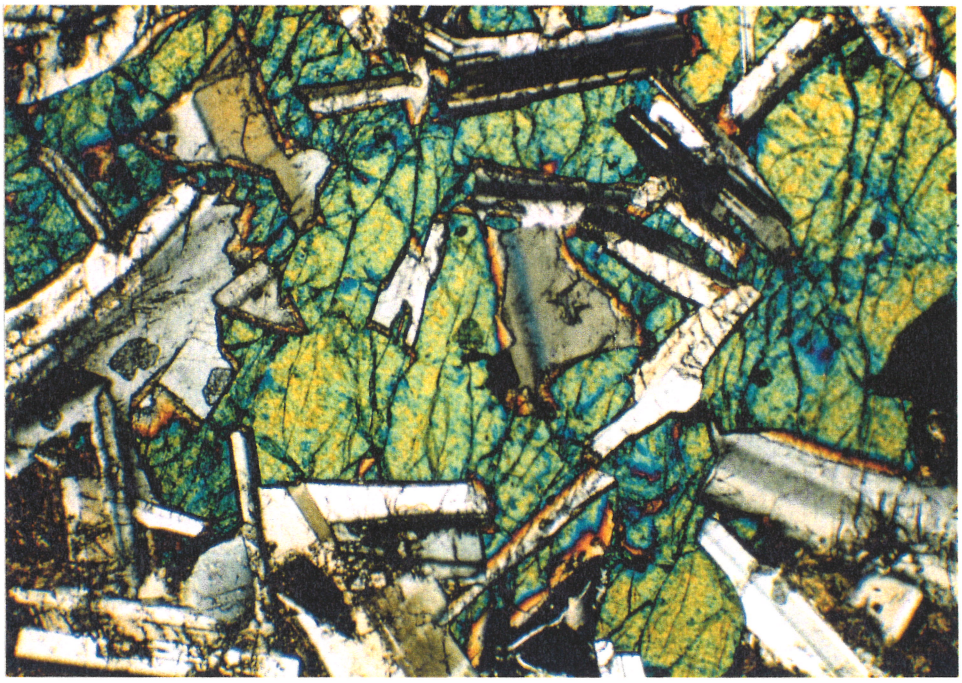
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BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

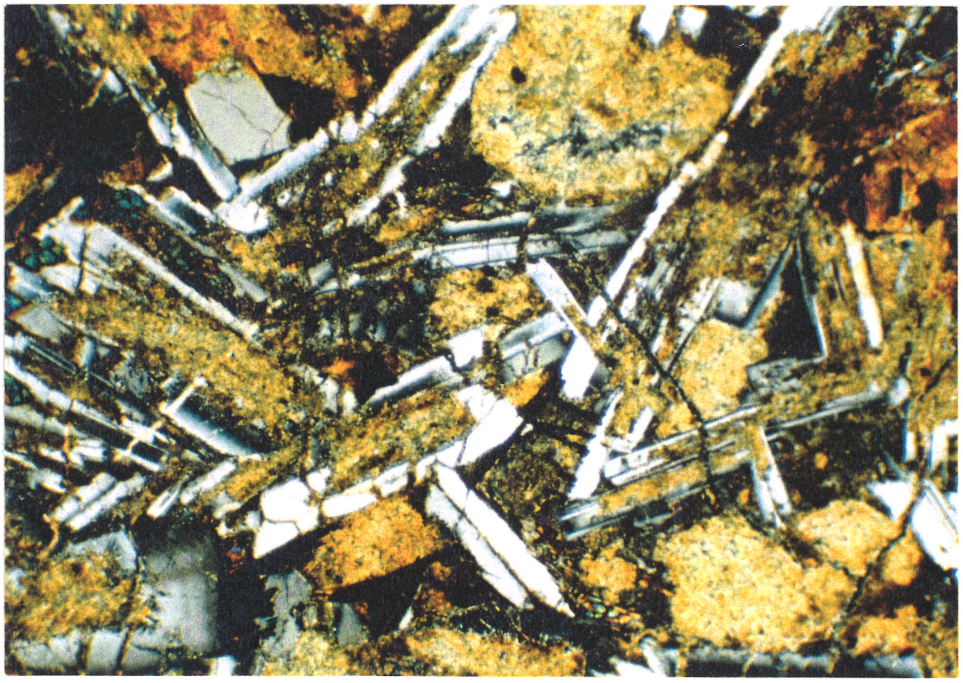
PROJECT NO.: 49-97D | DATE: DECEMBER 1991

PHOTO MICROGRAPHS OF BASALT AT 40X MAGNIFICATION

FIGURE B-1.9(A & B)



C. UNALTERED OPHITIC DIABASE



D. ALTERED OPHITIC DIABASE AFFECTING ALL MINERALS

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

PHOTO MICROGRAPHS OF DIABASE
AT 40X MAGNIFICATION

FIGURE B-1.9(C & D)

APPENDIX C

Project Name:	BIGROCK MESA LANDSLIDE	Sheet: 1 of 22	
Project Number:	49-97D	Borehole Number:	BYA-1
Location:	ROYALSTONE CUL - DE - SAC, MALIBU, CALIFORNIA		
Type of Drill Rig:	ROTARY WASH / AIR	Driller:	DATUM EXPLORATION
Bit Size:	2"	Drilling Fluid:	EZ-MUD
Inclination/Direction:	-90.0 /	Surface Elevation:	280' ±
Logged By:	GDT/GT/BC	Start: 7 FEB 89	End: 4 MAY 90

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
0		Not cored, no recovery. From Cuttings: Residual soil; silty clay, dark to medium brown with highly weathered black to salt and pepper Basalt fragments lenses.					
15	265	**BASALT:** Dark olive green, very hard, highly fractured. 1" calcorgillite (?), seam at 18 feet. Very highly fractured for Run 3.		1 2 3	100 65 40	24 0 0	Color change to tan to very light green/gray at 17'.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	2 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
20		Sandstone layer, 5" thick; light brown to brown, medium grain, highly fractured, varies from very hard to very soft.					
		Basalt: as above, but coarser and slightly less fractured.		4	80	0	Fractures = 50 degrees-70 degrees.
25		Basalt: as above. Coarser texture, weathered, much less fractured. About 3 joints intact infilled with slightly softer tan material with similar inclination.		5	100	0	Typical fracture spacing = 8" @ 40 - 70 degrees.
30		Basalt: dark green/gray rx. with black speckles, less fractures and harder. No obvious joints although there are slight changes in texture from one section to another.		6	100	0	Typical fracture spacing = 12"
35		Basalt: As above. Several additional recemented fractures. Orientations from horizontal to vertical.		7	80	0	Typical fracture spacing = 6"
		As above.					
		Fragments of Basalt up to 3" in length with soft light brown silty clay inclusions.		8	25	0	Inclusions = 30 degrees.
				9	100	0	
40		Basalt as above 39 feet - hard but highly weathered.		10	60	0	
	239						
				11	0	0	
		No recovery					
	237			12	57	0	
		Basalt: Greenish olive green to greenish black ; very weathered fine grained hard viens and fractures minezauzed (quartz) plagidclass laths 5 mm in length and pyroxenegrains 2 mm diabasic, texture (?)					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	3 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
45		Basalt: Same as above, weathering along fractures. Upper portion medium soft to medium hard, friable. 2 fractures > 5 mm. apart.		13	78	0	Gouge (?)
		Highly fractured(very weathered), friable.					
50		Basalt: Same as above. Very weathered along fractures, friable. Vein or cavity infilled with quartz grains. Very coarse grained subangular to subrounded. Fracture mineralized by quartz.		14	100	0	
		Basalt: Same as above. Very fractured and weathered. No mineralization along fractures.		15	90	0	
55		Basalt: Same as above. Very fractured, fragmented, upper 2" friable clayey. Fracture mineralized by quartz.		16	60	0	
60		Basalt, weathered. Fractures with slickensides on surfaces with some clay(1 mm. thick) greenish olive green to greenish black.		17	85	0	
		Weathered basalt same as above. More fractured with weathering along surfaces. Severely crushed in lower 1" of sample.		18	50	0	
65		Weathered basalt same as above.		19	45	0	
	211						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	4 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
70		Sandstone:(Topanga ?) fine to very fine grained; mixed with basalt fragments, moderate yellowish brown, soft contains some clay. Shears showing slickensides.					
	209						
		Weathered basalt same as above 69.2 ft. Very fractured. Slickensides or polished surfaces on fractures.		20	100	25	
75		Weathered basalt same as above. Material soft highly weathered, fine grained basalt fragments, moderate yellowish brown.		21	85	0	
		Weathered basalt same as above, weathering along fractures. Lower portion crushed.		22	100	13	
		Weathered basalt same as above. Hydrothermally altered dusky blue green. Gouge plastic soft, grayish blue green. Highly weathered soft with fragments moderate yellow brown.		23	100	10	Gouge Unoxidized from 78.4 to 80.0'
80		Weathered basalt as above. Slickensides along fractures. Highly fractured, broken up, becoming more fractured.		24	68	10	
		Weathered basalt as above. Clayey gouge. Lower half fragmented and fractured, shattered.		25	79	0	Gouge
		Fragments		26	0	0	
85	195						
		No Recovery.		27	0	0	
90				28	0	0	
	189						
		Fragments-Basalt, Aphanitic. Light gray hard. Up to 3 cm. angular to subangular, basalt.		29	42	0	
		Basalt: Medium dark gray , some Fragments as above up to 4 cm. in length. Lower 1"-Fragments in fine grained sandy clay, soft.		30	35	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	5 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
95	185						
		SESPE FORMATION (Slide Debris) Sandstone: Upper 4" soft, fine grained with medium grained sand.		31	80	0	
		Sandstone: Loosely cemented conglomeratic with pebble size clasts. Fine to very fine grained sand. Lower 2" grayish green angular fragments of basalt.		32	57	0	
	180						
100		No Recovery.		33	0	0	
	179						
		Sandstone: Hard, medium to coarse grained, weathered along fractures, finegrained. Sandstone: Medium to coarse grained, hard, well to moderate sorting. Patches of weathering. Clasts- 1" in length subrounded. No weathering along fractures. Lower 1" friable.		34	98	67	
105	175						
		Conglomeratic sandstone, 1"-2"Clasts.		35	44	0	
	172						
		No Recovery.					
110	170						
		Conglomeratic sandstone same as above. Becoming more fractured, yellowish gray, dry. Clay along fractures < 1mm. Bottom 6" little more coarse grained. Clast 2 cm. in length.		36	59	0	
	166						
115				37	0	0	
		No Recovery.		38	0	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	6 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	161						
120		Dark reddish brown clay, plastic, gouge (?).		39	100	34	Oxidized/ Unoxidized contact
	158						Fracture = 40 degrees.
		Siltstone dark greenish gray moist, medium hard. Some polished surfaces (slickensides)		40	97	11	
125		Siltstone: Same as above. Hard to medium hard. Veins or stringers of < 1mm. wide quartz(?).					
		Siltstone same as above. Upper 1.6' dark reddish brown.		41	100	65	
							Gouge = 30 degrees.
		Gouge 2mm wide					
130		Siltstone: Coarse to medium silt, medium hard to hard, color same as above, approximately 3% biotite. Mineralization along fracture, quartz 3mm, thicker near base of sample.		42	92	34	Gouge = 25 degrees.
		Siltstone: Same as above. Silt with clay, soft, plastic. Clay along fractures.		43	100	36	
135	145						
		Sandstone: Lower 2.8' fine grained sandstone, well sorted, hard, pale blue green to gray blue green. No sharp contact seen, gradational or obscured by fractures. Sandstone: Same as above. Siltstone lens interfingering. Clay between fractures.		44	100	86	Bedding = 31-39 degrees.
140	140						
		Siltstone Quartz stringers or veins < 1mm. wide. Surfaces on fractures, polished.		45	100	85	Bedding = 21 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	7 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	136						
145		Sandstone: Gray blue green very fine grained. Well sorted.		46	95	18	
		Lower portion of sample fine to medium grained.					
		Sandstone: Same as above. Medium grained, hard, well sorted, becoming more fractured, fractures clean, medium light gray.		47	90	0	
150		Sandstone: Same as above.		48	100	36	
		Gouge - Clay plastic.					
		Laminations.					
	126			49	94	18	
155		Siltstone: Medium dark gray, hard.		50	100	32	
		2" clayey silstone, plastic.					
		Bottom 1" of sample becoming sandy, medium to fine grained sand.		51	59	78	
160	120						Gradational Contact
		Sandstone: Upper 4" dark green gray, becoming lighter in color down to 11" from top of sample. Fine grain grades to medium to coarse grained down length of sample.		52	100	21	
165		Sandstone: Coarsed grained with siltstone lenses. Medium to fine grained sand. Gouge clay plastic dark gray 6mm. wide.					Gouge (?)
	114						
		No Recovery		53	100	48	
	112						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	8 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
170		Sandstone: Fine to coarse grained, 70-100% sand, light blue gray to pale green, medium coarse grained subrounded, crushed to close fracturing, friable hardness, weak strength, moderately weathered. Sandstone: pale green to grayish green, fine grained, close fracture, low-medium hardness, low-moderate strength, unweathered.		54	100	38	
		Sandstone: As above, but coarser (medium to very coarse grained, locally with conglomerate) and lighter color (light blue gray to pale green.		55	100	33	
175							
		Sheared gouge, clayey silt with sand graininess, soft.		56	100	20	Gouge
	101						
180		Conglomeratic sandstone, light bluish gray. 30-50% very coarse to gravel, 20-30% coarse, 20-30% fine to medium, subangular subrounded, moderate very hard, moderatly stong. Coarse Sandstone: Same as above but without very coarse to gravel fraction, slicks along most fractures.		57	100	28	
		Sandstone: Same as above, medium coarse grained, intensely to closely fractured.		58	63	33	
185		Clay silt along fractures, numerous slicks.					Shear = 45 degrees. Shear = 67 degrees. Shear = 50 degrees.
	93			59	83	25	Shear = 56 degrees. Shear = 59 degrees. Shear = 60 degrees.
		Silty Claystone: Dusky green, crushed, friable-low hardness, plastic/friable strength, unweathered.					
	92						
		Silty Sandstone: Light bluish gray to light gray, 40-60% fine sand, 20-30% silt, 10-20% clay, crushed, soft hardness, friable strength, moderately weathered.					
190							Shear = 54 degrees, locally oxidized from 190 - 192.5.
	89			60	100	20	
		Silty Claystone: Dusky green, moderate fractures, low hardness, weak strength.					
	87						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	9 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Silty Sandstone: Light bluish gray, grayish green, dusky green, crushed, low hardness, friable.		61	37	25	
195	85						
		Sandstone: Bluish gray, medium coarse grained, friable to moderatly hard, fractures. Sandstone: Upper 3" fine grained, greenish gray, medium to coarse grained, pebble size clasts, friable, 40-50% fine to medium sand, 20-30% silt. Lower 2" crushed and softer.		62	94	34	
200		Sandstone: Same as above. Medium to fine grained sand. Friable soft with harder fragments. Lower 6" fine grained, silty.		63	93	9	
		Clay gouge grayish red. Sandstone: Very fine grain, light gray, medium hard. Quartz veins.		64	100	21	Shear = 45 degrees. Gouge = 51 degrees. Bedding = 45 degrees.
205	74						Shear = 58 degrees.
		Silty Clay, olive gray. Moderately fractured, 40-60% silt, 10-20% clay interbedded. Bottom 4" of run very light gray medium grained sandstone, vein quartz, recrystallized.		65	100	38	
		Gouge pale green. Clay along slicks.					
210	70						
		Sandstone: Same as above. Intensely fractured. Completely crushed sandstone. Pulverized.		66	95	54	Shear = 57 degrees.
		Sandstone Same as above. Badly fractured upper 2', less fractured below, fine grained sand, medium hard. 1.7' -2.3', cobble size clasts, conglomeratic.		67	100	36	
215							
		Sandstone: Same as above. Medium to coarse grained conglomeratic sand, moderately hard, medium to fine grained.		68	100	12	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	10 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Bottom 2" soft.					
				69	100	0	
220		Crushed sandstone as above. Quartz veins. Clay Gouge, pale green, soft, plastic.					
	59						Bedding = 30 degrees.
		Sheared Basalt: Same as above. Clay gouge along fractures, medium glue gray, soft plastic. Veins subparallel to fractured calcite.		70	69	8	
		Basalt fragments aphanitic light gray, hard, Plagioclase Laths 5mm., pyrite approximatly 30%.		71	10	0	
225		Basalt: As above, calcite veins throughout, upper 6" crushed. Plagioclase latha < 1mm. in length, pyrite fresh in veins < 1mm. thick in Calcite mineralization along shears, some slickensided surfaces, greenish gray, clay gouge, plastic with small (<3mm.) angular fragments.					
				72	63	50	
	51						
230		Switched to air rig - no core recovery. Logging from cutting only 230'-364'.					
235							
40							Casing at 241' 1200 psi.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	11 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	36						
245		Sandstone: Medium hard, slightly friable, medium light gray, fine grained, well sorted.					Logged from cuttings.
250							
255		Sandstone: Medium hard, medium to fine grained, well sorted.					Logged from cuttings.
260		Becoming more fractured.					Logged from cuttings.
		Becoming less fractured, smoother.					
265		Sandstone - Grayish green, medium hard, fine grained pebble size clasts, conglomeratic(?), basalt(?).					Logged from cuttings.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	12 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	11						
270		Clay with angular fragments of sandstone up to 5 mm in length, pale green, soft, plastic. Sandstone fragments same as above, some grayish red clay, basalt.					Logged from cuttings.
275		Clay soft plastic, brownish gray with angular fragment of sandstone, same as above. Basalt.					Logged from cuttings.
	1						
280		Sandstone - Angular fragments with brownish gray clay same as above. Sheared Basalt.(?)					Logged from cuttings.
285	-6						Logged from cuttings.
		Clay, grayish red, soft, plastic with sheared basalt aphanitic grayish green, slickensided surfaces, color change sharp sandstone, fine grained, slightly metamorphosed(?).					
		Clay, grayish red, soft, plastic with fragments of sandstone, fine grained and sheared basalt.					
290							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	13 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Clay, grayish red, with angular fragments of sandstone, basalt same as above, with clayey sand soft plastic, pale green.					
295							Logged from cuttings.
		Quartzite or basalt firm.					
300							Logged from cuttings.
	-24						
		Siltstone: Light gray sandstone (Metasandstone?).					
305							Logged from cuttings.
	-29						
		Sandstone: Light gray, fine grained, hard, grains angular, bleached mica flakes. Sheared basalt/meta-sandstone. Quartzite - grayish orange pink.					
310							Logged from cuttings
		Harder zone.					
		Same as above.					
315							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	14 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Same as above.					
320							Logged from cuttings.
325		Sandstone: Fine grained, medium light graying, friable, medium hard (RH-2). Siltstone. Some basalt, calcite-sheared with slickensides.					Logged from cuttings.
330		Sandstone and Siltstone, with some basalt rock fragments, may be from pebble size clasts - conglomeratic sandstone(?).					
335							Logged from cuttings.
		Sandstone: Fine grained, medium light graying, friable, medium hard.					
340	-60	Siltstone: Reddish dark gray, medium hard, silt 80%.					Logged from cuttings.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	15 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	-64						
345		Metasandstone/basalt dark green, with fine grained sandstone, light gray siltstone. Rock is highly fractured, cuttings may be going into them or rock is being crushed too fine for sieve. Water is moderate brown.					Logged from cuttings.
350							
		Fractures: hard or real hard material 5' zone.					
355							Logged from cuttings.
360							
	-84	Boring terminated at 364 feet, due to caving.					
		Boring excavation resumed with air rig, No Recovery, 364'-498'.					
365							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	16 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
370		No recovery from 364' to 498'.					
375		No recovery.					
380		No recovery.					
385		No recovery.					
390							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	17 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
395		No recovery.					
400		Basal Rupture Surface (?)					Disapation of artesian pressures; significant increase in drilling resistance.
405		No recovery.					
410		No recovery.					
415							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	18 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
420		No recovery.					
425		No recovery.					
430		No recovery.					
435		No recovery.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	19 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
440							
		No recovery.					
445							
		No recovery.					
450							
		No recovery.					
455							
		No recovery.					
460							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	20 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
465							
		No recovery.					
470							
		No recovery.					
475							
		No recovery.					
480							
		No recovery.					
485							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	21 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
490							
495							
	-218	**SESPE FORMATION** (Continued).					
		Sandstone: Poorly sorted, well cemented, light gray in color,numerous siltstone lenses up to 1" thick.					
500							
	-224						
		Siltstone, highly sheared.					
505	-226						
		Sandstone, poorly sorted,light gray, calcite infilling of fractures.					
	-228						
		Siltstone, highly sheared, sandstone lenses up to 1" thick.					
510	-230						
		Sandstone, well cemented, poorly sorted, light gray in color.					
	-233						
		Hard, gray to gray brown, massive, coarse to medium grained sandstone. Localized					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	22 of 22
Project Number:	49-97D	Borehole Number:	BYA-1

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
515		sedimentary breccia.					
	-236	Same as above but becomes finer grained, no breccia.					
520	-241	End of boring at 520.5'.					
525							
530							
535							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	1 of 20
Project Number:	49-97D	Borehole Number:	BYA-2
Location:	COOL OAK WAY, MALIBU, CALIFORNIA		
Type of Drill Rig:	ROTARY WASH	Driller:	DATUM EXPLORATION
Bit Size:	2"	Drilling Fluid:	EZ-MUD
Inclination/Direction:	-90.0 / ------	Surface Elevation:	660' ±
Logged By:	JLA	Start:	3 MAY 90 End: 21 MAY 90

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
0		Not cored, no recovery.					
15	644	**TOPANGA FORMATION:** Sandstone, Yellow-tan to light brown; medium grained, highly fractured. Fractured rock size range from gravel size to 5". Often oxidized along fractures.		1	100	20	Fractured = 30 degrees - 45 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	2 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
20				2	95	10	
25		As above		3	55	9	
30	630	No recovery		4	0	0	
35	626	Sandstone (gravel sized) mixed with silty sand (SM). 8" Long core fractured longitudally; Oxidation. Highly fractured along joints and also longitudinally. Highly fractured; oxidized along fractures.		5	100	17	Fracture = +60 degrees - (-60) degrees. Joint = 50-65 degrees. Bedding = 40-60 degrees.
				6	100	25	
40	620	Conglometric Sandstone Tan to yellow-light brown; cemented, highly fractured; 2 to 3" fracture spacing; subhorizontal fracturing; vertical fracturing above 45.5'; yellow oxidation along fractures. Clasts range in size between 3 mm and 50 mm. Generally, clast size increases with depth.		7	100	8	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	3 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
45		Piece of hardened sandstone/shells in between conglometric sandstone. Lower contact oxidized highly fractured; subparallel vertical fractures.		8	100	28	Fracture = 40 degrees. Contract = 60 degrees. Joint = 60 degrees.
50		Vertical fracturing above 55.7; becomes coarser with depth, clasts and numerous voids (animal cavities), fossil bed.		9	50	0	
	607	Sandy Siltstone, Dark yellow brown, Moderately bioturbated					
55		Highly fractured from gravel size to 2"; above 57.9' yellow-tan plastic clay.		10	30	0	
		Highly fractured, 2" spacing of slickensides, becomes moist and not as hard; grades yellow-brown fractured to gravel size.		11	100	0	
60		Fracture spacing 2-4"; friable; oxidation spots (oxidized biotite?). Clastic Slickensides; above 60' fresh Slickensides.		12	100	0	Slickenslide = 50 degrees.
		Sandstone: Coarse grained; tan to light brown; fractured; pebbles inclusion to small diameter.					Bedding = 40 degrees.
		Yellow-brown highly oxidized; Slickensides along joints.		13	70	0	Slickenslide = 40 degrees
65		Highly fractured zone, white crystalization along fracture. Above 66' yellow-tan clay layer 4-5" thick; Slickensides appear to be fresh.					
		Highly fractured zone below 66'. Sandstone - friable; highly oxidized along joints.		14	90	0	Joint = 50 degrees.
		Grades: tan medium-coarse grained sandstone with fractures, moist, highly fraiable; becomes relatively hard above 70.8'.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	4 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
70		Highly fractured, white-tan coarse grained. Subhorizontal fracturing at about 2-4" intervals.		15	45	5	
75				16	0	0	
	583						
		Siltstone/Sandstone/Silty Clay; hard brittle fractured pieces of siltstone; sandstone; dark brown moist, very friable.		17	100	0	Highly oxidized (blue-purple-yellow) along fractures. Fracture Dip = 60 degrees, highly oxidized along fractures.
				18	100	0	
80		Traces of silty clay, gray brown. Indurated, siltstone. Contains small portion of reddish brown silty clay.		19	100	0	
		As above, but silty clay is gray-brown.					
		Sandstone medium grained, fractured, cemented, vertical fracturing.					
		Grey-greenish, highly fractured, ranging in size from pea gravel to 2".					
85	575						Shear = 34 degrees.
		Sandstone: Tan-greenish highly fractured crystallization along fractures; oxidized along fractures. Grades coarser with depth, white crystallization along fractures.		20	100	0	Fracture = 40 degrees.(shear ?)
							Fracture = 80 degrees.
90		As above, locally grades into Siltstone; fractured, oxidize, very hard.		21	95	34	Fracture = 60 degrees.
		Shells.					
	567						
		Sandy Siltstone, Bioturbated					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	5 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
95	565	Sandstone: coarse grained fractured to gravel size. Becomes coarser with depth. Tan, highly fractured to 3". Lower portion: silty sand dark brown with pieces of indurated rock; moist.		22	100	0	Bedding = 55 degrees.
				23	25	0	
100	560	Silty clay to clayey silt; gray; precedes indurated pieces of rock.		24	40	0	
		Same as above, but becomes sandier, rock fragments are smaller (gravel sized).		25	100	0	
105		Clayey content increases and becomes wet and plastic. Indurated rock. Sandstone fragments 2-4". Coarse grained.					
	554	Sandstone: dark brown, highly fractured; gravel size.		26	50	0	Bedding = 35 degrees.
	551	Gravelly clay; medium brown, very moist; soil matrix diminishes with depth, becoming fractured sandstone.		27	100	25	
110	549	Sandstone, subvertically fractured. Above 114.1': sandstone is fractured longitudinally along the middle.					
115		Sandstone becomes lighter in color and grades coarser. 11" long core split longitudinally; becomes highly fractured to the end of the run. Tan; indurated, high quartz content, longitudinal split; dip 30 degrees.		28	100	0	Bedding = 30 degrees.
		Clast inclusion to 2" diameter. Becomes					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	6 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		coarser and more friable with depth. Subparallel fracturing at 50 degrees. Becomes highly fractured.		29	100	32	Joint = 50 degrees.
120		Above 124.5' becomes lighter in color (white to tan) with abundant pink and clear quartz.					
		As above, but includes come clasts and contains yellow (limonite?) deposits. Longitudinal fracturing; fractures and friability increases to the end of run.		30	90	0	
125							
		Highly fractured Clasts to 2" in length.		31	100	0	Fracture = 30 degrees.
130		Gravel size pieces of sandstone.					
	527			32	100	0	
		Clay; Brown to gray; plastic; soft; gouge zone. Dark brown plastic; Slickensides. Highly fractured zone to 137.7 (siltstone?). Highly fractured zone to end of run.		33	100	0	Slickenslides = 60 degrees.
135							
	523						
		Sandstone; Light brown-tan, very hard; contains occasional clasts; high in quartz.		34	100	37	
140		Grades coarser and slightly darker with depth; becomes more friable; Fracture Dip at 40 degrees.					Bedding = 53 degrees. Fracture = 40 degrees.
		As above.		35	100	36	Fracture = 25-60 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	7 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
145	514	Highly fractured sandstone with dark brown clay.					
		Siltstone, Dark Brown.		36	100	0	
	513			37	100	0	Bedding = 21 degrees. Slickenslides = 30 degrees. Slickenslide = 30 degrees.
		Sandstone highly fractured old Slickensides. Highly oxidized.					
150		Becomes tan coarse grained with round pebble clasts, oxidized along fractures. Shear striations; Shear Dip 30 degrees; contact with less weathered sandstone of a granitic texture.					Bedding = 33 degrees. Fracture = 25-30 degrees. Joint = 30 degrees Shear = 32 degrees. Bedding = 39 degrees.
				38	100	70	
		As above.					
155				39	100	60	
		Siltstone; Lense of dark brown to gray.					Bedding = 34 degrees.
160							Contact = 60 degrees.
	499						
		Basalt: Green; highly weathered; intrudeed in between sandstone. Clasts in Sandstone Longitudinal split; becomes yellow dark brown; highly oxidized.		40	55	9	
	496						
165		Sandstone; highly fractured; contact with basalt is highly weathered.					
		Lense of dark yellow-brown siltstone at 163'.		41	100	49	
		Highly fractured.					Bedding = 18 degrees.
	492			42	90	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	8 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Basalt; Highly weathered and fractured. Longitudinal fracturing; carbonated (?) deposits on a previous slide (?) surface (along fracturing).		43	20	0	Previous sliding surface.
170		Basalt becomes highly weathered.					
	489						
		Sandstone; medium grained friable.		44	0	9	
				45	60	9	
175							Bedding = 36 degrees.
		As above, but contains metamorphosed clasts. Some longitudinal fracturing, yellow-tan; well indurated, medium grained, fractured.		46	100	94	
				47	100	14	
							Bedding = 36 degrees.
180	480						
		Basalt, dark brown, highly weatherd and fractured friable, gouge? Becomes less weathered at bottom of run. Light tan with high quartz content. Horizontal jointing; split longitudinally.		48	50	0	
	477						
		Sandstone as above.		49	75	0	Fracture = 50 degrees.
185	475						
		Basalt (?) Sandy clay, dark brown; plastic, mixed with gravel sized sandstone.		50	100	0	
		As above, but clay contact decreases and sandstone fragment size increases.		51	50	0	
	472						
190		Sandstone, dark brown to black; black where oxidized along prefailed plane; old Slicksides are calcite filled. Grades tan to white and coarser with depth; high quartz content. Vertical jointing and fracturing.					
		Sandstone: tan-white, medium-coarse grained, highly fractured slightly friable.		52	100	0	
		Fragments decreases in size and are covered with dark brown sandy clay.		53	100	0	
				54	100	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	9 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Mixed clay with sandstone. Sandstone is tan to light brown; Highly fractured.		55	100	30	
	466						
195		Basalt; dark brown - green; old Slickensides infilled with calite.		56	100	21	
		Lense of Medium to Coarse Grained Sandstone. Dark green to black, old Slickensides, joints infled with calcite. Old Slickensides Dip Subparallel joints infilled with calcite.					Joint = 60 degrees. Slickenslides = 50-60 degrees. Joint = 40 degrees
	461						
		Sandstone tan to light brown; medium to coarse grained. Longitudinal fracturing.		57	100	63	Joint = 60 degrees, Fracture = 30 degrees.
200	459						
		Basalt greenish-grayish; joints infilled with calcite. Slickensides along joints and calcite infill. Lateral shear striations. Old Slickensides; Shear infilled with calcite. Highly jointed with calcite infill maximum 3 mm; old Slickensides. Oxidized along slickenslide surfaces. Highly jointed. Some infilled with calcite. Joints are subvertical and subparallel. Fractured every 3". Slickenslides weathered, vertical fracturing. Shear striations along slickenside surface.		58	100	0	Slickensides = 30 degrees.
205		Basalt dark green to dark gray, highly fractured Slickensides.		59	10	0	
210				60	50	0	
	447						
		Sand, black, very fine to fine grained. Grades into medium to coarse, salt and pepper appearance with prevelent black color; well rounded.		61	100	0	
				62	100	0	
215	445						
		Basalt dark green gray, fracture from gravel size to 4" long. Basalt dark gray - greenish fractured; Grades lighter in color; Slickensides.		63	95	10	Slickenslides = 60 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	10 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Becomes very fractured. A 16" core split longitudinally; Slickensides along split. Some calcite infill.					
220		As above, Slickensides along longitudinal plain.					
		Becomes highly friable along cracks.		64	80	0	Fracture = 35 degrees.
		Greenish-gray Slickensides; Calcium infilled joints.		65	80	0	Slickenslides = 70 degrees. Slickenslides = 30 degrees.
225		Basalt; dark gray-black and fractured. Slickensides shear striations.					Subvertical slickenslide = 60 degrees. Shear = 60 degrees. Fracture = 50 degrees.
		Friable.					
		As above, fractures. Slickensides calcite infilled; very friable.		66	100	36	Fracture = 40 degrees.
230		Basalt, As above, but fracture at 5"-6" spacings.					
				67	100	27	Fracture = 30 degrees.
		As above, fracturing every 2"-3".					
		Fracturing increases with depth.		68	80	11	Slickenslides = 40 degrees. Slickenslides = 70 degrees.
235		Fractures, Slickenside.					
				69	65	0	Fractures = 40-60 degrees. Slickenslides = 50 degrees.
240		Little or no calcite in filling. Fracturing increases at end of run. Light gray, hard contact with a metasandstone, medium to fine grained; shear striations; Slickensides Pyrite inclusion. Fractures oriented at random. Locally very friable.		70	100	0	Slickenslides = 75 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	11 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	417						Slickenslides = 60 degrees/-30 degrees.
		Metasandstone longitudinally fractured, gravel size. Fractured longitudinally at 30 degrees off horizontal. Fracture spacing 2-3"; friability increases with depth.		71	100	0	
245		Lower portion slickensides, weathered, becomes very fractured (gravel size) at end of run.					
	413						
		Sandstone/Basalt: 3" of sandstone contact with 9" of fracted basalt followed by 4" of sandstone followed by weathered basalt to the end run.		72	100	0	
250	410			73	100	0	
		Basalt, dark gray-black, highly fractured below 249.7' to 1" diameter. Less fractured . Slickensides longitudinal and subhorizontal. Less Fractured.		74	100	0	Slickensides longitudinal and subhorizontal.
		Alternate black Basalt and light gray Sandstone, both highly fractured.		75	85	0	
255		Basalt; black; but have numerous cracks/ fractures.					
		As above; becomes very friable contains white streaks.		76	50	0	
260		Contact zone Basalt/Sandstone. Core fractured every 4".		77	100	0	Fracture = 65 degrees.
		Basalt, black; moderately hard, fracture spacing 2"; Fractures - pyrite inclusion; abundant Slickensides. As above but longitudinal fracturing is absent. White inclusion Slickensides calcite along slip surfaces. Fracturing spacing increases with depth; longitudinal fracturing reappears at 266.		78	100	0	Fracture = 30 degrees/Subvertical
265							Slickenslides = 30 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	12 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		As above.		79	90	0	
		Basalt hard as above, Slickensides along axis.		80	100	0	
270		As above, but less fractured.		81	100	19	
	387	Sandstone, medium gray, fine to medium grained; hard; fracturing increases with depth. Fracture Dip=40 degrees.		82	90	19	Fracture = 40 degrees.
275	383	Basalt; white infiling along some cracking; Slickensides.		83	25	0	
280	380	Siltstone, dark gray to black, moderately hard; gouge at contact. Slickensides in Siltstone Longitudinal fracturing; Fractures subparallel.		84	75	0	Slickenslides = 30 degrees. Fractures = 30-50 degrees.
		Siltstone as above.		85	58	0	
285	374	Basalt dark gray-black, highly fractured, Slickensided.		86	77	0	Slickenslides = 30-40 degrees.
		Basalt as above, highly fractured, occasional white streak. Gouge in contact with Siltstone.		87	44	0	
290	369	Siltstone dark gray-black fractured; hard.		88	42	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	13 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		As above, but fractured spacing at 3"; Slickensides in Gouge.					Slickenslides = 30 degrees. Bedding = 25-27 degrees.
		Siltstone as above.		89	100	0	
295		Fracturing becomes more abbundant. Slickensides. Fracture Crumbles.					
		As above, but Siltstone slightly lighter in color; well developed Slickenside surfaces .		90	64	0	Fractures = +40 degrees to -40 degrees. Slickenslides 50 degrees to subhorizontal
				91	67	0	
300		Siltstone as above, but grades darker and fracturing is subparallel every 1"; contact with 2" thick layer of Alternating with Sandstone: gray, fine to medium grained; hard. Becomes very fractured with local white infill in cracks. At bottom of run, contact with siltstone.		92	80	43	Upper contact at 40 degrees, lower at 30 degrees.
		Gouge Zone fresh slickenslides Highly fractured zone		93	75	0	
305		Very fractured zone - crumbles. Fragments of calcite 3-4 mm thick.		94	79	0	
		Siltstone Black, Sandstone lense at top of run. Hard; longitudinal and subhorizontal fracturing. Sandstone fragments as above, 3" long Fracture.		95	62	12	
		Gouge at local contact with siltstone.					Fractures = 30 degrees.
310							Bedding = 27 degrees.
		Siltstone highly fractured. Old Slickensides; locally crumbley.		96	65	0	
		Pieces of sandstone with subparallel white streaks; well developed gypsum crystals in cavities, below that siltstone, as above.		97	44	0	
315				98	42	0	
		Siltstone, as above but fractured. Slickensides, Fractures.		99	98	65	Slickenslides = 50 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	14 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Subvertical jointing infilled with calcite.					Fractures = -50 degrees.
320		Fractured (gravel size) siltstone. Lense of sandstone as above. Fractures, gypsum crystals developed along joints.		100	43	12	
		Siltstone as above. Siltstone highly fractured zone; old slickensides.					Bedding = 54 degrees. Bedding = 45 degrees. Bedding = 41 degrees.
	337						
		Siltstone/sandstone; fracture dip 60 degrees.		101	83	73	Fractures = 60 degrees.
325							Bedding = 19 degrees.
	334						
		Siltstone as above with thin layers (0.1-5") of sandstone (as above) interbedded.		102	94	74	
		Highly fractured zone above 330.9'. Gouge on 2" piece of sandstone. Slckensides Bedding.					
330		Siltstone, as above. Becomes fractured (vertical/horizontal) with depth joint dip 60 degrees; bedding dip 10 to 30 degrees. Calcite infill of joints.					Slickenslides = 30 degrees. Bedding = 10-45 degrees.
		Siltstone. Fractured (subvertical and subhorizontal), 8" long core split longitudinally.		103	96	23	
		Sandstone lense, as above 6" long.					
335		Siltstone as above. Slickensides joints infilled with calcite. Jointed. Fracturing increases with depth to 2" spacing. Subparallel slickensides.					Bedding = 26 degrees.
				104	89	14	Joint = 60 degrees. Slickenslides = 45 degrees.
		As above, some subvertical fracturing; comes more friable.		105	68	0	
340		Sandstone/siltstone. Fractured spacing 1-3" below 340.8.		106	99	53	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	15 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Slickenside - gouge above sandstone.					Fractures = 50 degrees.
							Slickenslides = 30 degrees.
		Siltstone gravel-sized fragments at end of run.					Bedding = 18 degrees.
		Sandstone lense, as above 6" long.		107	58	26	
345							Bedding = 20 degrees.
		Highly factured at beginning of run; fractured spacing 1-3". Subhorizontal jointing infilled with calcite.		108	57	54	
							Joint = 10 degrees.
350		Siltstone.		109	97	81	
		As above. Sheared, calcite infilled joints.		110	100	83	Shear = 65 degrees.
							Bedding = 30 degrees.
355		As above. Fish scales in siltstone.		111	100	97	
360		Siltstone as above, but fractured with local gouge zone. Shiny small surfaces may be fish scales.		112	71	19	
		As above; fracture dip 70 degrees, slickensides.					
365		Sandstone lense as above. Contact with		113	99	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	16 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		siltstone joint infilled					Contact = 60 degrees. Bedding = 30 degrees.
		Siltstone as above, fractured spacing 2"- 3"; slickensides. Fracturing increases with depth; frequent cracking. Fracturing thereafter occurs at 1"-2" spacing along joints; infilled with calcite.		114	93	0	Slickenslides = 20 degrees.
370		Slickensides along joints. Fracturing spacing 3-4".		115	88	36	Slickenslides = 40 degrees. Slickenslides = 30 degrees.
		Joints filled with calcite; (subvertical and subhorizontal) fracturing. Bentonite(?) light gray, molded with white (calcite) and orange inclusions, waxy.					
375	285			116	80	19	
		Sandstone light gray, fine to medium grained. Joint infilled with gray very plastic clay; joint dip 40 degrees. Sandstone below.					Joints = 40-70 degrees. Bedding = 19 degrees.
		Joints infilled with calcite. Sandstone as above. 4" zone of clay, gray, very plastic		117	80	0	Shear
380		1.5" of clay (as above) interbedded at bottom of run (383.5) subhorizontal contact of sandstone/siltstone. Siltstone: dark brown-black fractured inclusions of sandstone fragments.					
	276						Shear
385		**SESPE FORMATION**		118	87	0	Contact = 70 degrees.
		Siltstone, highly fractured. Clay, green to gray - plastic, molded, 10" long. 70 degree contact with piece of sandstone.					
		Silty sandstone. Light gray-green with alternating zones of silty sandstone and red clay to 389.3'. 5" zone of Plastic Clay.					Shear
390		Sandstone Lense: light green, medium grained; friable at 391'; 2" zone of red clay.		119	99	30	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	17 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Siltstone, red to brown, fractured and highly cracked.					
		As above. Gouge zone 2" of green sandstone below gouge zone. Becomes clayey and grades to brown siltstone. Fracturing spacing 2-5". Alternate intermixed green sandstone with red siltstone.		120	95	20	
395							Fractures = 15 degrees.
		As above, Fractures.					Fractures = 50 degrees.
		Gouge.		121	97	32	Shear = 28 degrees. Bedding = 20 degrees.
400		Alternate green sandstone to red siltstone. A 21" zone of highly molded fractured jointed material; green and red clay with sandstone.					Shear = 43 degrees. Shear = 30 degrees.
		Siltstone dark brown, moderately hard, fractured. Becomes slightly harder; white inclusions. Alternating siltstone and friable sandstone with hard sandstone inclusions. Locally mottled.					Fractures = 30 degrees.
		Siltstone/Sandstone, as above. Gouge zone mottled.		122	100	60	Joint = 50 degrees.
405							
		Gouge Zone					
	252						Shear = 38 degrees. Shear = 51 degrees.
		Sandstone, gray hard, mdeium grained, slickensides. Becomes friable with depth; longitudinal fracturing. Grades finer and darker at about 410'. Contact with coarser sandstone at about 411' at 50 degrees; becomes weathered and friable.		123	90	17	
410							Contact = 50 degrees.
		Sandstone, gray fractured at 2-3" spacing, grades greenish medium grained. Slickensided .		124	86	0	Slickenslides = 70 degrees.
415							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	18 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Sandstone, greenish medium grained. Fractured to gravel size.		125	24	0	
420		As above, but fractured spacing 3-4". Slickensides 60 degrees.		126	76	31	Slickensides 60 degrees.
		Friable and coarse grained. Includes fine gravel.					
		As above, but includes zones of 0.5-2" of dark brown siltstone. Also includes occasional clasts to 1" diameter. Grades to a salt/pepper texture, fine-grained. Contact with tan-greenish medium grained sandstone.		127	65	63	Slickenslide/Shear = 30 degrees.
425	231			128	0	0	Bedding = 28 degrees.
		No Recovery					
430	228			129	96	90	
		Sandstone, greenish, medium to coarse-grained; friable.		130	90	32	Bedding = 30 degrees.
		As above.					
435	224			131	83	65	
		Alternate layers of dark brown siltstone and green sandstone.					
	221						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	19 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
440		Sandstone, red-brown medium grained. Alternate green sandstone with lenses of medium soft siltstone. Dark brown sandstone, fine grained.		132	50	44	Shear Bedding = 17 degrees.
		Sandstone as above.					
445		As above, grades coarser with depth.		133	56	44	
		As above, but with clasts. Banded with siltstone; contact at 55 degrees. Slickensides. Grades into brown-red siltstone moderately hard.					Slickenslides = 55 degrees.
450	209			134	97	83	
		Siltstone, dark brown, hard, intact.					Bedding = 45 degrees.
		Grades rapidly into sandstone.					
455	204			135	49	28	Shear = 48 degrees.
		Sandstone, red-dark brown fine grained. Occasional cracking. Grades into a dark gray-brown, fine to medium grain sandstone, friable.					
460							Bedding = 26 degrees.
		Sandy-clay to silty-clay, dark brown; moist medium-firm. Grades into a gray, dark brown sandstone, medium to coarse grained.		136	61	0	
	197			137	89	16	
		Silty sandstone, as above; fractured at 3-4" spacing, jointed.					Slickenslides = 70 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	20 of 20
Project Number:	49-97D	Borehole Number:	BYA-2

