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TR-809-1

HYPOTHESIS TESTING FOR RESOURCE EVALUATION

An Application to Geothermal Potential
Estimation in Nevada

October 1978

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FOREWORD

This document describes a continuing application of a hypothesis testing methodology developed by TASC to the evaluation of geothermal resources in the state of Nevada. Clayton R. Nichols of the U.S. Department of Energy and David L. Williams of the U.S. Geological Survey both offered helpful suggestions; technical contributions were also made by TASC Consultant, Peter L. Briggs. Programming support was provided by Gary P. Bogar. The first phase of this effort was performed under contract with the U.S. Geological Survey and has been reported in TASC document TR-682-1 dated 1 March 1977. The present effort includes documentation of computer programs developed to implement the methodology; these are discussed in a companion report, TR-809-2.

ABSTRACT

A hypothesis testing methodology for the statistical integration of diverse data types has been further investigated. In an earlier study the technique was developed and applied, with limited data, to evaluation of the geothermal potential of Nevada. That effort has been extended in this report to include the implementation of data on major lineaments and surface lithology. Information from the new data bases is integrated with that from the seismicity and small scale linear data previously studied. The new data added in this study has improved the results considerably. A number of new areas appropriate for further, more detailed geophysical investigation are indicated by high likelihood ratios.

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1. INTRODUCTION

1.1 BACKGROUND

Though the geosciences have become quite sophisticated, their application to exploration for many resources is still in its infancy. Little is known, for example, about the occurrence of geothermal anomalies. Apart from occasional surface manifestations in the form of hot springs, hydrothermal alterations and obvious volcanic activity, the presence of geothermal energy is generally unrecognized. Theoretical models for such occurrences are not well developed, and only a limited number of heat flow determinations are available because of the considerable expense of obtaining such data. Similar types of comments could be made regarding knowledge of the occurrence of uranium and other important earth resources.

Most geophysical and geochemical exploration methods have been developed for the discovery of oil, natural gas or the metallic ores. Though a wealth of data exists, its application to exploration for geothermal energy and some other important resources is, to a certain degree, subjective. In addition, the diversity of data becoming available strains the ability of the human mind to assimilate the information.

In response to these problems a hypothesis testing methodology has been developed (Ref. 1) which is capable of resolving in a structured statistical fashion the discriminating aspects of a specified resource. This technique employs any number of selected data resources. Some potential candidates are indicated in Fig. 1.1-1. The method determines mathematically those patterns or characteristic signatures which can be used to differentiate (probabilistically) regions

Figure 1.1-1 Some Possible Data Sources for Hypothesis Testing as Applied to Geothermal Resource Evaluation

containing the desired resource from those areas which do not. The statistical signature of the specified resource is determined from a learning set. In this study the learning set is comprised of known high temperature hot springs in Nevada. Their statistical characteristics or signature then serve to differentiate areas of similar nature from the balance of the region of interest.

In some ways the technique used here is similar to more traditional multivariate discriminant analysis. It

differs, however, in the end result. The product of this method is an expression of the mathematical likelihood that the resource is present in the test area. A contour map of the test area can easily be created from the calculated likelihood functions; this will show the relative probability of finding the resource in any particular area.

This method might also be considered analogous to the "pattern recognition" technique described in Ref. 2. While that technique is based upon a binary presence or absence consideration of various recognition factors, the TASC methodology evaluates statistically the continuous distributions of selected signature parameters.

It must be emphasized that the hypothesis testing methodology described here is a powerful new adjunct for the geoscientist. It has been designed to complement rather than supplement his interpretive abilities.

1.2 PREVIOUS WORK

In a previous study for the U.S. Geological Survey (USGS), TASC developed the hypothesis testing methodology and applied it to geothermal anomalies in the state of Nevada (Ref. 1). Two data bases were used. The first was an historical record of seismic activity, provided by NOAA and containing 10,900 events in the region of interest. The second was a file of 7638 linear features (presumed faults and joints) in Nevada; these were identified and digitized by the USGS from a LANDSAT composite image.

Data extracted from both of these sources provided interesting results. The study did successfully demonstrate

the feasibility of hypothesis testing for geothermal resource exploration. The addition of new data, however, would theoretically result in a further improvement of that resource evaluation.

1.3 STUDY OBJECTIVES

The original purpose of the effort reported here was to integrate surface geologic and gravity data (with correlative topographic data) into the previous evaluation of geothermal resources in Nevada (Ref. 1). Unfortunately, the gravity and topographic data bases did not become available in time. The effort was then redirected toward a more complete evaluation of the surface geologic data.

One aspect of surface geology had been addressed during the previous study through the analysis of linear features. That work has been extended in the current work, with some changes in approach, to include major lineaments -- linear features of much greater extent. A second aspect of the current program has been concerned with analysis of the surface lithology. The intent was to discern and integrate the information implicit in mapped geologic units at the surface. Geologists routinely interpret rock chemistry and lithology to provide insights to geologic history, paleoenvironments, and the nature of dynamic processes affecting the crust. The objective of this study has been to determine whether statistical methods can successfully be applied to the integration of information derived from these data sources for the evaluation of geothermal resources.

1.4 REPORT ORGANIZATION

The statistical methodology developed for the USGS is reviewed in Section 2.1. The test region, grid base, and learning set are defined and data sources, deliverable programs, and previous results discussed in the balance of Chapter 2.

The approach and results of analyses on major lineaments and surface geology are presented in Chapters 3 and 4, respectively. Covariance analysis and likelihood calculations for the integrated evaluation of the data are given in Chapter 5, followed by conclusions and recommendations in Chapter 6.

2. HYPOTHESIS TESTING FOR RESOURCE EVALUATION

2.1 HYPOTHESIS TESTING CONCEPT

The classification of geophysical characteristics, or signatures, according to implied resource potential is a problem well-suited to hypothesis testing. Specific geological and geophysical characteristics have long been associated with natural resources. Magnetic anomalies, for example, have been particularly useful in locating large deposits of iron ore. The intensity and width of the anomaly are key features for consideration, but frequency spectra of these anomalies are also used in order to infer source depth.

Seismic, gravity and electrical techniques are, of course, widely used exploration tools. The utility of information provided by such geophysical measurements is often, however, limited by the ability for data interpretation and integration. Too often there is major difficulty in reconciling the information provided by different types of geological and geophysical survey data. For this reason, the techniques described herein are especially attractive. They lead naturally to a formulation that uses all data in a rational manner for evaluating the relative resource potential.

Hypothesis testing supposes that a number of hypotheses (situations of interest), $H_1, \dots, H_n$, can exist, and that one desires to establish the probability that each hypothesis exists at a site, given a set of site signature parameters. The nature of these parameters, or indices, will be discussed shortly.

Of primary interest is the positive hypothesis, that the desired resource, geothermal energy in this case, does exist at the specified site. The values of site signature parameters associated with this hypothesis are determined from a learning set. This set is comprised of sites where the resource is, in fact, known to exist; for the geothermal study it is a group of high temperature hot springs. These are in essence assumed to be samples from a single generic class of the desired resource.

An appropriate contrasting hypothesis is that no geothermal resources exist at a particular location -- the "null hypothesis". If site data were available at locations known to be unproductive, this data might be used to support such a hypothesis. In lieu of hard data to that effect, we assume for an alternative hypothesis that geothermal energy is generally absent and that the signature of the large region under study is representative of that absence. Such an assumption is justified if the percentage of the region that actually contains geothermal energy is small. Summarizing then, the hypotheses that will be tested are:

- H_1 : The data at a site are samples of a population belonging to a set of known geothermal resource areas
- H_0 : The data at a site are samples of a population typical of a large region which is generally lacking in geothermal resources.

The problem is to determine in a quantitative sense which of the hypotheses is best represented by the data at each location. Such a decision is never unambiguous. Therefore, a formulation which embodies these alternative hypotheses in a continuously defined, scalar likelihood ratio is used for evaluating the relative merit of exploration in various areas.

The first step in the method is to calculate signature indices for each point on a gridded representation of the survey area. These indices may simply be measured values, such as gravity or magnetic anomalies, or they may be values derived from a data source through some appropriate preprocessing. In the previous study, for example, an historical record of all seismic events was analyzed to determine several indices of earthquake activity. One index was defined as the number of seismic events occurring within a specified radius of each grid point. These indices are intended to embody a quantitative measure of specific features that are identified by earth scientists as being related to the hypothesis of interest.

The rationale for specifying preprocessing algorithms is subjective, based on experience and intuition. Although much current research is devoted to the subject of defining optimal preprocessing algorithms for pattern recognition, there is no definite and unique algorithm for performing this operation. The utility of hypothesis testing lies in separation of the preprocessed signature in a way that allows discrimination between the alternate hypotheses defined.

Mathematically the technique may be viewed as computing the probability of the positive hypothesis given a vector, $\underline{x}$, representing the site signature indices evaluated at a particular location. In general, the probability that the i^{th} hypothesis is true, given the data at a particular site, is written as $P(H_i | \underline{x})$ and is given by the well known Bayes' Rule,

$$P(H_i | \underline{x}) = \frac{P(\underline{x} | H_i) P(H_i)}{P(\underline{x})} \quad (2.1-1)$$

where $P(\underline{x}|H_i)$ is the probability that $\underline{x}$ is the signature that would be measured at the site if the hypothesis H_i is satisfied. $P(H_i)$ is the a priori probability that the i^{th} hypothesis is true and $P(\underline{x})$ is the a priori probability that the specific signature, $\underline{x}$, will be observed. A more convenient form of Eq. 2.1-1 allows for the fact that signatures at sites for which a particular hypothesis is true are not always identical, but have some spread of values. This spread is characterized by a probability density function of the signature indices. Accordingly, $P(H_i|\underline{x})$ is given by,

$$P(H_i|\underline{x}) = \frac{p(\underline{x}|H_i) P(H_i)}{p(\underline{x})} \quad (2.1-2)$$

where the probability density functions (lower case p) are expressed as functions of the vector space (all possible values) of site signature indices in which $\underline{x}$ resides.

In theory, for each site within the region to be evaluated, $P(H_i|\underline{x})$ could be computed according to Eq. 2.1-2. The terms $p(\underline{x}|H_i)$ and $p(\underline{x})$ are the conditional and unconditional probability density functions. In particular, with the normal distribution assumed for each of the signature indices represented in $\underline{x}$,

$$p(\underline{x}|H_i) = \frac{1}{(2\pi)^{n/2} \sqrt{|M_i|}} \exp \left\{ -\frac{1}{2} (\underline{x} - \underline{m}_i)^T M_i^{-1} (\underline{x} - \underline{m}_i) \right\} \quad (2.1-3)$$

where the mean vectors and covariance matrices are defined by

$$\underline{m}_i = E_{H_i} \{ \underline{x} \} \quad \text{an } n \text{ vector} \quad (2.1-4a)$$

$$M_i = E_{H_i} \{ (\underline{x} - \underline{m}_i)(\underline{x} - \underline{m}_i)^T \} \quad \text{an } n \times n \text{ matrix} \quad (2.1-4b)$$

and where

$E_{H_i} \{ \} =$ Expectation of the argument taken over all locations for which H_i is true. ($i = 0$ or 1 corresponding to the alternate hypotheses.)

In practice, $\underline{m}_i$ and M_i must be estimated from the signatures in the usual manner for estimating the mean and standard deviation from a finite number of samples of a random variable, i.e.,

$$\underline{m}_i = \frac{1}{N} \sum_{u,v} \underline{x}(u,v) \quad (2.1-5a)$$

$$M_i = \frac{1}{(N-1)} \sum_{u,v} \left\{ \left[\underline{x}(u,v) - \underline{m}_i \right] \left[\underline{x}(u,v) - \underline{m}_i \right]^T \right\} \quad (2.1-5b)$$

where N is the number of independent data points used for evaluation over the span of spatial coordinates, u,v . Other distributions might also be considered for evaluating $p(\underline{x}|H_i)$. However, since the normal distribution is completely specified by the mean and variance, it is usually more attractive. In certain cases when the distribution of the index is clearly non-normal, a transformation of variables may be suggested to convert the data into a form more suitable for the normality assumption.

The term $P(H_i)$ in Eq. 2.1-2 refers to the unconditional probability that hypothesis H_i is true. In effect it represents an average probability that H_i is true over the entire region under study. The denominator, $p(\underline{x})$, is in effect a normalizing parameter, taking into account the finite

probability of getting the measurement $\underline{x}$ from a population including all H_1 . It should be noted that the essential part of the expression in Eq. 2.1-2 which permits discrimination is the term $p(\underline{x}|H_1)$, which is defined for a normal distribution in Eq. 2.1-3.

One approach for deciding between alternate hypotheses is to evaluate the probabilities as defined by Eq. 2.1-2 for the alternate hypotheses H_1 and H_0 and choose H_1 corresponding to the greater of $P(H_1|\underline{x})$ and $P(H_0|\underline{x})$. Alternatively, the likelihood ratio (Ref. 3) may be evaluated as

$$\Lambda(\underline{x}) = \frac{p(\underline{x}|H_1)}{p(\underline{x}|H_0)} \quad (2.1-6)$$

Values of Λ higher than unity would then suggest the hypothesis H_1 is correct and vice versa for Λ less than unity.

Combining Eqs. 2.1-3 and 2.1-6

$$\Lambda = \sqrt{\frac{|M_0|}{|M_1|}} \frac{P(H_1)}{P(H_0)} \exp \{C_0 - C_1\} \quad (2.1-7)$$

where

$$C_1 = \frac{1}{2} (\underline{x} - \underline{m}_1)^T M_1^{-1} (\underline{x} - \underline{m}_1) \quad (2.1-8)$$

The ratio $P(H_1)/P(H_0)$ is a constant determined by a priori probability of the alternate hypotheses. This is generally unknown except in thoroughly explored areas, which are of little interest here. However, the ratio is not of importance in defining a figure of relative merit. For this purpose Eq. 2.1-7 may then be simplified to

$$\Lambda \triangleq \sqrt{\frac{|M_0|}{|M_1|}} \exp \{C_0 - C_1\} \quad (2.1-9)$$

giving a readily calculated expression for the relative likelihood of the specified hypotheses.

2.2 THE TEST SITE

The test site for evaluation of this methodology was defined to be essentially the entire state of Nevada. This selection was made at the beginning of the study for the USGS. The object was to study a region for which several different data types were available, which contained well-recognized geothermal activity, and all of which consisted of a geologically similar domain. Nevada was chosen as it met these criteria and, lying within the Basin and Range Province as shown in Fig. 2.2-1, provided the potential for expansion to other areas of interest.

To enable numerical correlation of the data a spatial grid was first defined. Consideration of initial data sources, data management, and exploration value led to the selection of an eight kilometer spacing. The grid actually developed is an equal area array initialized somewhat to the southeast of Nevada at latitude 34°N and longitude 113°W . Grid points were located by measuring eight kilometer increments northward along the meridian to determine the rows of the array. Each row was subsequently extended westward along the associated latitude in eight kilometer increments to define the columns. Consequently, each row lies exactly in a geographic east-west line, and that column coincident with longitude 113°W is precisely north-south. Moving westward, however, each column is aligned slightly more to the west of north because of the equal area design.

Figure 2.2-1 Nevada with Reference to the Basin and Range Province

There are actually 4551 grid points within the Nevada state border. A number of these are, however, masked out before final data processing to minimize undesirable edge effects.

2.3 THE LEARNING SET

The methodology developed requires utilization of a learning set upon which the statistical signature of the desired resource will be based. For this evaluation of the geothermal resources of Nevada a number of hot springs exist

upon which such a set may be based. White and Williams of the USGS define forty-five such springs with indicated subsurface temperatures ranging from 105°C to 240°C (Ref. 4). Accepting some penalty to the statistical significance of this effort, it was determined during the earlier study that only those springs with subsurface temperatures greater than 150°C should be used in the learning set. The rationale was that these represented higher quality springs, more representative of the resource sought. The question of whether there may be any real generic difference between those and the lower temperature springs has not been addressed in this study.

A further loss to the learning set resulted due to the proximity of one of the springs to the state border. Since much of the data being considered was available only for points within the state, utilization of that spring would have created edge effect biasing.

The final learning set consisted of seventeen known hot springs. Table 2.3-1 gives their name, location, and temperature and dimensional data. Their locations are also shown graphically in Fig. 2.3-1.

2.4 INPUT DATA SOURCES

Two major considerations effect the use of data in the resource evaluation; these are applicability and availability. In the case of this Nevada geothermal study, encompassing such a large geographic region (over 2.9×10^5 km²), availability has often been the limiting factor. One would prefer, of course, to select data bases according to their expected information content. With the advent of significantly advanced satellite sensing systems and nationwide data acquisition programs such as the National Uranium

TABLE 2.3-1
CHARACTERISTICS OF HOT SPRINGS USED FOR NEVADA
GEOTHERMAL LEARNING SET

T0288a

Regional Name	Location (deg,min)		Temperature Estimates (deg Centigrade)				Size Properties			
	Latitude	Longitude	Surface	S ₁ O ₂	Na-K-Ca	Subsurface	Subsurface Area (km ²)	Thickness (km)	Volume (km ³)	Heat Content 10 ⁸ Calories
Pinto H.S.	41 21.0	118 47.0	93	162	176	165	5.0	1.5	7.5	0.7
Great Boiling Sprs.	40 39.7	119 21.7	86	167	205	170	10.0	2.5	25.0	2.3
Hot Sulphur Springs	41 28.2	116 09.0	90	167	184	185	1.5	1.5	2.2	0.2
Near Wells	41 10.9	114 59.4	61	140	181	180	1.5	1.5	2.2	0.2
Sulphur H.S.	40 35.2	115 17.1	93	183	181	190	4.0	2.5	10.0	1.1
Beowawe H.S.	40 34.2	116 34.8	NA	226	242	240	21.0	2.0	42.0	5.7
Kyle H.S.	40 24.5	117 52.9	77	161	211	180	1.5	1.5	2.2	0.2
Leach H.S.	40 36.2	117 38.7	96	155	176	170	4.0	2.5	10.0	0.9
Hot Springs Ranch	40 45.7	117 29.5	85	150	100	180	1.5	1.5	2.2	0.2
Jersey Valley H.S.	40 10.7	117 29.4	29	143	182	185	1.5	1.5	2.2	0.2
Stillwater Area	39 31.3	118 33.1	96	159	140	160	10.0	2.5	25.0	2.2
Soda Lake	39 34.0	118 49.0	90	165	161	165	5.0	2.5	12.5	1.1
Brady H.S.	39 47.2	119 00.0	98	182	NA	214	12.0	2.5	30.0	3.6
Steamboat Springs	39 23.0	119 45.0	96	207	226	210	6.0	2.7	16.0	1.9
Wabuska H.S.	39 09.7	119 11.0	97	145	152	155	1.5	1.5	2.2	0.2
Lee H.S.	39 12.6	118 43.4	88	173	162	175	1.5	1.5	2.2	0.2
Smith Creek Valley	39 21.4	117 32.8	86	143	157	160	1.5	1.5	2.2	0.2

NA = Not Available

Data Source: Ref. 4.

Resource Evaluation (NURE) availability may soon be less of a problem. It is almost certain, in fact, that data integration methods like the one discussed here will become a prerequisite to interpretation of the large volumes of information anticipated.

Figure 2.3-1 Locations of Hot Springs Used for Nevada Geothermal Learning Set

During the previous study for the USGS two data bases for the state of Nevada were identified. Both were implemented in a demonstration of the hypothesis testing methodology. The first was a digitized data file of seismic events provided by NOAA. This file, describing all earthquakes and aftershocks recorded since 1834, contained records of over 19,000 events. The file was edited to eliminate "non-tectonic events" and those events with epicenters lying outside the primary region

of interest leaving a total of 10,900 events. In order to eliminate a possible bias due to the fact that all recording stations were located west of the region of interest, a separate file was defined in which events whose local magnitude was estimated as less than 3.5 on the Richter Scale were also deleted. A total of 3,019 events remained in this file. The second data source evaluated for the USGS was a file of digitized linear features in Nevada. This record, identified and digitized by USGS personnel working with a LANDSAT composite image, contained a total of 7,638 straight line segments, each generally less than twenty kilometers in length.

Both of these data sources were investigated in depth for the USGS and the results reported in a project final report (Ref. 1). Other data sources have also become available and the integration of two of these is investigated in this report. Section 3 reports on the use of major lineaments, features exceeding one hundred kilometers in length, discerned from LANDSAT imagery. Section 4 is concerned with rock type occurrence and distribution in Nevada. Both of these new data sources were found to add substantially to the integrated information content of the total data base with regard to assessment of geothermal resources.

In principle any additional information will further improve and refine the resultant likelihood assessment. Most significant, perhaps, would be new data relating to the deep crustal structure of the region. As noted previously, it had been anticipated that a gravity data base for the state would be available for this study. Though that data is still not complete, an appropriate, digitized aeromagnetic data base of Nevada has recently been compiled. In addition, the NURE Program will soon provide considerable hydrogeochemical data which may be of significant value to the geothermal assessment problem.

Integration of any of these new data sources could add substantially to the evaluation of geothermal resources in Nevada.

2.5 IMPLEMENTATION

The data processing procedures for this hypothesis testing methodology are outlined graphically in Fig. 2.5-1. Given the selected data sources a preprocessing phase is initiated. This includes a general analysis and, if required, editing of the raw data base. Preprocessing also includes statistical analysis of the data which may be performed to examine regional variations and to aid in the development of meaningful indices for discrimination.

It is important to recognize that preprocessing data analysis and index generation are interactive processes. The success of the methodology is strongly dependent upon meaningful participation and contributions by the geoscientist. In this study that role was particularly important in the preliminary assessment of the lithologic data. Frequency of occurrence and spatial distributions of the various rock units were both evaluated to aid in the development of meaningful indices.

The calculation of index values is the output of the preprocessing step. As will become evident later in this report, many indices can rationally be produced from one raw data source. Indices could take many forms; examples from this study are the distance to the nearest major lineament intersection and the distance to the nearest occurrence of a particular rock type.

In come cases, the geoscientist may recognize that several indices contain more information when synergistically

R-24308

Figure 2.5-1

Data Processing Overview - Hypothesis Testing for Resource Evaluation

evaluated as a unit than as the sum of their individual contributions. Such was the case in this study where Paleozoic carbonates were evaluated as a unified miogeosynclinal facies rather than as separate carbonate unit.

All of these considerations lead to the realization of one fundamental objective -- to maximize the information derived from the data sources. Utilization of that information, contained in indices, can also be taken as an iterative process. The entire hypothesis testing data sequence may be exercised, whereupon the analyst may determine new information that can be obtained from the input data. New indices may be generated and the entire sequence repeated. The success criteria are determined by the technical personnel most familiar with the resource being evaluated.

Ultimately a number of indices will be selected for their potential to discriminate occurrences of the desired resource. If the index distributions are non-Gaussian, a non-linear, normalizing transformation may be performed. This is done to satisfy the assumption of normality introduced in the development of equations in Section 2.1. The method is discussed fully in the final report of the earlier study for the USGS (Ref. 1). After appropriate transformations have been made the new indices are merged with any pre-existing indices, usually those generated from other raw data sources. This merging procedure simply places all candidate indices together in a common format. Two data bases actually result. Each contains information for all indices, but one consists of data and statistics for all grid points in the region being evaluated and the other for only those points in the learning set.

Given the merged indices, program COVAR can be run. This computes covariance and correlation matrices for selected

indices extracted from the data bases. In addition, a set of eigenvectors is computed, along with the eigenvalues, and stored in a file for subsequent transformation of the data in the likelihood evaluations. Finally, the program LIKE performs the relative likelihood calculation using the statistics generated from COVAR. The output from LIKE may be input into any mapping routine desired for graphical display. Further discussion of these procedures and associated numerical considerations may be found in Ref. 1.

The procedures outlined above require numerous computer programs for data editing, filtering, and evaluation, index generation and transformation, and data base management. Two programs developed for this study are, however, of particular utility. These are programs COVAR and LIKE referred to above and in Fig. 2.5-1. Complete descriptions and listings of these programs may be found in a companion report (Ref. 5).

2.6 PREVIOUS RESULTS

During the earlier study of the geothermal resources of Nevada (Ref. 1) a total of thirty-one indices were generated. Twelve of these were derived from the seismic data base and the remainder from the LANDSAT linears. Subsequently, twenty-one of these were transformed to insure that each had a Gaussian distribution. Eight of this subset were seismic indices. After further evaluation thirteen of the indices were selected for further analysis using the programs COVAR and LIKE, discussed in Section 2.5.

Seven cases were studied, each comprised of from one to seven indices. The most successful case consisted of the seven indices described in Table 2.6-1. These represent

TABLE 2.6-1
MOST SUCCESSFUL INDICES DEVELOPED
IN USGS STUDY

DESCRIPTION
Average released seismic strain in 16 km circle
Total length of linears partially or totally within an 8 km circle
Length of linears in a 16 km circle striking between 15 and 20 deg
Length of linears in a 16 km circle striking between 25 and 30 deg
Length of linears in a 16 km circle striking between 30 and 35 deg
Length of linears in a 16 km circle striking between 95 and 100 deg
Length of linears in a 16 km circle striking between 100 and 105 deg

average released strain in recorded seismic events, the total length of LANDSAT linears proximate to a given point, and several indices based upon selected azimuth classes of those LANDSAT linears. The reader is referred to Ref. 1 for a complete discussion of the calculation, selection and evaluation of those indices.

The output of program LIKE for the case described above is presented graphically in Fig. 2.6-1; the locations of learning set hot springs are indicated with circles. This case results in a computed likelihood ratio greater than one for all but two of the hot springs in the learning set and provides a reasonably high degree of selectivity throughout the entire state in its assessment of geothermal resources. Because of these considerations it has been chosen as a basis to which the new data from the present study will be added. Figure 2.6-1 and all similar likelihood ratio maps in this report are not to scale because they are generated directly on the computer printer.

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Figure 2.6-1 Likelihood Ratio Map for Most Successful Case from USGS Study

3.

MAJOR LINEAMENT ANALYSIS

3.1 DATA SOURCE AND APPROACH

As discussed in Section 2.4, a data base of linear features identified from LANDSAT imagery was integrated into the previous geothermal study for the USGS (Ref. 1). Implementation of that data sought to convey information regarding structural control on crustal permeability and the near surface distribution of hot springs water.

All of those (assumed) fractures previously analyzed are rather small scale features, generally no longer than twenty kilometers. Other investigators have, however, discerned larger scale features within this region. Rowan and Wetlaufer presented an analysis of seven major lineament systems (Ref. 6) as related to ore mineralization in Nevada (Ref. 7). This lineament data was also identified from a LANDSAT photomosaic of the state. One of these lineament zones, the Midas Trench system, extends from near Lake Tahoe approximately 500 kilometers to the northeast into Idaho. Aeromagnetic data suggests a continuation to and possibly beyond the Yellowstone region (Ref. 7). The other lineament systems identified by Rowan and Wetlaufer are somewhat shorter and trending in various directions. None of the others are parallel to the Midas Trench.

For the purposes of the present study the twenty-five fracture segments mapped by Rowan (Ref. 7) have been represented as eleven straight line features, each at least one

Figure 3.1-1 Major Lineaments in Nevada Considered in this Study

hundred kilometers in length, as shown in Fig. 3.1-1. Integration of this data is a logical extension of the rationale for study of the small scale linears. With the larger scale lineaments, however, one is attempting to gain information regarding deep crustal and upper mantle structures as they relate both to the presence of heat producing bodies and to mechanisms for the upward transfer of that heat. Heated fluids or partially molten material may reach the surface most readily

via these zones of crustal weakness. If the near-surface thermal anomalies associated with geothermal areas are supplied with heat from deeper sources, it is natural to expect that these LANDSAT lineaments might be loci of areas with enhanced geothermal potential. From a more causative perspective, major lineaments may mark areas extensively fractured at depth creating enhanced hydrothermal circulation. Likewise these may be areas where rising molten material is invading the crust.

3.2 INDEX GENERATION

The length of a fracture may be related to its downward extent, its age, the frequency with which it has been activated or the magnitude of the geologic processes that caused its growth. Other geometric parameters may also relate to fracture dynamics and the associated stress fields and history. Given a configuration of lineaments such as those discovered by Rowan and Wetlaufer, one can measure several properties. Consider, for example, two intersecting lineaments in a plane. Several areas are of geometrical interest and are distinguished from other locations in the plane. The points in the plane corresponding to the lineaments themselves are distinct from surrounding points; the point of intersection is distinguished both from points on either lineament and from surrounding locations; similarly the end points and midpoints of the lineaments are unique.

Lineaments have repeatedly been shown to be somewhat correlated with concentrations of certain resources; however, no universal technique for interpreting the significance of a configuration of linear features of the crust has yet been discovered. In the present study physical distance is used as a simple, direct way to describe an arbitrary

location in Nevada in relation to the geometrically unique areas associated with a system of lineaments. The character of any point can be specified in terms of its proximity to particular geometrical features of the lineament system. These considerations suggest a number of indices which are both readily calculable and provide reasonable potential as statistical measures for possible geothermal resources. Twelve different indices were defined for this study. They are listed below with a brief description of the geologic rationale for their use.

Distance from a point to the nearest lineament

(LIN. 1) - This provides a broad measure of how close a point is to an assumed mobile zone of the crust.

Distance from a point to the nearest lineament inter-

section (INT. 1) - An intersection implies not only the unique intersecting point, but also two major lineaments of different trends, perhaps developed in response to sequential periods of different tectonic activity. Regarding the Nevada lineaments, this could include response to stresses generated by rising, low density molten or plastic remnants of the Farallon plate. Depending on its strike, a fracture may be activated during one period of tectonic activity and quiet during another. Intersecting lineaments may enhance the frequency of activity at their intersection point; the crust may be most weakened and fractured at depth around lineament intersections, favoring fluid circulation and geothermal potential.

Distance from a point to the second nearest linea-

ment intersection (INT. 2) - There are two intersections within this distance, and at least three major lineaments. This index is a measure of the fracture intersection density in the vicinity of each point.

Distance from a point to the third nearest lineament intersection (INT. 3) - This index more closely reflects the density of intersections in the vicinity of each grid point. The measurement is, however, taken over a larger area than with the preceding index and is thus less specifically related to the particular location in question.

Distance from a point to the nearest lineament end point (EP. 1) - Lineament end points may be areas of stress concentration. Consequently they may represent the most recent zones of activity for whatever forces are generating and propagating the lineament.

Distance from a point to the second nearest lineament end point (EP. 2) - Two different lineaments may have terminated in a region for structural reasons. Proximity of their end points may provide evidence of such situations. Multiple end points in an area may also be expected as a result of high stress concentrations or large strain rates.

Distance from a point to the third nearest lineament end point (EP. 3) - This is also a measure of the stress, strain, and structural factors noted in regard to the previous index. It does, however, average over a larger area and is then less specific to the grid point in question.

Distance from a point to the nearest lineament midpoint (MP. 1) - This is another measure of proximity to a lineament, and possibly to the focus of whatever forces are responsible for that lineament.

Distance from a point to the second nearest lineament midpoint (MP. 2) - This is a spatial density measure for the number of lineaments near a point and for the possible foci of lineament-generating forces.

Distance from a point to the nearest lineament intersection plus distance to the nearest lineament end point (INT. 1 + EP. 1) -

Distance from a point to the nearest lineament intersection plus distance to the nearest lineament (INT. 1 + LIN. 1) -

Distance from a point to the nearest lineament plus distance to the nearest lineament end point (LIN. 1 + EP. 1) -

The last three indices are complex measures developed to give a weighting factor dependent upon the joint spatial relationship of their two components. These indices should be construed as experimental and have no specific geologic rationale or expectation.

Major lineament indices were generated using all twelve of the criteria above to evaluate the full set of eleven lineaments interpreted from Rowan's work. Additional studies were also conducted on a subset of eight lineaments thought to be more closely associated with known geothermal anomalies. All twelve index types were again calculated for this subset.