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
465							
		Siltstone - dark brown. Contact with sandstone at 60 degrees; sandstone: gray-brown fine to medium grained. Grades coarser with gravel inclusions and then finer again.		138	99	95	Shear = 45 degrees. Contact = 60 degrees. Bedding = 16 degrees.
470		As above, medium grained. Grades into a pinkish sandstone, medium to coarse grained. Contact with dark brown siltstone.		139	82	54	Contact = 28 degrees Fracture = 50 degrees. Bedding = 15-20 degrees.
		Siltstone dark brown; slickensides; fractured and jointed.					
475		Siltstone as above, but highly mottled and cracked. Slickensides. Zone of compression highly cracked. Siltstone grades briefly into greenish fine grained sandstone. Grades into a brown sandstone, fine to medium grained. Grades lighter at end of boring.		140	100	41	Contact = 70 degrees. Slickenslides = 70 degrees. Bedding = 20 degrees.
480	180	Boring terminated at 480.9'.					
485							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	1 of 21
Project Number:	49-97D	Borehole Number:	BYA-3
Location:	PINNACLE WAY, MALIBU, CALIFORNIA		
Type of Drill Rig:	ROTARY WASH	Driller:	DATUM EXPLORATION
Bit Size:	2"	Drilling Fluid:	EZ-MUD
Inclination/Direction:	-90.0 /	Surface Elevation:	510' ±
Logged By:	JLA	Start: 30 MAY 90	End: 13 JUN 90

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
0		Not cored, no recovery.					
5	504	**TOPANGA FORMATION:**		1	67	10	
		Sandstone, hard to medium soft, yellowish brown.					
10				2	91	8	
15	495	Sedimentary Breccia, yellowish brown, medium soft, contains primarily pebble-sized angular sedimentary clasts of varied composition; generally lithic rich; matrix is yellow brown to red brown siltstone.		3	45	11	
	491	Sandstone, yellowish brown, hard to medium soft, massive, medium to coarse					

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 2 of 21

Project Number: 49-97D | Borehole Number: BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
20		grained, lithic-rich, commonly with scattered angular pebble-size sedimentary clasts.		4	75	26	
25		Sandstone: As Above.					
30		Sandstone: As Above.		5	73	14	
	479	Tectonic(?) Breccia; medium soft, yellowish-brown, in sand-stone and sedimentary breccia, as above, and gray-brown, massive siltstone; mostly clast supported.					
35		Tectonic (?) Breccia, As Above.		6	75	10	
				7	55	20	
40		Tectonic (?) Breccia, As Above.					
	469	Sedimentary(?) Breccia; Medium soft to medium hard, gray-brown, clast supported but locally matrix supported; clasts are gray-brown to yellow-brown, angular, coarse sand to pebble-sized, siltstone fragments; matrix is yellow brown silty clay. Sedimentary Breccia, As Above.		8	51	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	3 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
45							
		Sedimentary Breccia, As Above.		9	100	73	
50				10	43	32	
	457	Sandstone: Hard, yellow-brown to light yellow-brown, massive to laminated, medium-to coarse-grained quartzo-feldspathic.					Bedding = 24 degrees.
55				11	37	20	
		Sandstone: As Above.					
60							
65	445	Silty sandstone, dark brown.		12	6	0	Bedding = 29 degrees. Bedding = 20 degrees.
	443	Sandstone: Hard, yellow-brown to light yellow-brown, massive to laminated, medium to coarse grained quartzo-felopathic.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	4 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
70		Sandstone, As Above.		13	67	48	Bedding = 15 degrees. Shear = 79 degrees.
75		Sandstone, As Above.		14	35	19	
80		Sandstone, As Above.		15	10	8	
85		Sandstone, As Above.		16	100	0	Soft.
				17	100	19	
	422	Siltstone: Hard, yellow-brown, dark gray-brown, and dark greenish gray-brown, gradational contact with overlying sandstone, sandstone contains abundant siltstone fragments (eroded clasts).					
90				18	79	8	Shear = 34 degrees.
	419	Sandstone: Hard, yellow-brown, massive to faintly laminated, medium-grained, quartzo-feldspathic, in fault contact with siltstone above.					Bedding = 27 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	5 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
95	415	Siltstone and Silty Sandstone; Hard, dark gray-brown, massive.		19	19	8	
		Silty sandstone.					
100				20	0	0	
		Red brown clay at contact.		21	66	0	
	406	Basalt; Hard, greenish-black, aphyric(?) ferromagnetic; alteration probably serpentinization; highly sheared (slickensides); no vesicles; microlites of plagioclase visible with magnification.					
105							
		Basalt: Highly sheared, as above.					
110				22	7	0	
		Basalt: Highly sheared, as above.					
115				23	75	0	

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 6 of 21

Project Number: 49-97D | Borehole Number: BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
120		Basalt, As Above.		24	50	20	
				25	100	30	
125		Basalt, As Above		26	65	8	
		Gouge at Contact.					
	381						Basal Rupture Surfaces at Sespe-Basalt Contact.
130		**SESPE FORMATION;** Sandstone; hard, green (locally reddish), quartzo-feld-spathic, fine to coarse-grained, massive, contains calcite veins; some silty intervals.		27	42	17	Shear = 48 degrees.
	377	Siltstone; Medium soft, red-brown, pervasively shattered to a matrix-supported breccia.					
135							Shear = 50 degrees.
				28	100	47	
				29	91	0	
				30	91	39	
	372						Shear = 63 degrees.
		Sandstone; hard, green, fine to coarse grained, massive.					
140				31	92	40	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	7 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Sandstone, as above.		32	100	73	Bedding = 24 degrees.
145	363	Gouge; Soft, dark green-gray/brown-gray, in older tectonic breccia described below.		33	93	70	
		Tectonic Breccia; Medium soft, green-gray/brown-gray, derived from sandstones and siltstones; pervasively slickensided.		34	100	80	
150	359	Sandstone; Hard, green-gray to dark green-gray, quartzo-feldspathic, fine silty to coarse-grained, massive to faintly laminated, pebbles locally.		35	98	95	
		Sandstone, As above.					
155				36	100	99	
		Sandstone, as above.					
160				37	100	57	Bedding = 19 degrees.
		Sandstone, As above.					
165				38	95	58	Shear = 60 degrees.
				39	97	88	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	8 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
170		Sandstone; as above.		40	96	88	Bedding = 16 degrees. Bedding = 18 degrees. Bedding = 21 degrees.
175		Sandstone, as above.		41	86	80	Bedding = 17 degrees. Bedding = 18 degrees.
180	330	Sandstone with interbedded siltstone layers; Hard, dark green-gray (red-brown near top), irregularly laminated, siltstone is preferentially sheared; sandstone is shattered.		42	100	50	Bedding = 23 degrees.
185	326	Sandstone; Hard, green-gray to very dark green-gray, quartzo-feldspathic and lithic-rich, fine silty to coarse-grained, massive, pebbly near top.		43	95	40	
190		Sandstone, as above.		44	75	70	
				45	98	65	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	9 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
195	315						
		Siltstone; Hard, red-brown and red-gray, massive, some intervals are sandy.		46	88	45	
200		Siltstone, as above.		47	80	12	
	307						
		Sandstone; Hard, green-gray to dark green-gray, quartzo-feldspathic, medium- to coarse- grained, massive to faintly laminated, pebbles locally.		48	79	58	Bedding = 15 degrees.
210		Sandstone, as above.		49	97	65	Bedding = 20 degrees.
215	295						
		Siltstone, red brown.		50	69	45	
	293						
		Sandstone; Hard, green gray to dark green gray, medium to coarse grain, massive to					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	10 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		faintly laminated.					
220		Sandstone, as above.		51	96	80	
225		Sandstone, as above.		52	98	63	
230		Sandstone, as above.					Bedding = 16 degrees.
	279	Siltstone; Hard, dark red-brown, massive, locally soft (possibly due to drilling).		53	100	90	
235		Siltstone, as above.		54	46	14	
				55	100	80	
	272	Sandstone and pebble to cobble Conglomerate; Hard, greenish-gray, pebbly, medium-grained, matrix supported; sandstone is massive to locally laminated; conglomerate clasts are subrounded to rounded metasedimentary and metaigneous rocks; sandstone is locally moist.					
240				56	64	50	Bedding = 20 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	11 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
245		Sandstone, as above.		57	100	75	
	261						
250		Pebble to cobble conglomerate.		58	100	62	Bedding = 18 degrees. Bedding = 17 degrees.
255		Pebble to cobble conglomerate, as above.		59	100	95	Moist. Bedding 16 degrees.
260	249			60	92	70	Bedding = 19 degrees.
		Sandstone; Hard, red-brown to dark red-brown, massive to laminated, silty fine-grained, and Siltstone interbedded with layers of hard, medium- to coarse-grained, massive to faintly laminated, pebbly Sandstone and pebble to cobble Conglomerate; matrix supported; clasts are metasedimentary and meta-igneous rocks; some calcite veins.					
265				61	100	100	Bedding = 24 degrees. Bedding = 25 degrees.

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 12 of 21

Project Number: 49-97D | Borehole Number: BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	241						Shear = 51 degrees.
		Predominantly Sandstone, as above.					Bedding = 24 degrees.
270				62	100	80	
		Sandstone.					Bedding = 34 degrees.
275				63	100	100	Bedding = 32 degrees.
	231						
280		Pebble to Cobble Conglomerate.		64	96	96	
	229						
		Interbedded Sandstone and Siltstone as above.					
285				65	100	100	
	221						
		Predominantly Sandstone.					
290				66	63	63	Shear = 35 degrees.



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Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	13 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
295		Sandstone, as above.		67	100	100	
300		Sandstone, as above.		68	100	95	Shear = 36 degrees. Shear = 35 degrees. Shear = 25 degrees.
	208	Cobbles.					
	206	Interbedded Siltstones, Sandstones and Conglomerate- as described above.		69	88	60	Bedding = 20 degrees. Shear = 40 degrees. Shear = 36 degrees. Shear = 37 degrees. (contact)
305	201	Predominantly Sandstone, as above to 318.5'.		70	100	72	Shear = 38 degrees. Shear = 33 degrees.
310							
315				71	100	80	Bedding = 32 degrees. Bedding = 40 degrees. (cross bedded) Bedding = 26 degrees.

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 14 of 21

Project Number: 49-97D | Borehole Number: BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	192						Bedding = 34 degrees.
							Shear = 52 degrees. (contact)
		Siltstone; Hard, red-brown to dark red-brown, massive, comparatively more sheared than overlying sandstone sequence; some sandstone locally.					
320				72	98	90	
		Siltstone as above, pervasively sheared.					Shear = 15 degrees.
							Shear = 29 degrees.
							Shear = 39 degrees.
							Shear = 30 degrees.
							Shear = 29 degrees.
325							
	184			73	88	43	
		Sandstone; Hard, gray to dark brownish-gray, medium-grained, massive to faintly laminated, quartzo-feldspathic, some interbedded dark red-brown siltstone similar to above.					
		Sandstone, as above.					
330				74	39	15	
				75	57	10	
		Siltstone Lense					
335				76	73	30	
				77	95	66	
							Bedding = 32 degrees.
							Shear = 47 degrees.
		Sandstone, as above.					
340				78	100	50	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	15 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
345		Sandstone, as above.		79	90	34	
							Shear = 62 degrees.
		Silstone Lense.					
350	160			80	96	35	
		Sandstone and Silty Sandstone; Hard, dark red-brown, massive, scattered calcite veins.					
							Shear = 32 degrees. Shear = 48 degrees. Shear = 47 degrees.
355		Sandstone and silty Sandstone, as above.		81	100	45	
360		Sandstone and Silty sandstone, as above.		82	100	50	
							Shear = 70 degrees. Breccia Zone
		Sandstone and Silty Sandstone, as above.					
365				83	100	59	Shear = 36 degrees.

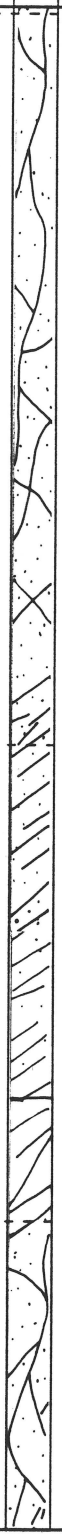
Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	16 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
370		Sandstone and Silty Sandstone, as above.		84	100	58	Shear = 59 degrees.
							Shear = 29 degrees. Shear = 28 degrees.
375		Sandstone and Silty Sandstone, as above.		85	100	81	
	134	Sandstone; Hard, gray massive, quartzofeldspathic, medium-grained, conglomeratic locally.					Shear = 20 degrees. Shear = 40 degrees.
380		Sandstone, as above.		86	100	95	
		Conglomeritic to 388.00					
385				87	100	60	
	122						Conglomeratic Shear = 17 degrees. (contact)
390		Siltstone, massive and fine to medium-grained. Silty Sandstone, massive; Hard, dark red brown, scattered calcite veins.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	17 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Massive Silty Sandstone to 397'.		88	100	68	
395				89	96	20	Shear = 60 degrees.
	113	Siltstone: Hard, red-brown, massive.					
400		Siltstone as above.		90	100	50	Shear = 38 degrees.
405		Silstone, as above.		91	94	63	
410		Siltstone ,as above.		92	84	38	
415	95						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	18 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Sandstone; Hard, greenish-gray to dark greenish-gray, massive medium-grained quartzo-feldspathic.		93	94	0	
				94	79	8	
420		Sandstone, as above.					
				95	78	9	
425		Sandstone, as above.					
	83						
		Siltstone: Massive and massive fine sandy siltstone; Hard, dark red-brown.		96	100	40	
430							
		Massive silstone, as above.		97	100	35	
							Shear = 24 degrees.
435	75						Shear = 72 degrees.
				98	100	29	
		Sandstone; Hard, green-gray to dark green-gray, fine silty to medium-grained, massive to faintly laminated (rare), quartzo-feldspathic, scattered calcite veins.					

Project Name: BIGROCK MESA LANDSLIDE

Sheet: 19 of 21

Project Number: 49-97D

Borehole Number: **BYA-3**

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
440				99	100	0	Bedding = 32 degrees.
		Massive.					
		Sandstone, as above.		100	58	0	
445				101	100	10	
		Sandstone, as above.					Bedding = 26 degrees.
450				102	100	0	
		Medium grained.					
				103	48	0	
		Sandstone, as above.					
455				104	100	21	
	53						
		Siltstone; Hard, dary gray, massive, and Sandstone; olive green, medium to coarse-grained massive, green coloration from alteration (?), rock within 2 ft. of underlying diabase is altered to a pale yellow green probably as the result of hydrothermal alteration of feldspar; slickensides are serpentinized.					Shear = 45 degrees.
460				105	80	33	Shear= 45 degrees.
				106	100	17	Shear = 76 degrees.
							Shear = 61 degrees
	46						
		Diabase; Hard, black (plag. altered to					

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Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	20 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
465		white in much of the core), massive.		107	100	15	
				108	100	10	
470		Hard Black Diabase, as above.					
				109	83	0	
				110	100	37	
475		Diabase, as above.					
				111	92	0	
480		Diabase, as above.					
				112	69	14	
		Diabase, as above.					
485				113	96	14	
				114	100	10	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	21 of 21
Project Number:	49-97D	Borehole Number:	BYA-3

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
490		Diabase, as aove.					
				115	100	0	
495		Diabase, as above.		116	100	18	
500	10	Boring terminated at 500 feet.					
505							
510							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	1 of 21
Project Number:	49-97D	Borehole Number:	BYA-4
Location:	WEST SEABOARD ROAD, MALIBU, CALIFORNIA		
Type of Drill Rig:	ROTARY WASH	Driller:	DATUM EXPLORATION
Bit Size:	2"	Drilling Fluid:	EZ-MUD
Inclination/Direction:	-90.0 / ------	Surface Elevation:	360' ±
Logged By:	JLA	Start:	23 AUG 90 End: 5 SEP 90

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
0		Not cored, no recovery.					
5	354	**TOPANGA FORMATION:**		1	100	20	
		Sedimentary Breccia; medium hard, yellowish brown, matrix-supported; matrix is medium soft to hard (locally well-cemented), dark yellowish brown, fine to medium grained sandstone; clasts include mainly granitics, sandstones, siltstones and basalt fragments. No visible structure.		2	88	32	
10		Sedimentary Breccia as above except some clasts are much larger (up to 15 cm long); larger clasts are hard, greenish tan, massive sandstone.					
15		Sedimentary Breccia as above except highly broken up to the extent that it is soft; difficult to tell what original character was.		3	60	32	
	341	Sandstone; hard, yellow brown, massive quartzo-feldspathic fossiliferous; contains					Fault - 65 degrees (top of Sandstone). Bedding - 66 degrees (Fossil Bed)

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	2 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
20		abundant imbricated pelecypods with less abundant small gastropods (sections).		4	78	0	Recovered 0.4' from previous run.
		Sedimentary Breccia; highly broken up - possibly due to drilling; soft fine sandstone with angular breccia clasts; large (5-10 cm) isolated clasts of hard sandstone and basalt observed.					
	336						
25		Sandstone; hard yellow-brown quartzo-feldspathic massive; scattered small pits suggesting dissolution of fossil fragments; small rootlets in top of run; grades downward into sedimentary breccia as in Run 1, except with dark gray siltstone clasts dominant; lowest part of core may be tectonically shattered (appears		5	100	0	
	332	limonitic).		6	100	32	
		Sedimentary Breccia as in run above grading downward into hard yellowish-brown thinly-bedded sandstone;					
30	330	some large angular sandstone clasts 2-4 cm long in this unit.		7	100	63	Bedding - 54 degrees (thin beds in Sandstone). Fossil Bed.
		Sandstone; hard, yellowish-brown, locally laminated, massive; contains fossil horizon containing predominantly pelecypods; well-cemented with calcium carbonate.					
		Sandstone as above; contains isolated fossil fragments and is laminated locally, otherwise massive.		8	82	24	Bedding - 52 degrees fine laminae in sample.
35							Fossil fragments.
		Sandstone as above, except locally medium coarse grained; still quartzo-feldspathic.		9	100	52	
40							Fossil fragments.
		Sandstone as above.					
		Broken up 45.5 - 47.5.		10	100	11	Bedding = 50 degrees.

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	3 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
45							Bedding/Fault = 47 degrees (Slickensides and clay gouge = 1 cm).
		Sandstone as above, except coarsens downward; also, fossil horizon near top of run 71 containing pelecypods.		11	71	11	Fossils.
50		Sandstone, massive, as above.		12	100	66	Fault = 54 degrees (Slickensides).
55		Sandstone, massive, as above, with localized laminae. Coarsens slightly near base of run 13.		13	100	66	Bedding = 43 degrees (Sandstone laminae).
60		Sandstone, massive, medium to coarse pebbly, but otherwise as above.		14	80	48	
65				15	100	78	
	293	Pebbly Sandstone and Sedimentary Breccia, angular pebble clasts; medium coarse to coarse sand.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	4 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
70		Pebbly Sandstone, As Above.		16	100	73	
	288	Sandstone, hard, yellow brown, massive.					
75		Massive Sandstone as above with rare laminae.		17	80	72	Bedding = 54 degrees (Sandstone laminae).
							Bedding = 38 degrees (Sandstone laminae).
80		Massive Sandstone as above alternating with Sandstone containing laminations; some laminae are slickensided.		18	100	66	Bedding = 58 degrees (Sandstone laminae).
							Bedding = 40 degrees (Thin Siltstone bed).
85		Massive Sandstone as in run 17.		19	100	67	Bedding = 40 degrees (Thin Siltstone bed - slickensided).
							Bedding = 54 degrees (Sandstone laminae).
90				20	80	66	Bedding = 41 degrees (Sandstone laminae).

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	5 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
95							Fault = 55 degrees (with striae on slickensides).
				21	80	65	Bedding = 41 degrees (Sandstone laminae).
							Bedding = 38 degrees (Siltstone laminae).
100		Sandstone, mottled greenish tan, may be bioturbated, penecontemporaneously deformed.		22	78	64	
	259						
		Minor Siltstone.					
	257						
		Massive Sandstone, as above.					
		Sandstone; thin-bedded to laminated medium coarse-grained as above, with scattered pebbles.		23	100	68	Bedding = 56 degrees.
105							Bedding = 39 degrees.
		Sandstone; thin-bedded to laminated with occasional thin beds of dark gray siltstone.		24	100	67	Bedding = 53 degrees.
110							Shear = 90 degrees.
		Sandstone, as above.					Bedding = 40 degrees.
				25	80	66	
115							Bedding = 36 degrees.
		Sandstone as above, but no laminae.		26	20	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	6 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
120		Sandstone, as above.		27	80	8	
125				28	75	26	
130		Sandstone, as above.					
		Medium soft to hard, light yellow brown, massive sandstone; contains some slickensided fractures.		29	94	16	
135		Sandstone, as above.		30	100	10	
	221	Sandy siltstone, hard gray-brown, grading downward into sandstone, yellow-brown, fine to medium grained, massive sandstone.		31	53	5	Siltstone is highly broken up.
140	218	Sandstone, yellow-brown, massive, fine to medium grained.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	7 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
145	215	Tectonic Breccia in sandstone similar to above; grades downward into soft clay gouge (approx. 10 cm thick) with abundant slickensided surfaces; gouge is underlain by medium hard, brown, fine sandy siltstone; all rocks below gouge zone appear to be significantly less oxidized than above.		32	79	5	Silde plane or fault. Fault/Slide plane (gouge lined) = 45 degrees.
150	210	Clayey Siltstone, hard, dark blue gray, massive, contains isolated subtle laminae; locally oxidized along fractures; some veins (non-carbonate) along fractures near base of core; also slickensides at base.		33	100	99	Bedding = 31 degrees.
		Siltstone, as above, shattered pervasively, but cohesive with abundant slickensides suggesting tectonic brecciation.		34	100	55	
155		Siltstone, as above, shattered with cohesive, fracture spacing averaging 2 cm, rock appears to be fissile but all surfaces are slickensided. Veinlets near base of core.		35	100	36	Shattered with slickensides.
160		Siltstone; hard, medium gray, bioturbated (?), half oxidized and half not; some laminae still visible but mostly disrupted; core is largely intact with scattered fractures.		36	100	78	
165		Siltstone, as above.		37	100	90	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	8 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
170		Siltstone, as above.		38	100	66	
175		Siltstone, as above, all unoxidized.		39	100	87	
180		Siltstone as above, oxidized along one fracture, light blue green, otherwise unoxidized; all fractures are slickensided; core is pervasively fractured (avg. spacing approx. 1 cm) but is highly cohesive suggesting relative old tectonic brecciation.		40	100	76	Bedding = 38 degrees.
185		Siltstone, as in run 36.		41	100	68	
190	170	Siltstone, as in runs 36-39, grading downward into hard, med. dark gray, silty sandstone; oxidized in some areas to yellow brown; has some bioturbated character as siltstones, above.		42	88	25	Bedding = 19 degrees. Bedding = 27 degrees.

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 9 of 21

Project Number: 49-97D | Borehole Number: BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Basalt, hard, black, olivine-phyric, in intrusive contact with sandstone above; has baked (oxidized) irregular contact; no vesicles evident; some oxidation of iron minerals with resultant loss of ferromagnetism; abundant slickensides near contact.		43	100	20	Contact = 11 degrees.
195		Basalt, as above, ferromagnesian minerals are serpentized giving the rock a generally greenish color; freshest samples are still nonferromagnetic reflecting the degree of alteration of iron minerals.		44	55	12	
200		Basalt, as above, pervasively shattered to the extent that the core is cohesive, and softened.		45	87	21	
		Basalt, as above, notable increase in olivine phenocrysts up to 2 mm long; degree of brecciation has decreased from that of previous run; basal contact is exposed (although rotated by core barrel).					
	157						
		Silty Sandstone; hard, gray-brown, massive, baked at contact; contains veinlets of calcite; has mottled coloration near base.		46	100	18	
205		Continuation of mottled unit in base of run 43; coarsens downward into massive sandstone with subtle bedding at base; also contains calcite veinlets and is cemented with calcite; in intrusive contact with basalt.					
	151						
		Basalt; hard, black, aphyric, locally vesicular/amygdaloidal; oxidized red near contact; no olivine pheocrysts and ferromagnetic in contrast to above; upper contact cross-cuts bedding at an angle of approx. 50 degrees; shearing evident along both contacts appears relatively old.		47	100	6	Bedding = 30 degrees. Contact = 26 degrees.
210	147						
		Soft, light whitish tan, sandstone, originally quartzofeldspathic, but all feldspar altered to clay leaving quartz crystals scattered through a clay matrix; core loss in this interval due to softness.		48	54	0	
215				49	59	0	
	144						
		Basalt, as in run 47, upper contact lost, lower is highly sheared.					

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	10 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	142						
		Sandstone; hard, light gray-brown, massive, similar to that above uppermost basalt.					
220		Sandstone, as above, above and below basalt.		50	84	10	
				51	100	0	Bedding = 24 degrees.
	137						
		Basalt, as in runs 47 and 49, approx. 1 ft. thick.					
225	135						Contact = 26 degrees.
		Sandstone, as above, in intrusive contact with basalt.		52	100	18	Contact = 32 degrees.
	132						Bedding = 29 degrees.
		Basalt, hard, black, medium to coarse grained, aphyric, ferromagnetic; no vesicles; veinlets of calcite; contact cross-cuts bedding at an angle of 63 degrees.					
230		Basalt, as above.		53	100	0	
		Basalt, as above.					
235				54	100	0	
				55	83	0	
240		Basalt, as above.					
				56	100	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	11 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
				57	100	91	
				58	100	92	
		Basalt, as above.					
245				59	100	34	
		Basalt, as above.					
250				60	100	10	
				61	100	0	
		Basalt, as above.					
255				62	100	38	
		Basalt, as above.					
260				63	100	26	
		Basalt, as above.					
265				64	100	12	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	12 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
270		Basalt, as above.		65	100	8	
				66	100	8	
275		Basalt, as above.		67	86	8	
				68	53	0	
280		Basalt, as above.		69	77	0	
	76	Gouge at Contact					
285		SESPE FORMATION		70	100	0	Basal Rupture Surface-gouge-at Sespe-Basalt.
		Conglomerate; hard, light greenish gray; matrix is coarse sandstone; pebble to cobble metavolcanic and metasedimentary clasts including preimarily quartzite and porphyroblastic rocks, matrix supported contact with basalt not intact but gouge present.		71	100	0	
		Pyrite crystals on some fracture surfaces.					
	71						
290		Siltstone, hard, dark reddish-brown massive.		72	100	0	
		Siltstone, as above, in fault contact with similar gray siltstone; both are shattered					

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 13 of 21

Project Number: 49-97D | Borehole Number: BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		with avg. fracture spacing of approx. 1 cm; coarse cohesive, indicating that the brecciation represents a relatively old event.		73	81	0	
	67						
295		Sandstone; hard, gray, massive fine; appears to be in fault contact with siltstone; contact is probably in base of previous run.					
	64						
		Sandstone, as above, grades downward into soft, gray, bedded sandstone.		74	77	0	
	62						
		Siltstone, hard gray, bioturbated (?), generally brecciated as in run 72.		75	100	0	
300	60						
		Sandstone, as above, grades downward into soft, gray bedded sandstone.		76	91	0	Bedding = 32 degrees.
		Sandstone, as above, except coarser.					
		Sandstone, hard, dark gray, massive to laminated, silty, fine-grained, laminae are subtle.		77	43	0	Bedding = 20 degrees.
305		Hard, gray, medium-grained massive to laminated sandstone.					Bedding = 22 degrees.
		Sandstone, as above.		78	39	0	Bedding = 22 degrees.
310	50						
		Siltstone; hard, dark gray, massive, highly fractured with slickensides.		79	87	16	
	46						
315		Sandstone, as in the top of run 77, except medium soft, both rock units are highly fractured and locally brecciated but cohesive.		80	43	16	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	14 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Med. soft to soft, gray, massive, cementation seems to be nil.					
320	40						
		Tectonic Breccia; med. soft to hard, appears to be developed in laminated siltstone. (Sandstone fragments at base of run appear to be re-cut, making origins questionnable.)		81	24	16	
325		Tectonic Breccia in Gouge; med. soft; highly cohesive and does not have readily evident slickensides; angular fragments are matrix supported by gouge.		82	54	0	
	32						
		No recovery.		83	0	0	
330							
				84	0	0	
335							
	23						
		Sandstone, med. soft to hard, reddish gray-brown to gray, upper part contains rounded sandstone pebbles (2 cm across); lower part is massive.		85	38	0	
							Bedding = 42 degrees.
340		Soft, red-brown, clay gouge recovered at the very top of the core (approx. 3 cm thick).					