The results for all lineament index calculations are presented in Table 3.2-1. For each of the indices generated the values of the all Nevada means and standard deviations, $\bar{x}_N$ and σ_N respectively, are presented. These are followed by the correlative values for the hot springs, $\bar{x}_{HS}$ and σ_{HS} . In addition, the absolute values of the difference between the two means, normalized in turn to each of the standard deviations, are given as measures of the index discriminant potential.

TABLE 3.2-1
UNTRANSFORMED MAJOR LINEAMENT INDEX STATISTICS

INDEX	LINEAMENTS EVALUATED	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $
INT. 1	11	1.54E 02	9.71E 01	7.46E 01	3.77E 01	0.82	2.11
INT. 2	11	1.69E 02	9.47E 01	1.03E 02	3.86E 01	0.70	1.73
INT. 3	11	2.52E 02	1.24E 02	1.42E 02	6.24E 01	0.89	1.76
LIN. 1	11	6.78E 01	7.05E 01	2.13E 01	2.07E 01	0.66	2.25
EP. 1	11	8.85E 01	7.36E 01	5.56E 01	3.46E 01	0.45	0.95
EP. 2	11	1.30E 02	7.65E 01	8.67E 01	3.72E 01	0.56	1.15
EP. 3	11	1.56E 02	7.56E 01	1.03E 02	3.96E 01	0.69	1.32
INT. 1 + EP. 1	11	2.43E 02	1.63E 02	1.30E 02	5.00E 01	0.69	2.25
INT. 1 + LIN. 1	11	2.22E 02	1.62E 02	9.59E 01	4.82E 01	0.78	2.61
LIN. 1 + EP. 1	11	1.56E 02	1.42E 02	7.69E 01	3.76E 01	0.56	2.11
MP. 1	11	1.31E 02	9.13E 01	5.51E 01	3.23E 01	0.83	2.35
MP. 2	11	1.61E 02	9.13E 01	8.26E 01	3.78E 01	0.86	2.07
INT. 1	8	2.10E 02	1.44E 02	7.46E 02	3.77E 01	0.94	3.58
INT. 2	8	2.28E 02	1.39E 02	1.05E 02	4.06E 01	0.88	3.01
INT. 3	8	2.66E 02	1.28E 02	1.46E 02	6.20E 01	0.94	1.93
LIN. 1	8	6.84E 01	7.02E 01	2.13E 01	2.07E 01	0.67	2.28
EP. 1	8	1.27E 02	1.13E 02	5.56E 01	3.46E 01	0.64	2.07
EP. 2	8	1.62E 02	1.04E 02	8.78E 01	3.69E 01	0.71	2.01
EP. 3	8	1.93E 02	1.01E 02	1.05E 02	3.82E 01	0.87	2.30
INT. 1 + EP. 1	8	3.37E 02	2.53E 02	1.30E 02	5.00E 01	0.82	4.13
INT. 1 + LIN. 1	8	2.78E 02	2.09E 02	9.59E 01	4.82E 01	0.87	3.78
LIN. 1 + EP. 1	8	1.96E 02	1.79E 02	7.69E 01	3.76E 01	0.66	3.16
MP. 1	8	1.90E 02	1.46E 02	5.61E 01	3.42E 01	0.91	3.90
MP. 2	8	2.15E 02	1.36E 02	8.46E 01	4.03E 01	0.96	3.24

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

Because the indices calculated above are all somewhat non-Gaussian, a nonlinear normalizing transformation was applied to all the data. This was done to insure that the assumptions made for the likelihood calculations would be satisfied. The technique is fully described in Ref. 1, and statistics for the transformed indices are presented in Table 3.2-2. The format of this table is similar to that of Table 3.2-1, with one addition. The final column, headed "CONF.", is a confidence level indicating the probability that the hot springs mean can be distinguished from the all Nevada value for the given index.

In comparing the values in this table with those in the previous section small differences will be noted. This is primarily a consequence of the nonlinear transformation. Lesser effects also result from the fact that the statistics in Table 3.2-2 are evaluated over a slightly smaller subset of Nevada. The masking used truncates the southern-most tip as well as a very narrow band around the entire state. This is done to ensure minimization of edge effects and compatibility of all data bases.

3.3 OBSERVATIONS

The discriminant potential of many of the major lineament indices appears to be quite strong, typically 0.5 to $1.0 \sigma_N$. Since all of the mapped fractures occur in the northern two-thirds of the state, distribution was, however, a concern. It was initially thought that the indicated discrimination might be a consequence only of the distribution and not the association of hot springs with specific lineaments. To evaluate this possibility a subset consisting of the northern half of the state was evaluated. Though some degradation of the discriminant power was noted, several indices performed quite well.

TABLE 3.2-2
TRANSFORMED MAJOR LINEAMENT INDEX STATISTICS

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INDEX	LINEAMENTS EVALUATED	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $	CONF.
INT. 1	11	1.43E 02	9.03E 01	7.56E 01	5.33E 01	0.747	1.266	0.998
INT. 2	11	1.58E 02	8.89E 01	1.06E 02	5.55E 01	0.576	0.922	0.982
INT. 3	11	2.37E 02	1.18E 02	1.16E 02	1.07E 02	1.031	1.136	1.000
LIN. 1	11	5.77E 01	6.87E 01	8.79E 00	5.41E 01	0.712	0.905	0.997
EP. 1	11	8.17E 01	6.75E 01	5.47E 01	6.51E 01	0.401	0.416	0.902
EP. 2	11	1.22E 02	7.10E 01	8.71E 01	5.97E 01	0.491	0.584	0.957
EP. 3	11	1.46E 02	7.03E 01	9.66E 01	6.34E 01	0.706	0.783	0.996
INT. 1 + EP. 1	11	2.25E 02	1.53E 02	1.23E 02	1.15E 02	0.663	0.879	0.994
INT. 1 + LIN. 1	11	2.02E 02	1.53E 02	8.45E 01	9.03E 01	0.765	1.298	0.998
LIN. 1 + EP. 1	11	1.40E 02	1.34E 02	7.37E 01	1.04E 02	0.496	0.636	0.959
MP. 1	11	1.19E 02	8.60E 01	4.31E 01	6.09E 01	0.888	1.254	1.000
MP. 2	11	1.49E 02	8.50E 01	7.67E 01	5.79E 01	0.855	1.256	1.000
INT. 1	8	1.95E 02	1.39E 02	5.88E 01	7.33E 01	0.980	1.853	1.000
INT. 2	8	2.13E 02	1.34E 02	9.57E 01	7.73E 01	0.876	1.517	1.000
INT. 3	8	2.52E 02	1.21E 02	1.22E 02	1.06E 02	1.068	1.217	1.000
LIN. 1	8	5.83E 01	6.84E 01	7.74E 00	5.38E 01	0.740	0.940	0.998
EP. 1	8	1.20E 02	1.03E 02	4.91E 01	8.99E 01	0.683	0.786	0.995
EP. 2	8	1.52E 02	9.69E 01	7.20E 01	8.54E 01	0.831	0.943	0.999
EP. 3	8	1.83E 02	9.44E 01	8.41E 01	7.96E 01	1.045	1.239	1.000
INT. 1 + EP. 1	8	3.11E 02	2.42E 02	7.69E 01	1.76E 02	0.970	1.332	1.000
INT. 1 + LIN. 1	8	2.56E 02	1.99E 02	6.38E 01	1.06E 02	0.964	1.815	1.000
INT. 1 + EP. 1	8	1.78E 02	1.70E 02	5.86E 01	1.25E 02	0.702	0.949	0.996
MP. 1	8	1.76E 02	1.39E 02	2.32E 01	8.81E 01	1.099	1.729	1.000
MP. 2	8	2.01E 02	1.30E 02	5.05E 01	8.85E 01	1.151	1.696	1.000

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

Most notable were distance to the third nearest lineament intersection and distance to the first and second nearest mid-points. The calculated confidence level for these indices further emphasizes their potential.

A second consideration was the subjective assessment of the lineaments themselves. It appeared that the southernmost three of these features were unrelated to geothermal energy, in that there was no obvious association between them and the learning set hot springs. To test this, indices were calculated using both the preferred eight and all eleven of the major lineaments. Though some improvement in discrimination was seen using only the eight lineaments, the effect was not judged substantial enough to justify the subjectivity introduced. Likelihood calculations using indices based on all eleven lineaments would, of course, highlight areas associated with the additional three in comparison with indices from the limited data. Recognizing that this may be a debatable issue, both sets of indices have been included in the unified data base for further analysis.

In reviewing any of the index statistics it is important to understand that a high discriminant factor does not necessarily imply that geothermal occurrences are either positively or negatively associated with the feature being addressed. Referring to Table 3.2-1, it can be seen, evaluating all eleven lineaments, that the nearest intersection is on the average 75 km from each hot spring, approximately half the distance for the average point in Nevada. Looking at the data for the nearest lineament, however, it can be seen that hot springs are typically 21 km away. In the spatial sense there is a much closer tie between hot springs and lineaments than with the lineament intersections. Yet because of the spatial distribution of these features the intersections serve as a

superior discriminating index. In each case the analysis implies that there is a characteristic, generally non-zero distance between the hot springs and the observed feature.

3.4 SUMMARY

The locations of known hot springs in Nevada were analyzed with respect to the distribution of major lineaments, as mapped from a LANDSAT photomosaic of that state. Twenty-four signature indices were calculated from this lineament data to assess its utility in discriminating geothermal resources. Preliminary statistics generated from these indices were reviewed and all were found to have significant discriminant potential. The entire set of twenty-four major lineament indices were merged into a common data base for further evaluation (see Chapter 5).

4. SURFACE GEOLOGY ANALYSIS

4.1 DATA SOURCE AND APPROACH

The second data source to be evaluated in this study was a map of the surface geology of Nevada. The reference used was the "Preliminary Geologic Map of Nevada", compiled by John H. Stewart and John E. Carlson, and published by the U.S. Geological Survey in 1974 (Ref. 8). That publication was prepared in cooperation with the Nevada Bureau of Mines and Geology. It differentiates 101 separate units, generally at the formation or group level. The map is presented in two sheets at a scale of 1:500,000. Independent Lambert conformal conic projections are used for the two halves.

To implement this data TASC undertook the digitization of the reference map. The sheets were first hand-gridded in conformity with the system previously specified for this study. The geology associated with each grid point was subsequently recorded according to the procedure described below. For this purpose a mask of six kilometer radius was employed. The mask dimension was chosen so as to provide one hundred percent coverage with minimal averaging or overlap. The surface geology could be reasonably defined for a total of 4551 points.

For each point all rock formations lying within the mask were noted. This information was then entered in a digitized file for further study. The coding utilized to describe the rock types was an alphanumeric derived from the standard geologic notation employed on the source map.

Table 4.1-1 lists these codes in alphabetic sequence along with their correlative geologic codes and a brief description. Further information regarding these units is available from Ref. 8. Two formations keyed on the map legend were never identified in the digitization process. These were a Triassic quartz monzonite (TRGR) occurring in northern Esmeralda County and a massive, Mississippian limestone (ML) mapped in the San Antonio Mountains of western Nye County. Further checking indicated aggregate exposures for these formations of approximately one and four square kilometers, respectively. Changes in the data base were not made as this was considered well within the range of error that should be expected for data extraction given the 1:500,000 scale and the quality of the preliminary source sheets.

Special record was made of the dominant rock type within the mask area at each grid point. In this regard, however, Nevada presents some significant problems. The purpose of this effort was to establish a data base potentially useful in discriminating geothermal anomalies. Much of Nevada is actually covered with evaporites, alluvium or other allochthonous Quarternary sediments. There was virtually no expectation that these would serve as useful discriminants. For this reason the decision was made to record as the dominant rock type the most widely distributed formation excluding a selected set of sedimentary units. This exclusion list consisted of Quaternary and undifferentiated Quarternary-Tertiary alluvium (QA and QTOA) and Quarternary playa, landslide and morainal deposits (QP, QLS and QM). Record of the presence of these formations was made; they were eliminated only from the specialized "dominant" rock type file.

There were grid points for which no formations except those on the exclusion list were found within the mask area. For these points record of that fact was made by entering

TABLE 4.1-1
NEVADA GEOLOGIC MAP ROCK TYPE CODES

CODE	GEOLOGIC CODE	DESCRIPTION
DC	Dc	Devonian dolomite and limestone
DEC	DCc	Undifferentiated Lower Paleozoic dolomite and limestone
DESV	DCsv	Undifferentiated Lower Paleozoic eugeosynclinal rocks
DS	Ds	Devonian eugeosynclinal rocks
DSL	Dsl	Devonian Slaven Chert
DT	Dt	Devonian argillaceous limestone, chert and shale
EC	Ec	Cambrian limestone and dolomite
EH	Ch	Cambrian Harmony Formation
EPEQ	CpCq	Cambrian quartzite
EPES	CpCs	Cambrian phyllitic siltstone, quartzite and carbonates
ESC	Csc	Cambrian Scott Canyon Formation
ESS	Css	Cambrian sandstone and quartzite
ET	Ct	Cambrian shale and limestone
JD	Jd	Jurassic Dunlap Formation
JGB	Jgb	Jurassic gabbroic complex
JGR	Jgr	Jurassic quartz monzonite and granodiorite
JPU	JPu	Permian to Jurassic volcanogenic sedimentary rocks
JTRA	JRa	Triassic-Jurassic Aztec Sandstone
JTRS	JRs	Triassic-Jurassic shale, sandstone and carbonate rocks
JTRV	JRvs	Triassic-Jurassic shale, sandstone and volcanogenic rocks
JV	Jv	Jurassic volcanic sandstone, tuff and rhyolite
KGR	Kgr	Cretaceous quartz monzonite and granodiorite
KJD	KJd	Jurassic-Cretaceous diorite
KJIM	KJim	Jurassic-Cretaceous igneous and metamorphic complex

TABLE 4.1-1 (Continued)

CODE	GEOLOGIC CODE	DESCRIPTION
KS	Ks	Cretaceous continental sedimentary rocks
MC	Mc	Mississippian limestone
MDMC	MDmc	Devonian-Mississippian conglomerate, limestone and phyllite
MDS	MDs	Devonian-Mississippian shale, sandstone and limestone
*NL	Ml	Mississippian massive limestone
MSV	Msv	Mississippian siliceous and volcanic rocks
MZGR	Mzgr	Mesozoic quartz monzonite and granodiorite
OC	Oc	Ordovician carbonates, shale and quartzite
OEC	OEc	Cambrian-Ordovician dolomite and limestone
OET	OEt	Cambrian-Ordovician phyllite, shale and limestone
OS	Os	Ordovician eugeosynclinal rocks
OSV	Osv	Ordovician siliceous and volcanic rocks
OT	Ot	Ordovician shale, chert and limestone
PC	Pc	Permian cherty limestone
PCD	Pcd	Pennsylvanian limestone and chert-pebble conglomerate
PEGR	pEgr	Precambrian granitic rocks
PEM	pEm	Precambrian gneiss and schist
PEQS	pEqs	Precambrian quartzite, conglomerate and carbonates
PES	pEs	Precambrian Wyman Formation
PMC	PMc	Mississippian to Permian carbonates and shale
PMH	PMh	Mississippian to Permian Havallah sequence
PNC	Pc	Pennsylvanian limestone
PPA	PPa	Pennsylvanian-Permian Antler sequence
PPC	PPc	Pennsylvanian-Permian limestone
PPCD	PPcd	Pennsylvanian-Permian limestone, siltstone and conglomerate
PSC	Psc	Permian siltstone, sandstone, carbonates and gypsum
PZSP	Pzsp	Paleozoic serpentinite

*Formation not occurring in the digitized map

TABLE 4.1-1 (Continued)