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 15 of 21

Project Number: 49-97D | Borehole Number: BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		No recovery.		86	0	0	
	16			87	15	0	
		Breccia and Sandstone fragments (loose sample).					
345	15			88	10	0	
		Sandstone; hard, gray, massive.					
350		Sandstone, as above.		89	14	0	
		Sandstone; hard, dark gray, massive fine grained.		90	36	0	
355				91	100	0	
360		Sandstone, as above.		92	74	62	Bedding = 36 degrees. Bedding = 40 degrees. Bedding = 38 degrees.
	-4			93	0	0	
		No recovery from 364' to 372'.					
365							

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	16 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
				94	0	0	
370				95	0	0	
	-12						
		Sandstone, hard, gray, massive.		96	20	0	
		Hard, greenish gray, massive coarse grained; abundant lithic clasts.		97	25	0	
375		Hard, dark gray-green, massive, medium-grained.					
	-17						
		Tectonic Breccia; medium soft, gray-green; in dark gray-green sandstone described in previous run. Partly matrix supported by gouge.		98	30	0	
		Tectonic Breccia; in hard dark brown, siltstone.		99	71	0	
380				100	100	10	
	-21						
		Siltstone; hard, dark brown, some contains fine sand; closely fractured with largest unbroken pieces approx. 3 cm long; contains calcite veinlets.					
	-24						
		Tectonic Breccia; soft to medium soft; in siltstone grading downward into hard dark gray-green, massive sandstone; most matrix supported by gouge, but locally clast supported (essentially shattered rock).		101	46	0	
385	-27						
		Sandstone; hard, dark gray-green, massive; contains veins of gouge suggesting that this is shattered rock with tectonic breccia.		102	87	0	
	-30						
390				103	100	26	

Project Name: BIGROCK MESA LANDSLIDE | Sheet: 17 of 21

Project Number: 49-97D | Borehole Number: BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Siltstone; hard, gray-green to dark gray-green, bioturbated; contains possible recrystallized small shell fragments (< 10 mm long); has a mottled appearance. Grading downward into uniform siltstone.		104	100	26	
		Siltstone, as above; relatively intact with gouge appearing in a vein approx. 2 cm thick near base of core.		105	100	25	Fault = 60 degrees. (Gouge)
		Medium soft, gray-green gouge.		106	100	40	
395		Siltstone, as above, shattered.					
	-37						Fault = 30 degrees. (Gouge)
		Tectonic Breccia; med. soft, greenish-brown, matrix supported with gouge; contains siltstone fragments.		107	45	0	
	-39			108	100	0	
		Sandstone; hard, gray-green, medium to coarse grained.		109	93	0	
400				110	93	0	
	-41			111	93	0	
		Tectonic Breccias in run 107.		112	93	0	
				113	93	0	
	-43			114	93	0	
		Basalt; hard, black aphyric, ferromagnetic; contains plagioclase microphenocrysts; contact not observed.		115	93	0	
				116	93	0	
				117	16	0	
405							
				118	16	0	
	-48			119	16	0	
		Sandstone; hard, dark gray-green, massive, medium-grained.		120	6	0	
410							
		Sandstone, as above, with a small amount of tectonic breccia/gouge at base of core.		121	39	0	
415	-55						

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	18 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Tectonic Breccia; med. soft, gray-green, much of it is matrix supported with gouge.		122	64	0	
420		Tectonic Breccia, as above; matrix supported with gouge; some slickensided shale fragments near base with sandstone fragments below.		123	48	0	
	-64						
		Sandstone, hard, gray-green, massive.		124	17	0	Bedding = 40 degrees.
425							
	-69						
430		Tectonic Breccia, as in run 123; in fine sandstone; in part matrix supported with gouge.		125	31	0	
		Tectonic Breccia, as above, except mostly matrix supported with gouge.		126	50	0	
435				127	8	0	
		Tectonic Breccia, as in run 125; fragments are laminated fine sandstone.					Bedding = 38 degrees.
				128	38	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	19 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
440				129	38	0	
	-82						
		Siltstone; hard, dark gray, massive.		130	27	0	
				131	27	0	
445	-85						
		Tectonic Breccia, as above, containing some shattered fragments locally.		132	27	0	
				133	10	0	
				134	10	0	
				135	10	0	
				136	20	0	
450				137	20	0	
				138	20	0	
				139	20	0	
				140	20	0	
	-94						
		Silt, very soft (unlithified), massive, gray-green; hardens into soft siltstone downward with gouge present.		141	42	0	
455				142	42	0	
	-97						
		Tectonic Breccia, mainly clast supported, but with gouge present.		143	42	0	
				144	42	0	
	-99						
		Siltstone, hard, dark gray-green, locally laminated; shattered but cohesive; some gouge near top.		145	42	0	
460				146	90	0	
	-101						Bedding = 46 degrees.
		Tectonic Breccia in siltstone, mostly clast supported.		147	52	0	Bedding = 52 degrees.
				148	52	0	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	20 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
465	-105	Siltstone, hard, dark gray, massive; has subtle distorted bedding; pyritic, siliceous (?) veinlets; overlain by a small amount of tectonic breccia.		149	100	0	
		Siltstone, as above.		150	100	0	
				151	100	0	
470							
				152	85	0	
		Siltstone, as above, increasingly brecciated downward.					
475				153	100	5	
		Siltstone, as above.					
480				154	100	25	
		Siltstone, as above.					
485							Fault = 45 degrees.
	-128	Tectonic Breccia, as above, in siltstone. Becomes increasingly matrix rich upward.		155	100	32	

Project Name:	BIGROCK MESA LANDSLIDE	Sheet:	21 of 21
Project Number:	49-97D	Borehole Number:	BYA-4

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
490							
	-134	Grades downward almost immediately into siltstone.		156	100	20	
495	-136	Siltstone, hard, dark gray, laminated; bedding looks somewhat disturbed.					Bedding = 50 degrees. Bedding = 48 degrees.
	-139	Pebble Conglomerate, hard, gray (mottled); matrix supported; clasts are clastic sedimentary rocks, matrix is medium to coarse lithic-rich sandstone.					Bedding = 56 degrees.
500	-141	Siltstone, hard, dark gray.					Bedding = 54 degrees.
		No Recovery.					
505	-145	Boring terminated at 505 Ft. (No recovery 500 to 505).					
510							

Project Name:	BIG ROCK MESA	Sheet: 1 of 14	
Project Number:	49-97D	Borehole Number:	BYA-5
Location:	ROCKPORT WAY, MALIBU, CALIFORNIA		
Type of Drill Rig:	ROTARY WASH	Driller:	LAYNE
Bit Size:	2"	Drilling Fluid:	EZ-MUD
Inclination/Direction:	-90.0 / ------	Surface Elevation:	185' ±
Logged By:	SPC/JLH/JLA	Start: 16 JAN 91	End: 2 FEB 91

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
0		Not Cored 0-10', no recovery.					
10	175	SESPE FORMATION: Sandstone; Olive brown, medium hard to medium soft, massive, Medium grained, subvertically fractured, oxidized along fracture.		1	98	26	Subvertically fractured.
15	170	Siltstone: Reddish brown, medium soft, fine grained, massive, clayey, fracture size to 1", old slickensides.		2	88	24	Longitudinally fractured. Slickensides.

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Figure - 1

Project Name:	BIG ROCK MESA	Sheet:	2 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
20	165	Diabase: dark olive brown to black, hard. Calcite veins, small pyrite crystals, feldspars weathered to clay minerals but relatively fresh locally.		3	90	72	Highly sheared.
25				4	82	74	
				5	83	69	
30		Clasts of sandstone, brown to dark brown, hard, massive, coarse grained, old slickensides. Highly sheared and brecciated.					
		Clasts of sandstone, as above. Locally fractured, fracture size to 1".		6	76	42	
35				7	65	50	
40	145	Sandstone and Conglomerate: Medium hard to hard, light greenish tan to red-brown, medium to coarse-grained, thick-bedded.		8	82	62	
		Sandstone is fine grained to silty locally;					
		Conglomerate contains gravel to pebble-sized clasts of durable granitic and		9	77	58	

Project Name:	BIG ROCK MESA	Sheet:	3 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
45		metasedimentary lithologies; only pebbles recovered in some runs suggesting soft clay matrix locally; beds are 3-5 feet thick. Differentially oxidized along fractures.					
		Sandstone as above. Soft and Friable, Highly weathered.		10	63	46	
50				11	75	33	
55		Sandstone: Light brown to medium brown, coarse grained, fracture size to 3". Grades finer at 60'. Highly weathered and friable.		12	83	25	Longitudinally fractured.
60		Sandstone as above.		13	90	66	
65		Sandstone as above, fine to medium grained, highly oxidized along fractures with occasional white calcite.		14	92	58	
				15	84	59	

Project Name:	BIG ROCK MESA	Sheet:	4 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
70		Sandstone: Light brown-pink, fine to medium grained with occasional pebbles. Small percentage of coarse grained sand.		16	70	30	Fracture = 30 degrees.
		Grades: Medium brown-red and friable at 72 feet.					
		Grades are brownish red, becomes very friable at 73 feet. Grades, Medium brown-red and becomes medium coarse grained; well indurated.		17	70	30	
75		Becomes friable again @ 76					
	108	Conglomerate: olive green-red hard metasedimentary rock 2-3" long clasts.					
		Only clast recovered suggesting soft soil matrix.		18	20	0	
80		Conglomerate as above.					
85	100	Sandstone: Tan Yellow, coarse grained, moderately cemented with gravel size clasts. Fractured zone of contact between the tan sandstone and a dark brown-red, fine-medium grained sandstone. Silty material at the contact.		19	70	25	
		Highly fractured zone of light brown coarse grained sandstone.					
90	95	Conglomerate: Clasts metamorphic.		20	20	0	
		Minor amounts of a pink clayey matrix.					
	82	Sandstone: Dark-brown to red fine grained.		21	70	10	

Project Name:	BIG ROCK MESA	Sheet:	5 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
95		Cobble sized clasts.		22	20	0	
		Sandstone: Tan to green, fine to medium grained, relatively friable.		23	30	20	
		Grades finer and become very friable.		24	70	60	
		Highly fractured.					
100		Sandstone: brown-red, fine grained, will cemented, Including occasional pebbles. Fracture spacing 2-4"		25	100	90	
	82						
		Conglomerate: Gravel sized clasts embedded in a tan-pink clayey matrix.					
105				26	80	70	
	79						
		Sandstone: Light brown-red, fine to medium grained occasional pebbles.					
		Pebble to Cobble sized clasts.					
110		Mixture of sandstone and clay.		27	90	80	
		Sandstone: Light brown-pink fine-medium grained. Contains occasional pebbles. Highly fractured zone.					Bedding = 27-28 degrees.
							Fractures = 3 degrees. (4"-6" spacing)
115		Sandstone: Dark brown-red, fine grained, very friable, with gravel size clasts.		28	50	45	
		Sandstone: tan - light green coarse grained, highly fractured, with pebble sized clasts.					

Project Name:	BIG ROCK MESA	Sheet:	6 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
120		Same as above, Fracturing decreases below 125'.		29	50	33	
		Becomes lighter in color and well cemented.		30	70	65	
125		Sandstone, well cemented, brown-red, fine grained.					
		Pebble sized clasts.		31	90	85	
130		1" thick clayey gouge zone.					Fault = 30 degrees.
		Grades to light green, medium coarse grained, will inturbated. Fracture spacing 2-4".		32	80	70	
135							
		Light green sandstone, same as above, Fracture spacing increases to 4-6".		33	100	92	
140							

Project Name:	BIG ROCK MESA	Sheet:	7 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
145		Grades to brown-gray sandstone.		34	100	90	
		Becomes Friable.					
150		Grades to dark brown-red, fine grained.		35	90	82	Fracture = 30 degrees. (Spacing 4"-6")
		Grades coarser.					Fracture = Subhorizontal (Spacing 2"-4")
155		Grades to light green to tan sandstone, medium to coarse grained.		36	90	88	
		Cobble to pebble sized clasts.					
160		Grades to brown, fine to medium grained, very friable, Highly fractured zone to 162'		37	100	91	
		Gray, medium to coarse grained, shear striations.					
165		Becomes dark brown-red.		38	96	85	
		Becomes very friable.					

Project Name:	BIG ROCK MESA	Sheet:	8 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
170		Becomes very moist, dark brown-red, fine to medium grained, very friable. Distorted/cruched/sheared, from 170'-180'.		39	80	72	Possible slip surface zone to 188'.
		Grades to gray, medium grained sandstone, highly fractured.					
175		Brown-red, medium grained, very moist to wet, very friable.		40	90	85	
		Gray-brown, medium grained, well indurated sandstone.					
		Dark brown-red, medium grained, friable.					
180		More intact.		41	100	92	
							Bedding = 63 degrees.
185		Alternate layers of dark brown-red, fine grained, Sandstone; friable and gray medium to coarse grained, indurated.		42	95	89	
							Shears = 24-33 degrees.
190		Sandstone as above.		43	90	88	

Project Name:	BIG ROCK MESA	Sheet:	9 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Highly fractured zone between 194-195'					
195				44	80	72	Highly fractured.
		Soft gray-green, Gouge, Shear zone at 198.5 to 200.00.					Possible Basal Rupture Surface.
200		Hard, light greenish gray, pebbly, coarse Sandstone.					
205		Soft to medium soft, red-brown.					
		Poorly indurated.					
	-24						
210		Tectonic Breccia: Medium hard, greenish black, basaltic pervasively shattered basalt; ferromagnetic.		45	50	40	
	-26	**VAQUEROS FORMATION:**					
		Sandstone and Siltstone, interlayed, Sandstone: Medium soft to medium hard, gray-green, pebble clasts. Siltstone: Red-brown, clayey bioturbated (?).					
215				46	90	86	
				47	90	88	

Project Name:	BIG ROCK MESA	Sheet:	10 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
220		Oxidized above/Unoxidized below		48	100	96	
		Sandstone and Siltstone as above.		49	20	0	
225				50	100	100	
	-43	Claystone: Silty, dark brown (mottled), medium hard, contains abundant irregular pebble-sized clasts of gray fine sandstone.					
230	-46	Siltstone: Dark gray-brown, medium hard, pervasively shattered and sheared; possibly bioturbated; contains many calcite veins.		51	90	80	Shear = 30 degrees.
				52	90	83	
235		Highly disturbed, shattered, and mixed soil zone.					Shear = 30 degrees.
		Grades to green, with white clast inclusion and calcite veins.		53	80	76	
		Gouge Zones 238'-240'.					
240		Irregular clasts of sandstone less than 2" in diameter.					

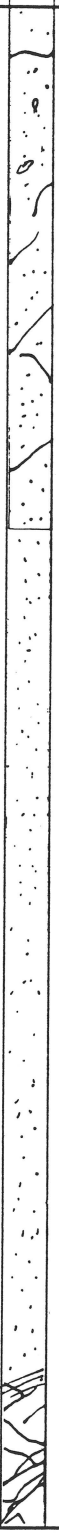
Project Name:	BIG ROCK MESA	Sheet:	11 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Grades to gray, well cemented siltstone, calcite infilling.					
245				54	80	75	
		Gouge zone 247.5'- 250'.					
250		Sandstone: Gray, fine grained, highly cemented, fracturing infilled with calcite.					
		Gouge Zone 253'-254'.		55	90	88	Fracture = 30 degrees.
255		Shattered		56	100	90	
		Sandstone as above.					Shear = 30 degrees.
		Gouge Zone 259'-261'.					
260				57	50	35	
				58	70	48	Shear = 30 degrees.
265		Gray to greenish-gray, medium hard to hard, medium to locally fine-grained, massive to locally pebbly, sandstone; numerous old tight fractures; bioturbated; occasional thin calcite veins.		59	80	72	

Project Name:	BIG ROCK MESA	Sheet:	12 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
		Fossils 268'-269', gastropods.					
270		Gray, fine grained sandstone, frequent fracturing.					Fracturing = 30 degrees. (1"-3" spacing)
				60	70	62	
275		Light gray, fine to medium grained sandstone, well cemented.					
		Sandstone as above.		61	70	66	
280							
		Sandstone as above.					
285							
		Light gray, well cemented sandstone, poorly sorted.					
		Small gouge zone (25").		62	70	51	Shear = 30 degrees.
290				63	50	38	

Project Name:	BIG ROCK MESA	Sheet:	13 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
295		Light gray, well cemented sandstone, clasts of dark gray siltstone less than 1 inch in diameter.		64	50	43	
300		Sandstone, same as above.		65	50	34	
305		Grades darker for 2 feet.		66	70	65	
310		Gray, well cemented sandstone, poorly sorted.		67	50	33	
315		Highly fractured between 315'-331'.		68	50	28	Bedding = 15 degrees.
		Slickensides.					Shear = 63 degrees.

Project Name:	BIG ROCK MESA	Sheet:	14 of 14
Project Number:	49-97D	Borehole Number:	BYA-5

Depth (Feet)	Elevation (Feet)	Description/Lithology	Graphic Log	Run	Recovery (%)	RQD (%)	Structure/Remarks
	-132						
		Basatlt: Hard, dark brownish black, plagioclase poryphyritic; penetratively shattered; upper contact sheared with slickensides.					
320				69	50	40	
		Gouge Zone, Highly sheared, 1.0 thick		70	20	0	
				71	50	46	
		Highly fractured.		72	70	55	
				73	100	100	
325				74	80	72	
				75	80	79	
		Basalt, highly sheared, dark green to black.					
330							
		Basalt as above.					
				76	50	46	
	-149						
		Boring Terminated at 334'.					
335							
340							

APPENDIX D

Appendix D

LABORATORY TESTING PROGRAMS

I. Multi-Stage Consolidated Undrained Triaxial Tests (with Pore Water Pressure Measurement)

Multi-stage consolidated undrained triaxial tests were conducted on five undisturbed samples obtained from BYA's borings. Samples were trimmed to a height/diameter ratio of 2.0. Triaxial tests were performed on saturated samples by circulating de-aired water through the bottom to the top of sample. Skempton's B-value was then measured to ensure sample saturation. Potential friction at the end platen was minimized by inserting two lubricated 0.014" thick rubber disks between the sample and the surface of the platens. Pore water pressure was measured by closing the drainage valves and with a pressure transducer. Axial loads were measured by a load cell and the displacement was measured by a linear variable digital transducer (LVDT) in conjunction with a 16 bit high speed data acquisition system. A constant axial displacement of rate of 0.08%/min. was maintained throughout the tests.

The test procedures for multi-stage consolidated, undrained triaxial tests included the following steps:

1. Isotropically consolidate the sample.

2. Shear the sample and continuous monitor the pore water pressure change until no further increases in deviator (shear) stress.

3. Unload the sample.

4. Repeat the above steps by isotropically consolidating the sample to the next confining stress level and shearing.

Relevant characteristics of the samples and test results of multi-stage consolidated undrained triaxial tests are summarized in Table D-1 and Figure I-1 to I-10.

II. Direct Shear Tests

A number of direct shear tests were conducted on remolded sludgy samples of various formational units. Each sample was consolidated to or above the corresponding in situ overburden stress. Shear loads were measured by a 600 lb. capacity load cell and shear displacement by LVDT. Shearing rate was controlled by a servo-controlled system at about 0.05"/hr. Samples were then cyclically sheared for 4 cycles with total displacement of 2" for each normal stress to ensure that residual strength is reached and the previous fabric obliterated. Relevant characteristics of the samples and test results of direct shear tests are summarized in Table D-1 and Figures II-1 to II-6.

Additionally, test results of direct shear tests with 3 different chemical additives are also shown in Figures II-7 to II-10.

III. Ring Shear Tests

The obvious advantages of the ring shear tests are that there is no change in the cross sectional area of the shear plane as the test proceeds and that the sample can be sheared through an uninterrupted displacement of any magnitude. Thus, the shearing resistance can be investigated at large displacements.

In the ring shear tests, an assumption is made that the normal stress and shear stress are uniformly distributed across the plane of relative rotary motion. It is difficult to set an undisturbed specimen in a ring shear device, therefore ring shear tests were performed on remolded sludgy Sespe gouge samples. Samples were overconsolidated and sheared at different normal stress by applying a displacement rate of 0.084"/hr. (displacement of 3-in. for each normal stress). Two ring shear tests were performed on sludgy Sespe gouge material. Results of these tests are summarized in Table D-1.

IV. Unconfined Compression Tests (ASTM D-2938)

Unconfined compression tests were conducted on selected samples with or without fracture features (joints, shears, bedding planes, etc.). Sample ends were saw-cutted to a height/diameter ratio of at least 2.0. Axial load was measured by a 10, 20, 40 or 60 kips capacity load cell and a displacement rate of 1%/min. was maintained throughout the test. Relevant characteristics of the samples and test results of unconfined compression tests were summarized in Table D-2, Figures IV-1 to IV-2.

V. Brazilian Tensile Tests (ASTM D-3967-86)

Brazilian tensile strength tests were conducted on BYA samples with or without fracture features (joints, shears, bedding planes, etc.). Sample ends were saw-cutted to height/diameter ratio of about 1.0. Splitting load was measured by a 1000, 2000 or 5000 lb. capacity load cell and the displacement rate was controlled at about 1%/min. Relevant characteristics of the samples and test results are summarized in Table D-2 and Figures V-1 to V-2.

VI. Atterberg Limits (ASTM D-4318)

Atterberg limits of gouge materials for individual formations (Sespe, Basalt, Topanga and Vaqueros) were performed according to ASTM D-4318. The results are summarized in Table D-3.

VII. Energy Dispersive Spectroscopy (EDS) and Scanning Electron Microscope (SEM)

Energy dispersive x-ray spectroscopy analyses were made on Sespe gouge materials taken from the Southeast Region. EDS results are shown in Figure VII-1 revealing the elemental composition of: Si, Al, Na, Cl, Fe, Mg, K and Ca.

A Scanning Electron Microscope (SEM) examination of selected Sespe gouge materials was performed. The results are shown in Figure VII-2 and VII-3. The clay platelets are clearly visible in SEM photo when the magnification is at 5000X.

TABLE D-1

SUMMARY OF TRIAXIAL AND DIRECT SHEAR TEST RESULTS

I. CONSOLIDATED, UNDRAINED TRIAXIAL TEST (With Pore Water Pressure Measurement)

SAMPLE LOCATION	SAMPLE DEPTH (Ft.)	FORMATION/ ROCK TYPE	LL (%)	PL (%)	DRY DENSITY d (pcf)	EFFECTIVE CONFINING STRESS (ksf)	COHESION c (psf)	FRICTION ANGLE, ϕ (Deg.)
BYA-1*	221.4	Basalt (g)	31	25	126.9	11.5/23.0/40.3	0	27.5
BYA-3*	109.3	Basalt (g)	33	27	130.5	5.8/11.5/23.0	1000	22.0
BYA-5*	319.0	Basalt (g)	50	29	141.9	11.5/23.0/34.6	700	26
BYA-2*	394.0	Sespe/SLS (g)	35	21	123.6	11.5/23.0/40.3	0	17
BYA-5*	210.0	Sespe/SLS (f)	27	24	119.4	11.5/23.0/41.8	1500	28

II. CONSOLIDATED DRAINED DIRECT SHEAR TESTS

SAMPLE LOCATION	SAMPLE DEPTH (Ft.)	FORMATION/ ROCK TYPE	LL (%)	PL (%)	DRY DENSITY d (pcf)	EFFECTIVE CONFINING STRESS (ksf)	COHESION c (psf)	FRICTION ANGLE, ϕ (Deg.)
BYA-5*	200.0	Basalt (g)	18	10	124	7.5/15/30	3000	26
BYA-5*	148.0	Sespe/SLS (f)	42	15	119	5/10/20	500	27
BRM-5	60.0	Sespe/SLS (f)	31	22	121	1.3/3.8/5.0/10.0/20	0	29
CTNL *	* *	Sespe/SLS (g)	35	24	119	5/10/20	0	18
BYA-3*	86	Topanga/S	Non-Plastic		118	5/10/20	100	40
BYA-4*	108	Topanga/S	Non-Plastic		118	5/10/20	0	38

TABLE D-1 (Page 2)

SUMMARY OF TRIAXIAL AND DIRECT SHEAR TEST RESULTS

III. CONSOLIDATED DRAINED DIRECT SHEAR TEST ** (with Chemical Additive)

SAMPLE LOCATION	CHEMICAL ADDITIVE	FORMATION/ ROCK TYPE	LL (%)	PL (%)	DRY DENSITY d (pcf)	EFFECTIVE NORMAL CONFINING STRESS (ksf)	COHESION c (psf)	FRICTION ANGLE, ϕ (Deg.)
CTNL *	None	Sespe/SLS (g)	35	24	119	5/10/20	0	18
CTNL 1*	2% Al (NO)	Sespe/SLS (g)	- -	- -	125	5/10/20	1300	19
CTNL 2*	2% Na SiO	Sespe/SLS (g)	- -	- -	122	5/10/20	3200	11
CTNL 3*	2% KF	Sespe/SLS (g)	- -	- -	114	5/10/20	2500	21

IV. RING SHEAR TEST

TEST SERIES NUMBER	SAMPLE FORMATION	LL (%)	PL (%)	DRY DENSITY d (pcf)	EFF. NORMAL STRESS (ksf)	COHESION C (psf)	RESIDUAL FRICTION ANGLE, ϕ (Deg.)
1	Sespe (g)	51	25	114	2.4/5/ 10.3/20.5	320	10
2	Sespe (g)	51	25	115	4.2/8.25/ 16.4	0	10

TABLE D-1 (Page 3)

SUMMARY OF TRIAXIAL AND DIRECT SHEAR TEST RESULTS

NOTES: * = Multi-stage consolidation shear test

** = Sample was taken from 800 ft. west of intersection of Big Rock Drive and PCH, base of slope along PCH (eastern region of main slide).

SLS = Siltstone

S = Sand

(g) = Gouge material

(f) = Sample contains fracture features (joints, shears, bedding planes, etc.)

LL = Liquid limit

PL = Plastic limit

CNTL = Samples from the Southeast Region

TABLE D-2

SUMMARY OF BRAZILIAN TENSILE AND UNCONFINED COMPRESSION TESTS

BORING NO.	SAMPLE DEPTH (Ft.)	ROCK TYPE (FORMATION)	BRAZILIAN TENSILE TEST* DENSITY γ_t, pcf	σ_t psi	SAMPLE CONDITION	UNCONFINED COMPRESSION TEST* DENSITY γ_t, pcf	σ_{uc} psi	SAMPLE CONDITION	σ_{uc}/σ_t
BYA-1	103	SLS (Ts)	141	86	F	144	2672	I	31
	130	SLS (Ts)	146	99	F	153	2727	I	28
	144	SLS (Ts)	157	925	I	156	12460	I	14
	162	SS (Ts)	138	329	I	137	4680	I	14
	203	SS (Ts)	150	550	I	152	2086	I	4
	505	SS (Ts)	144	42	F	- -	- -	- -	- -
BYA-2	36	SS (Tt)	142	494	I	144	5732	I	12
	50	SS (Tt)	145	150	I	147	5373	I	36
	120	SS (Tt)	142	282	I	145	4115	I	15
	155	SS (Tt)	148	457	I	146	3550	I	8
	200	BS	157	177	F	156	895	F	5
	267	BS	151	310	I	- -	- -	- -	- -
	383	SLS (Ts)	141	20	F	- -	- -	- -	- -
	398	SS (Ts)	155	228	I	- -	- -	- -	- -
	400	SLS (Ts)	139	61	F	141	125	F	2
	429	SS (Ts)	137	53	F	135	398	F	8
	443	SS (Ts)	141	72	F	138	392	F	5
	465	SS (Ts)	148	156	I	156	1433	I	9
	475	SLS (Ts)	149	253	I	151	2829	I	11
BYA-3	20	SS (Tt)	119	2	L	121	62	L	31
	70	SS (Tt)	140	190	I	140	2819	I	15
	151	SS (Tt)	141	79	I	145	2377	I	30
	153	SS (Tt)	143	35	F	144	852	F	24
	175	SS (Tt)	146	258	I	145	4806	I	19

TABLE D-2
SUMMARY OF BRAZILIAN TENSILE AND UNCONFINED COMPRESSION TESTS
(Cont'd)

BORING NO.	SAMPLE DEPTH (Ft.)	ROCK TYPE (FORMATION)	BRAZILIAN TENSILE TEST			UNCONFINED COMPRESSION TEST*			
			DENSITY γ_t, pcf	σ_t psi	SAMPLE CONDITION	DENSITY γ_t pcf	σ_{uc} psi	SAMPLE CONDITION	σ_{uc}/σ_t
BYA-3	260	SS (Ts)	139	30	J	- -	- -	- -	- -
	265	SS (Ts)	146	170	I	148	3889	I	23
	285	SS (Ts)	155	338	I	150	3268	I	10
	300	SS (Ts)	- -	- -	- -	151	2290	I	- -
	310	SS (Ts)	157	152	I	145	1355	I	9
	325	SLS (Ts)	136	34	F	144	282	F	8
	359	SLS (Ts)	150	350	I	- -	- -	- -	- -
	415	SLS (Ts)	159	628	I	160	5844	I	9
	460	SS (Ts)	- -	- -	- -	137	142	F	- -
	500	Diabase	151	124	I	- -	- -	- -	- -
BYA-4	30	SS (Tt)	145	120	I	145	2525	I	21
	58	SS (Tt)	143	344	J	145	1889	I	6
	90	SS (Tt)	149	205	I	151	4609	I	23
	150	SLS (Tt)	139	113	I	- -	- -	I	23
	175	SLS (Tt)	147	299	I	148	3238	I	11
	231	BS	163	523	I	163	821	F	2
	260	BS	- -	- -	- -	161	3395	I	- -
	366	SS (Ts)	147	409	I	150	3016	I	7
	394	SLS (Ts)	- -	- -	- -	134	293	F	- -
BYA-5	110	SS (Ts)	141	34	F	148	500	I	15
	134	SS (Ts)	144	20	F	149	396	F	20
	149	SS (Ts)	147	115	I	146	929	I	8
	185	SS (Ts)	148	19	F	- -	- -	- -	- -
	188	SS (Ts)	138	7	F	- -	- -	- -	- -
	190	SS (Ts)	126	9	F	133	79	F	9

TABLE D-2

SUMMARY OF BRAZILIAN TENSILE AND UNCONFINED COMPRESSION TESTS

(Cont'd)

BORING NO.	SAMPLE DEPTH (Ft.)	ROCK TYPE (FORMATION)	BRAZILIAN TENSILE TEST* DENSITY γ_t, pcf	σ_t psi	SAMPLE CONDITION	UNCONFINED COMPRESSION TEST* DENSITY γ_t, pcf	σ_{uc} psi	SAMPLE CONDITION	σ_{uc}/σ_t
BYA-5	200	SS (Ts)	122	11	F	142	65	F	6
	215	SS (Tv)	133	9	F	138	106	F	12
	230	CLS (Tv)	145	80	F	147	387	F	5
	231	CLS (Tv)	145	67	F	149	381	F	6
	245	SLS (Tv)	150	33	F	150	99	F	3
	265	SS (Ts)	- -	- -	- -	149	336	F	- -
	287	SLS (Ts)	155	629	I	- -	- -	- -	- -
	314	SLS (Ts)	153	366	I	158	5290	I	20
	320	BS	- -	- -	- -	148	100	F	- -
	321	BS	164	28	F	154	87	F	3
	443	SS (Ts)	140	45	F	146	304	F	7

NOTES:

* : Strain Ration = 1%/Min.