CODE	GEOLOGIC CODE	DESCRIPTION
QA	Qa	Quaternary alluvial deposits
QLS	Qls	Quaternary landslide deposits
QM	Qm	Quaternary morainal deposits
QP	Qp	Quaternary playa deposits
QTA	QTa	Tertiary-Quaternary andesite flows and breccias
QTB	QTB	Tertiary-Quaternary basalt flows
QTOA	QToa	Tertiary-Quaternary alluvial deposits
QTR	QTr	Tertiary-Quaternary rhyolite flows and shallow intrusives
QTS	QTs	Tertiary-Quaternary sedimentary rocks
SC	Sc	Silurian dolomite
SE	Se	Silurian Elder Sandstone
SOC	S0c	Ordovician-Silurian dolomite
SS	Ss	Silurian shale and chert
ST	St	Silurian limestone, siltstone and chert
TA1	Ta1	Lower Tertiary andesite flows and breccias
TA2	Ta2	Middle Tertiary andesite flows and breccias
TA3	Ta3	Upper Tertiary andesite flows and breccias
TB	Tb	Tertiary basalt flows
TBA	Tba	Tertiary andesite and basalt flows
TBG	Tbg	Tertiary Banbury Formation
TBR	Tbr	Tertiary breccias
TGR	Tgr	Tertiary quartz monzonite and granodiorite
THS	Ths	Tertiary Horse Spring Formation
TI	Ti	Tertiary granitic to dioritic intrusives
TJGR	TJgr	Jurassic to Tertiary quartz monzonite and granodiorite
TKS	TKs	Cretaceous and Tertiary continental sedimentary rocks
TKSU	TKsu	Cretaceous-Tertiary undifferentiated continental sedimentary rocks
TMI	Tmi	Tertiary mafic and intermediate intrusives

TABLE 4.1-1 (Continued)

CODE	GEOLOGIC CODE	DESCRIPTION
TOB	Tob	Lower Tertiary basalt flows
TRC	Tc	Triassic limestone and conglomerates
TRCH	Tch	Triassic Chinle Formation
*TRGR	Tgr	Triassic quartz monzonite
TRI	Tri	Tertiary rhyolitic intrusives
TRK	Tk	Triassic Koipato Group
TRLG	Tlgr	Triassic leucogranite and rhyolite porphyry
TRMT	Tmt	Triassic Moenkopi and Thaynes Formations
TRPD	Tpd	Permian-Triassic Diablo and Candelaria Formations
TRPS	Tps	Permian-Triassic silty limestone and greenstone
TRPV	Tpvs	Permian-Triassic andesitic flows and breccias
TRT	Trt	Tertiary rhyolitic flows, shallow intrusives and tuffs
TR1	Tr1	Lower Tertiary rhyolitic flows and shallow intrusives
TR2	Tr2	Middle Tertiary rhyolitic flows and shallow intrusives
TR3	Tr3	Upper Tertiary rhyolitic flows and shallow intrusives
TS1	Ts1	Lower Tertiary sedimentary rocks
TS2	Ts2	Middle Tertiary tuffaceous sedimentary rocks
TS3	Ts3	Upper Tertiary tuffaceous sedimentary rocks
TTS	Tts	Tertiary undifferentiated ash-flow tuffs and tuffaceous sedimentary rocks
TT1	Tt1	Lower Tertiary silicic ash-flow tuffs
TT2	Tt2	Middle Tertiary silicic ash-flow tuffs
TT3	Tt3	Upper Tertiary silicic ash-flow tuffs

*Formation not occurring in the digitized map

"NONE" in the dominant file, but also recording in a supplementary file the name of the nearest formation not on the exclusion list.

From the digitized geologic map various types of indices might have been generated. A measure of the spatial density could have been developed with an index similar to those used for the seismic data (e.g., number of events within mask area) in the earlier study (Ref. 1). Here, however, one is not looking at discrete events which occurred at specific locations. Rather, a geologic formation, or mapped unit, is defined over one or more semicontinuous regions, each in general encompassing a number of grid points.

The occurrence of a rock type for a particular grid point says nothing about the area over which that rock exists, only that it does exist within the mask region. Any attempt to integrate occurrences over numerous grid points to approximate the fractional area of occurrence might produce misleading results. In consideration of this factor it was decided to utilize a "nearest occurrence" index as was calculated for the lineament data. Here the index value was simply the distance to the nearest grid point with respect to which the selected rock type had been identified during the digital mapping exercise. A minor exception to this is introduced with the calculation of "micro" indices, discussed in Section 5.2. Otherwise, however, the expression, nearest occurrence of a specified rock type, should be understood to mean the nearest grid point within six kilometers of which the rock type occurs.

A significant disadvantage in this type of index is its inherent non-Gaussian distribution. This factor is further aggravated by the semi-contiguous nature of rock formation definition and occurrence. The data can still be appropriately transformed, but with some degradation of the information

content. This matter will be more fully discussed later in the report.

4.2 PREPROCESSING ANALYSIS

The first task in evaluating the new data base was to determine the frequency of occurrence of the various rock types both for the entire state of Nevada and for selected regions within it. Statistics for statewide rock type occurrence are given in Tables 4.2-1(a) and 4.2-1(b); the first table gives statistics for a composite, or aggregated, file developed from the digitization of the state geologic map. This file contains a record for the occurrence of each separate rock type associated with each of the 4551 designated grid points in Nevada. The second table presents similar statistics for the dominant file of statewide rock occurrence. This includes records of only the single, spatially predominant rock types occurring within a six kilometer radius of each grid point. As discussed in the previous section, certain rock units were excluded in the tabulation of the dominant file. The statistics given in both of these tables are the frequency of occurrence of each rock type within the specified file, and the percentage of the total file records in which each rock type appears. Similar statistical studies were made on the regional partitions illustrated in Fig. 4.2-1. The actual data from these regional studies is presented in Appendix A.

Consideration of rock type characteristics in the vicinity of hot springs was considered to be of particular importance. The hot springs were first studied from the perspective of four regional clusters referred to below as geothermal areas. These are illustrated in Fig. 4.2-2. They were selected subjectively and defined so as to be approximately

TABLE 4.2-1(a)
COMPOSITE ROCK TYPE OCCURRENCE STATISTICS FOR
DIGITIZED GEOLOGIC MAP OF NEVADA

ROCK TYPE	FREQUENCY	PERCENT	ROCK TYPE	FREQUENCY	PERCENT
DC	693	3.709	PZSP	3	0.016
DEC	42	0.225	QA	3680	19.695
DESV	19	0.102	QLS	112	0.599
DS	13	0.070	QM	13	0.070
DSL	33	0.177	QP	416	2.226
DT	9	0.048	QTA	18	0.096
EC	414	2.216	QTB	152	0.813
EH	25	0.134	QTOA	254	1.359
EPEQ	218	1.167	QTR	5	0.027
EPES	52	0.492	QTS	38	0.203
ESC	4	0.021	SC	246	1.317
ESS	19	0.102	SE	8	0.043
ET	69	0.369	SOC	130	0.696
JD	25	0.134	SS	6	0.032
JGB	27	0.145	ST	67	0.359
JGR	110	0.589	TA1	282	1.509
JPU	15	0.080	TA2	325	1.739
JTRA	42	0.225	TA3	356	1.905
JTRS	257	1.590	TB	318	1.702
JTRV	128	0.685	TBA	607	3.249
JV	11	0.059	TBG	93	0.498
KGR	192	1.028	TBR	34	0.182
KJD	76	0.407	TGR	78	0.417
KJIM	30	0.161	THS	48	0.257
KS	24	0.128	TI	35	0.187
MC	148	0.792	TJGR	79	0.423
MDMC	14	0.075	TKS	33	0.177
MDS	455	2.435	TKSU	16	0.086
MSV	5	0.027	TMI	49	0.262
MZGR	308	1.648	TOB	16	0.086
NONE	174	0.931	TRC	106	0.567
OC	506	2.708	TRCH	32	0.171
OEC	44	0.235	TRI	19	0.102
OET	50	0.268	TRK	44	0.235
OS	156	1.049	TRLG	7	0.037
OSV	173	0.926	TRMT	118	0.632
OT	5	0.027	TRPD	10	0.054
PC	235	1.258	TRPS	3	0.016
PCD	4	0.021	TRPV	55	0.294
PEGR	25	0.134	TRT	40	0.214
PEM	82	0.439	TR1	258	1.381
PEQS	57	0.305	TR2	184	0.985
PES	23	0.123	TR3	648	3.468
PMC	53	0.284	TS1	78	0.417
PMH	157	0.840	TS2	79	0.423
PNC	26	0.139	TS3	1031	5.518
PPA	61	0.326	TTS	207	1.108
PPC	529	2.831	TT1	106	0.567
PPCD	23	0.123	TT2	1241	6.642
PSC	273	1.461	TT3	649	3.473

TABLE 4.2-1(b)
DOMINANT ROCK TYPE OCCURRENCE STATISTICS
FOR DIGITIZED GEOLOGIC MAP OF NEVADA

ROCK TYPE	FREQUENCY	PERCENT	ROCK TYPE	FREQUENCY	PERCENT
DC	181	3.977	PSC	77	1.692
DEC	22	0.483	QTA	7	0.154
DESV	4	0.088	QTB	55	1.209
DSL	10	0.220	QTS	15	0.330
DT	2	0.044	SC	11	0.242
EC	120	2.637	SE	1	0.022
EH	13	0.286	SOC	4	0.088
EPEO	77	1.692	SS	1	0.022
EPES	23	0.505	TA1	80	1.758
ET	10	0.220	TA2	90	1.978
JD	1	0.022	TA3	105	2.307
JGB	15	0.330	TB	139	3.054
JGR	40	0.879	TBA	272	5.977
JTRA	7	0.154	TBG	76	1.670
JTRS	143	3.142	TBR	2	0.044
JTRV	33	0.725	TGR	12	0.264
JV	10	0.220	THS	8	0.176
KGR	78	1.714	TI	20	0.439
KJD	4	0.088	TJGR	20	0.439
KJIM	28	0.615	TKS	5	0.110
KS	4	0.088	TKSU	12	0.264
MC	14	0.308	TMI	3	0.066
MDMC	3	0.066	TOB	2	0.044
MDS	86	1.890	TRC	37	0.813
MSV	3	0.066	TRCH	1	0.022
MZGR	107	2.351	TRK	13	0.286
OC	108	2.373	TRLG	4	0.088
QEC	5	0.110	TRMT	12	0.264
QET	11	0.242	TRPD	1	0.022
QS	49	1.077	TRPV	26	0.571
OSV	59	1.296	TRT	14	0.308
PC	44	0.967	TR1	72	1.582
PEGR	7	0.154	TR2	37	0.813
PEM	29	0.637	TR3	261	5.735
PEQS	18	0.396	TS1	11	0.242
PES	3	0.066	TS2	7	0.154
PMC	7	0.154	TS3	439	9.646
PMH	63	1.384	TTS	41	0.901
PNC	1	0.022	TT1	24	0.527
PPA	4	0.088	TT2	701	15.403
PPC	127	2.791	TT3	252	5.537
PPCD	8	0.176			

Figure 4.2-1 Regional Partitions Designated for Statistical Studies of Rock Type Occurrence

equal in area. No generic significance was assumed or is implied. This analysis was performed purely to discern which rock types might be used to discriminate areas of hot spring activity from the region in general. Statistics for the geothermal areas are also presented in Appendix A.

The partitioning and subsetting were both used in an effort to isolate those discriminant factors which could best

Figure 4.2-2 Geothermal Areas Designated for Statistical Studies of Rock Type Occurrence

be applied uniformly over the entire state. Table 4.2-2 summarizes the results of these analyses. For each designated region, as well as the state as a whole, the frequency of occurrence for several generic rock type classes is given. This is done for both the dominant rock type at each grid point and for all units present. The figures given are adjusted upward to discount the excluded Quarternary sediments. Each grouping has been normalized independently to that adjusted base.

TABLE 4.2-2
GENERIC COMPARISON OF REGIONAL ROCK TYPE
OCCURRENCE IN NEVADA

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REGION	ROCK TYPE* COMPOSITE OCCURRENCES, %					ROCK TYPE* DOMINANT OCCURRENCES, %				
	1	2	3	4	5	1	2	3	4	5
All Nevada	8.1	15.5	24.2	25.7	73.5	8.4	18.2	32.6	16.0	75.2
Partition 1	13.1	26.2	22.2	0.1	61.6	14.8	29.6	15.4	0.0	59.8
Partition 2	9.5	12.3	27.5	22.3	71.6	13.3	16.4	30.8	16.3	76.8
Partition 3	5.0	27.0	29.7	0.7	62.4	1.0	31.1	39.9	0.0	72.0
Partition 4	5.9	8.6	15.7	44.5	74.7	8.0	10.5	23.8	35.0	77.3
Partition 5	7.3	12.9	25.1	31.0	76.3	5.1	11.2	43.9	23.2	83.4
Geothermal Area 1	16.0	31.6	25.6	0.0	73.2	18.8	38.0	14.8	0.0	71.6
Geothermal Area 2	5.2	13.6	27.5	0.7	47.0	3.0	7.7	36.7	0.0	47.4
Geothermal Area 3	8.1	5.7	28.7	24.8	67.3	13.7	2.5	37.5	23.2	76.9
Geothermal Area 4	4.8	27.2	30.2	0.9	63.1	1.0	33.7	38.8	0.0	73.5

*Rock Type Key:

- 1 Cenozoic rhyolitic volcanics
- 2 Cenozoic andesitic and basaltic volcanics
- 3 Tertiary tuffs and tuffaceous sediments
- 4 Paleozoic carbonates
- 5 Sum of 1 through 4

Table 4.2-2 indicates that the selected classes account for sixty to eighty percent of the mapped units in most areas (again, excluding the Quarternary sediments). Rhyolites are most abundant in the northern part of the state while intermediate and mafic rocks predominate in the west. Tuffs and tuffaceous sediments are very widespread throughout the state, becoming second in importance to Paleozoic carbonates in the east-central and southern portions of Nevada. The designated geothermal areas are conspicuous for the near absence of Paleozoic carbonates in all but Area 3.

Apart from the selected classes it is also interesting to note the actual rock units which predominate in the same regions. This information is presented in Tables 4.2-3(a) and 4.2-3(b). Indices were subsequently calculated for all of these rock units.

Specific consideration was also given to the six kilometer area about each hot spring. Table 4.2-4 shows all rock types present at each of the seventeen springs. In an effort to discern variations in igneous and sedimentary characteristics through geologic history these formational units were subdivided into Paleozoic, Mesozoic and Cenozoic associations. The study was felt to be inconclusive, at least to subjective evaluation. Indices were nevertheless evaluated for all of those rock types occurring at any hot spring.

Consideration of frequency of occurrence at a hot spring in comparison to the all Nevada average did suggest eight rock units that might be of particular usefulness. These were KGR, JTRS, JTRV, MZGR, PMH, TB, TBA, and TT3. Most efforts for index development focused on these units. Likewise, consideration was given to the apparent negative correlation between geothermal activity and the Paleozoic carbonates.

TABLE 4.2-3(a)
 PREDOMINANT ROCK TYPES OCCURRING
 IN SELECTED REGIONS OF NEVADA
 Composite Occurrences in Digitized Map

REGION	PREDOMINANT ROCK TYPES*
All Nevada	TT2, TS3, (DC), (TT3), (TR3), (TBA)
Partition 1	TBA, JTRS, TR3, TB, (TT3), (TS3)
Partition 2	TS3, TR3, (TT3), (MDS), (PPC), (TA1)
Partition 3	TT2, TBA, TS3, MZGR, TA3, (JTRV)
Partition 4	DC, TT2, MDS, PPC, OC, (TA1)
Partition 5	TT2, TT3, DC, (TS3), (EC), (OC)
Geothermal Area 1	TB, TR3, TTS, TBA, JTRS, TT3
Geothermal Area 2	PMH, OSV, TT2, TBA, TS3, (TRC)
Geothermal Area 3	TS3, (TR3), (MDS), (PPC), (PC), (PSC)
Geothermal Area 4	TT2, TBA, TS3, TA3, MZGR, (JTRS)

*Explanatory Note: This tabulation lists in decreasing order of occurrence the six most common rock types, excepting those on the exclusion list, in each region. All eligible rock types with five or more percent occurrence are indicated. Any of the rock types listed which have less than five percent appear in parentheses.

TABLE 4.2-3(b)
 PREDOMINANT ROCK TYPES OCCURRING
 IN SELECTED REGIONS OF NEVADA
 Dominant Occurrences in Digitized Map

REGION	PREDOMINANT ROCK TYPES*
All Nevada	TT2, (TS3), (TBA), (TR3)
Partition 1	JTRS, TB, TR3, TBA
Partition 2	TS3, TR3, (TBG), (TT3)
Partition 3	TT2, TBA, (TA3), (MZGR)
Partition 4	TT2, DC, (TA1), (TR1)
Partition 5	TT2, TT3, (TS3), (DC)
Geothermal Area 1	TB, TR3, (JTRS), (TBA)
Geothermal Area 2	PMH, OSV, TBA, TT2
Geothermal Area 3	TS3, TR3, (KJIM), (PC)
Geothermal Area 4	TT2, TBA, (TA3), (MZGR)**

*Explanatory Note: This tabulation lists in decreasing order of occurrence the four most common rock types, excepting those on the exclusion list, in each region. All eligible rock types with ten or more percent, occurrence are indicated. Any of the rock types listed which have less than ten percent occurrence appear in parentheses.

**Rock type TS3 occurs with abundance equal to that of MZGR.

TABLE 4.2-4

ROCK TYPES OCCURRING WITHIN SIX KILOMETERS OF LEARNING SET HOT SPRINGS

HOT SPRINGS	ROCK TYPES PRESENT			
	DOMINANT	PALEOZOIC	MESOZOIC	CENOZOIC
Pinto H.S.	TB		JTRS, MZGR	TB, TT2, TT3, QA, QLS
Great Boiling Sprs.	KGR		KGR	QA, QP
Hot Sulphur Springs	TR3	PMH		TA2, TR3, TS1, TT1, TT3, QA, QTOA
Near Wells	TS3	DT, MDS, PPCD		TR3, TS3, QA
Sulphur H.S.	KJIM		KJIM	QA, QP
Beowawe H.S.	TBA	OS		TBA, QA, QLS
Kyle H.S.	OSV	OSV, PMH		QA
Leach H.S.	PMH	PMH	TRC, TRK	QA, QTOA
Hot Springs Ranch	ET	ET, OSV, PMH, PPA	KGR	TT2, TT3, QA
Jersey Valley H.S.	PMH	PMH	TRC, TJGR	TJGR, TA2, TA3, TS3, TT2, QA, QTOA
Stillwater Area	TBA*			TBA*, QA, QP
Soda Lake	QTB			QTB, QA, QP
Brady H.S.	TS3			TBA, TS3, TT3, QA, QP
Steamboat Springs	QTB		JTRV, MZGR	TA3, QTB, QTR, QA, QTOA
Wabuska H.S.	TA3		JTRV	TA2, TBA, TS3, TT2, QA, QTOA
Lee H.S.	TBA		JTRV	TBA, TRT, TR3, TS3, QA, QP
Smith Creek Valley	TT2			TT2, QA, QP

*Nearest occurring "non-excluded" rock type.

4.3 INDIVIDUAL ROCK TYPE INDICES

In order to avoid possible subjective biasing it was decided to process indices for all rock types which were defined at more than one hundred grid points. Indices were also calculated for units not meeting this criterion but which had special interest due to considerations discussed in the previous section. The value actually calculated was, for each grid point, the distance to the nearest occurrence of the specified rock type. The results of these index calculations are shown in Table 4.3-1. The means and standard deviations for the hot springs and all of Nevada are given, along with two discriminant parameters and the confidence level, as discussed in Chapter 3. The actual number of occurrences of any particular rock type can be determined from Table 4.2-1(a). Spatial distributions for those rock types determined to be most useful are given in Appendix B.

As anticipated, the distributions for the majority of these indices were non-Gaussian, markedly so in some cases. All indices calculated were transformed, frequently with a strong impact on their discriminant potential. The post-transformation statistics are presented in Table 4.3-2. Since the mean and standard deviation for Nevada are constrained by the transformation to be very near their pre-transformation values, the change in discriminant function obviously results from a shift in the hot spring values. In most cases the sign of Δx , the difference in the means, did not change; however, in some cases with hot springs of relatively high index variance the transformation did cause a sign reversal. In these cases the index should be considered insufficiently developed to implement as a meaningful indicator.

TABLE 4.3-1
UNTRANSFORMED INDIVIDUAL ROCK TYPE INDEX STATISTICS

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ROCK TYPE	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\frac{ \Delta\bar{x} }{\sigma_N}$	$\frac{ \Delta\bar{x} }{\sigma_{HS}}$	CONF.
DC	6.85E 01	7.69E 01	1.07E 02	7.03E 01	0.501	0.548	NC
EC	7.22E 01	7.37E 01	1.31E 02	7.34E 01	0.796	0.800	0.999
EPEQ	6.10E 01	5.56E 01	8.92E 01	6.43E 01	0.507	0.439	NC
JGR	8.20E 01	6.52E 01	4.50E 01	3.63E 01	0.567	1.019	NC
JTRS	1.26E 02	1.05E 02	4.49E 01	6.06E 01	0.768	1.336	0.998
JTRS (m)	1.26E 02	1.05E 02	4.45E 01	6.08E 01	0.773	1.339	0.999
JTRV	1.59E 02	1.04E 02	1.01E 02	9.27E 01	0.550	0.618	0.997
JTRV (m)	1.59E 02	1.04E 02	9.88E 01	9.55E 01	0.576	0.628	0.983
KGR	4.64E 01	3.16E 01	3.47E 01	2.33E 01	0.370	0.502	0.873
KGR (m)	4.64E 01	3.16E 01	3.41E 01	2.37E 01	0.387	0.515	0.889
MC	2.28E 02	1.30E 02	3.33E 02	1.05E 02	0.805	1.004	0.999
MDS	8.46E 01	8.96E 01	1.55E 02	9.38E 01	0.789	0.754	0.999
MZGR	1.01E 02	8.52E 01	6.64E 01	6.97E 01	0.401	0.490	0.901
MZGR (m)	1.01E 02	8.52E 01	6.64E 01	6.98E 01	0.401	0.490	0.902
OC	6.12E 01	7.01E 01	9.92E 01	6.91E 01	0.542	0.550	NC
OS	9.68E 01	7.68E 01	9.38E 01	6.36E 01	0.039	0.047	NC
OSV	1.10E 02	8.51E 01	7.14E 01	5.70E 01	0.454	0.677	NC
PC	1.50E 02	1.13E 02	2.20E 02	1.12E 02	0.624	0.627	0.990
PMH	9.40E 01	6.99E 01	6.69E 01	5.20E 01	0.387	0.520	0.889
PHM (m)	9.40E 01	6.99E 01	6.66E 01	5.24E 01	0.392	0.523	0.894
PPC	6.33E 01	6.70E 01	1.01E 02	7.18E 01	0.563	0.525	NC
PSC	1.29E 02	1.05E 02	2.02E 02	1.00E 02	0.692	0.724	0.996
QTB	8.22E 01	6.15E 01	5.65E 01	5.42E 01	0.418	0.474	NC
SC	8.00E 01	7.03E 01	1.12E 02	6.16E 01	0.455	0.519	NC
SOC	1.28E 02	9.91E 01	1.77E 02	8.35E 01	0.494	0.587	NC
TA1	8.07E 01	8.23E 01	3.59E 01	2.70E 01	0.544	1.659	NC
TA2	4.85E 01	3.86E 01	3.96E 01	2.55E 01	0.231	0.349	NC
TA3	5.27E 01	4.70E 01	2.87E 01	2.05E 01	0.510	1.170	0.965
TA3 (m)	5.27E 01	4.70E 01	2.89E 01	2.03E 01	0.507	1.175	0.963
TB	4.70E 01	3.43E 01	4.37E 01	2.22E 01	0.096	0.149	NC
TBA	3.87E 01	3.72E 01	1.94E 01	2.24E 01	0.516	0.860	0.967
TGR	6.08E 01	4.73E 01	5.04E 01	3.15E 01	0.220	0.330	NC
TJGR	9.25E 01	7.65E 01	5.59E 01	4.81E 01	0.478	0.761	NC
TRC	1.24E 02	8.77E 01	6.83E 01	5.54E 01	0.637	1.008	0.991
TRMT	1.51E 02	1.09E 02	2.22E 02	1.13E 02	0.645	0.618	0.992
TRT	1.31E 02	8.76E 01	9.56E 01	8.77E 01	0.404	0.404	NC
TR1	3.52E 01	2.83E 01	3.80E 01	1.77E 01	0.099	0.158	NC
TR2	6.21E 01	4.95E 01	5.81E 01	3.07E 01	0.081	0.253	NC
TR3	3.24E 01	2.82E 01	2.31E 01	1.58E 01	0.330	0.589	NC
TS3	1.60E 01	1.52E 01	1.35E 01	9.57E 00	0.164	0.261	NC
TTS	7.39E 01	5.06E 01	6.82E 01	3.68E 01	0.113	0.155	NC
TT1	1.50E 02	1.04E 02	1.62E 02	9.85E 01	0.115	0.122	NC
TT2	2.89E 01	3.45E 01	2.03E 01	2.00E 01	0.249	0.430	NC
TT3	4.46E 01	4.25E 01	3.51E 01	2.30E 01	0.224	0.413	NC

Note: $\Delta\bar{x} = \bar{x}_N - \bar{x}_{HS}$

NC = not calculated

(m) = "micro" index for specified rock type
(see Section 5.2 for explanation)

TABLE 4.3-2
TRANSFORMED INDIVIDUAL ROCK TYPE INDEX STATISTICS

T-2898

ROCK TYPE	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $	CONF.
DC	6.35E 01	7.19E 01	3.76E 01	7.43E 01	0.831	0.804	NC
EC	7.23E 01	7.41E 01	4.52E 01	7.12E 01	0.366	0.381	NC
EPEQ	5.64E 01	5.19E 01	3.58E 01	6.83E 01	0.391	0.302	NC
JGR	7.43E 01	5.68E 01	4.52E 01	5.06E 01	0.512	0.575	0.965
JTRS	1.26E 02	1.06E 02	4.88E 01	7.05E 01	0.728	1.092	0.997
JTRS (m)	1.26E 02	1.06E 02	5.05E 01	6.61E 01	0.712	1.139	0.997
JTRV	1.59E 02	1.04E 02	1.08E 02	8.75E 01	0.485	0.576	0.954
JTRV (m)	1.59E 02	1.04E 02	1.02E 02	9.49E 01	0.543	0.595	0.975
KGR	4.64E 01	3.18E 01	3.33E 01	3.57E 01	0.410	0.366	0.909
KGR (m)	4.64E 01	3.18E 01	3.85E 01	2.25E 01	0.246	0.347	0.690
MC	2.28E 02	1.29E 02	2.19E 02	1.06E 02	0.070	0.085	NC
MDS	8.46E 01	8.89E 01	4.39E 01	1.06E 02	0.458	0.384	NC
MZGR	1.01E 02	8.52E 01	7.27E 01	8.71E 01	0.328	0.320	0.823
MZGR (m)	1.01E 02	8.52E 01	8.93E 01	4.91E 01	0.133	0.231	0.416
OC	5.51E 01	6.38E 01	3.19E 01	6.57E 01	0.364	0.353	NC
OS	8.75E 01	6.78E 01	9.45E 01	6.15E 01	0.104	0.115	0.332
OSV	1.00E 02	7.55E 01	6.73E 01	8.47E 01	0.438	0.391	0.929
PC	1.50E 02	1.12E 02	1.07E 02	1.57E 02	0.384	0.274	NC
PMH	9.40E 01	6.99E 01	5.25E 01	8.64E 01	0.593	0.480	0.986
PMH (m)	9.40E 01	6.99E 01	7.05E 01	5.64E 01	0.336	0.417	0.834
PPC	6.04E 01	6.38E 01	4.60E 01	7.46E 01	0.226	0.193	NC
PSC	1.29E 02	1.05E 02	9.10E 01	1.11E 02	0.362	0.342	NC
QTS	7.55E 01	5.61E 01	5.91E 01	7.78E 01	0.292	0.211	NC
SC	7.30E 01	6.57E 01	5.95E 01	6.81E 01	0.205	0.198	NC
SOC	1.24E 02	8.77E 01	6.38E 01	1.03E 02	0.688	0.584	0.995
TA1	7.21E 01	7.18E 01	5.09E 01	4.35E 01	0.296	0.488	0.778
TA2	4.38E 01	3.34E 01	3.96E 01	4.68E 01	0.058	0.090	NC
TA3	5.27E 01	4.70E 01	2.88E 01	4.37E 01	0.507	0.546	0.964
TA3 (m)	5.27E 01	4.70E 01	3.73E 01	2.83E 01	0.327	0.542	0.822
TB	4.78E 01	3.33E 01	5.96E 01	4.69E 01	0.354	0.252	NC
TBA	3.87E 01	3.72E 01	1.81E 01	3.78E 01	0.551	0.543	0.977
TGR	5.28E 01	3.99E 01	5.45E 01	3.02E 01	0.043	0.057	0.141
TJGR	8.30E 01	6.55E 01	5.70E 01	5.78E 01	0.396	0.449	0.898
TRC	1.24E 02	8.77E 01	6.38E 01	1.03E 02	0.688	0.584	0.995
TRMT	1.51E 02	1.09E 02	1.08E 02	1.76E 02	0.394	0.244	NC
TRT	1.25E 02	8.37E 01	1.19E 02	9.47E 01	0.072	0.063	NC
TR1	3.21E 01	2.44E 01	2.68E 01	2.38E 01	0.217	0.223	NC
TR2	5.63E 01	4.28E 01	6.45E 01	2.41E 01	0.191	0.341	0.570
TR3	3.29E 01	2.81E 01	3.08E 01	3.31E 01	0.075	0.063	NC
TS3	1.54E 01	1.43E 01	8.83E 00	1.68E 01	0.459	0.391	NC
TTS	7.11E 01	4.83E 01	7.94E 01	6.06E 01	0.172	0.137	NC
TT1	1.42E 02	9.66E 01	9.72E 01	9.99E 01	0.464	0.448	NC
TT2	2.38E 01	2.85E 01	1.25E 01	3.10E 01	0.396	0.365	NC
TT3	4.63E 01	4.23E 01	5.36E 01	4.86E 01	0.173	0.150	NC

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

NC = not calculated

(m) = "micro" index for specified rock type
(see Section 5.2 for explanation)

4.4 DOMINANT ROCK TYPE INDICES

Only a limited number of indices were calculated for the dominant occurrence of a rock type. Here the value used is the distance to the nearest grid point at which the specified rock type is the dominant mapped unit. Statistics for these indices are given in Table 4.4-1. Frequency of occurrence of these rock types as the dominant member can be determined from Table 4.2-1(b).

Nearly all dominant occurrence indices were found to be very highly correlated with their corresponding individual rock type indices. Because of this redundancy it was decided to rely upon the previously calculated indices, and not proceed with the normalizing transformation of the dominant indices. Two of the untransformed dominant indices, rock types EC and JTRS, were, however, selected for further study because of their high discriminant potential. Spatial distributions of their occurrences are included in Appendix B.

TABLE 4.4-1
UNTRANSFORMED DOMINANT ROCK TYPE INDEX STATISTICS

T-2894

ROCK TYPE	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $	CONF.
EC	8.86E 01	8.13E 01	1.58E 02	7.18E 01	0.857	0.970	1.000
EPEQ	7.28E 01	5.33E 01	9.83E 01	5.61E 01	0.478	0.455	NC
JTRS	1.70E 02	1.22E 02	6.45E 01	6.32E 01	0.860	1.665	1.000
JTRV	2.15E 02	1.12E 02	1.41E 02	1.16E 02	0.573	0.555	0.982
KGR	9.35E 01	8.08E 01	5.11E 01	2.68E 01	0.525	1.582	NC
MZGR	1.30E 02	9.37E 01	8.03E 01	7.30E 01	0.531	0.684	0.971
TB	7.80E 01	4.97E 01	5.74E 01	2.89E 01	0.414	0.713	NC
TBA	5.77E 01	5.02E 01	3.11E 01	3.83E 01	0.530	0.695	NC
TJGR	1.28E 02	8.17E 01	8.36E 01	4.40E 01	0.548	1.018	0.976
TR1	8.53E 01	5.39E 01	8.83E 01	4.05E 01	0.056	0.074	NC
TR2	1.08E 02	8.22E 01	1.12E 02	7.54E 01	0.049	0.053	NC
TR3	4.66E 01	3.53E 01	5.26E 01	2.68E 01	0.170	0.224	NC
TT1	2.17E 02	1.28E 02	1.77E 02	1.02E 02	0.313	0.392	NC

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

NC = not calculated

4.5 GROUP ASSEMBLAGE INDICES

The definition of a formation or other geologic mapping unit is often based upon considerations which are not uniformly applied across an entire state. In one region, for instance, it may be feasible to differentiate between rocks of different age or composition. In another area, however, these variations may be gradational or undistinguishable, often according to the specification of detail in the survey. Essentially, map units are defined within the context of the field survey for which they were used. The source map for the Nevada data is a compilation of many surveys. As a consequence rock formation definitions should not necessarily be expected to apply uniformly across the entire state.