I : Sample without fracture features (joints, shears, bedding planes, etc.)
F : Sample with fracture features (joints, shears, bedding planes, etc.)
L : Loose Sample

SS : Sandstone
SLS : Siltstone
CLS : Claystone
BS : Basalt
Ts : Sespe Formation
Tt : Topanga Formation
Tv : Vaqueros Formation
σ_t : Tensile strength
σ_{uc} : Unconfined Compressive Strength

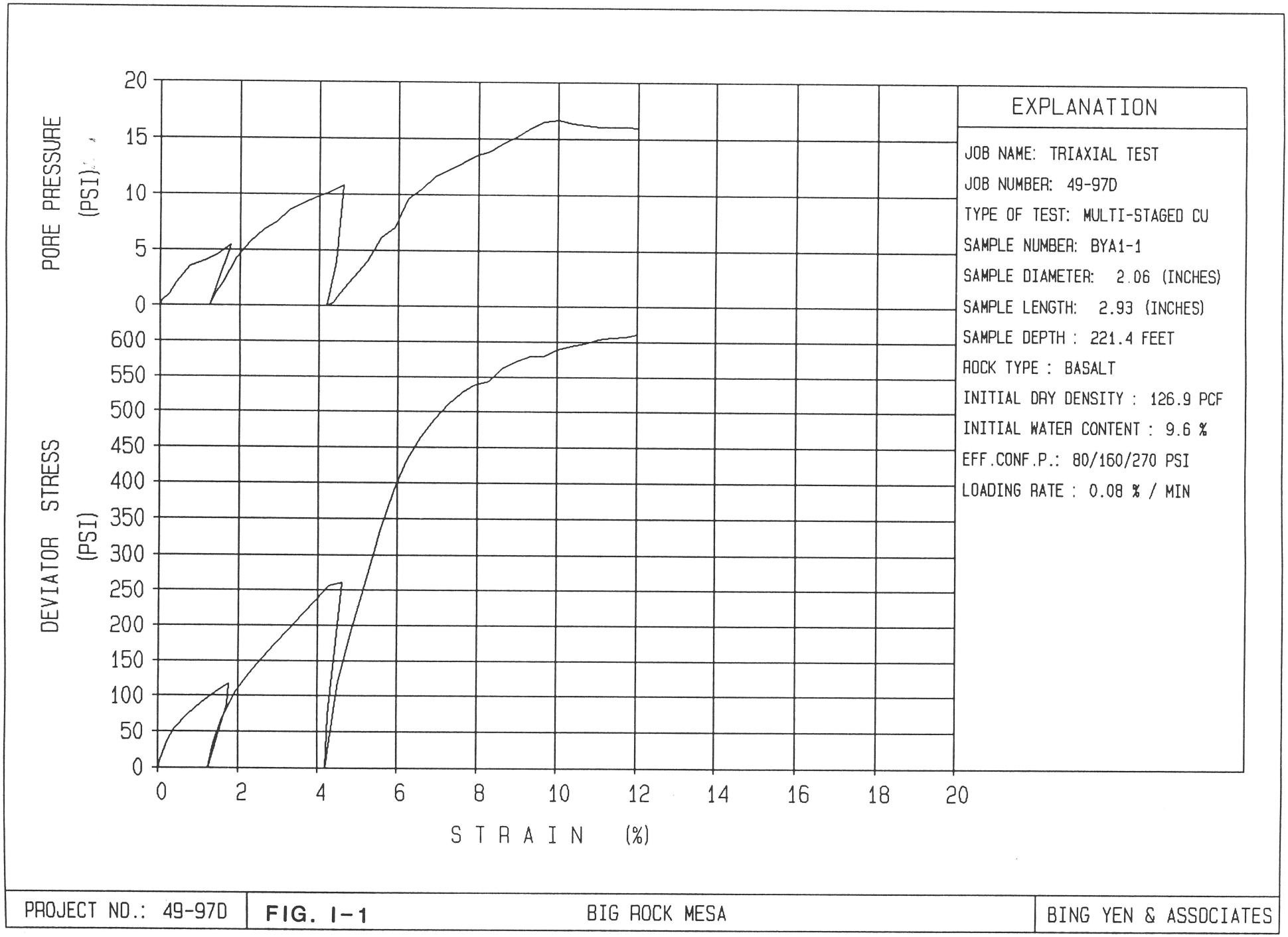
TABLE D-3
SUMMARY OF ATTERBERG LIMITS OF GOUGE MATERIALS

FORMATION	LOCATION	SAMPLE DEPTH (Ft.)	ATTERBERG LIMITS (%) LL	PL	PI
Sespe	BYA-2	394	40	12	28
	BYA-2'	394	35	21	14
	BYA-4	337	47	11	36
	BYA-4	325	24	15	9
	BYA-5	148	42	15	27
	CNTL	* *	35	24	11
	AVERAGE	- -	36	17	19
Basalt	BYA-1	221	31	25	6
	BYA-3	104	36	29	7
	BYA-3	109	33	27	6
	BYA-3	195	21	9	12
	BYA-4	195.2	31	22	9
	BYA-4	284	29	11	18
	BYA-5	200	18	10	8
	BYA-5	319	50	29	21
	AVERAGE	- -	31	20	11
Topanga	BYA-3*	146	41	27	14
	BYA-4*	154	39	10	29
	AVERAGE	- -	40	19	21
Vaqueros	BYA-5*	221	41	22	19

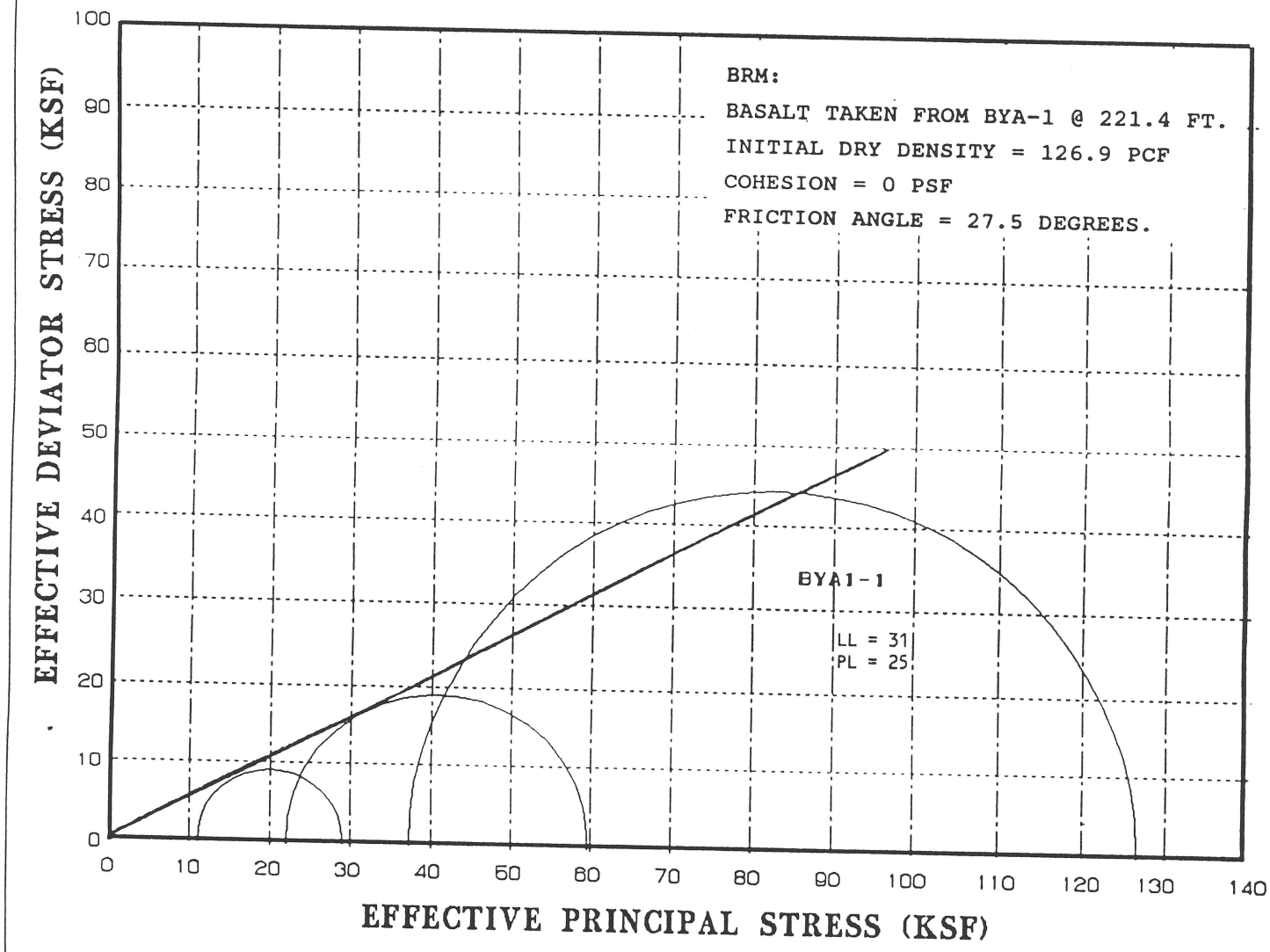
NOTES:

* = Clayey sample
** = Sample was taken from Southeast Region
CNTL = Surficial samples
LL = Liquid limit
PL = Plastic limit
PI = Plasticity index

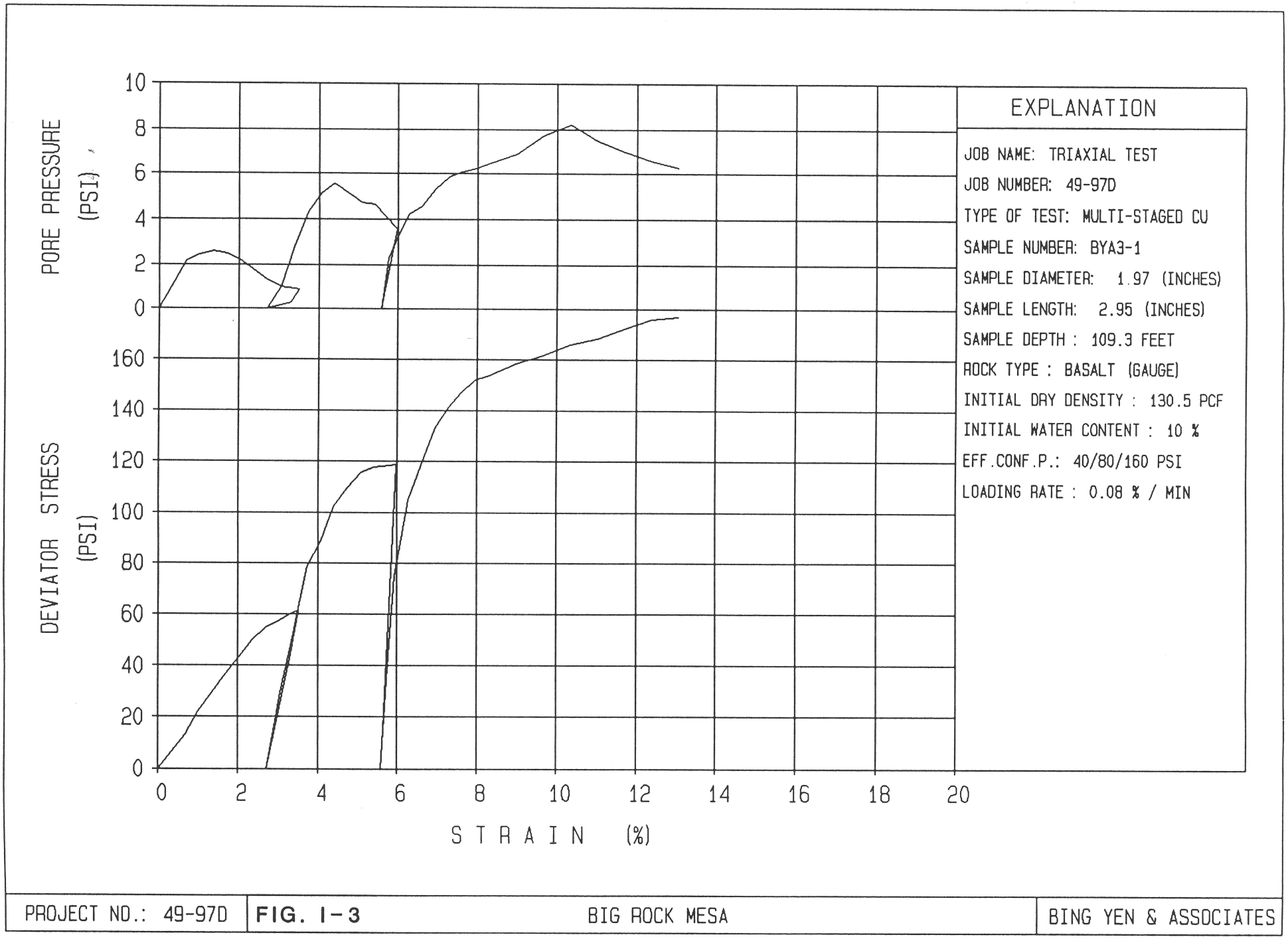
(I) Consolidated undrained Triaxial Tests
(with pore water pressure measurement)



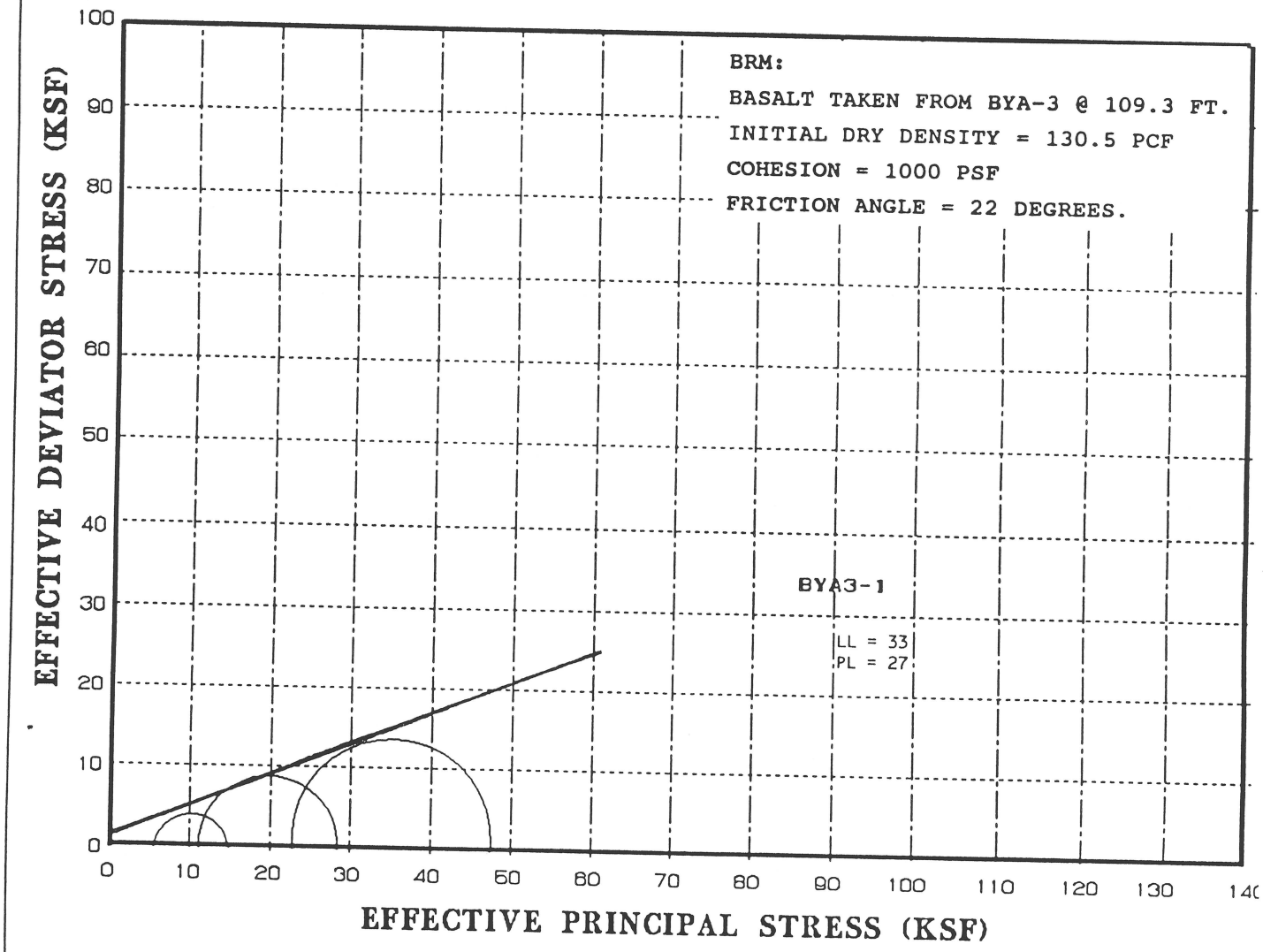
PROJECT NO.: 49-97D	**FIG. 1-1**	BIG ROCK MESA	BING YEN & ASSOCIATES



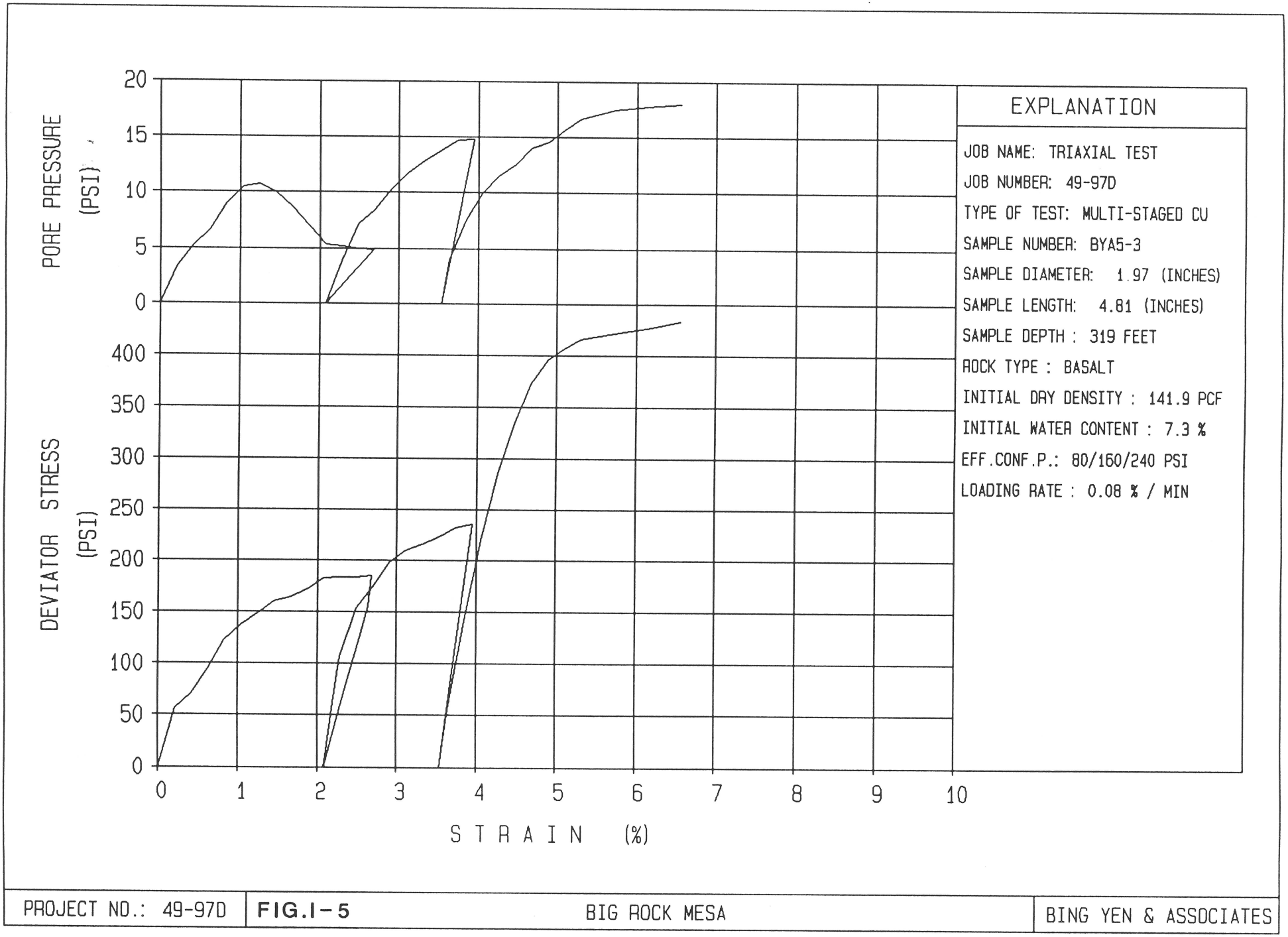
PROJECT #: 49-97D	FIG. 1-2 BIG ROCK MESA - CU TRIAXIAL TEST RESULTS	BING YEN AND ASSOCIATES



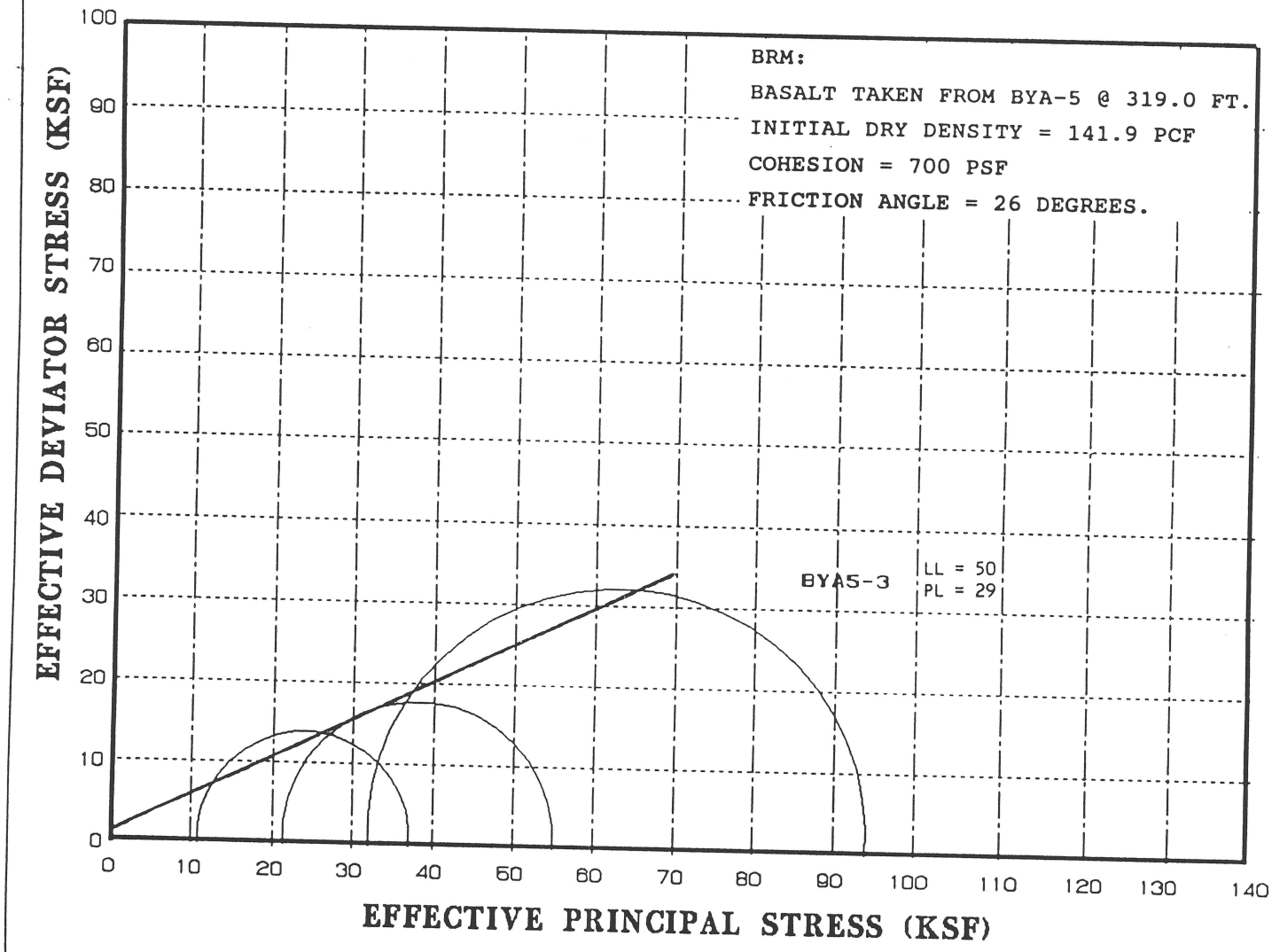
PROJECT NO.: 49-97D	**FIG. I-3**	BIG ROCK MESA	BING YEN & ASSOCIATES



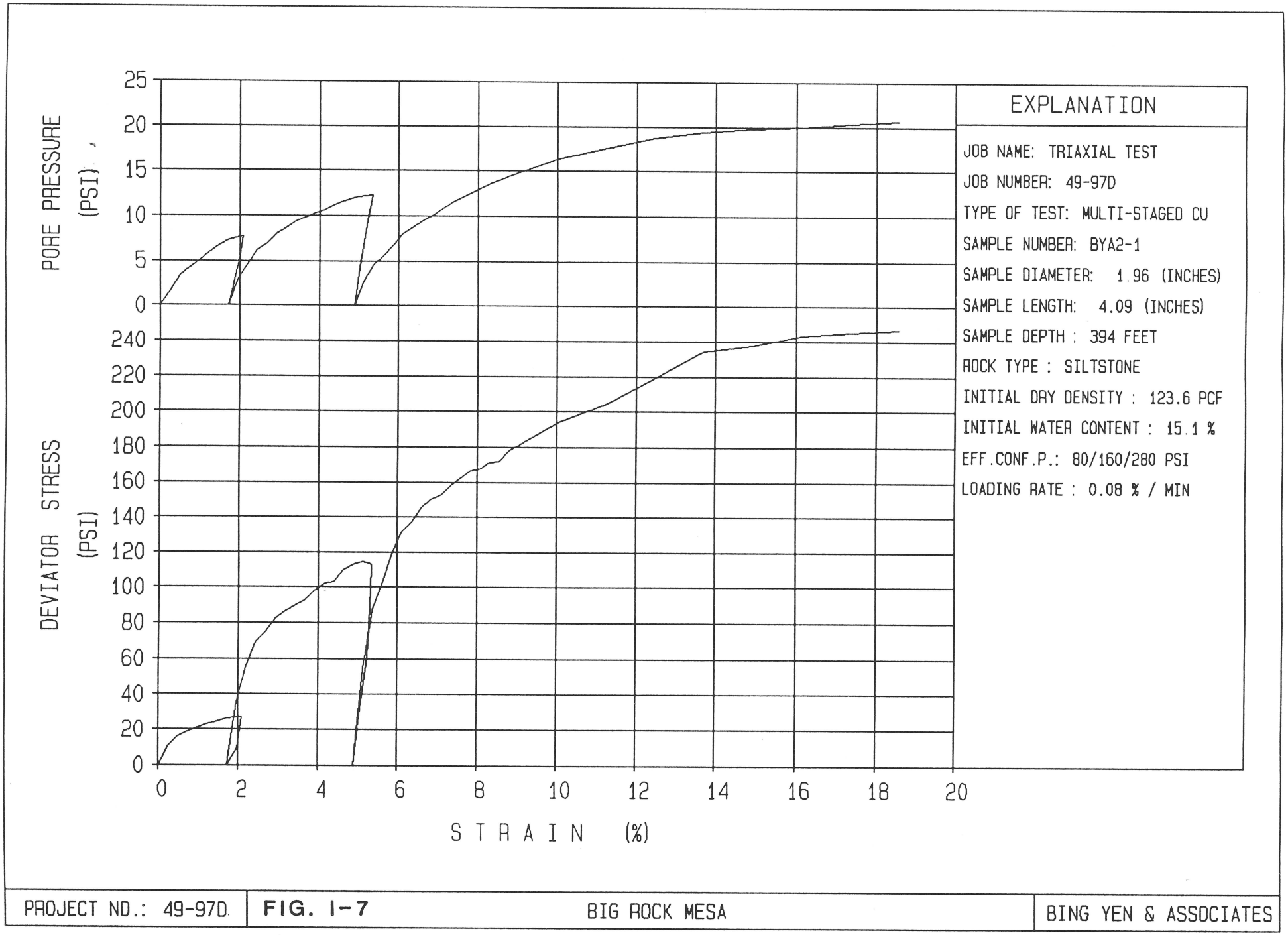
PROJECT #: 49-97D	FIG. 1-4 BIG ROCK MESA - CU TRIAXIAL TEST RESULTS	BING YEN AND ASSOCIATES



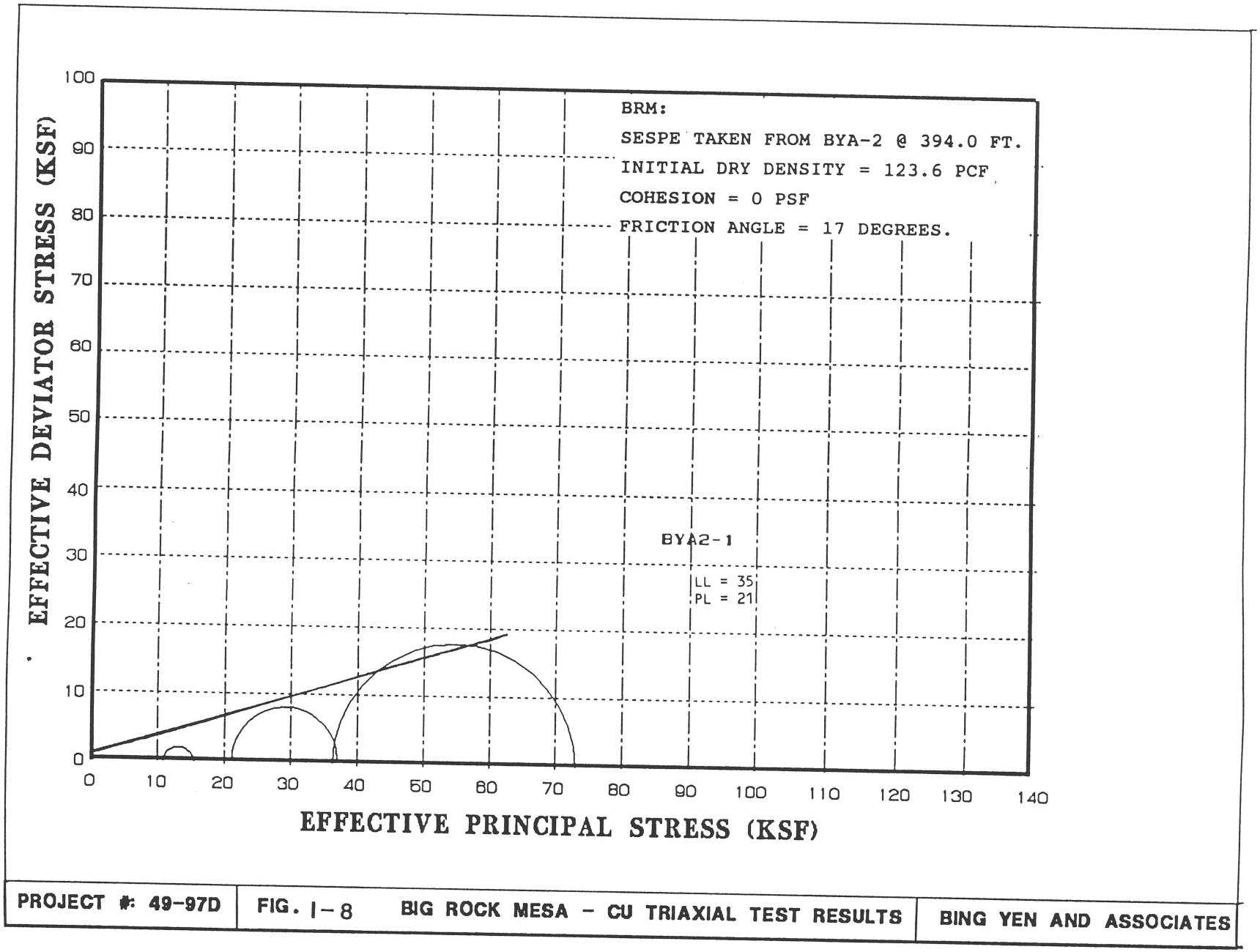
PROJECT NO.: 49-97D	**FIG.I-5**	BIG ROCK MESA	BING YEN & ASSOCIATES



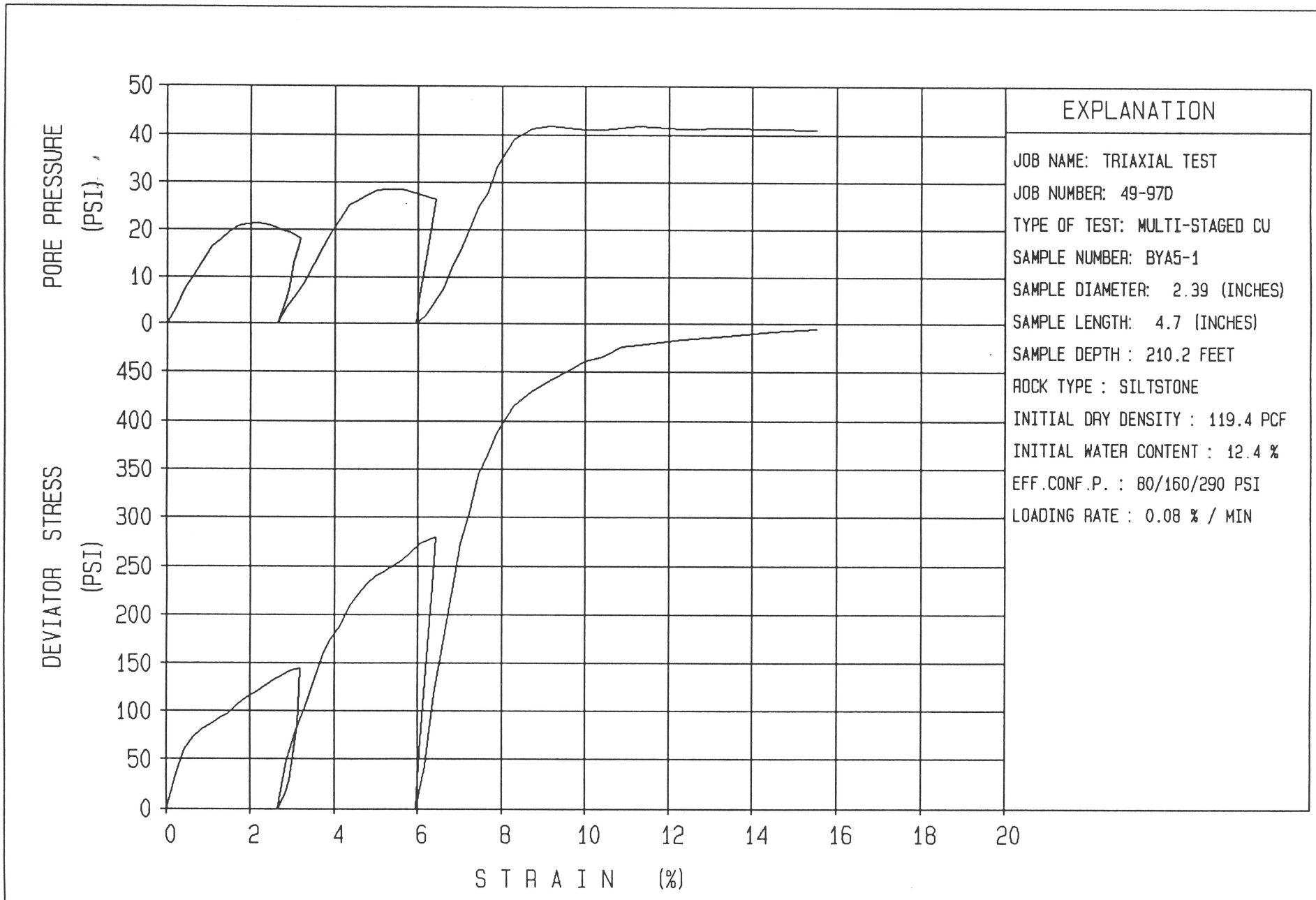
PROJECT #: 49-97D	FIG. 1-6 BIG ROCK MESA - CU TRIAXIAL TEST RESULTS	BING YEN AND ASSOCIATES



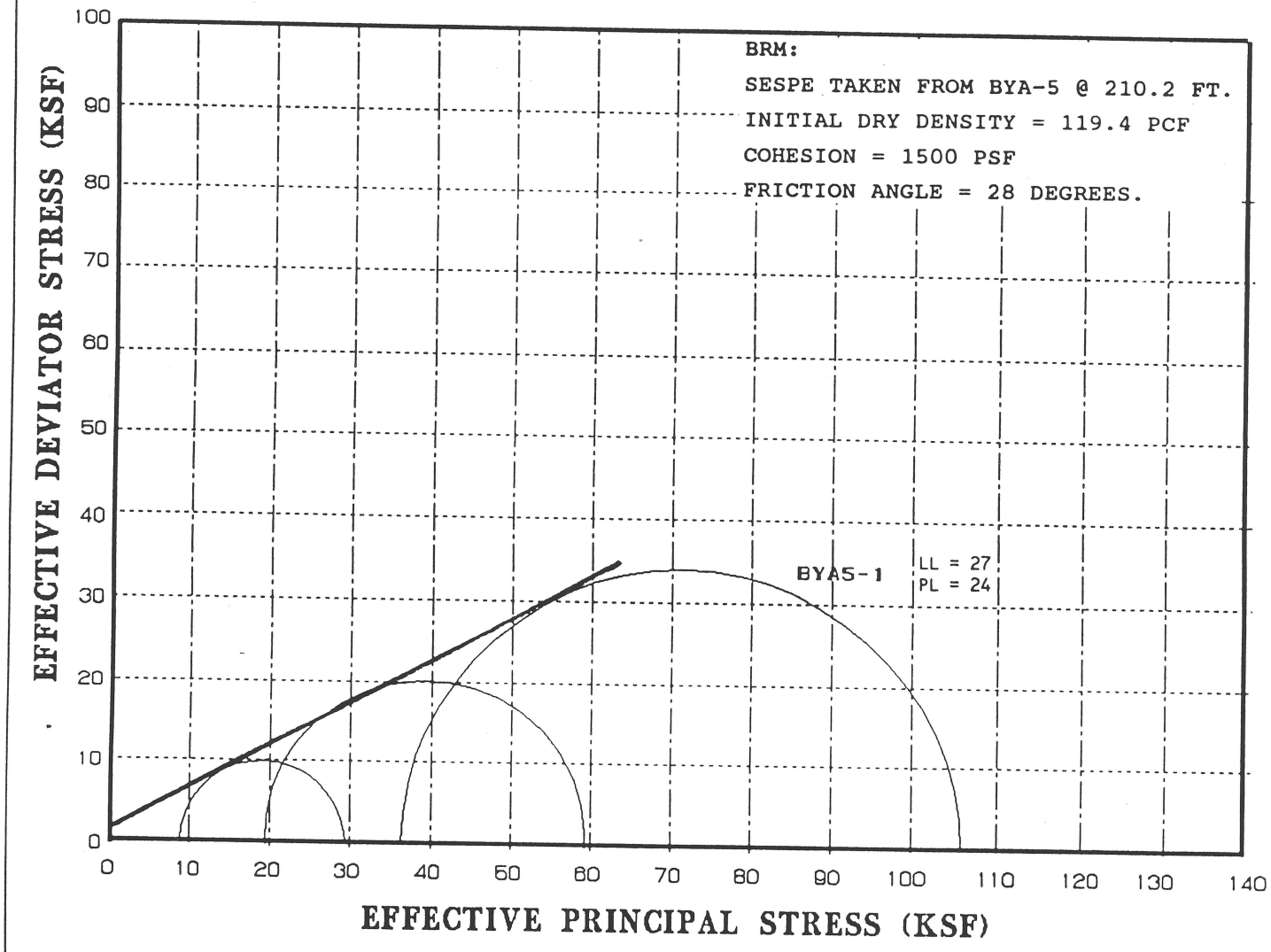
PROJECT NO.: 49-97D	**FIG. I-7**	BIG ROCK MESA	BING YEN & ASSOCIATES



PROJECT #: 49-97D	FIG. I-8 BIG ROCK MESA - CU TRIAXIAL TEST RESULTS	BING YEN AND ASSOCIATES



PROJECT NO.: 49-97D	**FIG. I-9**	BIG ROCK MESA	BING YEN & ASSOCIATES



PROJECT #: 49-97D	FIG. I-10 BIG ROCK MESA - CU TRIAXIAL TEST RESULTS	BING YEN AND ASSOCIATES

(II) Consolidated Drained Direct Shear Tests

Malibu City Council
Regular Meeting Agenda

Monday, November 25, 1996

Hughes Research Laboratories
3011 Malibu Canyon Road

6:00 P.M. - CLOSED SESSION, Auditorium
6:30 P.M. - REGULAR CITY COUNCIL MEETING, Auditorium

Six p.m. **Closed Session**

Existing litigation per Government Code Section 54956.9 (a):

1. Cariker v. City of Malibu, Los Angeles County Superior Court Case No. SC040986

2. Two Blankenship, Inc. v. City of Malibu, Los Angeles County Superior Court Case No. SC040948

Six thirty p.m. **Regular Session** Estimated Time

The times indicated are only estimated times to be used as a guideline to ensure that the Council allocates its time to complete all agenda items. They do not indicate the time when items will be heard by the Council. The agenda order is subject to change.