The definition factor has obvious ramifications on the statistical treatment of such data. To minimize these problems various assemblages of rock types have been defined. The intent here is to group units which can be merged to define assemblages representative of different sedimentary and metamorphic facies, igneous chemistry, extrusive (geologic) history, etc. Conceptually, at least in some regions, such assemblages could be chosen to represent almost any facet of geologic history or environment and many important geologic mechanisms. The potentials are limited only by the detail implicit in the mapped units.

In the present study this technique was employed in three different ways. Most obvious to the search for geothermal energy was examination of the igneous units. Numerous assemblages were defined to ascertain the importance of various extrusive rock chemistries and the temporal continuity of igneous activity, for example, since the Mesozoic. A second application of this method was developed in regard to the

Paleozoic geosynclinal sedimentary facies in Nevada. Finally, some assemblages were defined to represent specific historic sequences, joint occurrences of particular igneous rock types, or associations of certain igneous units in a specific paleoenvironment.

To delineate assemblages logical "AND" and "OR" operators were defined. In the context of index calculation, a sequence of rock types each linked by the OR operator means simply that the index value is calculated to be the distance to the nearest occurrence of any one of the specified rock types.

The AND operator was used in two modes, a conjunctive form and an areal integrator. An index calculated for two rock types joined by the conjunctive AND was interpreted to be the distance to the nearest grid point at which both rock types coexist. For the areal integrating AND the value calculated was the smallest range, or radius, from each grid point within which both rock types could be found. Thus, given the distance to nearest occurrence of each individual rock type the value used is actually that for the more distant of the two, the other unit also being found within that range but not necessarily in the same direction.

The AND and OR operators were used in combination with up to nine distinct rock types where each operator would function on the result of the preceding calculation. For example, given rock types A, B, C and D in the logic sequence

A OR B AND C OR D

the index calculation would perform the following functions:

For the conjunctive AND operator

- Determine all grid points containing rock type A, B or both.
- Determine which of the above also contain a rock type C; relabel such occurrences X.
- Determine all grid points containing X, D, or both and relabel Y.
- Calculate for each grid point (i) the distance $y(i)$ to the nearest point containing Y; $y(i)$ is the index value.

For the areal integrating AND operator

- Calculate for each grid point the distance to the nearest occurrence of each rock type individually; let these values be $a(i)$, $b(i)$, $c(i)$ and $d(i)$ for rock types A, B, C and D, respectively, at grid point (i).
- For each point define $x(i)$ such that it equals the smaller of $a(i)$ and $b(i)$.
- Compare $x(i)$ to $c(i)$ and reassign $x(i)$ with the larger of the two values.
- Compare $x(i)$ to $d(i)$ and reassign $x(i)$ with the smaller of the two; $x(i)$ is now the index value.

A total of twenty-two assemblages were defined. Of these, twelve employed only the OR operator. The other ten cases actually consisted of five unique logic sequences repeated for both modes of AND operator definition. The composition of these cases is indicated in Table 4.5-1; the geologic rationale for their selection is implied in the description of the "Index Feature".

TABLE 4.5-1
GROUP ASSEMBLAGE INDICES

T-2867

ROCK GROUP DESIGNATOR	LOGICAL COMPOSITION	MODE*	INDEX FEATURE
A03A	KGR OR MZGR AND TA3	C	Mesozoic granitics and Tertiary andesite
A03B	KGR OR MZGR AND TBA	C	Mesozoic granitics, and Tertiary basalt or andesite
A03J	JTRS OR JTRV AND PMH	C	Eugeosynclinal facies continuing from Late Paleozoic to Early Tertiary
A03R	KGR OR MZGR AND TR3	C	Mesozoic granitics and Tertiary rhyolite
A03T	TBA OR TA3 AND TR3	C	Tertiary basalt or andesite, and Tertiary rhyolite
OR3I	JGR OR MZGR OR JTRV	-	Mesozoic granitics or Early Tertiary eugeosynclinal facies
OR3J	JTRS OR JTRV OR PMH	-	Eugeosynclinal facies anytime from Late Paleozoic to Early Tertiary
OR3M	MZGR OR PMH OR MDS	-	Mesozoic granitics or Middle to Late Paleozoic eugeosynclinal or transitional facies
OR3T	TBA OR TB OR TA3	-	Tertiary basalt or andesite
OR4A	QTA OR TA1 OR TA2 OR TA3	-	Tertiary or Quaternary andesite
OR4B	QTB OR TB OR TBG OR TOB	-	Tertiary or Quaternary basalt
O5RY	QTR OR TR1 OR TR2 OR TR3 OR TRT	-	Tertiary or Quaternary rhyolite
OR6E	MZGR OR PMH OR MDS OR TBA OR TB OR TA3	-	Late Paleozoic eugeosynclinal or transitional facies, Mesozoic granitics, or Tertiary basalt or andesite
OR6	EC OR MC OR OC OR PC OR PSC OR SOC	-	Paleozoic carbonates (miogeosynclinal facies)
OR7	EC OR EPEQ OR MC OR OC OR PC OR PSC OR SOC	-	Paleozoic carbonates, including somewhat metamorphosed Cambrian unit (miogeosynclinal facies)
O7MF	QTA OR TA1 OR TA2 OR TA3 OR TBA OR QTB OR TB OR TBG OR TOB	-	Tertiary or Quaternary andesite or basalt
O9IG	TI OR TMI OR TRI OR TGR OR KGR OR TJGR OR MZGR OR TRGR OR JGR	-	Mesozoic or Tertiary intrusive rocks of any composition
G2A03A	KGR OR MZGR AND TA3	A	Mesozoic granitics and Tertiary andesite
G2A03B	KGR OR MZGR AND TBA	A	Mesozoic granitics, and Tertiary basalt or andesite
G2A03J	JTRS OR JTRV AND PMH	A	Eugeosynclinal facies continuing from Late Paleozoic to Early Tertiary
G2A03R	KGR OR MZGR AND TR3	A	Mesozoic granitics and Tertiary rhyolite
G2A03T	TBA OR TR3 AND TA3	A	Tertiary basalt or rhyolite, and andesite

*The conjunctive AND operator is designated as Mode C while the areal integrating AND operator is designated as Mode A. Mode designation is arbitrary when the AND operator does not appear in the logical composition sequence. All group indices employing the Mode A AND operator have designators beginning with "G2".

A number of these indices appeared to have significant discriminant potential. Statistics for the entire set are presented in Table 4.5-2. Further evaluation of these indices did reveal a significant problem in their application to hypothesis testing. As with the individual rock type indices their distributions were non-Gaussian, but considerably more so than with any other indices developed. Though unimodal they were uniformly skewed quite strongly to the right. As with the previous indices a nonlinear transformation was employed to normalize the rock group data. This, however, resulted in major deterioration of the index discriminant potential. Post-transformation statistics are shown in Table 4.5-3.

4.6 OBSERVATIONS

Survey of the rock type indices and the associated statistics suggests several interesting relationships. It is commonly believed, for instance, that geothermal resources may be closely associated with recent rhyolitic extrusives. Tertiary rhyolites occur widely in Nevada and though they are found in reasonably close association with known geothermal resource areas they are generally well distributed throughout the rest of the state as well. From the prospectives studied here tertiary rhyolites offer no discrimination of geothermal areas.

The apparent conflict between this observation and the common expectation may be a matter of age, of scale, or, alternatively, of preconception. Admittedly, the source data is not sufficient to subdivide chronologically the late Tertiary events. Yet, the assumed association is based upon the evaluation of recent extrusives. It is also possible that any high correlation between rhyolites and hot springs must be viewed

TABLE 4.5-2
UNTRANSFORMED GROUP ASSEMBLAGE INDEX STATISTICS

T-2868

ROCK GROUP DESIGNATOR	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $	CONF.
AO3A	1.20E 02	8.63E 01	6.17E 01	4.38E 01	0.681	1.340	0.995
AO3B	1.21E 02	9.06E 01	6.97E 01	6.47E 01	0.567	0.793	0.980
AO3J	2.12E 02	1.21E 02	1.15E 02	6.59E 01	0.795	1.464	0.999
AO3R	1.00E 02	7.07E 01	6.59E 01	3.87E 01	0.489	0.893	NC
AO3T	5.92E 01	4.87E 01	3.55E 01	2.72E 01	0.486	0.872	NC
OR3I	4.28E 01	3.87E 01	1.87E 01	1.52E 01	0.626	1.587	0.990
OR3J	7.44E 01	7.64E 01	2.02E 01	3.15E 01	0.710	1.724	0.997
OR3M	2.27E 01	2.82E 01	1.44E 01	1.53E 01	0.292	0.536	NC
OR3T	2.16E 01	2.63E 01	1.03E 01	1.28E 01	0.431	0.885	NC
OR4A	1.77E 01	1.70E 01	1.48E 01	1.32E 01	0.166	0.215	NC
OR4B	3.76E 01	3.39E 01	2.81E 01	2.19E 01	0.280	0.432	NC
O5RY	1.45E 01	1.39E 01	1.56E 01	1.06E 01	0.083	0.108	NC
OR6E	8.78E 00	1.04E 01	6.04E 00	9.45E 00	0.264	0.290	NC
OR6	5.09E 01	6.60E 01	9.63E 01	7.12E 01	0.687	0.637	0.995
OR7	4.11E 01	5.50E 01	8.45E 01	6.67E 01	0.788	0.650	0.999
O7MF	9.29E 00	1.16E 01	5.48E 00	7.75E 00	0.328	0.491	NC
O9IG	1.71E 01	1.60E 01	1.47E 01	1.48E 01	0.154	0.166	NC
G2AO3A	6.42E 01	4.61E 01	3.84E 01	2.10E 01	0.558	1.223	NC
G2AO3B	5.61E 01	4.05E 01	3.32E 01	2.03E 01	0.565	1.128	NC
G2AO3J	1.39E 02	8.92E 01	8.92E 01	5.74E 01	0.555	0.862	0.978
G2AO3R	5.23E 01	3.20E 01	3.75E 01	1.73E 01	0.460	0.853	NC
G2AO3T	4.05E 01	2.88E 01	2.43E 01	1.44E 01	0.562	1.123	NC

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

NC = not calculated

TABLE 4.5-3
TRANSFORMED GROUP ASSEMBLAGE INDEX STATISTICS

T-2869

ROCK GROUP DESIGNATOR	$\bar{x}_N$ (km)	σ_N (km)	$\bar{x}_{HS}$ (km)	σ_{HS} (km)	$\left \frac{\Delta \bar{x}}{\sigma_N} \right $	$\left \frac{\Delta \bar{x}}{\sigma_{HS}} \right $	CONF.
AO3A	1.20E 02	8.63E 01	6.89E 01	8.39E 01	0.597	0.614	0.986
AO3B	1.21E 02	9.10E 01	1.10E 02	1.95E 02	0.115	0.054	NC
AO3J	2.16E 02	1.22E 02	1.50E 02	1.77E 02	0.507	0.350	NC
AO3R	9.76E 01	6.85E 01	7.51E 01	1.23E 02	0.329	0.183	NC
AO2T	5.79E 01	4.68E 01	3.66E 01	8.12E 01	0.454	0.261	NC
OR3I	4.28E 01	3.86E 01	2.62E 01	3.76E 01	0.431	0.442	NC
OR3J	7.44E 01	7.65E 01	4.93E 01	7.61E 01	0.329	0.331	NC
OR3M	1.79E 01	1.98E 01	1.28E 01	2.39E 01	0.247	0.204	NC
OR3T	2.18E 01	2.56E 01	1.75E 01	3.42E 01	0.168	0.126	NC
OR4A	1.63E 01	1.52E 01	8.20E 00	1.72E 01	0.536	0.473	NC
OR4B	3.86E 01	3.29E 01	4.90E 01	4.26E 01	0.316	0.244	NC
O5RY	1.39E 01	1.27E 01	9.96E 00	1.42E 01	0.314	0.280	NC
OR6E	8.51E 00	1.00E 01	5.54E 00	1.14E 01	0.297	0.262	NC
OR6	5.09E 01	6.68E 01	9.82E 01	3.33E 01	0.708	1.418	0.996
OR7	4.11E 01	5.42E 01	3.72E 01	4.95E 01	0.073	0.080	NC
O7MF	9.35E 00	1.14E 01	7.39E 00	1.18E 01	0.171	0.162	NC
O9IG	1.63E 01	1.48E 01	1.10E 01	1.26E 01	0.359	0.421	NC
G2AO3A	6.38E 01	4.64E 01	4.73E 01	7.54E 01	0.355	0.219	NC
G2AO3B	5.31E 01	3.75E 01	3.74E 01	5.54E 01	0.421	0.285	NC
G2AO3J	1.39E 02	8.90E 01	8.91E 01	7.16E 01	0.557	0.693	0.978
G2AO3R	5.11E 01	3.01E 01	3.70E 01	4.16E 01	0.469	0.340	NC
G2AO3T	3.97E 01	2.83E 01	3.62E 01	3.94E 01	0.124	0.089	NC

Note: $\Delta \bar{x} = \bar{x}_N - \bar{x}_{HS}$

NC = not calculated

on a scale with somewhat greater detail than that implemented here. The characteristic distance between any signature parameter and the desired resource will vary according to the mechanisms involved. It would be preliminary to say that the eight kilometer grid spacing is sufficient to resolve the rhyolite question. The third consideration, error in the common assumption, is of course a possibility.

In contrast to the rhyolite issue is the discovery of discriminant potential in the occurrence of Tertiary andesitic and basaltic extrusives. This is noted most clearly in the rock unit TBA. The correlation is not, however, unreasonable in that subducted relics of the relatively young Farallon plate may be melting and subsequently rising under the region to produce these volcanics. The presence of andesitic material may reflect conditions similar to the subduction of young sea floor under the western coast of South America. Basaltic material may result from the overriding of an oceanic spreading center by the continent.

Somewhat stronger discrimination of the geothermal areas can be seen with reference to the low alkali Mesozoic intrusives. These are typically comprised of quartz monzonite and granodiorite and may be derived from a magma source related to those producing the intermediate and basic volcanics. Rock types MZGR, KGR and, to a lesser extent, JGR all demonstrate this correlation.

More surprising is the observation that some older formations tend to outline zones of geothermal energy. Several Permian and Jurassic units of high silica content were found useful. These rocks, PMH, JTRS, and JTRV, may simply be indicative of silicification by hydrothermal alteration. In consideration of their total composition, however, it is

suggested here that they are generic extensions of the Paleozoic Antlerian eugeosynclinal facies. This would then imply that present-day geothermal resources are associated with a crustal zone which has been active in the same area for much of geologic history. To test this hypothesis it was felt desirable to evaluate larger group assemblages representative of the Paleozoic eugeosyncline. Late Paleozoic overthrusting precludes this method, however, in that representative blocks of that facies were displaced considerable distances to the east. These detached sheets and klippen would create a substantial bias with such a direct approach. As an alternative it was decided to obtain information in the form of a negative correlation. The Paleozoic miogeosyncline was instead represented by two group assemblages of up to seven carbonate units. The two indices resulting, OR6 and OR7, clearly indicate a region somewhat to the east, but parallel to the trend of the known hot springs. The index calculated, being the distance to the nearest occurrence of the specified rocks, produces a strong negative correlation with the learning set. Caution must be exercised in the interpretation of data using these indices as they will artificially emphasize the likelihood of geothermal resources in the extreme northwest corner of the state. Used in conjunction with other meaningful indices, however, this effect should be small.

A final observation regarding the use of rock type indices should be made. Unlike the other data types being integrated, surface geology relates information about areal occurrences which span many kilometers, often many tens of kilometers. This is in strong contrast to the use of seismic data which describes point events or fracture data associated with a discrete line along the surface of the earth. Any time rock type data is employed some spatial averaging must take place and the granularity of the resulting spatial resolution

compromised. This is not simply a consequence of the map grid spacing, but is inherent in the generic nature, the evolution, of rock masses. For most purposes, however, this is not a significant compromise since hypothesis testing is viewed primarily as a method to be used for reconnaissance exploration.

4.7 SUMMARY

A digitized record of rock type distribution in Nevada was developed from a preliminary geologic map of the state. Statistical studies of the digitized record were then used to assess the probable utility of rock types as discriminants for the identification of geothermal resources. On the basis of that assessment a number of rock types were selected for further evaluation. Signature indices were calculated from the occurrence data of forty-four individual rock types. In addition, thirteen other indices were based on the cominant occurrence of selected rock units and twenty-two indices were developed from the distributions of rock group assemblages. Of the total seventy-nine indices calculated, sixty-five were chosen for further study (see Chapter 5).

5.   IDENTIFICATION OF LIKELY GEOTHERMAL
RESOURCE AREAS

5.1   SIGNATURE INDICES

Earlier in this report data was presented to show the relative separation of index values for the hot springs population with respect to the general Nevada population. The major lineament data was given in Table 3.2-1 and 3.2-2 and the rock type indices in Tables 4.3-1, 4.3-2, 4.4-1, 4.5-2, and 4.5-3.

Some of the indices developed have little apparent discriminant power, judging from these statistics. It is instructive, however, to look at values associated with the individual hot springs, particularly when such a small learning set is being used. To facilitate compilation of this data all of the major lineament and most of the rock type indices generated were merged into a unified data base. A listing of the eighty-nine members of that data base is given in Table 5.1-1, sequenced according to index number. Indices of more general interest and greater information content were assigned number of 53 to 100, inclusive. The latter were also concatenated to the data base generated for the USGS study to enable the integrated likelihood evaluations discussed in Section 5.4. Studies of the new indices with respect to the individual hot spring locations were made using the eighty-nine number data base. The index values for the hot springs are presented in Table 5.1-2.

In Table 5.1-3 the hot spring values are compared with the statistics of the entire region to provide a measure

TABLE 5.1-1
SIGNATURE INDICES MERGED INTO UNIFIED DATA BASE

INDEX NUMBER	INDEX DESCRIPTION
1	DISTANCE TO ROCK TYPE EC
2	DISTANCE TO ROCK TYPE NC
3	DISTANCE TO ROCK TYPE NDS
4	DISTANCE TO ROCK TYPE PC
5	DISTANCE TO ROCK TYPE TRMT
6	DISTANCE TO ROCK TYPE PSC
7	DISTANCE TO ROCK TYPE TRC
10	TRANS. DISTANCE TO ROCK TYPE JGR
11	TRANS. DISTANCE TO ROCK TYPE OS
12	TRANS. DISTANCE TO ROCK TYPE OSV
13	TRANS. DISTANCE TO ROCK TYPE SOC
14	TRANS. DISTANCE TO ROCK TYPE TA1
15	TRANS. DISTANCE TO ROCK TYPE TGR
16	TRANS. DISTANCE TO ROCK TYPE TJGR
17	TRANS. DISTANCE TO ROCK TYPE TRC
18	TRANS. DISTANCE TO ROCK TYPE TR2
19	DISTANCE TO DOMINANT ROCK TYPE EC
20	DISTANCE TO DOMINANT ROCK TYPE JTRS
21	DISTANCE TO DOMINANT ROCK TYPE JTRV
22	DISTANCE TO DOMINANT ROCK TYPE NZGR
23	DISTANCE TO DOMINANT ROCK TYPE TJGR
24	DISTANCE TO ROCK GROUP OR3J
25	DISTANCE TO ROCK GROUP AQ3J
26	DISTANCE TO ROCK GROUP AQ3A
27	DISTANCE TO ROCK GROUP AQ3S
28	DISTANCE TO ROCK GROUP OR3I
29	DISTANCE TO ROCK GROUP G2AQ3J
30	DISTANCE TO ROCK GROUP OR6
31	DISTANCE TO ROCK GROUP OR7
32	DISTANCE TO ROCK TYPE NZGR
33	DISTANCE TO ROCK TYPE PMH
34	DISTANCE TO ROCK TYPE JTRS
35	DISTANCE TO ROCK TYPE JTRV
36	DISTANCE TO ROCK TYPE KGR
37	DISTANCE TO ROCK TYPE TA3
38	TRANS. DISTANCE TO ROCK TYPE NZGR
39	TRANS. DISTANCE TO ROCK TYPE PMH
40	TRANS. DISTANCE TO ROCK TYPE JTRS
41	TRANS. DISTANCE TO ROCK TYPE JTRV
42	TRANS. DISTANCE TO ROCK TYPE KGR
43	TRANS. DISTANCE TO ROCK TYPE TA3
53	DISTANCE TO ROCK TYPE NZGR (MICRO DATA)
54	DISTANCE TO ROCK TYPE PMH (MICRO DATA)
55	DISTANCE TO ROCK TYPE JTRS (MICRO DATA)
56	DISTANCE TO ROCK TYPE JTRV (MICRO DATA)
57	DISTANCE TO ROCK TYPE KGR (MICRO DATA)
58	DISTANCE TO ROCK TYPE TA3 (MICRO DATA)
59	TRANS. DISTANCE TO ROCK TYPE NZGR (MICRO DATA)
60	TRANS. DISTANCE TO ROCK TYPE PMH (MICRO DATA)
61	TRANS. DISTANCE TO ROCK TYPE JTRS (MICRO DATA)
62	TRANS. DISTANCE TO ROCK TYPE JTRV (MICRO DATA)
63	TRANS. DISTANCE TO ROCK TYPE KGR (MICRO DATA)
64	TRANS. DISTANCE TO ROCK TYPE TA3 (MICRO DATA)
65	TRANS. DISTANCE TO ROCK GROUP AQ3A
66	TRANS. DISTANCE TO ROCK GROUP G2AC3J
67	TRANS. DISTANCE TO ROCK TYPE JGR
68	TRANS. DISTANCE TO ROCK TYPE JTRV
69	TRANS. DISTANCE TO ROCK TYPE KGR
70	TRANS. DISTANCE TO ROCK TYPE OSV
71	TRANS. DISTANCE TO ROCK TYPE PMH
72	TRANS. DISTANCE TO ROCK TYPE SOC
73	TRANS. DISTANCE TO ROCK TYPE TRC
74	TRANS. DISTANCE TO ROCK GROUP GR6
75	TRANS. DIST. TO LINEAMENT INTERSECTION 1 (11 LINS)
76	TRANS. DIST. TO LINEAMENT INTERSECTION 2 (11 LINS)
77	TRANS. DIST. TO LINEAMENT INTERSECTION 3 (11 LINS)
78	TRANS. DIST. TO LINEAMENT 1 (11 LINS)
79	TRANS. DIST. TO LINEAMENT ENDCPOINT 1 (11 LINS)
80	TRANS. DIST. TO LINEAMENT ENDCPOINT 2 (11 LINS)
81	TRANS. DIST. TO LINEAMENT ENDCPOINT 3 (11 LINS)
82	TRANS. DIST. TO INTERSECTION 1 PLUS ENDCPOINT 1 (11 LINS)
83	TRANS. DIST. TO INTERSECTION 1 PLUS LINEAMENT 1 (11 LINS)
84	TRANS. DIST. TO LINEAMENT 1 PLUS ENDCPOINT 1 (11 LINS)
85	TRANS. DIST. TO LINEAMENT MIDPOINT 1 (11 LINS)
86	TRANS. DIST. TO LINEAMENT MIDPOINT 2 (11 LINS)
87	TRANS. DIST. TO LINEAMENT INTERSECTION 1 (8 LINS)
88	TRANS. DIST. TO LINEAMENT INTERSECTION 2 (8 LINS)
89	TRANS. DIST. TO LINEAMENT INTERSECTION 3 (8 LINS)
90	TRANS. DIST. TO LINEAMENT 1 (8 LINS)
91	TRANS. DIST. TO LINEAMENT ENDCPOINT 1 (8 LINS)
92	TRANS. DIST. TO LINEAMENT ENDCPOINT 2 (8 LINS)
93	TRANS. DIST. TO LINEAMENT ENDCPOINT 3 (8 LINS)
94	TRANS. DIST. TO INTERSECTION 1 PLUS ENDCPOINT 1 (8 LINS)
95	TRANS. DIST. TO INTERSECTION 1 PLUS LINEAMENT 1 (8 LINS)
96	TRANS. DIST. TO LINEAMENT 1 PLUS ENDCPOINT 1 (8 LINS)
97	TRANS. DIST. TO LINEAMENT MIDPOINT 1 (8 LINS)
98	TRANS. DIST. TO LINEAMENT MIDPOINT 2 (8 LINS)
99	DISTANCE TO ROCK TYPE TEA
100	TRANS. DISTANCE TO ROCK TYPE TBA

TABLE 5.1-2

[illegible]

*VALUE SHOWN IS x_{HS} . NEGATIVE VALUES RESULT FROM USING TRANSFORMED INDICES.

*VALUE SHOWN IS x_{HS} . NEGATIVE VALUES RESULT FROM USING TRANSFORMED INDICES.

TABLE 5.1-3

DISCRIMINATION* OF HOT SPRING INDEX VALUES FROM NEVADA MEAN

[illegible]

*VALUE SHOWN IS $y_N = \frac{x_{HS} - \bar{x}_N}{\sigma_N}$

of relative separation or discriminant potential, y_N (as defined in the table), between the springs and the corresponding Nevada mean value. Good discrimination by an index would be suggested by large separation and consistent sign. It does not matter whether that sign is positive or negative; that is a consequence of the index definition and whether a positive or negative correlation exists between the hot springs and the region as a whole. The likelihood is calculated as a function of the absolute value of that separation.

Another aspect of discriminant potential is the variation, y_{HS} , in individual hot spring values with respect to their mean value. This is shown in Table 5.1-4. An index should have a relatively small variation to be useful, thus indicating that its behavior is consistent for all springs in the learning set. Reference to this factor is also helpful in understanding some of the difficulties in performing a satisfactory normalizing transformation; that problem is further discussed in Section 5.2. With even moderate variation combinations of indices do not always indicate high likelihood of geothermal energy at every hot spring in the learning set. It will be seen, however, that with a judicious selection of indices one can achieve a composite indicator, or multidimensional signature, that highlights most of the hot springs in the learning set.

A final statistic that is most helpful in selecting appropriate indices for discrimination is the one-dimensional likelihood ratio, λ . These are given in Table 5.1-5 for each hot spring location. The ratios are computed from a simplified form of Eq. 2.1-9; for the case wherein only one index is being evaluated, that expression reduces to

TABLE 5.1-4

VARIATION* OF HOT SPRING INDEX VALUES FROM HOT SPRINGS MEAN

[illegible]

*VALUE SHOWN IS $v_N = \frac{x_{HS} - \bar{x}_{HS}}{\sigma_{HS}}$

TABLE 5.1-5
ONE-DIMENSIONAL HOT SPRING LIKELIHOOD RATIOS*

INDEX NUMBER	PINTO HOT SPRINGS	GREAT BOILING	HOT SULPHUR SPRINGS	NEAR WELLS	SULPHUR HOT SPRINGS	BOWAWE	KYLE HOT SPRINGS	LEACH HOT SPRINGS	HOT SPRINGS RANCH	JERSEY VALLEY	STILLWATER AREA	SODA LAKE	BRADY HOT SPRINGS	STEAMBOAT SPRINGS	WARUSKA HOT SPRINGS	LEE HOT SPRINGS	SMITH CREEK VALLEY
1-100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
101-200	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101	1.101
201-300	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102	1.102
301-400	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103	1.103
401-500	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104	1.104
501-600	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105	1.105
601-700	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106	1.106
701-800	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107	1.107
801-900	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108	1.108
901-1000	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109	1.109

*VALUE SHOWN IS $\lambda = \frac{v_N}{v_{HS}} \exp \frac{1}{2}(v_N^2 - v_{HS}^2)$

$$\Lambda = \frac{\sigma_N}{\sigma_{HS}} \exp\left\{\frac{1}{2} (y_N^2 - y_{HS}^2)\right\} \quad (5.1-1)$$

where y_N and y_{HS} are given in Tables 5.1-3 and 5.1-4, respectively.

By scanning Table 5.1-5 one may quickly appreciate which indices are likely to identify particular hot springs. A likelihood ratio greater than one indicates that the index value at that hot spring location is more representative of the total hot springs learning set than it is of the general Nevada population. Some of the springs, Brady Hot Springs for example, are readily identified by most of the indices. Others like Near Wells and Sulphur Hot Springs are consistently more difficult to identify with the major lineament and rock type indices. In selecting indices for further analysis one would attempt to choose those with maximum likelihood ratios at most hot spring locations, while minimizing the number of those locations for which the ratio was less than unity.

In a composite evaluation with several indices one would attempt to utilize a crosssection of information that would successfully recover all hot springs in the learning set. Occasionally one spring will consistently fail to be identified by indices generated from a particular data source. For example, a recently active, shallow thrust fault may cover rocks genetically associated with a hot spring with unrelated material displaced a considerable distance. In this case indices generated from surface geology data would quite possibly fail to identify that spring. If, however, a composite group of statistically independent indices were considered, the combined likelihood ratio at the hot spring would be the simple product of the respective one-dimensional values. In this case

proper selection of indices would enable the combined information to override the failure of one data source to identify a particular spring. The application of composite index evaluation will be discussed in Section 5.3.

5.2 NORMALIZING TRANSFORMATION

The implementation of hypothesis testing used in this study has been predicated on the assumption that all indices have a Gaussian distribution. This assumption is not a requirement of the general methodology, but was introduced to simplify the mathematic relationships. Other distributional models could be used.

To satisfy the Gaussian assumption, indices were routinely transformed by a method developed for the earlier work with the USGS (Ref. 1). The transformation is determined by the cumulative distribution of the original index, but is constrained such that the mean and variance of the resultant population will be essentially identical to the pre-transformation values.

For many indices this technique has functioned quite satisfactorily. Problems did, however, arise with some of the rock type indices. The difficulties are associated with two basic factors. Due to index definition only positive values are possible, yet because of the spatial distribution of the rock types, values at or close to zero are very common. It can be seen that with an index measuring the nearest occurrence of a rock type, a large number of well distributed occurrences will yield a preponderance of small index values. This in itself is not problematic, but possible index values consist only of combinations of grid point to grid point distances.

For some rock types the three smallest allowable values of 0, 8 and 11.3 are very heavily populated.

The difficulty is experienced not as a result of the skewness itself, but because such a large fraction of the total population rests with a small number of discrete values which in themselves are more widely separated than the higher index values for the population. When the nonlinear transformation is applied in this case the separation between hot spring values and the Nevada mean can be changed significantly, most typically being reduced. If, however, the distribution of hot spring values lies in a particularly nonlinear portion of the normalizing transformation function, the result may be quite unpredictable. As a result of this effect, many rock type indices which appeared to contain meaningful information were not useful after transformation. This effect was seen in the data presented in Section 4.