1. Call to Order - Mayor Harlow

2. Roll Call - Recording Secretary Pope

3. Pledge of Allegiance

4. Approval of Agenda

5. Closed Session Report - City Attorney Hogin

Presentations

6. Presentation of official City appreciation plaques to former Councilmembers and Mayors.

   Reference: Mayor Harlow

13. Approve scheduling a public workshop on the fire for December 17 at 6:30 p.m. at the Malibu Community Center on Point Dume.

Staff reference: Interim City Manager Lorimer

14. Approve participation in the Parental Resource Program sponsored by the Sheriff's Department Juvenile Intervention Team. The $3,000 program cost will be paid by COPS grant set aside funds (current balance $16,000) (no general funds).

Staff reference: Interim City Manager Lorimer

15. Adopt Resolution No. 96-083 appointing Peter Lippman as City Treasurer.

Staff reference: Interim City Manager Lorimer

16. Approve minutes of October 10, 1996 City Council meeting.

Staff reference: Deputy City Clerk Pope

17. Adopt Resolution No. 96-084 declaring the City Council's intent to initiate an amendment to the General Plan Housing Element.

Staff reference: Interim Planning Director Bertoni

18. Authorize the installation of additional speed limit signs, supplemental "radar use" and "speeding fine" signs and street painted speed limits on Point Dume streets. Set a public hearing date to discuss this matter for January 13, 1997 and authorize a mass mailing of staff's report. (This item does not include installation of speed humps, walkways or multiway stops and does not alter the MTA bus service or any road striping).

Staff reference: Public Works Director Clement

19. Award of Contract for emergency temporary repair of the burned retaining wall on Latigo Canyon Road and adopt Resolution No. 96-086 amending the budget allocating an amount to be determined after receipt of bids but not exceeding $50,000 from the 1996-97 general fund surplus (current balance $380,000).

Staff reference: Public Works Director Clement

20. Award of Contract for construction of new Latigo Canyon Road dewatering well and adopt Resolution No. 96-085 amending the budget allocating $15,000 from the 1996-97 general fund surplus (current balance $380,000).

Staff reference: Public Works Director Clement

"The mind, which sometimes presumes to believe there is no such thing as a miracle, is itself a miracle."

- Unknown

Future Meetings

Monday, December 9	6:30 p.m.	Regular Meeting	Hughes Auditorium
Monday, January 13	6:30 p.m.	Regular Meeting	Hughes Auditorium
Monday, January 27	6:30 p.m.	Regular Meeting	Hughes Auditorium

Copies of the staff reports or other written documentation relating to each item of business described above are on file in the office of the City Clerk, Malibu City Hall, 23555 Civic Center Way, Malibu, California and are available for public inspection during regular office hours which are 8:30 a.m. to 5:00 p.m., Monday through Friday. Pursuant to State law, this agenda has been posted at least 72 hours prior to the meeting at the Malibu City Offices, Malibu Community Center at Point Dume and Malibu Community Library. The City Hall phone number is (310) 456-2489. To contact City Hall using a telecommunication device for the deaf (TDD), please call (800) 735-2929 and a California Relay Service operator will assist you. In compliance with the Americans with Disabilities Act, if you need special assistance to participate in this meeting, please contact Building & Safety Director Victor Peterson, (310) 456-2489, ext. 251. Notification 48 hours prior to the meeting will enable the City to make reasonable arrangements to ensure accessibility to this meeting. [28 CFR 35.102-35.104 ADD Title II]

Forecast of Upcoming Agenda Items
[These dates are tentative and subject to change.]

ITEM	TENTATIVE DATE
Appeal of Planning Commission denial for car wash on PCH and Heathercliff (Mr. Justin Silvers, applicant) (Planning Department)	December 9, 1996 (Public Hearing)
Agreement for preparation of Zoning Ordinance Update/Local Coastal Plan/EIR (Planning Department)	December 9, 1996 (Discussion)
Award contract for Kanan-Dume Road construction project (Public Works Department)	December 9, 1996 (Discussion)
Marine Refuge (Planning Department)	December 9, 1996 (Discussion)
Malibu Pier Operating Agreements (City Manager's Office)	December 9, 1996 (Discussion)

SUPPLEMENTAL AGENDA

52-A. Recommendation as submitted by Supervisor Burke:
Waive fees in amount of $200, excluding the cost of liability insurance, for use of Athens Park Community Building by the Community Coalition for Change, Inc., for their first Annual Meeting, to be held December 1, 1996. **(CRON NO. 96327LAC0010)**

52-B. Recommendation as submitted by Supervisor Burke:
Award and instruct the Director of Parks and Recreation to execute contract with Advanced Construction, in amount of $2,190,000, funded with Safe Neighborhood Parks Prop A funds allocated to the Second Supervisorial District, for construction of new ball fields, a restroom and concession stand at Kenneth Hahn State Recreation area (2); and authorize Director of Parks and Recreation to supplement the contract by up to 10% for change orders and contingencies, if necessary. **(CRON NO. 96327LAC0009)**

52-C. Recommendation as submitted by Mayor Antonovich:
Approve recommendation of the Commission on Alcoholism to proclaim December 1996 as "National Drunk and Drugged Driving Prevention Month," throughout Los Angeles County, to help encourage and educate the public about the dangers of drinking and driving. **(CRON NO. 96327LAC0013)**

52-D. Recommendation as submitted by Mayor Antonovich:
Request the Federal Bureau of Investigation's (F.B.I.) Organized Crime Unit to apply the Racketeer Influenced and Corrupt Organizations Act to prosecute the 18th Street Gang members who are arrested; and request the F.B.I. to work with the Immigration and Naturalization Service to deport arrested 18th Street Gang members who are in the Country illegally. **(CRON NO. 96327LAC0015)**

EXECUTIVE OFFICE OF THE BOARD OF SUPERVISORS
COUNTY OF LOS ANGELES

JOANNE STURGES
Executive Officer

November 22, 1996

TO: Supervisor Michael D. Antonovich, Mayor
Supervisor Gloria Molina
Supervisor Yvonne Brathwaite Burke
Supervisor Zev Yaroslavsky
Supervisor Deane Dana
David E. Janssen, Chief Administrative Officer
DeWitt W. Clinton, County Counsel
Press Room

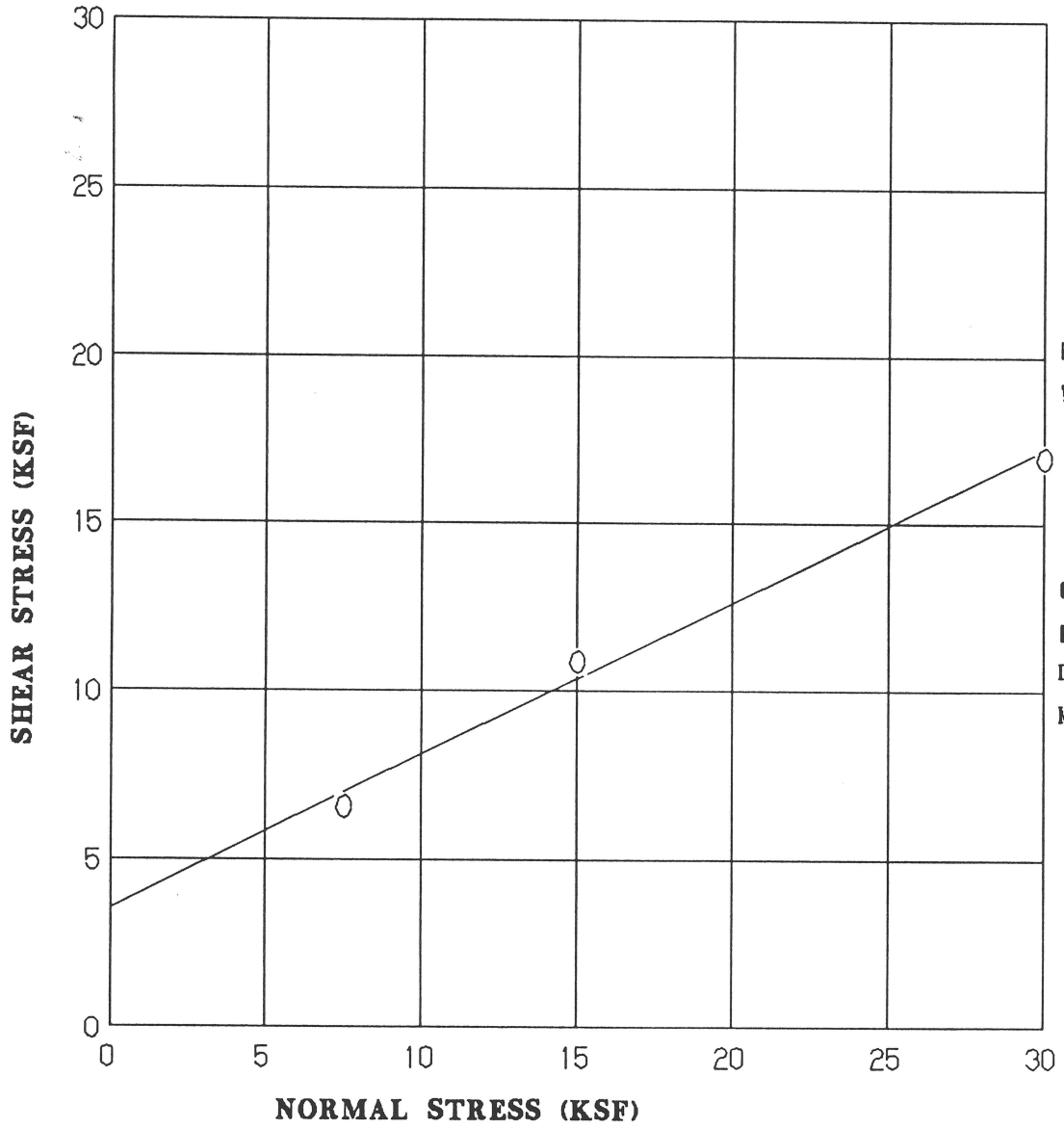
FROM: Joanne Sturges, Executive Officer

POSTED: November 22, 1996

RE: Additions to agenda for Board meeting of Tuesday, November 26, 1996.

Agenda No.	Change
	9:30 a.m.
ADD:	Presentation of scroll to Na'Amat USA Western Area for their generosity to the children and families of Los Angeles County, as arranged by Supervisor Yaroslavsky.
ADD:	Presentation of scroll to Jayne Frost for coming to the aid of Sam Dilworth who suffers from Alzheimer Disease, as arranged by Supervisor Yaroslavsky.

383 KENNETH HAHN HALL OF ADMINISTRATION / LOS ANGELES, CALIFORNIA 90012
(213) 974-1411 FAX (213) 620-0636



BRM:

WEATHERED BASALT TAKEN FROM BYA-5 @ 200 FT.

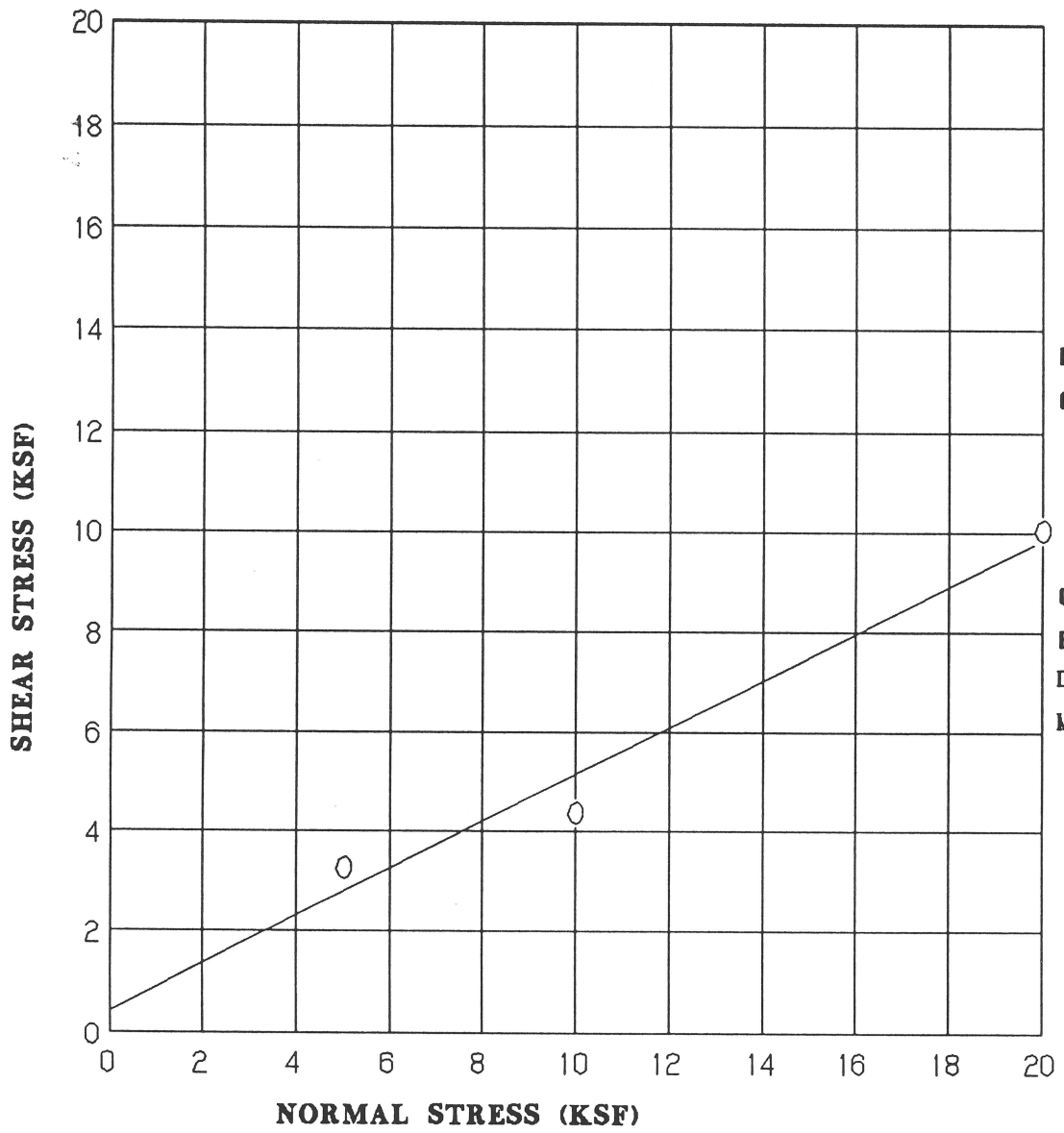
COHESION = 3000 PSF

FRICTION ANGLE = 26 DEGREES.

DRY DENSITY - 124 PCF

MOISTURE CONTENT = 21.0%

PROJECT #: 49-97D	FIG. II-1 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM:

CLAY TAKEN FROM BYA-5 @ 148 FT.

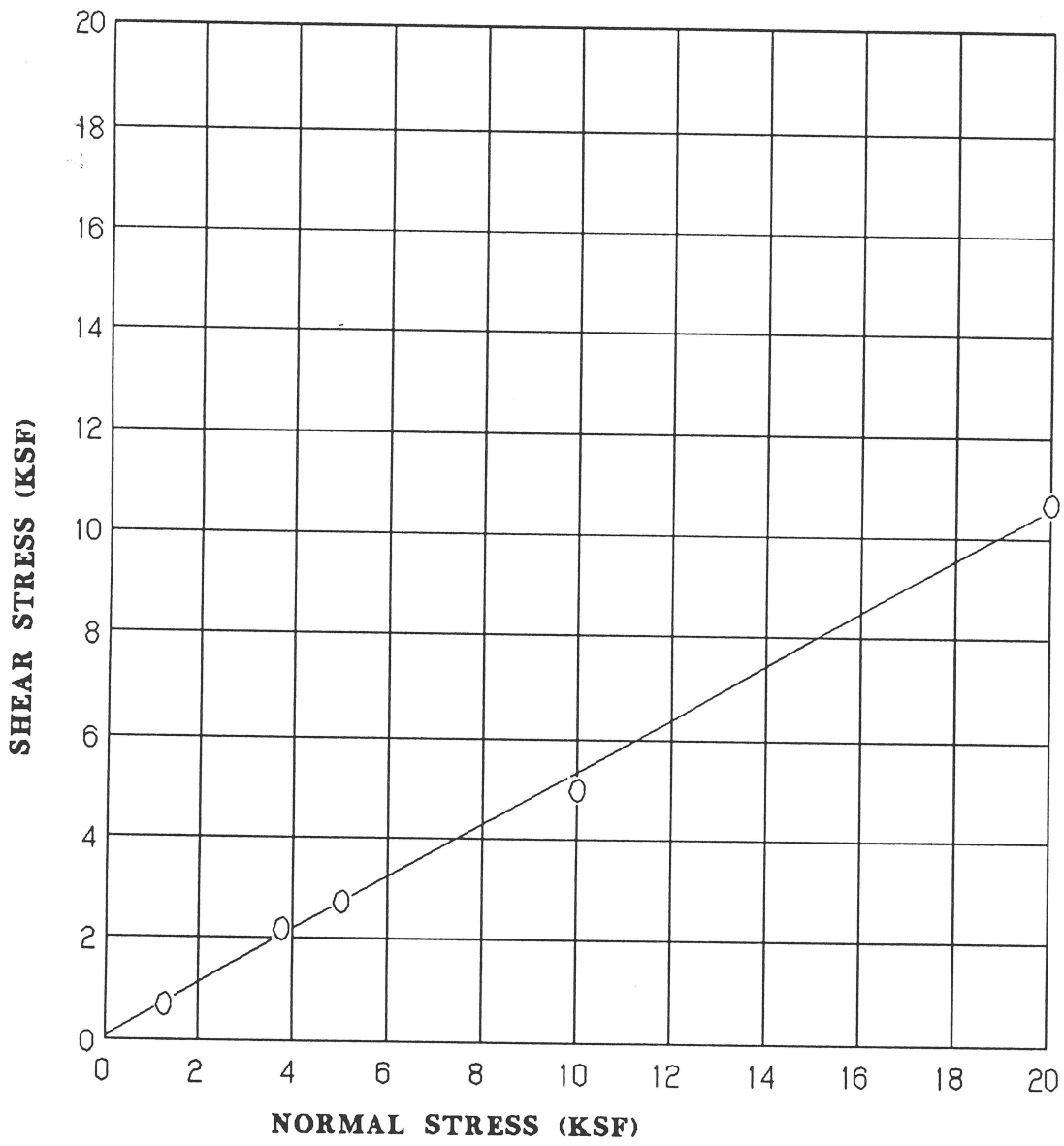
COHESION = 500 PSF

FRICTION ANGLE = 27 DEGREES.

DRY DENSITY = 119 PCF

MOISTURE CONTENT = 26.0%

PROJECT #: 49-97D	FIG. II-2 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



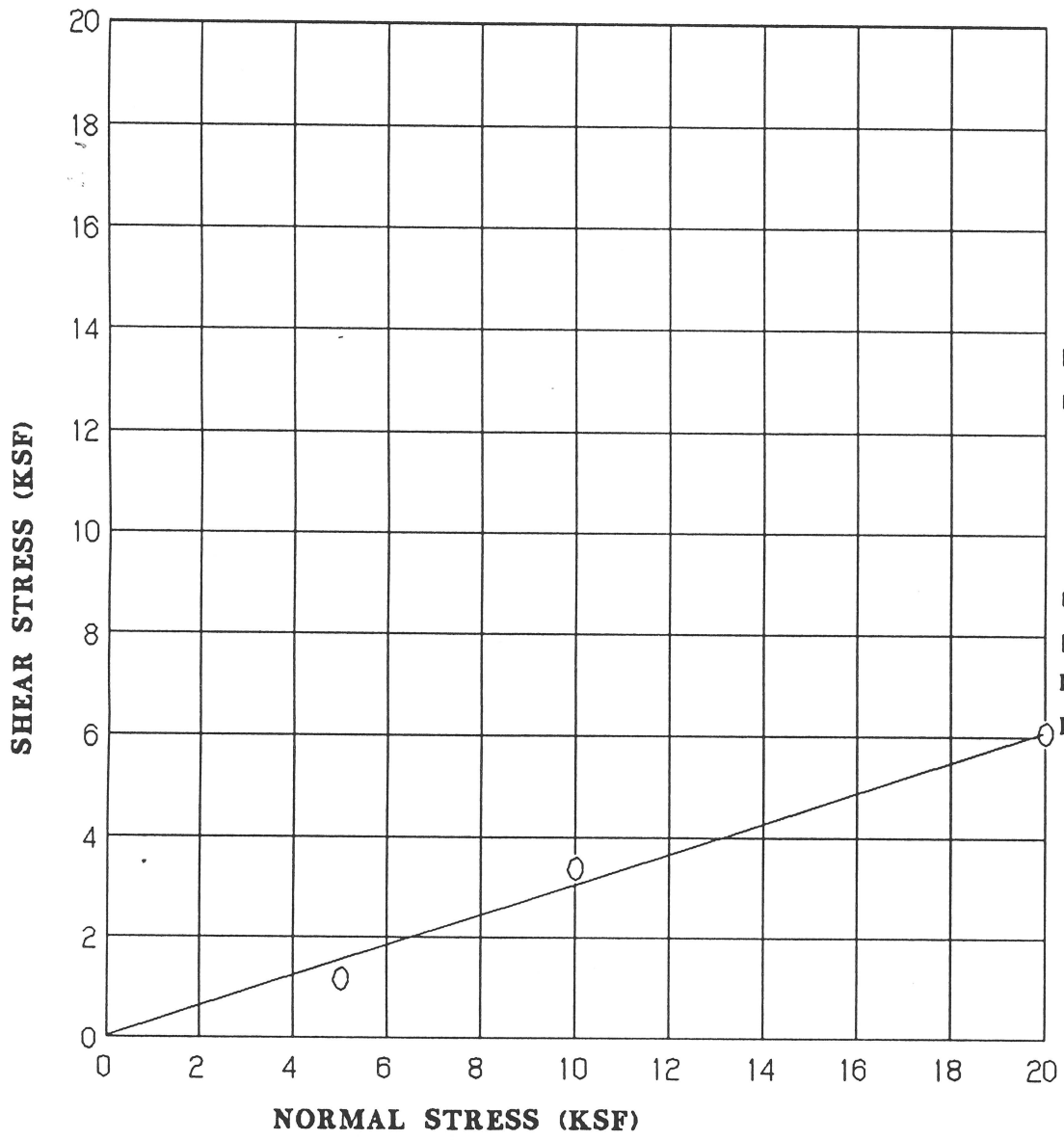
BRM:

SESPE SAMPLE TAKEN FROM BRM-5 @ 60 FT.

COHESION = 0 PSF

FRICTION ANGLE = 29 DEGREES.

PROJECT #: 49-97D	FIG. II-3 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM: CNTL

GOUGE TAKEN FROM EAST LANDSLIDE.

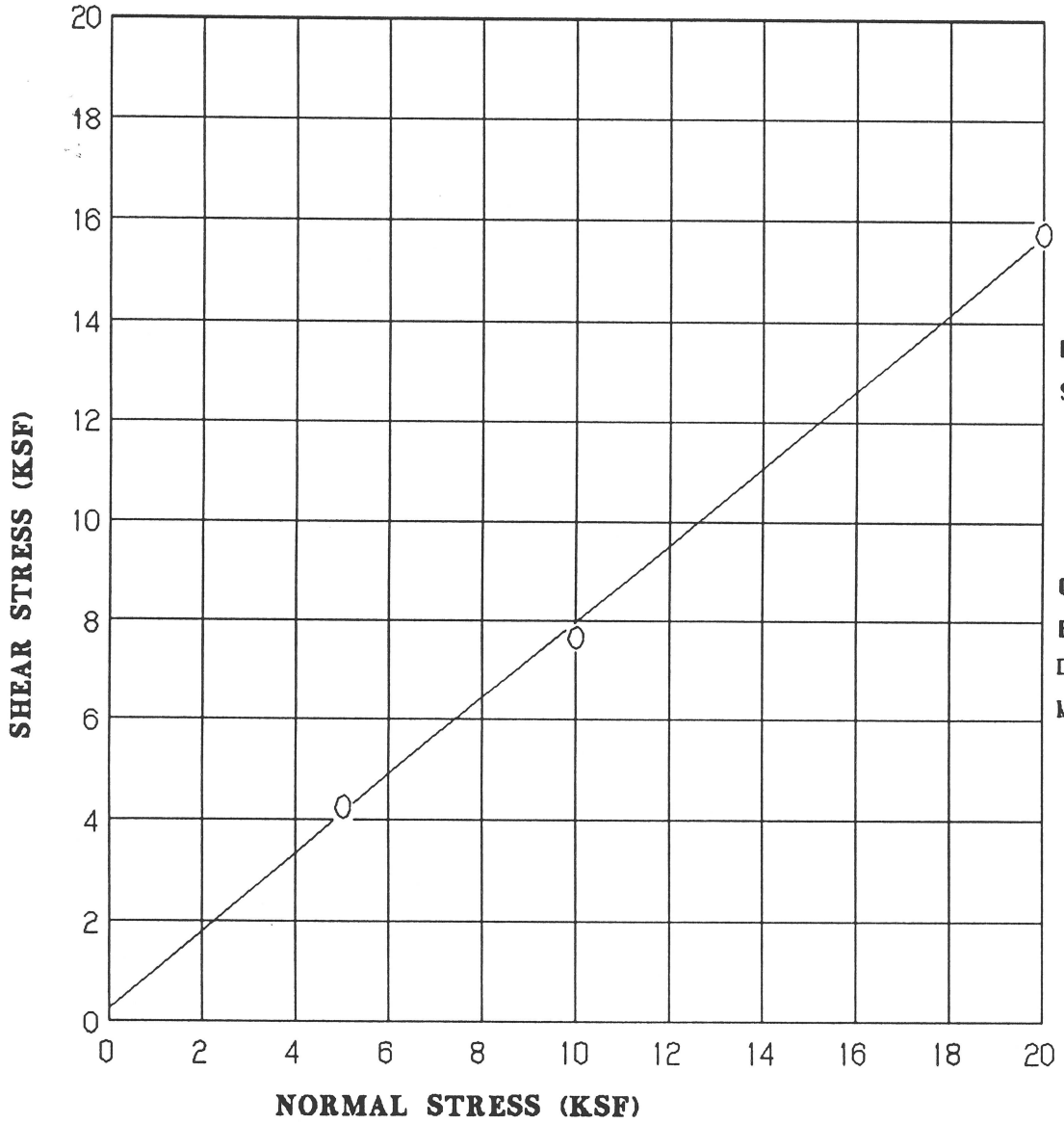
COHESION = 0 PSF

FRICTION ANGLE = 18 DEGREES.

DRY DENSITY = 119 PCF

MOISTURE CONTENT = 16.2%

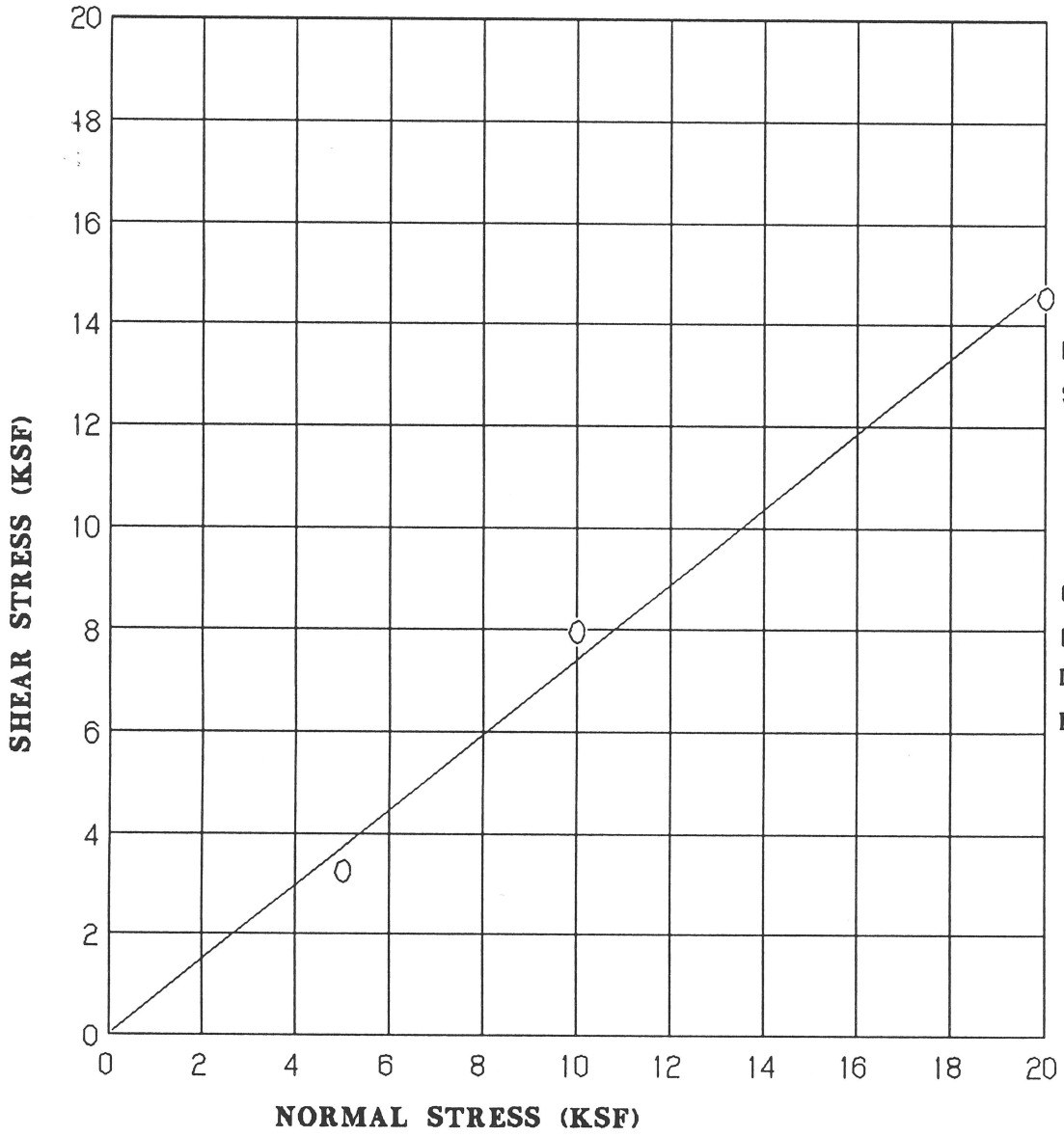
PROJECT #: 49-97D	FIG. 11-4 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM:
SAND TAKEN FROM BYA-3 @ 86 FT.

COHESION = 100 PSF
FRICTION ANGLE = 40 DEGREES.
DRY DENSITY - 118 PCF
MOISTURE CONTENT = 27.0%

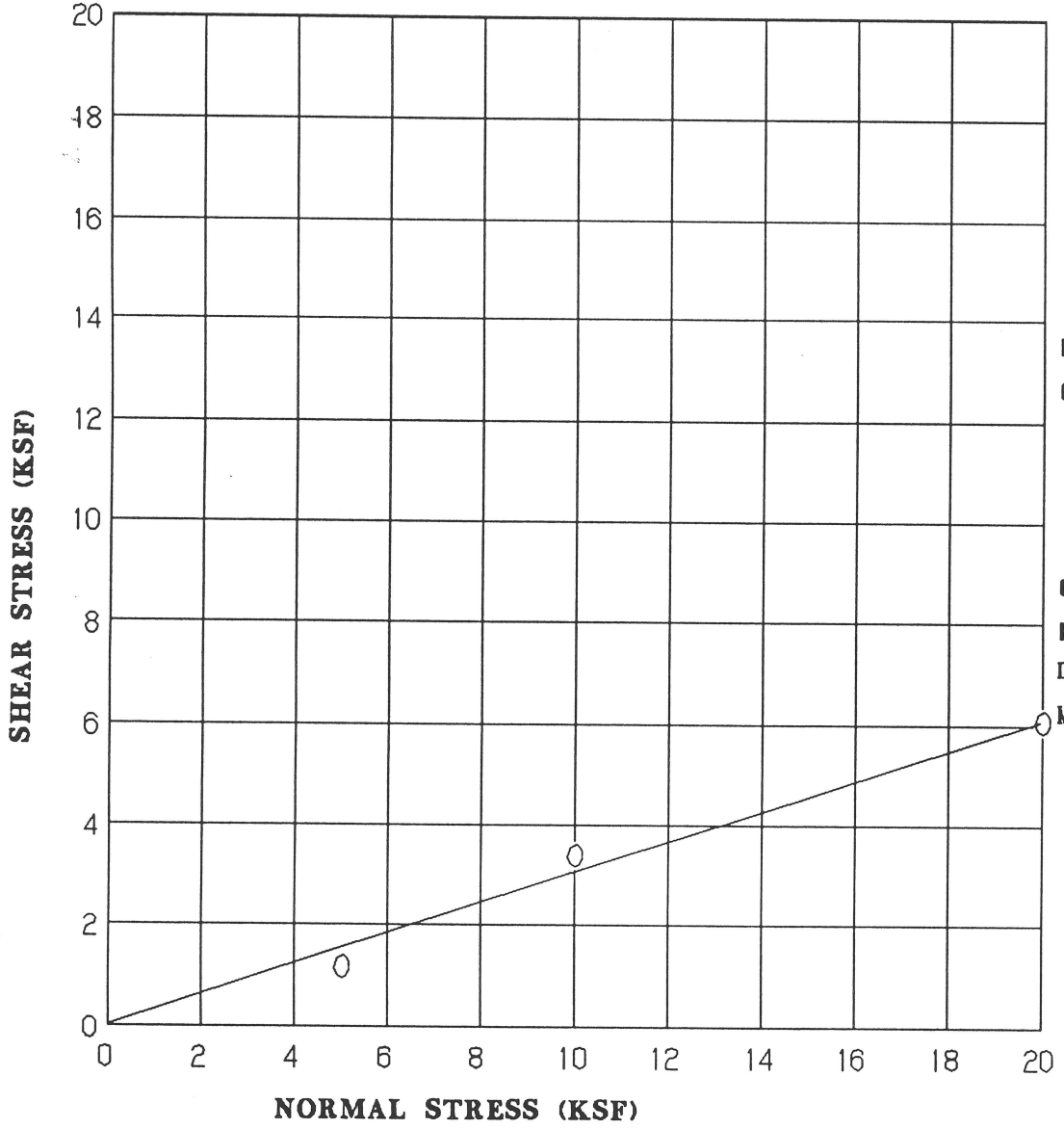
PROJECT #: 49-97D	FIG. II-5 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM:
SAND TAKEN FROM BYA-4 @ 108 FT.

COHESION = 0 PSF
FRICTION ANGLE = 38 DEGREES.
DRY DENSITY - 118 PCF
MOISTURE CONTENT = 30.8%

PROJECT #: 49-97D	FIG. II-6 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM: CNTL

GOUGE TAKEN FROM EAST LANDSLIDE.

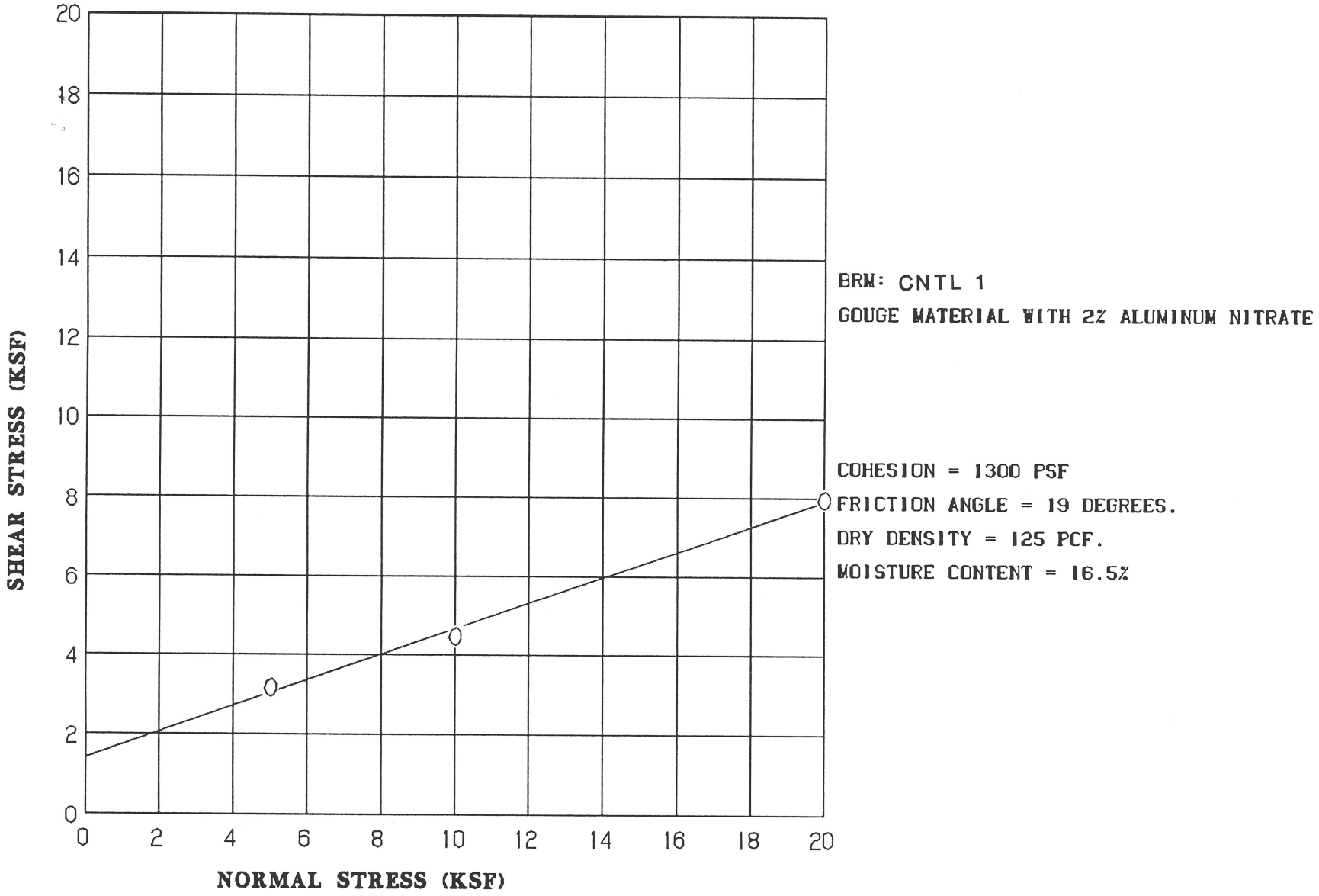
COHESION = 0 PSF

FRICTION ANGLE = 18 DEGREES.

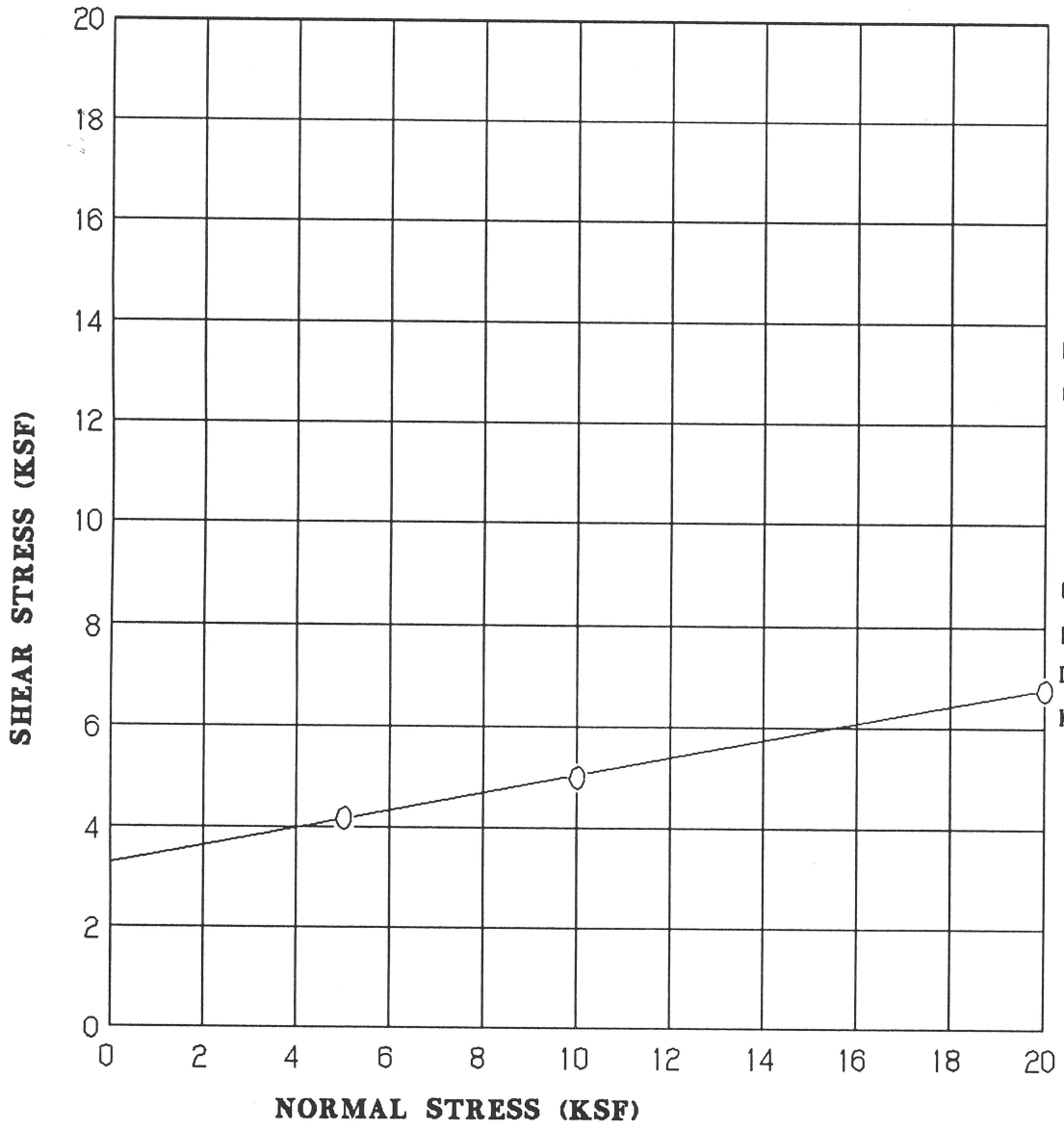
DRY DENSITY - 119 PCF

MOISTURE CONTENT = 16.2%

PROJECT #: 49-97D	FIG. II-7 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



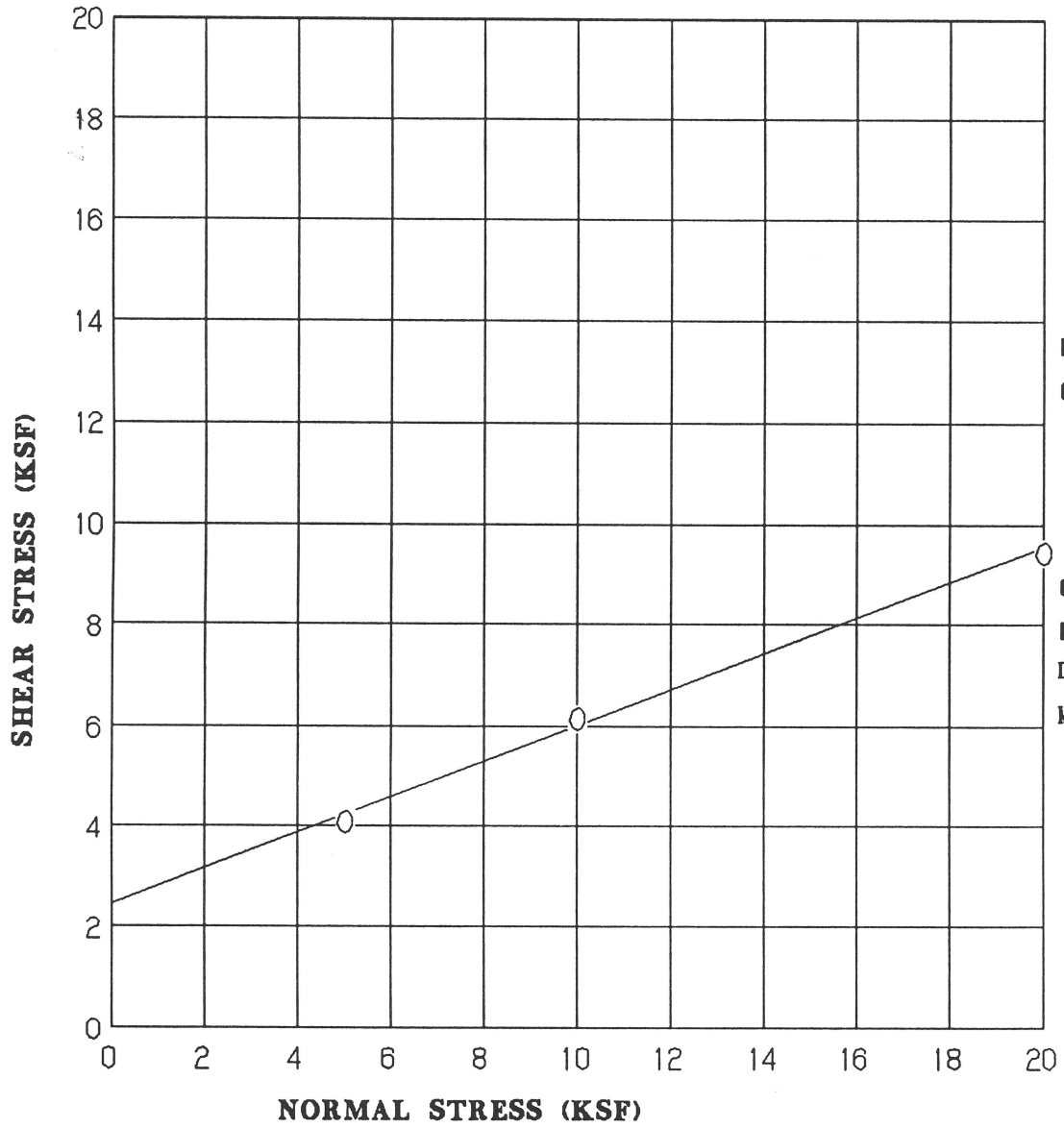
PROJECT #: 49-97D	FIG. 11-8 BIG ROCK MESA – DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM: CNTL 2
GOUGE MATERIAL WITH 2% SODIUM SILICATE.

COHESION = 3200 PSF
FRICTION ANGLE = 11 DEGREES.
DRY DENSITY = 122 PCF
MOISTURE CONTENT = 17.3%

PROJECT #: 49-97D	FIG. II-9 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS	BING YEN AND ASSOCIATES



BRM: CNTL3

GOUGE MATERIAL WITH 2% POTOSSIUM FLOURIDE

COHESION = 2500 PSF

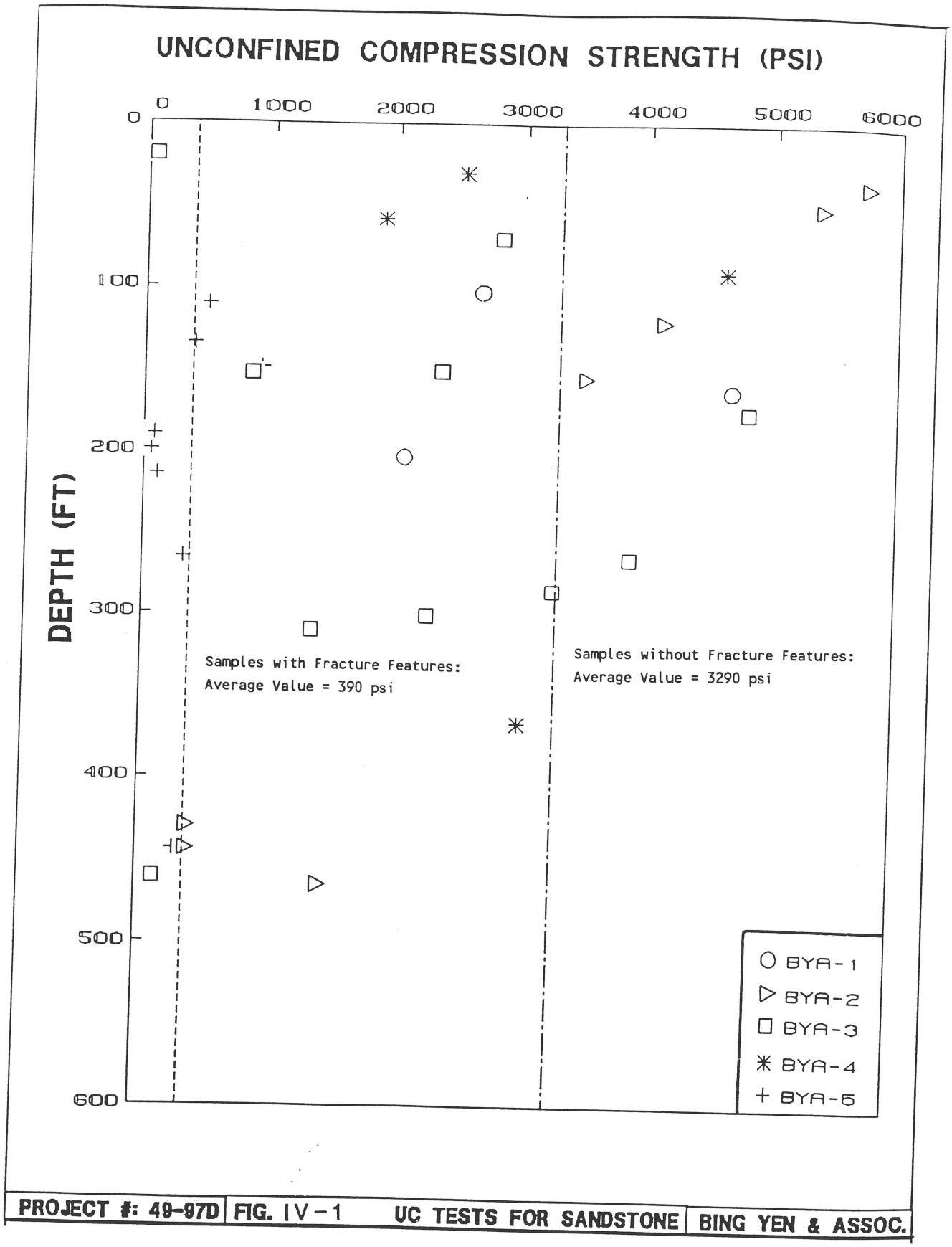
FRICTION ANGLE = 21 DEGREES.

DRY DENSITY - 114 PCF

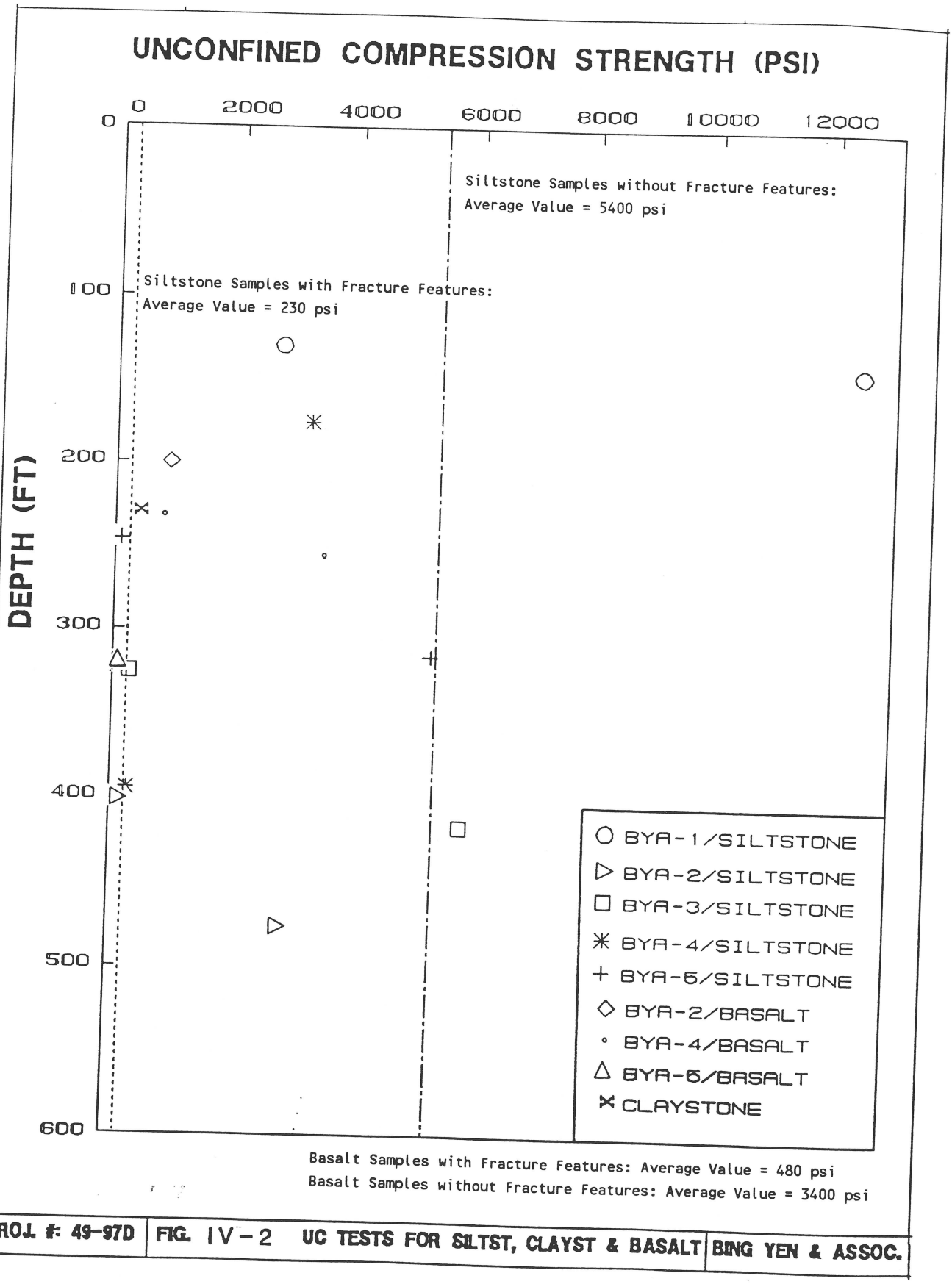
MOISTURE CONTENT = 20.6%

PROJECT #: 49-97D	**FIG. II-10 BIG ROCK MESA - DIRECT SHEAR TEST RESULTS**	**BING YEN AND ASSOCIATES**

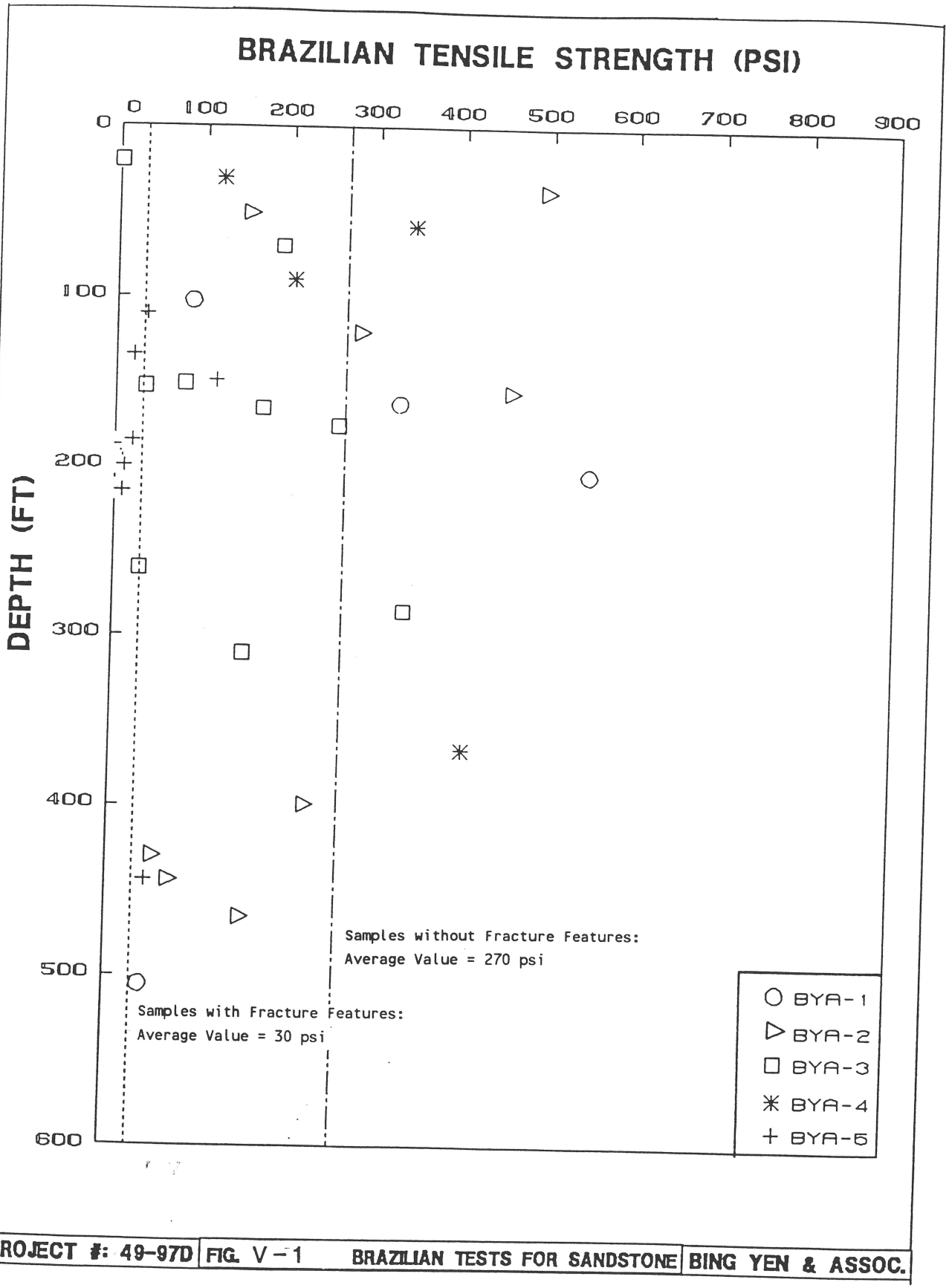
(IV) Unconfined Compression and Brazlian Tensile Strength Tests



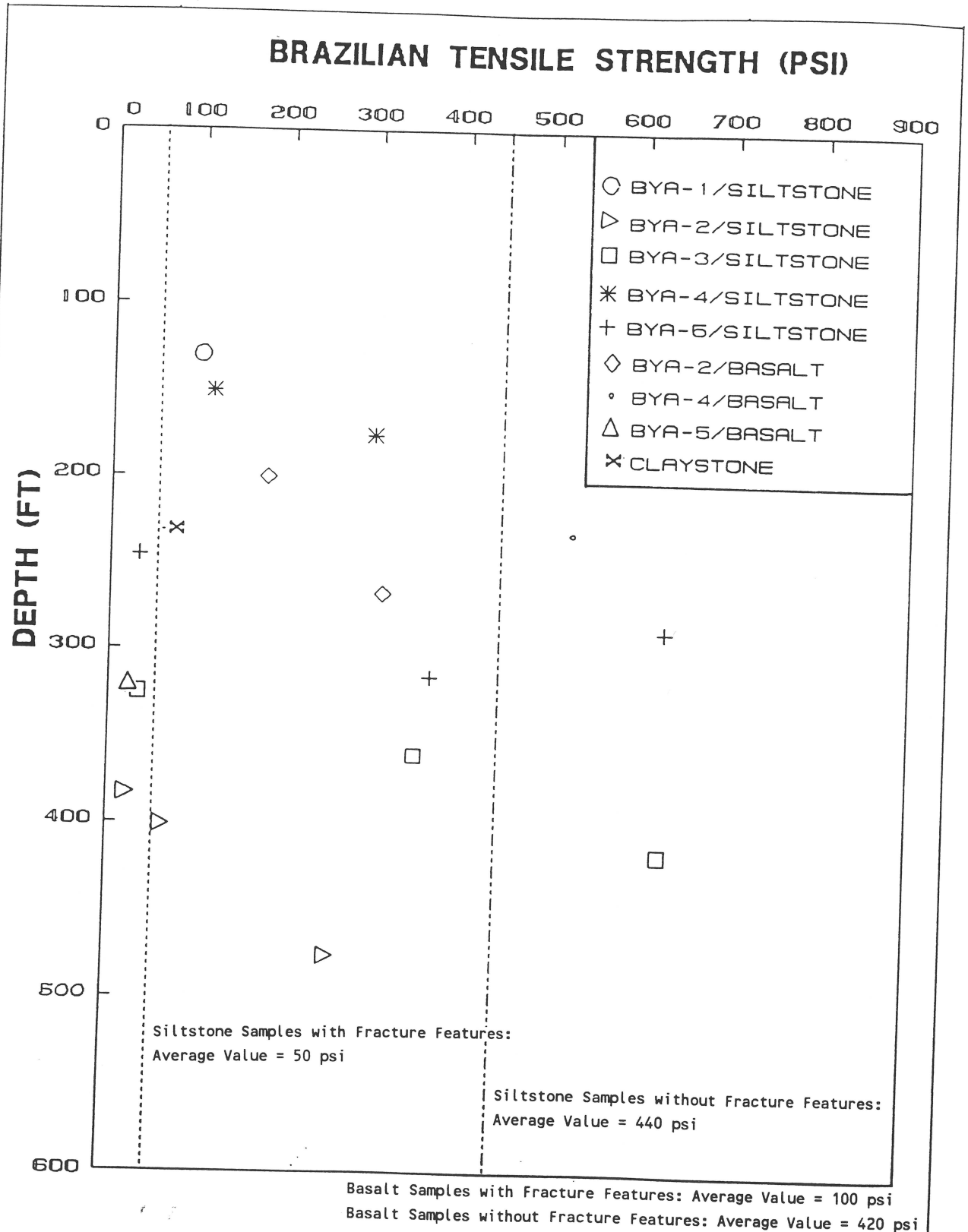
PROJECT #: 49-97D | FIG. IV-1 UC TESTS FOR SANDSTONE | BING YEN & ASSOC.



PROJ. #: 49-97D | FIG. IV-2 UC TESTS FOR SILTST, CLAYST & BASALT | BING YEN & ASSOC.

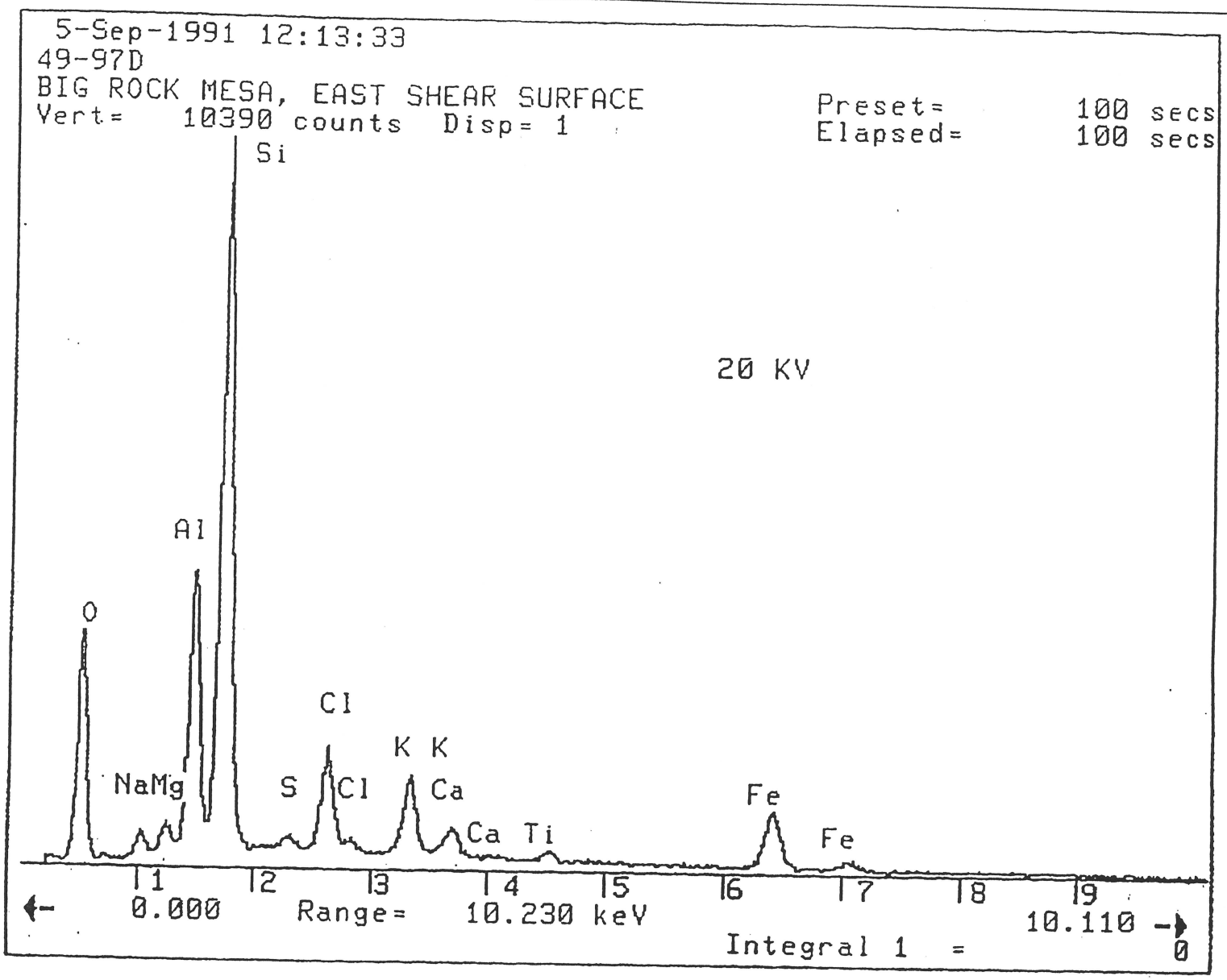


PROJECT #: 49-97D | FIG. V-1 BRAZILIAN TESTS FOR SANDSTONE | BING YEN & ASSOC.

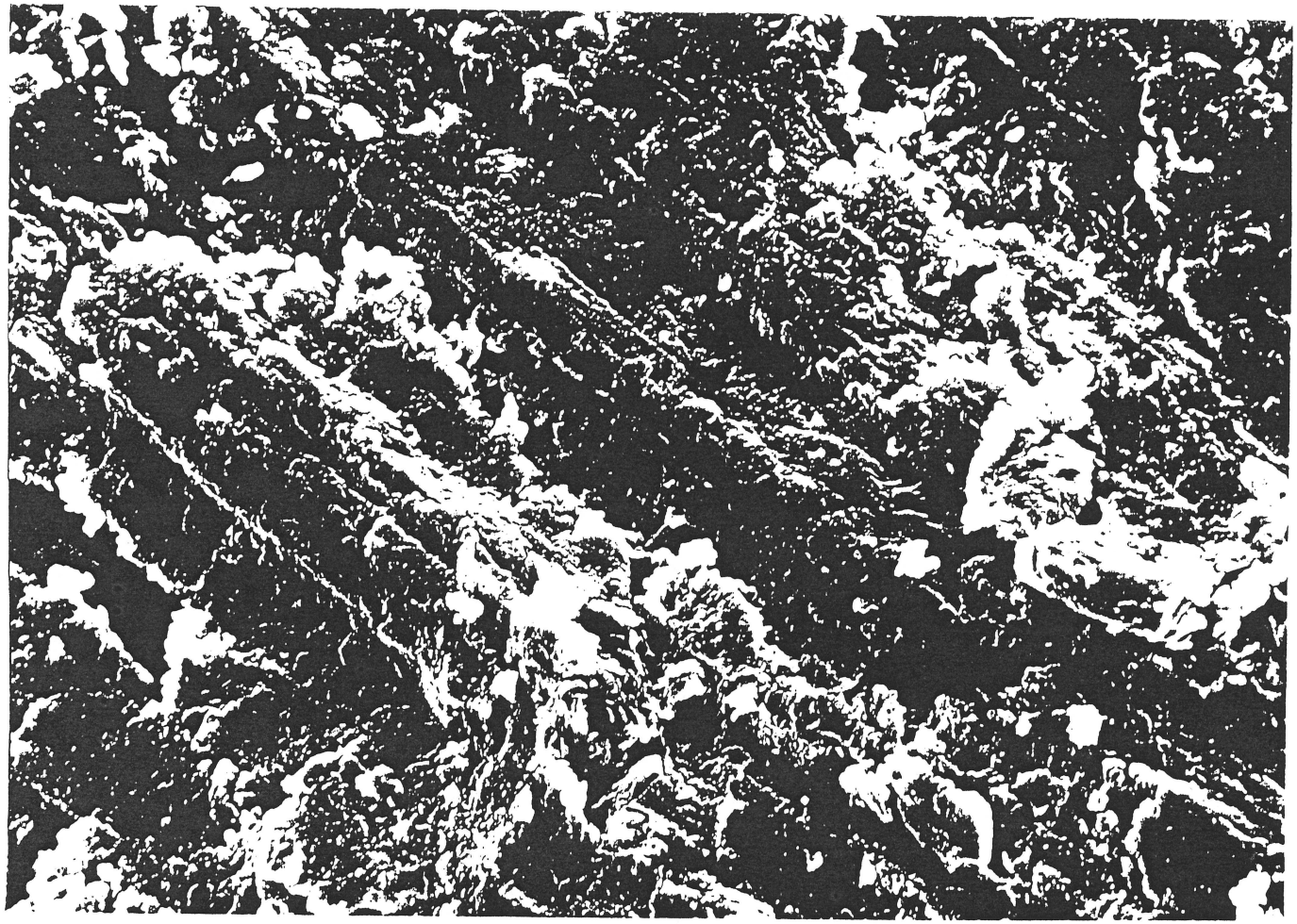


PROJ. #: 49-97D | FIG. V-2 BRAZILIAN TESTS FOR SLST, CLST & BS | BING YEN & ASSOC.

(VII) Energy Dispersive Spectroscopy and Scanning Electron Microscope



Project #: 49-97d	**Fig. VII-1 Energy Dispersive X-Ray Spectroscopy for Sespe Gouge Material from the Eastern Landslide**	**Bing Yen & Assoc.**



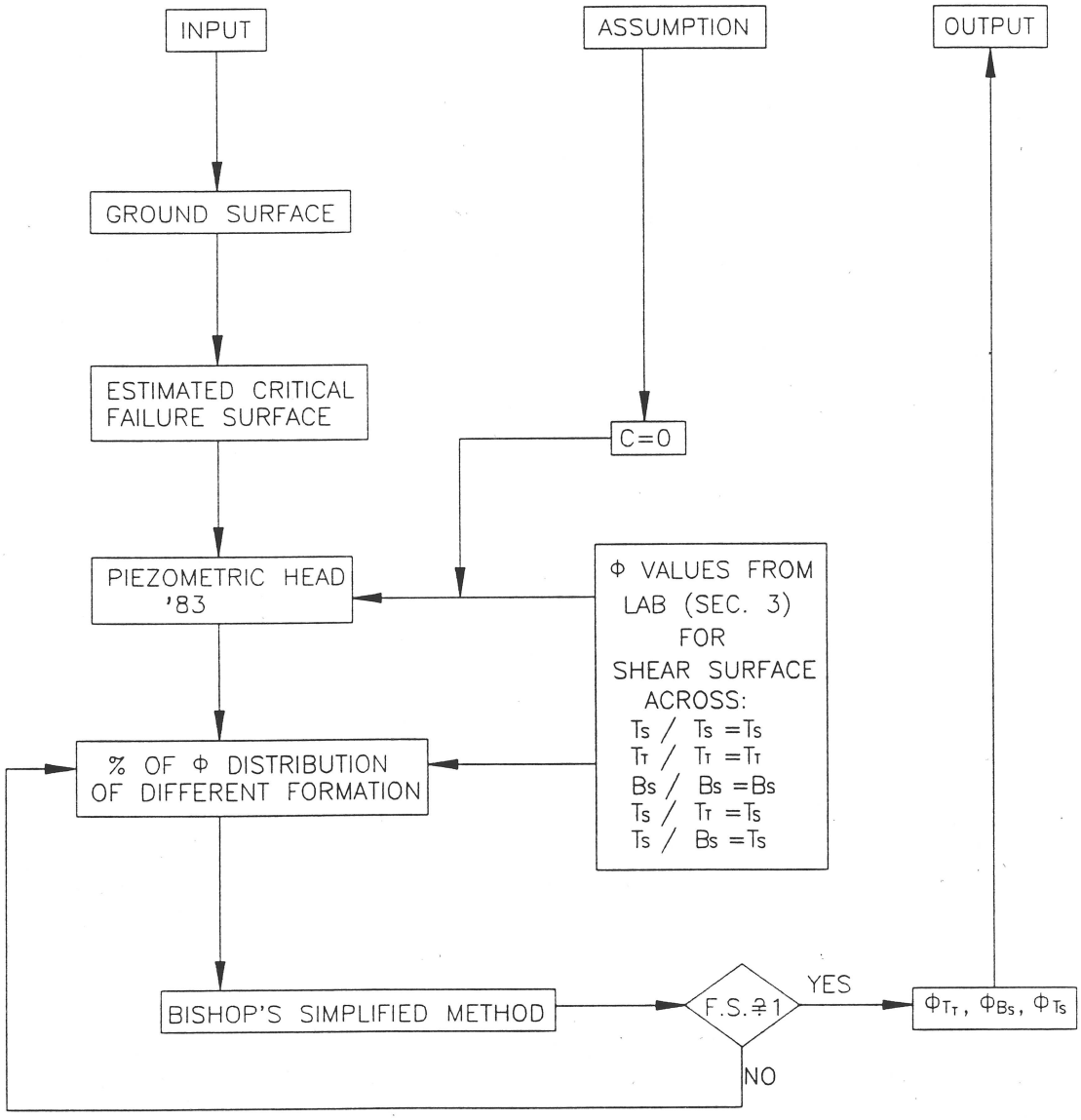
A) Manifaction of 500 X

Project #: 49-97D	Fig. VII-2 Scanning Electron Microscope for Sespe Gouge Material in Big Rock Mesa	Bing Yen & Assoc.



A) Manifaction of 5,000 X

Project #: 49-97D	Fig. VII-3 Scanning Electron Microscope for Sespe Gouge Material in Big Rock Mesa	Bing Yen & Assoc.



*Note: Ts : Sespe Formation
Tr : Topanga Formation
Bs : Basalt

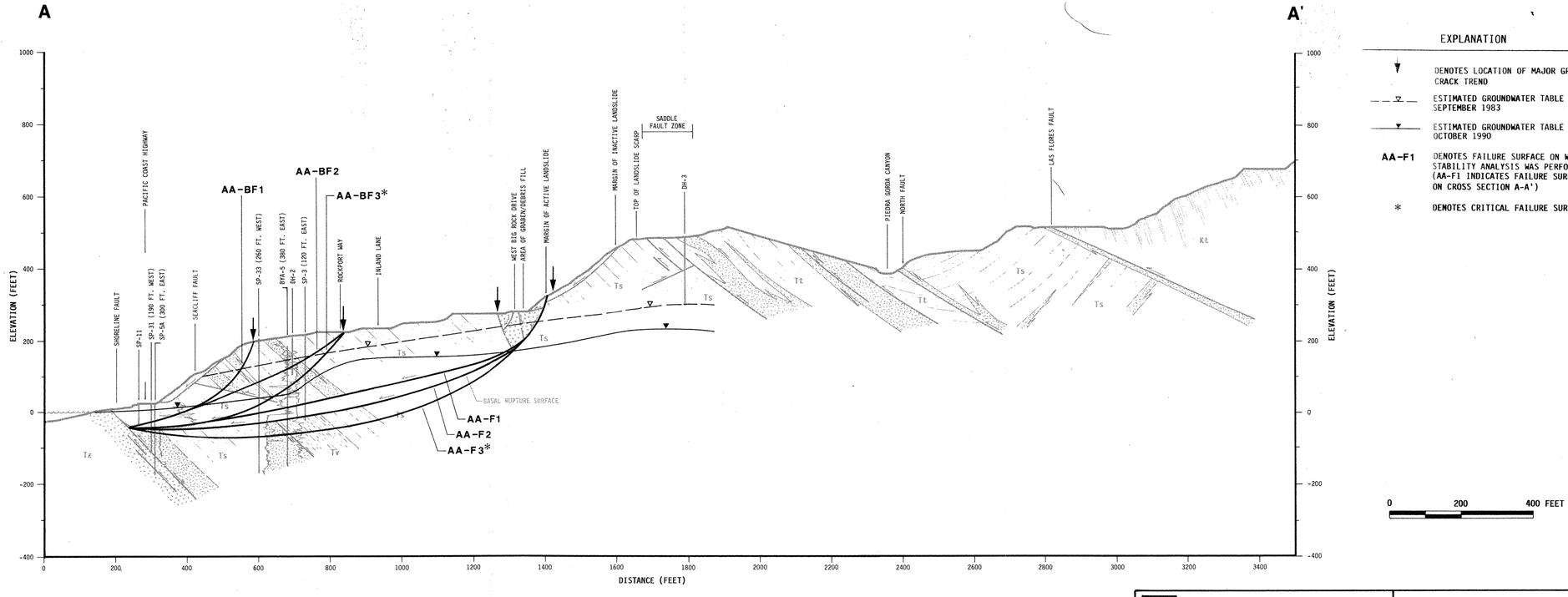
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

METHODOLOGY FLOW CHART-
PARAMETRIC STRENGTH VERIFICATION VIA
2-D AND 3-D SLOPE STABILITY ANALYSES

FIGURE 7-2.7



EXPLANATION

- DENOTES LOCATION OF MAJOR GROUND CRACK TREND
- ESTIMATED GROUNDWATER TABLE AS OF SEPTEMBER 1983
- ESTIMATED GROUNDWATER TABLE AS OF OCTOBER 1990
- **AA-F1** DENOTES FAILURE SURFACE ON WHICH STABILITY ANALYSIS WAS PERFORMED (AA-F1 INDICATES FAILURE SURFACE NO.1 ON CROSS SECTION A-A')
- * DENOTES CRITICAL FAILURE SURFACE

0 200 400 FEET

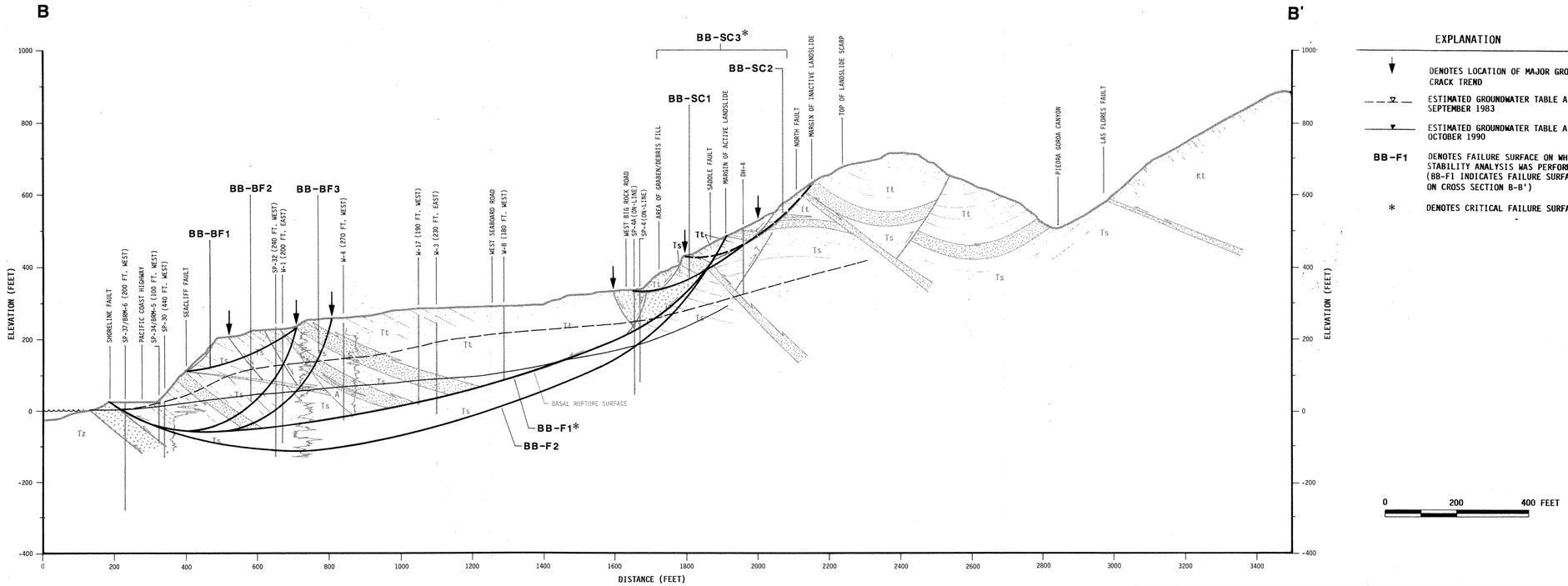
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SLOPE STABILITY ANALYSIS;
GEOTECHNICAL CROSS SECTION A-A'

FIGURE 7-2.1



EXPLANATION

- DENOTES LOCATION OF MAJOR GROUND CRACK TREND
- ESTIMATED GROUNDWATER TABLE AS OF SEPTEMBER 1983
- ESTIMATED GROUNDWATER TABLE AS OF OCTOBER 1990
- BB-F1 — DENOTES FAILURE SURFACE ON WHICH STABILITY ANALYSIS WAS PERFORMED (BB-F1 INDICATES FAILURE SURFACE NO.1 ON CROSS SECTION B-B')
- * — DENOTES CRITICAL FAILURE SURFACE

0 200 400 FEET

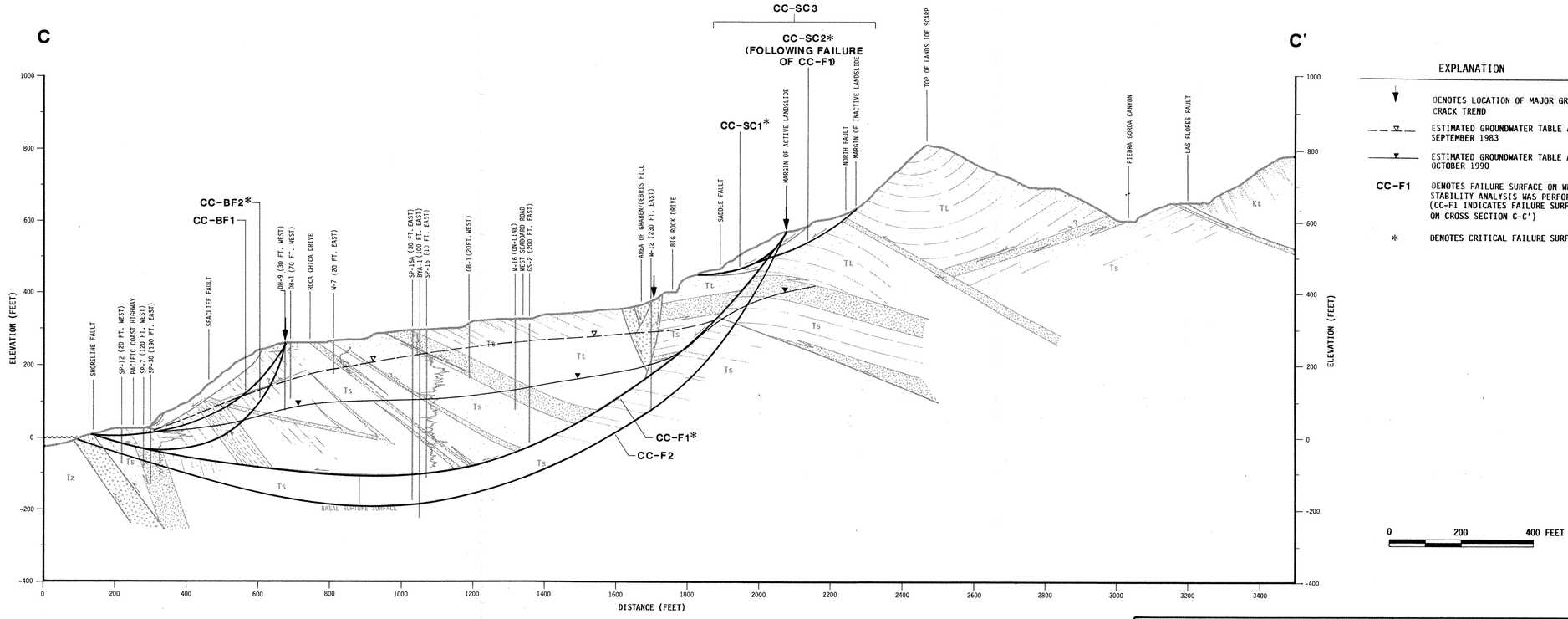
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SLOPE STABILITY ANALYSIS;
GEOTECHNICAL CROSS SECTION B-B'

FIGURE 7-2.2



EXPLANATION

- DENOTES LOCATION OF MAJOR GROUND CRACK TREND
- ESTIMATED GROUNDWATER TABLE AS OF SEPTEMBER 1983
- ESTIMATED GROUNDWATER TABLE AS OF OCTOBER 1990
- CC-F1 — DENOTES FAILURE SURFACE ON WHICH STABILITY ANALYSIS WAS PERFORMED (CC-F1 INDICATES FAILURE SURFACE NO.1 ON CROSS SECTION C-C')
- * — DENOTES CRITICAL FAILURE SURFACE

0 200 400 FEET

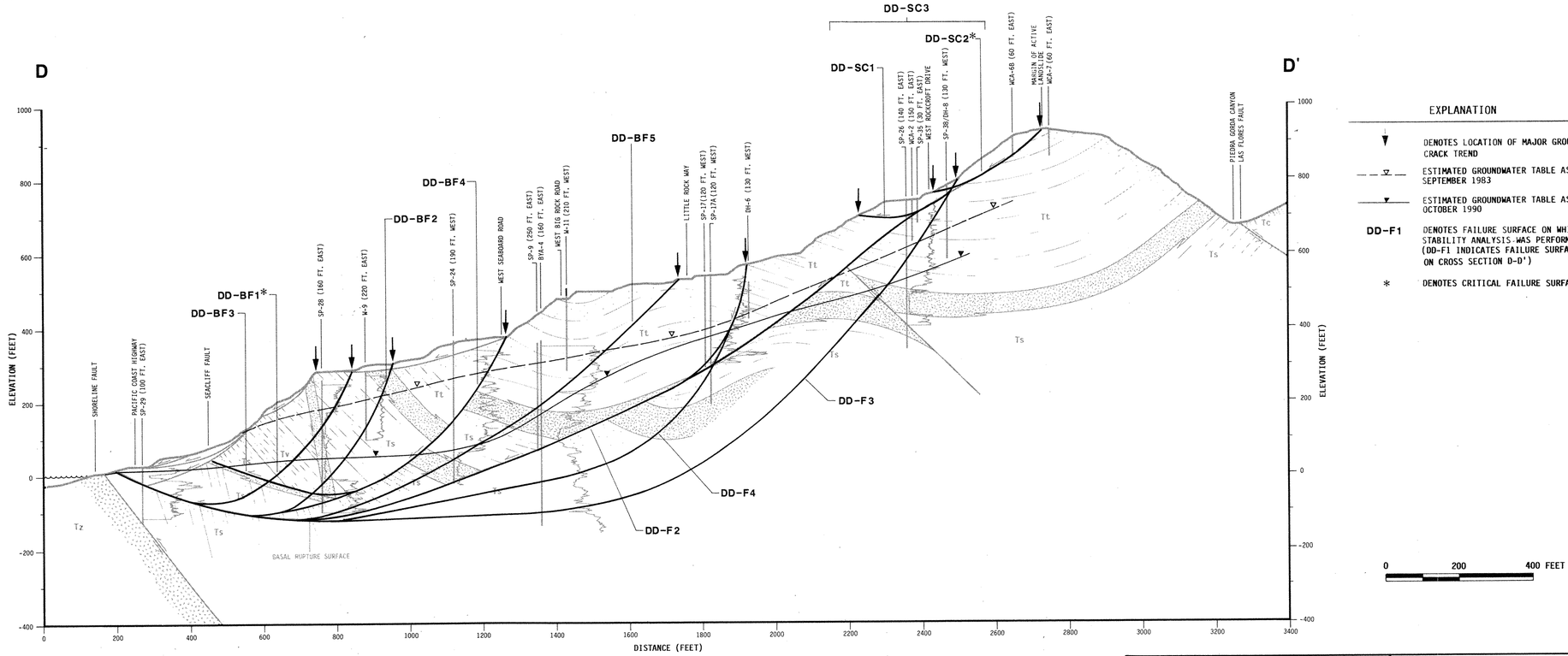
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SLOPE STABILITY ANALYSIS;
GEOTECHNICAL CROSS SECTION C-C'

FIGURE 7-2.3



EXPLANATION

- DENOTES LOCATION OF MAJOR GROUND CRACK TREND
- ESTIMATED GROUNDWATER TABLE AS OF SEPTEMBER 1983
- ESTIMATED GROUNDWATER TABLE AS OF OCTOBER 1990
- DD-F1 — DENOTES FAILURE SURFACE ON WHICH STABILITY ANALYSIS WAS PERFORMED (DD-F1 INDICATES FAILURE SURFACE NO.1 ON CROSS SECTION D-D')
- * — DENOTES CRITICAL FAILURE SURFACE

0 200 400 FEET

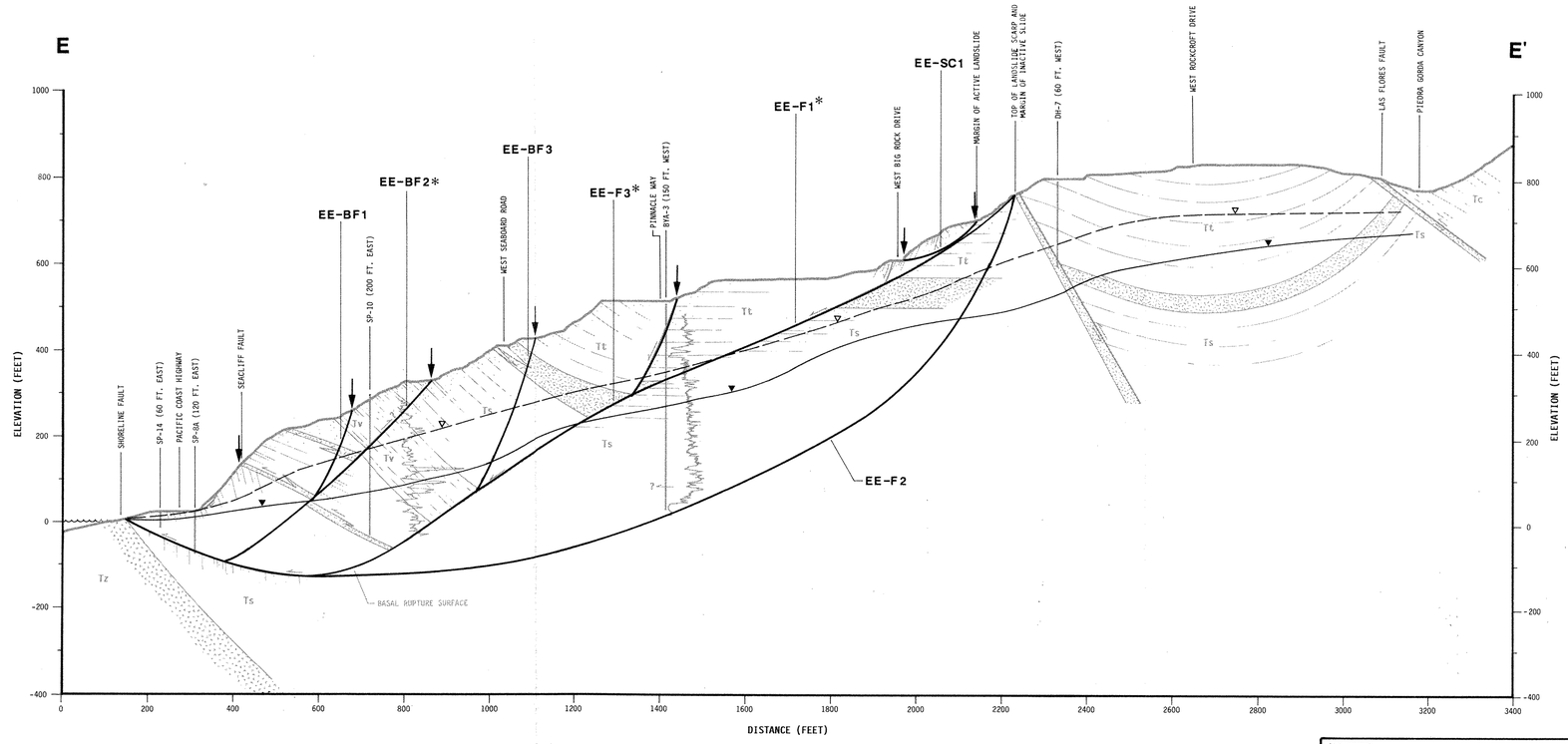
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SLOPE STABILITY ANALYSIS;
GEOTECHNICAL CROSS SECTION D-D'

FIGURE 7-2.4



EXPLANATION

- DENOTES LOCATION OF MAJOR GROUND CRACK TREND
- ESTIMATED GROUNDWATER TABLE AS OF SEPTEMBER 1983
- ESTIMATED GROUNDWATER TABLE AS OF OCTOBER 1990
- EE-F1 DENOTES FAILURE SURFACE ON WHICH STABILITY ANALYSIS WAS PERFORMED (EE-F1 INDICATES FAILURE SURFACE NO.1 ON CROSS SECTION E-E')
- * DENOTES CRITICAL FAILURE SURFACE

0 200 400 FEET

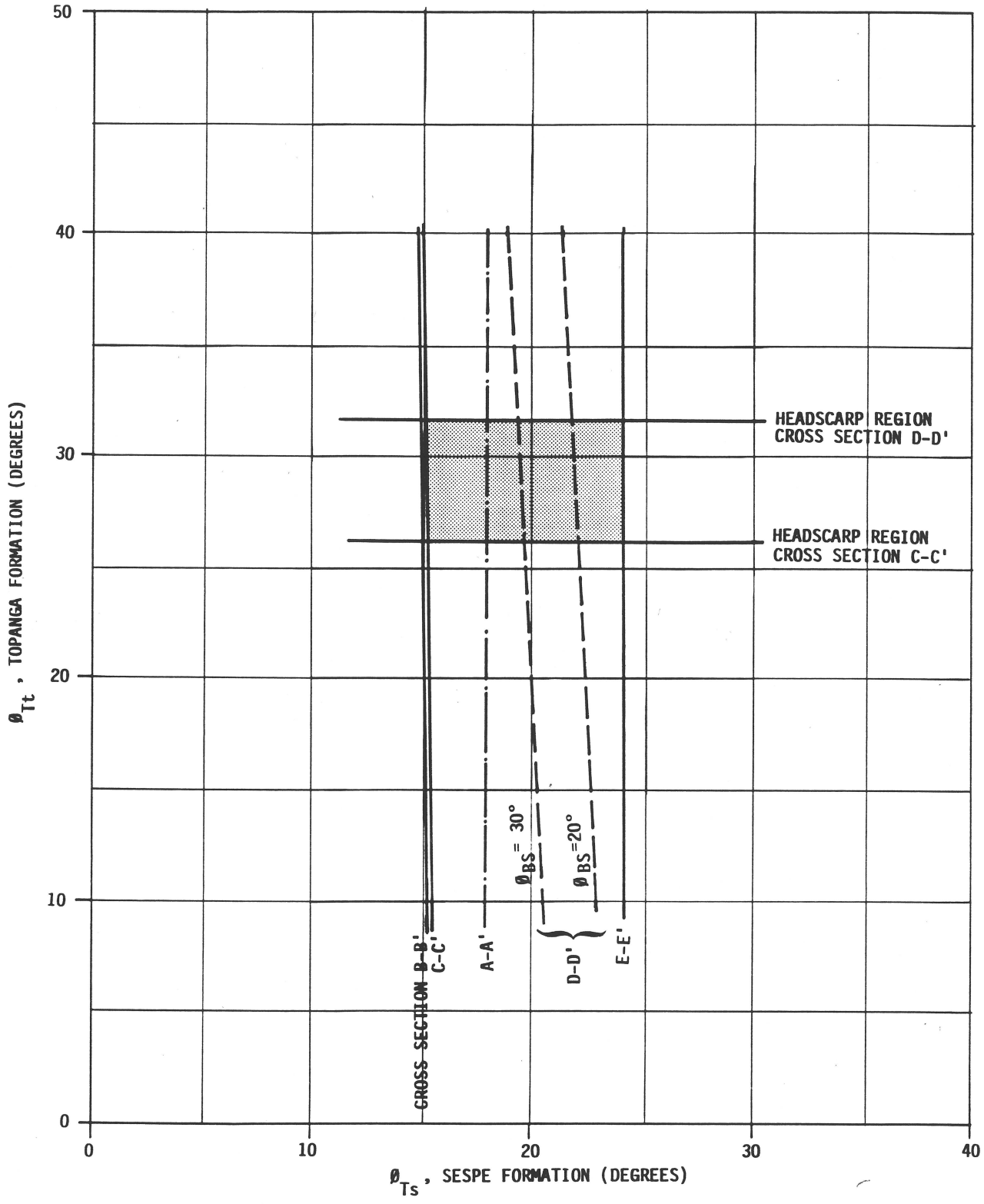
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

SLOPE STABILITY ANALYSIS;
GEOTECHNICAL CROSS SECTION E-E'

FIGURE 7-2.5



NOTE: 2-D FACTOR OF SAFETY= 1 AT 1983 GROUNDWATER LEVEL

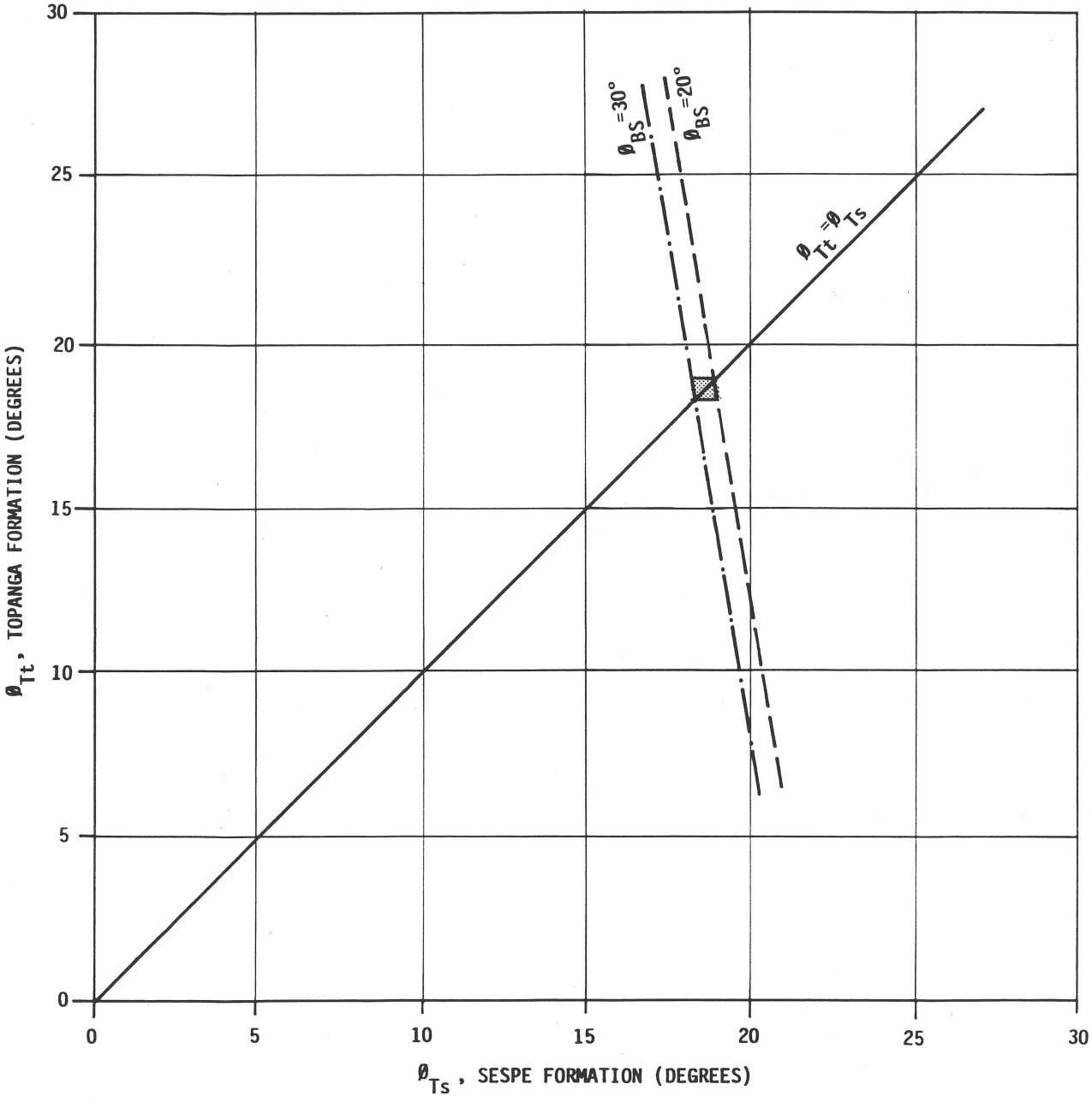
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ZONE OF VARIABILITY FOR Ø VALUES BASED ON 2-D STABILTY ANALYSIS OF MAIN BIG ROCK MESA SLIDE

FIGURE 7-2.8



ZONE OF Ø VALUE VARIABILITY

NOTE: 3-D FACTOR OF SAFETY=1 AT 1983 GROUNDWATER LEVEL

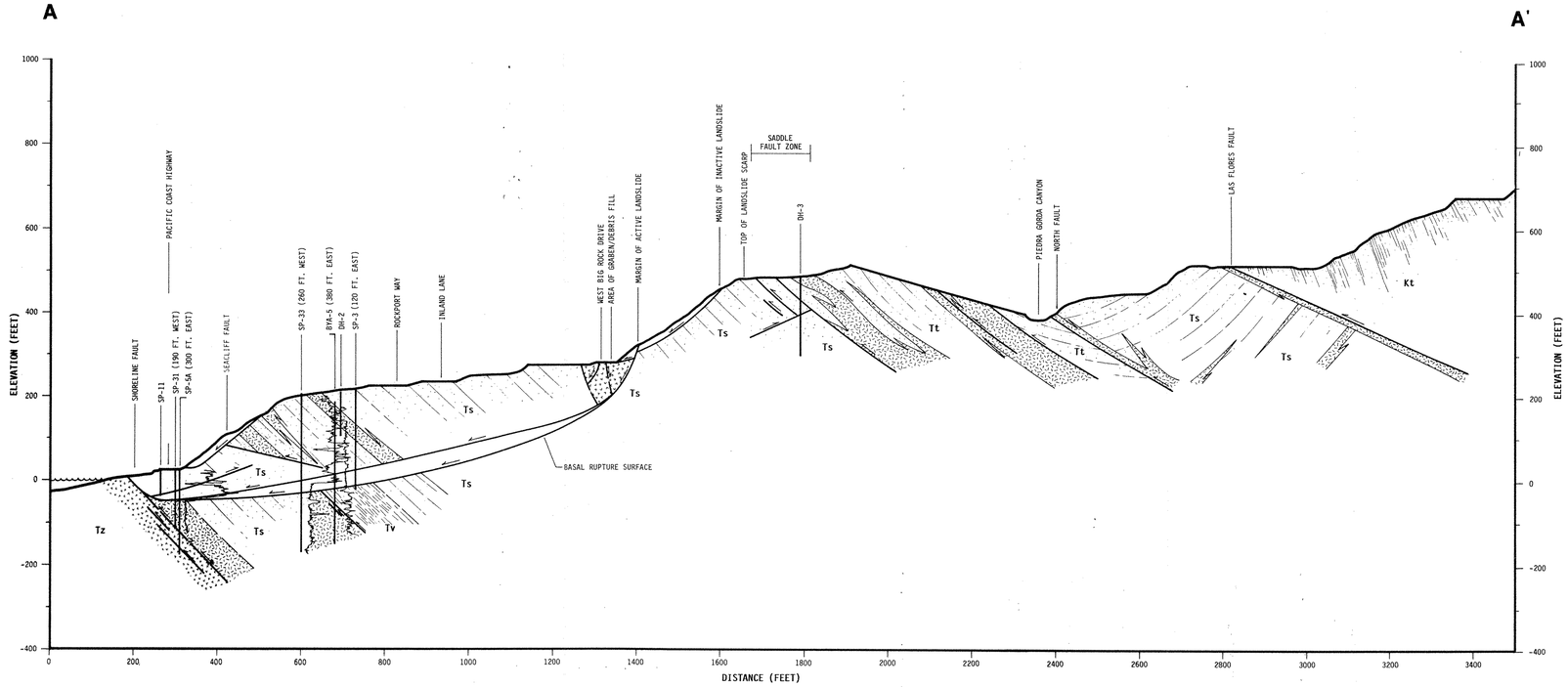
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

ZONE OF VARIABILITY FOR Ø VALUES BASED ON 3-D STABILTY ANALYSIS OF MAIN BIG ROCK MESA SLIDE

FIGURE 7-2.9



EXPLANATION

- Kt — TUNA CANYON FORMATION
- Ts — SESPE FORMATION
- Tt — TOPANGA FORMATION
- Tv — VAQUEROS FORMATION
- Tz — ZUMA VOLCANICS
- CONEJO VOLCANICS-INTRUSIVE ROCKS
- TECTONIC BRECCIA/GRABEN DEBRIS ZONE
- APPROXIMATE LOCATION OF INSTRUMENTATION/WELL OR BORING
- SIGNATURE OF GAMMA RAY LOGGING
- INDICATES RELATIVE MOVEMENT ALONG FAULT OR LANDSLIDE SURFACE

0 200 400 FEET

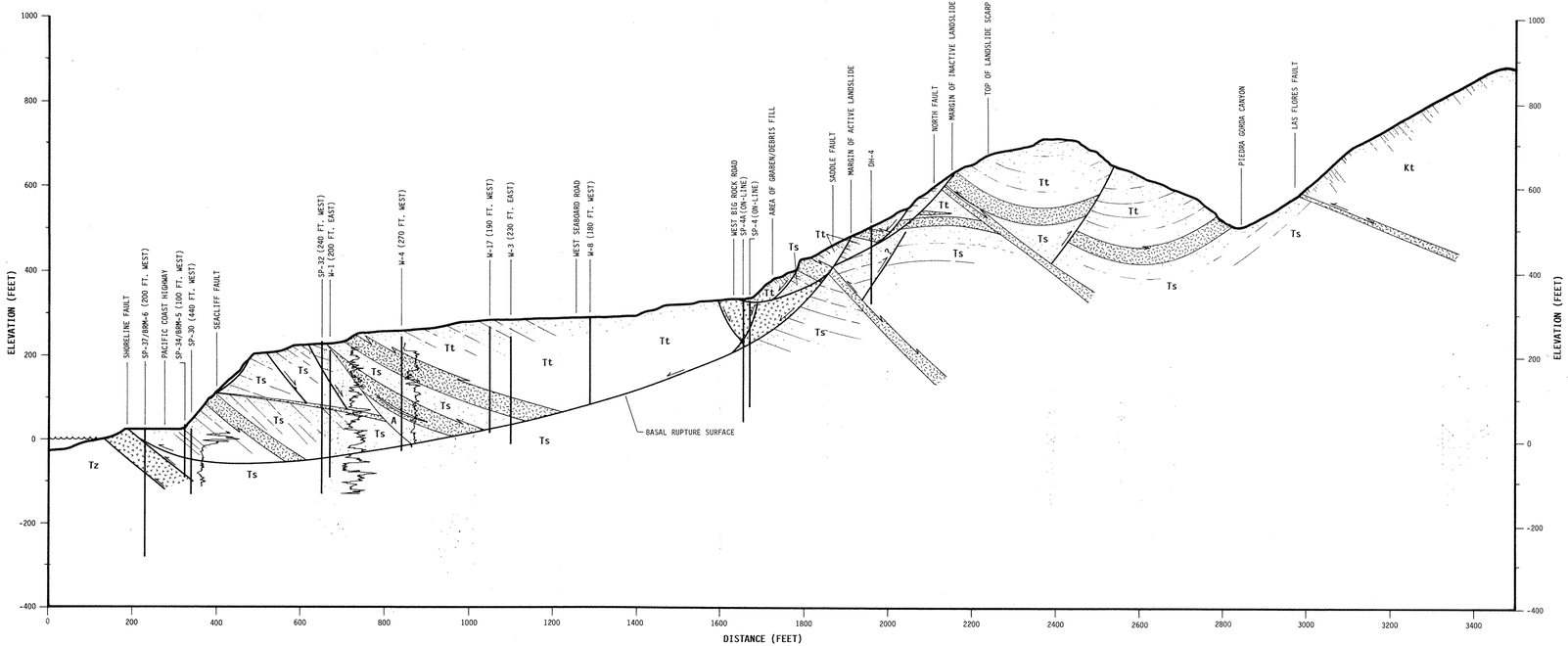
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION A-A'

FIGURE 4-1.4



EXPLANATION

- Kt — TUNA CANYON FORMATION
- Ts — SESPE FORMATION
- Tt — TOPANGA FORMATION
- Tv — VAQUEROS FORMATION
- Tz — ZUMA VOLCANICS
- CONEJO VOLCANICS-INTRUSIVE ROCKS
- TECTONIC BRECCIA/GRABEN DEBRIS ZONE
- APPROXIMATE LOCATION OF INSTRUMENTATION/WELL OR BORING
- SIGNATURE OF GAMMA RAY LOGGING
- INDICATES RELATIVE MOVEMENT ALONG FAULT OR LANDSLIDE SURFACE

0 200 400 FEET

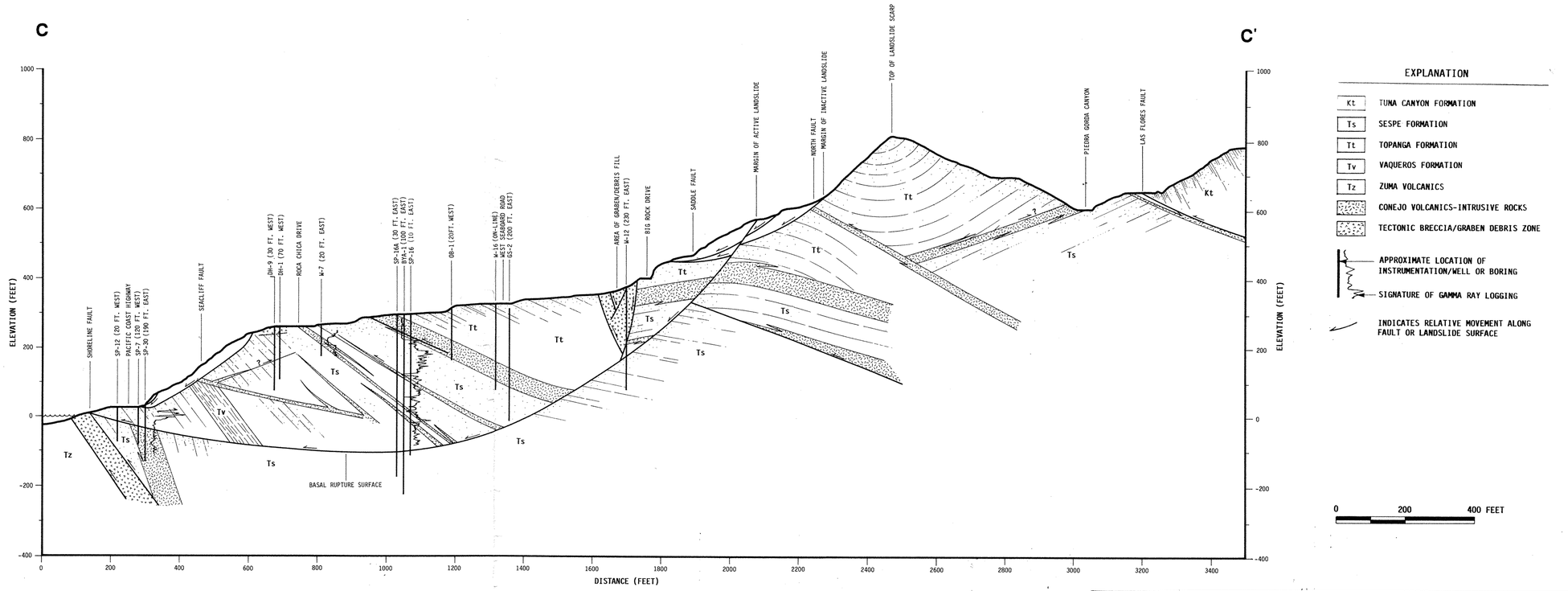
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION B-B'

FIGURE 4-1.5



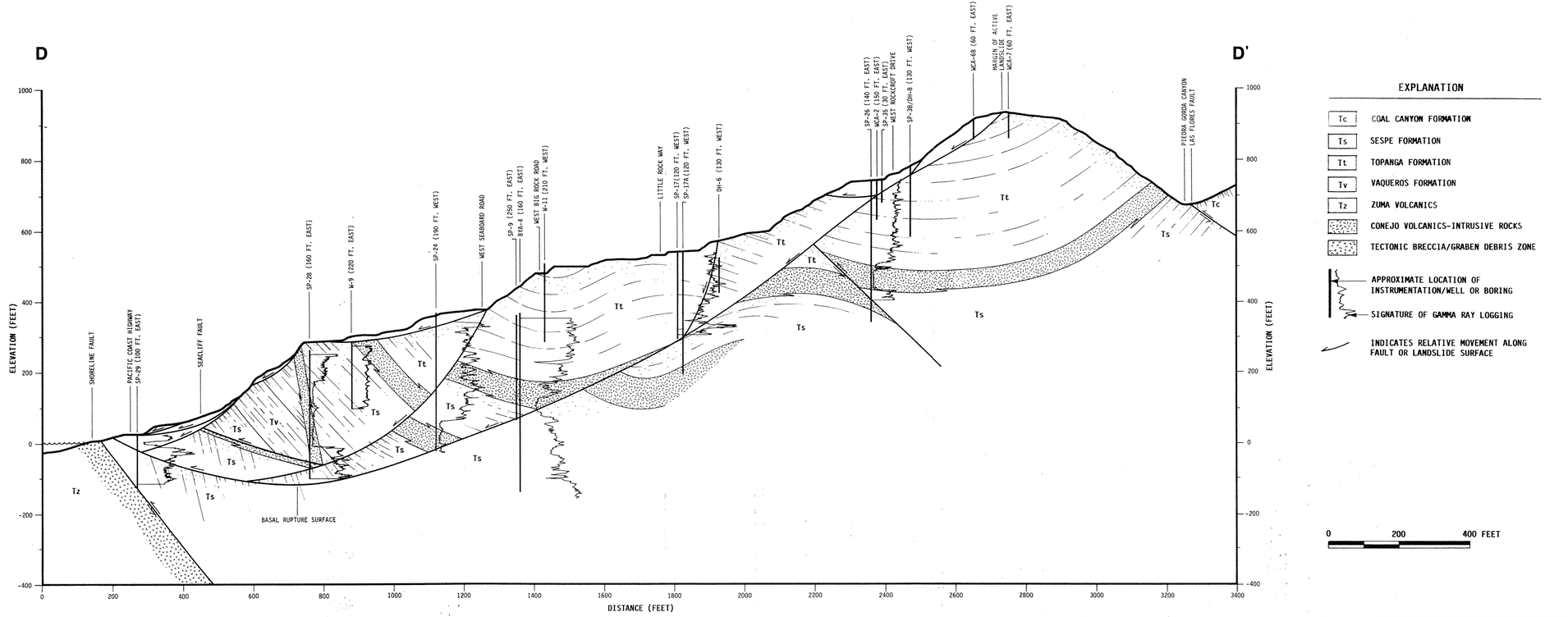
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION C-C'

FIGURE 4-1.6



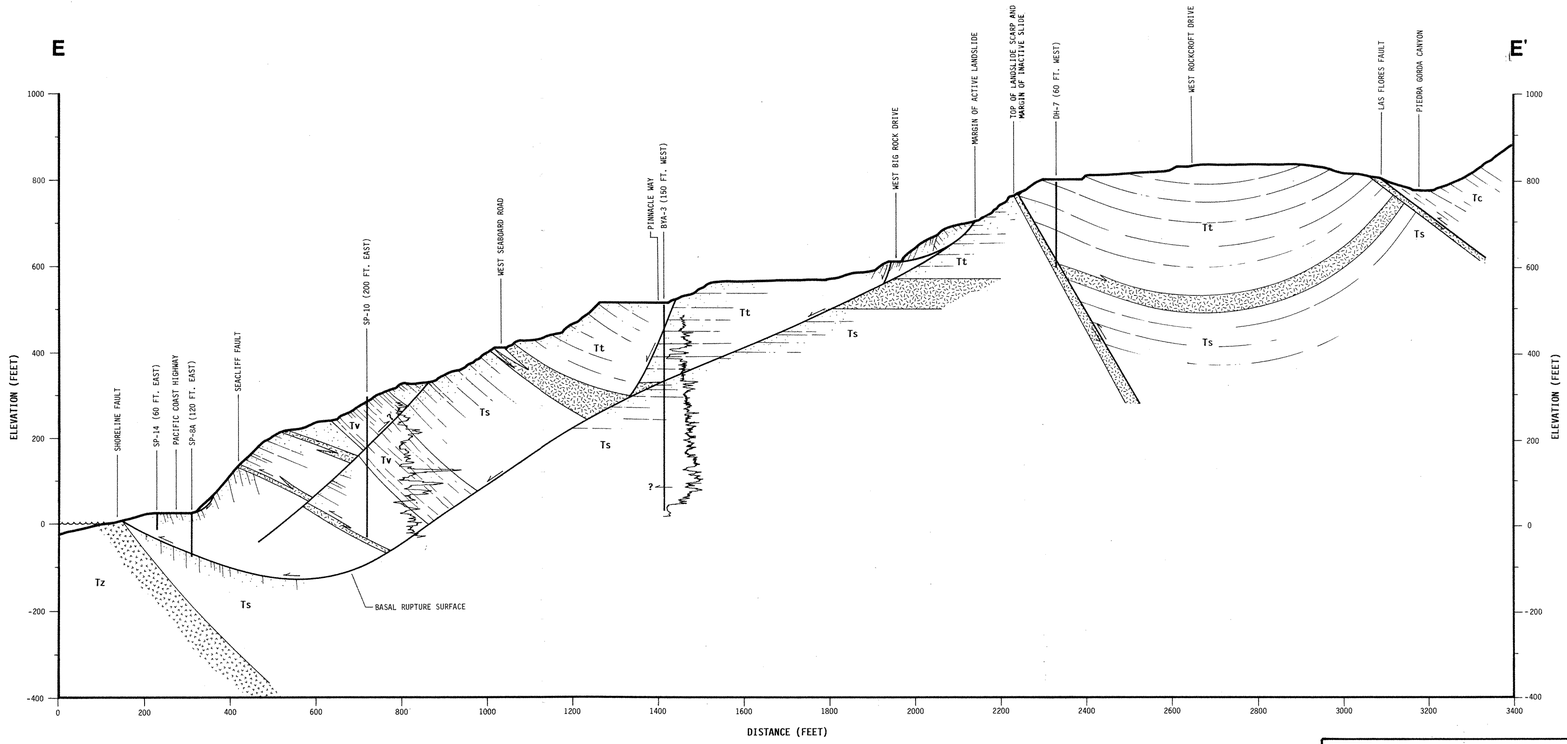
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION D-D'

FIGURE 4-1.7



EXPLANATION

- Tc — COAL CANYON FORMATION
- Ts — SESPE FORMATION
- Tt — TOPANGA FORMATION
- Tv — VAQUEROS FORMATION
- Tz — ZUMA VOLCANICS
- CONEJO VOLCANICS-INTRUSIVE ROCKS
- TECTONIC BRECCIA/GRABEN DEBRIS ZONE
- APPROXIMATE LOCATION OF INSTRUMENTATION/WELL OR BORING
- SIGNATURE OF GAMMA RAY LOGGING
- INDICATES RELATIVE MOVEMENT ALONG FAULT OR LANDSLIDE SURFACE

0 200 400 FEET

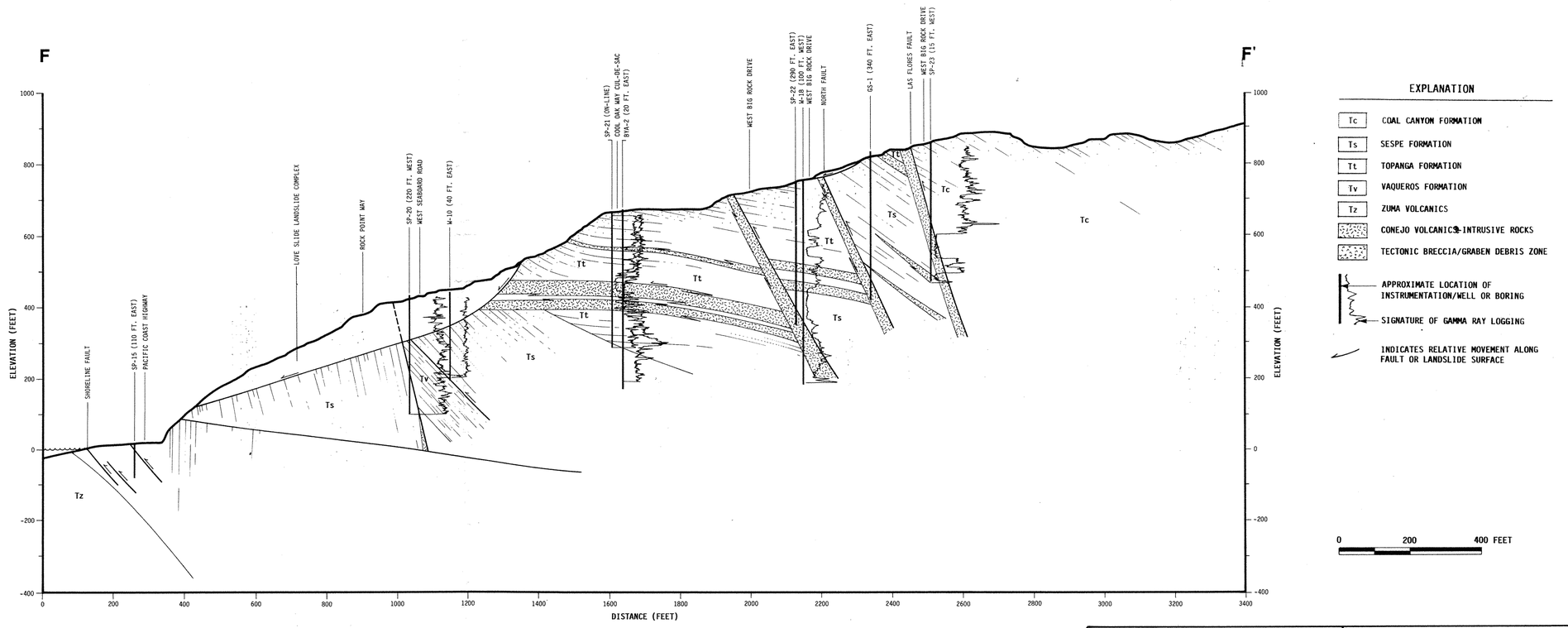
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION E-E'

FIGURE 4-1.8



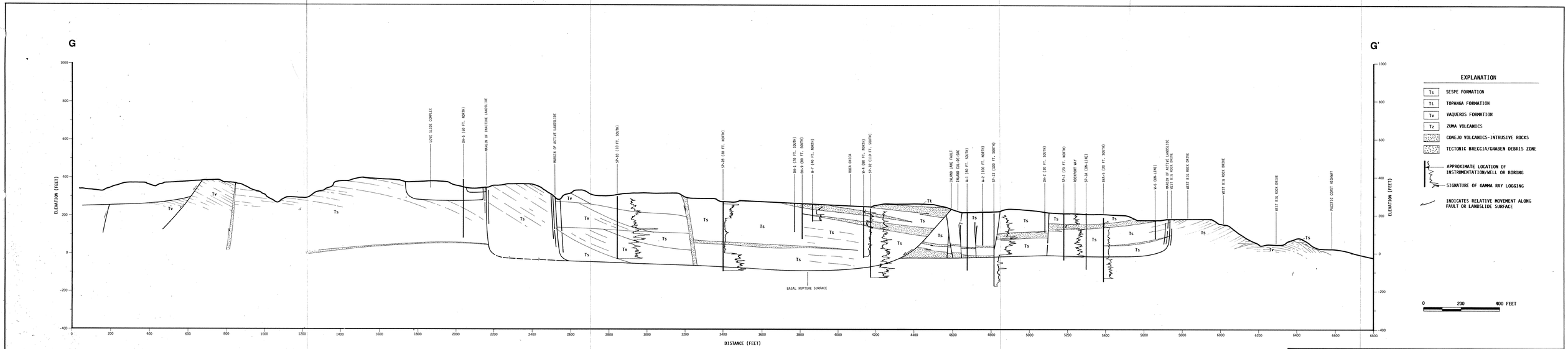
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION F-F'

FIGURE 4-1.9



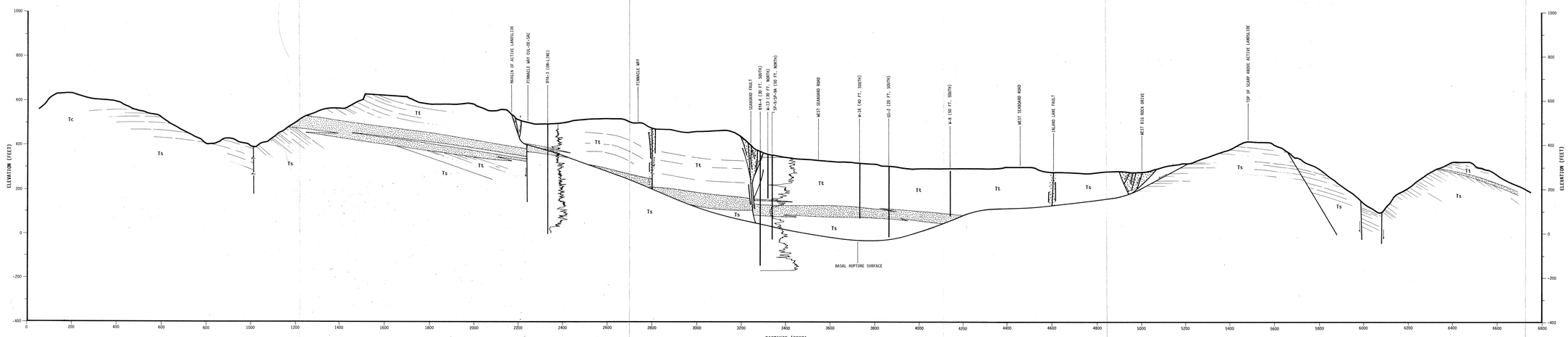
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION G-G'

FIGURE 4-1.10



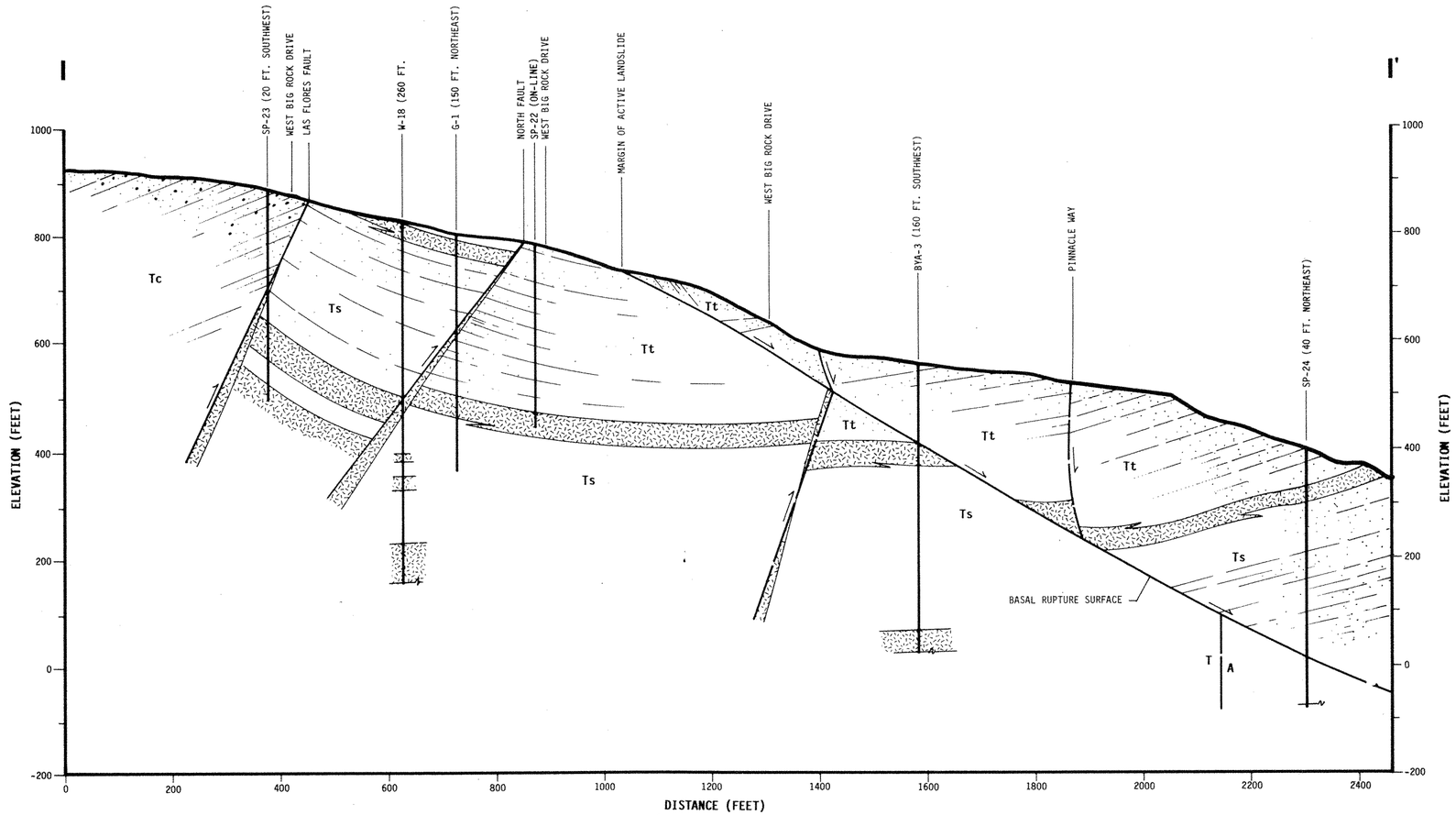
BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION H-H'

FIGURE 4-1.11



EXPLANATION

- Tc — COAL CANYON FORMATION
- Ts — SESPE FORMATION
- Tt — TOPANGA FORMATION
- Tv — VAQUEROS FORMATION
- Tz — ZUMA VOLCANICS
- CONEJO VOLCANICS-INTRUSIVE ROCKS
- TECTONIC BRECCIA/GRABEN DEBRIS ZONE
- APPROXIMATE LOCATION OF INSTRUMENTATION/WELL OR BORING
- SIGNATURE OF GAMMA RAY LOGGING
- INDICATES RELATIVE MOVEMENT ALONG FAULT OR LANDSLIDE SURFACE

0 200 400 FEET

BING YEN & ASSOCIATES

BIG ROCK MESA GEOTECHNICAL ENGINEERING EVALUATION

PROJECT NO.: 49-97D | DATE: DECEMBER 1991

GEOTECHNICAL CROSS SECTION I-I'

FIGURE 4-1.12



EXPLANATION

- ○ DEWATERING WELLS REDEVELOPED (DECEMBER 1988)
- ◒ DEEP DEWATERING WELL
- ● MULTI-STAGE PNEUMATIC PIEZOMETER
- ◍ SLOPE INCLINOMETER, MULTI-STAGE PNEUMATIC PIEZOMETER
- (3-89) DATE WELL/INSTRUMENTATION COMPLETED
- □ PASSIVE GAMMA RAY LOG
- ┼ DUAL INDUCTION LOG AND/OR MULTI-ELECTRODE DIPMETER
- △ ACOUSTIC VELOCITY LOG
- ◇ TILTMETER LOCATION
- HYDRAUGER CLEANED AND SOUNDED (SEPTEMBER 1991)
- MINIMUM LENGTH OPEN PER SOUNDING
- INSTALLED LENGTH
- MULTI-POINT BOREHOLE EXTENSOMETER (MPBX)

N

0 200 400 600 FEET

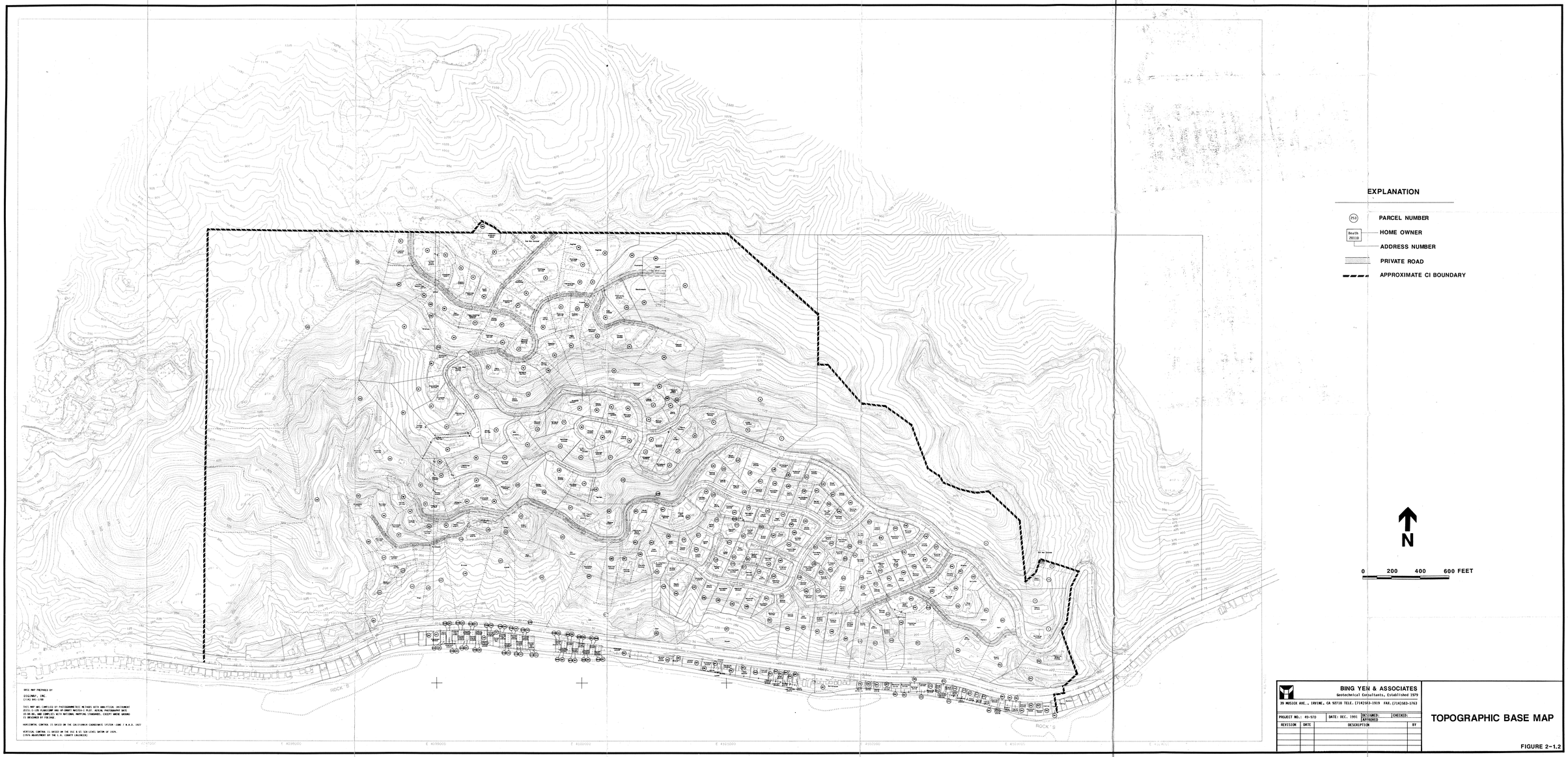
BING YEN & ASSOCIATES
Geotechnical Consultants, Established 1978
39 MOSCOW AVE., IRVINE, CA 92718 TELE.(714)583-1919 FAX.(714)583-1763

PROJECT NO.: 49-970 | DESIGNED: | CHECKED: | APPROVED: | DATE: DEC. 1991

REVISION	DATE	DESCRIPTION	BY

SUMMARY OF FIELD IMPROVMENTS AND EXPLORATIONS BY BYA

FIGURE 3-2.1



BASE MAP PREPARED BY
AERIAL MAP, INC.
(714) 841-1300

THIS MAP WAS COMPILED BY PHOTOGRAMMETRIC METHODS WITH ANALYTICAL INSTRUMENT (KELSH) 5-LENS PLANIMETRIC AND HYDROMETRIC MATRICA PLOT. AERIAL PHOTOGRAPHY WAS 10-00-00, AND COMPLIES WITH NATIONAL MAPPING STANDARDS, EXCEPT WHERE NOTED IS DESCRIBED BY FOLIAGE.

HORIZONTAL CONTROL IS BASED ON THE CALIFORNIA COORDINATE SYSTEM (ZONE 7 N.A.D. 1927

VERTICAL CONTROL IS BASED ON THE USC & GS SEA LEVEL DATUM OF 1929.
(1976 ADJUSTMENT BY THE L.A. COUNTY ENGINEER)

E 4095000 E 4096000 E 4097000 E 4098000 E 4099000 E 4100000 E 4101000 E 4102000 E 4103000 E 4104000

BING YEN & ASSOCIATES
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REVISION	DATE	DESCRIPTION	BY

TOPOGRAPHIC BASE MAP

FIGURE 2-1.2