In an effort to mitigate this effect a somewhat different approach was taken with six rock type indices. The source map for the surface geology was used to determine accurately the actual distance to the nearest occurrence of every rock type existing within sixteen kilometers of each hot spring. For this procedure the grid point locations themselves were ignored. This data is recorded in Table 5.2-1. Index values for each hot spring location were then taken from this file if the specified rock type existed within the sixteen kilometer range. This was done for each of the six rock types; the corresponding indices have been referred to as the "micro" indices for the given rock type. In turn both the standard and "micro" indices were transformed for comparison. The intent of this procedure was to ascertain if an improvement in the granularity of the effective grid spacing for the highly sensitive learning set would improve the quality of the transformation. Evaluation of the technique was done through composite

TABLE 5.2-1

DISTANCE TO NEAREST OCCURRENCE OF ROCK TYPES WITHIN
SIXTEEN KILOMETERS OF HOT SPRINGS

T-2873

HOT SPRINGS	ROCK TYPES AND ASSOCIATED DISTANCES*
Pinto H.S.	JTRS (2.25), KGR (9.75), MZGR (1.25), QA (0.00), QLS (2.50), QP (10.75), TB (0.75), TOB (11.75), TRPV (14.25), TR2 (11.25), TT2 (0.25), TT3 (3.25)
Great Boiling Sprs.	KGR (0.75), MZGR (11.00), QA (0.25), QP (0.00), TBA (6.75), TRPV (6.50), TTS (6.25)
Hot Sulphur Springs	EC (9.50), EPEQ (10.50), OSV (8.00), PMH (4.25), PPA (7.75), QA (2.25), QM (11.25), QTOA (1.75), ST (11.75), TA1 (7.00), TA2 (2.50), TBG (10.75), TR3 (1.00), TS1 (0.00), TT1 (3.50), TT3 (0.50)
Near Wells	DC (5.75), DEC (13.50), DESV (11.25), DT (4.00), EPEQ (14.50), MDS (2.50), OC (11.00), PC (14.00), PSC (14.00), PPC (12.75), PPCD (4.50), QA (0.00), SOC (12.50), ST (10.50), TR3 (4.00), TS3 (0.25)
Sulphur H. S.	JGR (15.50), KGR (13.50), KJD (15.00), KJIM (4.50), PC (11.75), PSC (12.00), QA (0.00), QM (6.25), QP (3.00)
Beowawe H.S.	DSL (15.25), JGR (15.50), JV (15.25), OS (0.75), OSV (3.75), PPA (12.50), QA (0.00), QLS (1.25), QP (6.00), QTOA (14.75), SC (15.75), TA1 (11.00), TBA (2.50), TS3 (11.25), TT2 (14.75)
Kyle H.S.	JGR (15.25), JTRS (14.50), MSV (12.25), OSV (1.00), PMH (2.50), QA (0.00), TBA (6.75), TGR (11.50), TRC (0.50), TRK (14.50), TRLG (12.25), TS3 (13.50)
Leach H.S.	EH (10.00), ET (12.50), JGR (5.50), JTRS (15.75), KGR (11.00), OSV (13.75), PMH (1.00), PPA (13.50), QA (0.00), QTOA (0.25), TBA (10.75), TJGR (12.50), TRC (4.00), TRK (3.25), TRLG (11.00), TS3 (12.50), TT2 (8.50), TT3 (15.25)
Hot Springs Ranch	EH (9.25), EPEQ (13.00), ET (0.00), JGR (5.75), KGR (1.75), OSV (6.25), PMH (2.75), PPA (1.50), QA (0.00), QLS (10.75), QTB (7.25), QTOA (10.00), TJGR (11.00), TRC (13.25), TRK (11.75), TT2 (2.25), TT3 (2.00)
Jersey Valley H.S.	JTRS (14.00), PMH (1.75), QA (0.00), QTB (15.50), QTOA (0.50), TA2 (6.00), TA3 (4.00), TBA (10.50), TJGR (1.75), TRC (6.00), TRK (6.25), TS3 (1.50), TT1 (13.00), TT2 (4.75)
Stillwater Area	QA (3.50), QP (0.00), TA1 (6.00), TBA (5.75), TR3 (9.50), TS3 (10.50)
Soda Lake	QA (0.00), QP (3.75), QTB (2.00), TBA (15.50)
Brady H.S.	JTRV (9.50), QA (0.00), QP (5.50), TA3 (10.25), TBA (0.25), TR3 (12.00), TS3 (0.25), TT3 (6.75)
Steamboat Springs	JTRV (1.00), MZGR (0.50), QA (0.00), QLS (11.75), QM (10.50), QTB (1.00), QTOA (0.50), QTR (2.00), TA3 (0.50), TB (13.25), TGR (9.50), TMI (6.50), TRI (12.25), TS3 (10.00), TT2 (8.00)
Wabuska H.S.	JTRV (0.75), MZGR (8.50), QA (0.00), QP (12.00), TA3 (1.00), TBA (4.00), TS3 (4.50), TT2 (3.50)
Lee H.S.	JTRV (1.75), MZGR (10.50), QA (0.00), QP (3.00), TA3 (7.50), TBA (0.50), TRT (1.00), TR3 (3.50), TS3 (3.25), TT2 (9.50)
Smith Creek Valley	QA (0.00), QP (2.50), TA1 (13.00), TRI (11.00), TR2 (11.00), TT2 (5.00)

*Format: Rock Type 1 (Distance, Km), Rock Type 2 (Distance, Km), ...

likelihood calculations and is presented in the following section. The method did not, however, prove sufficiently beneficial to warrant extension to the other indices.

As a consequence of the difficulties described above, a relatively small number of transformed rock type indices were actually used in the composite index evaluations. In consideration of their apparent information content a number of untransformed indices were also used in some test cases. The rationale for violating the initial governing assumption is taken from Ref. 9. The observations contained there, based upon extensive study of robustness to non-normality in the F test and the t test, might well be applied here. Basically the contention is that it may be preferable to violate a Gaussian assumption rather than to lose much of the information content of a data source as a result of transformation. The hypothesis test developed here is substantially similar to the t test which has been found to be a highly robust statistic. Acceptance of this argument is obviously debatable and should in any case be made only with appropriate caution. Evaluations both with and without the untransformed indices are presented in Sections 5.3 and 5.4.

5.3 COMPOSITE EVALUATION OF INDICES

Eight composite cases, using only indices developed in this study, were defined as indicated in Table 5.3-1. For each of these the multi-dimensional signatures of the hot springs and Nevada as a whole were compared using covariance analysis and calculation of the likelihood ratios. The cases defined consist of from six to thirty-four separate indices. Cases 1 and 2 consider only those indices developed from the

TABLE 5.3-1
INDICES USED FOR COMPOSITE LIKELIHOOD EVALUATIONS

CASE NUMBER	INDICES*
1	87-98 (inclusive)
2	75-86 (incl.)
3	1-7 (incl.), 10-29 (incl.), 34, 35, 39, 41, 42, 65, 66
4	10, 12, 13, 17, 39, 41, 42, 65, 66
5	32-37 (incl.)
6	38-43 (incl.)
7	53-58 (incl.)
8	59-64 (incl.)

*Indices are referenced by number as described in
Table 5.1-1.

major lineament data. Case 3 through Case 8 are concerned exclusively with rock type and rock group indices.

Case 1 evaluated the entire set of twelve indices calculated from the subset of eight lineaments. All eleven lineaments were used for the calculation of the twelve indices considered in Case 2. The covariance analysis program was run for both of these cases. Correlation matrices for both runs indicated, as anticipated, rather high cross-correlations between several indices. This was found to be particularly true for those indices created by summing two effects -- e.g., distance to the nearest lineament plus the distance to the nearest end point. The averaging indices -- those measuring second or third occurrences of a given parameter -- were also prone to high correlations between each other. Consideration of the

eigenvectors indicated that the least information regarding the hot springs is contained in the nearest lineament data. In general, however, the information content was rather evenly distributed among all the indices.

The likelihood calculation program was also run for the above cases; the mapped likelihood function is shown in Figs. 5.3-1 and 5.3-2 for the indices based on eight (Case 1) and eleven (Case 2) lineaments, respectively. Both cases are reasonably selective in their assessment of the state and identify most of the learning set hot springs located by circles on the figures with likelihood ratios greater than one. Hot Sulphur Springs was missed in both of these cases and both Pinto and Great Boiling hot springs were missed in the Case 2 evaluation. The southern part of Nevada is, of course, highly de-emphasized by the distribution of the mapped lineaments in both cases. The small difference in ability to identify the learning set is insufficient to support the rather subjective basis for sampling only eight lineaments; hence all further evaluations with lineament data were made with the eleven lineament indices.

For Case 3 a large covariance analysis was performed on thirty-four rock type indices as noted in Table 5.3-1. Individual, dominant, and group assemblage indices were all included, but only fourteen had been transformed. A few of the transformed indices are identical to untransformed indices. Study of the correlation matrix again indicated significant cross-correlation, but only between those elements with obvious associations. Individual rock type indices, for instance, were highly correlated with dominant occurrences or transformed indices of that rock type. The most significant exception to this observation was the close correlation between rock types PC, a Permian limestone, and TRC a Triassic limestone. This, of course,

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Figure 5.3-1 Likelihood Ratio Map - Case 1

Figure 5.3-2 Likelihood Ratio Map - Case 2

is not particularly surprising considering the continuity of their ages. The likelihood ratios for Case 3 are presented in Fig. 5.3-3. Recovery of the learning set is only fair, as both Pinto and several of the eastern-most hot springs have low likelihood ratios. Selectivity, however, as with the previous two cases, is improved over the results from Ref. 1, reviewed in Fig. 2.6-1.

Another study, Case 4, was made with a subset of nine indices, all of which had been transformed. The indices used are again indicated in Table 5.3-1. Only two were representative of group assemblages. With this set there were no cross-correlations of major significance. Consideration of the eigenvectors and eigenvalues indicated maximum information content in the group index, G2A03J; minimum information content was not well defined, but was probably associated with individual rock type SOC, an Ordovician-Silurian carbonate. The likelihood ratios for Case 4 are shown in Fig. 5.3-4. Recognition of the learning set hot springs is generally good except for those to the east.

Because of the concern over whether or not to incorporate untransformed data and the study of "micro" indices that evolved in an effort to mitigate that problem, several other cases were evaluated. Six individual rock types indicated by one-dimensional studies to have significant information content were used. They were MZGR, PMH, JTRS, JTRV, KGR and TA3. Four runs were made using all six indices for each. First untransformed and transformed indices were compared in Case 5 and Case 6, respectively. Then similar runs, Case 7 and Case 8, were made using the equivalent untransformed and transformed "micro" data containing the detailed information regarding rock occurrences near the learning set. Index composition is listed in Table 5.3-1, and likelihood ratios for these four cases are shown in Figs. 5.3-5 to 5.3-8. It

R-39896a

Figure 5.3-3 Likelihood Ratio Map - Case 3

R-39897a

Figure 5.3-4 Likelihood Ratio Map - Case 4

R-39898a

Figure 5.3-5 Likelihood Ratio Map - Case 5

Figure 5.3-6 Likelihood Ratio Map - Case 6

R-39900a

Figure 5.3-7 Likelihood Ratio Map - Case 7

R-39901a

Figure 5.3-8 Likelihood Ratio Map - Case 8

can be seen that some degradation occurs due to index transformation. The "micro" procedure, unfortunately, did little to reduce the transformation problem and was subsequently abandoned. Study of the statistics for these cases again indicated no high cross-correlations. The information content is quite balanced among the indices, judging from the eigenvectors and eigenvalues. The best learning set identification in this series was obtained with Case 7, the untransformed "micro" indices. As with the earlier rock type evaluations, learning set identification was generally good except for the eastern-most springs.

5.4 INTEGRATION WITH PREVIOUS DATA

Integration of new indices with previous data is an iterative process based upon many aspects of the indices involved. The decisions require some fundamental geologic knowledge, for the statistics generated will hopefully represent a cause and effect relation. The result must be more than numbers. Implicit in the decision process are beliefs regarding relative data quality and the quality of the learning set. There is also important input from the one-dimensional statistics and initial composite evaluations.

All of these factors play an important role in dictating the composition of the resource evaluation. That step in itself is subject to some iteration. This is an other opportunity for the analyst to filter the data. It may be difficult to alter the results substantially at this stage -- they are determined by indices already generated. The analyst can, however, depending upon his objectives, establish criteria for fine tuning the selectivity of the resource assessment. By eliminating data that is highly correlated, by choosing indices

generated from quality data, and by recognizing physical reasons for partial failure of some indices to identify some element of the learning set, he can enhance considerably the final evaluation.

Several rather difficult index selections were made for this integrated evaluation. The decisions involved represented an attempt to develop the best possible results through careful consideration of index cross-correlation and source data quality and statistical significance. The most successful case from the USGS study, discussed in Section 2.6., has been taken as a working base to which new data has been added. Table 2.6-1 shows the indices used in that earlier case, and Table 5.4-1 lists the new indices selected for integrated evaluation.

TABLE 5.4-1
INDICES USED FOR INTEGRATED LIKELIHOOD EVALUATIONS

CASE NUMBER	INDICES*
9	75-86 (inclusive)
10	53, 54, 55, 57
11	53, 54, 55, 57
12	54, 55, 57
13	53-57 (incl.)
14	53-58 (incl.)
15	59-63 (incl.)
16	53-57 (incl.), 74, 75, 77-79 (incl.), 85

*All cases include, in addition, the seven indices from the most successful evaluation in the USGS study; these are summarized in Table 2.6-1. Indices are referenced by number as described in Table 5.1-1.

Case 9 combines all twelve lineament indices with the USGS data. The likelihood ratios are shown in Fig. 5.4-1, and hot spring locations are again shown as circles. As with the lineament studies alone, there is a strong de-emphasis of southern Nevada. Learning set identification is quite good. Most of the hot spring locations have likelihood ratios greater than two; only Pinto and Lee hot springs were missed. This is a distinct improvement over Case 2 in which only the major lineament data was incorporated. Use of the additional data in Case 9 yields identification of one more hot spring and an increase in the likelihood ratios at several other hot spring locations.

Cases 10 through 15 consist of the seven USGS indices plus selected rock type indices. As seen from Table 5.4-1 the first three of these are very similar. All use untransformed rock type data. Cases 10 and 11, with more data, produce very highly peaked likelihood ratios. These are shown in Figs. 5.4-2 and 5.4-3. Near Wells is not identified, and recognition of Sulphur Hot Springs is marginal, but all other hot springs have likelihood ratios of approximately three or greater. Case 12 is identical to Case 10 but for the absence of the MZGR index. The geothermal likelihood ratios for this are illustrated in Fig. 5.4-4. Recognition of the hot springs and peaking of the likelihood ratios is very similar to the previous two cases. This is important in that the spatial distribution of geothermal anomalies must be unique. One would hope to converge upon the same solution for the location of those energy sources using a variety of different data sources. Confidence in these results is thus enhanced by their apparent independence of the specific index selection.

Cases 13 and 14, whose likelihood ratios are shown in Figs. 5.4-5 and 5.4-6, are identical except for the addition

R-39902a

Figure 5.4-1 Likelihood Ratio Map - Case 9

R-39903a

Figure 5.4-2 Likelihood Ratio Map - Case 10

R-39904a

Figure 5.4-3 Likelihood Ratio Map - Case 11

R-39905a

Figure 5.4-4 Likelihood Ratio Map - Case 12

R-39906a

Figure 5.4-5

Likelihood Ratio Map - Case 13

R-39907a

Figure 5.4-6 Likelihood Ratio Map - Case 14

of individual rock type index TA3 in the latter. The rock type indices are again untransformed. Southern and eastern Nevada are very strongly de-emphasized in both, especially the latter. Peaking is higher than in Cases 10-12, but Near Wells is again missed. This is to be expected with Case 13 since it is simply an aggregate of those indices evaluated in Cases 10 through 12.

Case 14 is very interesting in that it peaks so precisely and strongly around those learning set hot springs that it does identify. This effect can be understood from the one-dimensional ratios. Each index in general succeeds in identifying only a subset of the seventeen hot springs. Use of the TA3 index reinforces the identification provided by the other indices, thereby amplifying the Case 13 identification rather than adding substantial new information.

Recognizing the concern regarding use of non-Gaussian indices, Case 15 was defined as a transformed version of Case 13. The indices used are listed in Table 5.4-1 and the likelihood ratios are shown in Fig. 5.4-7. Near Wells is again missed, and a number of the other learning set springs, including Sulphur Hot Springs, Beowawe, and Steamboat Springs, are only marginally recognized.

Accepting the rationale for employing untransformed data, Case 16 was designed to include the best of the one-dimensional discriminants. The indices were carefully selected to minimize redundant information and transformed indices were used when feasible. Case 16 consists of the best USGS indices, the rock type indices in Case 13, five of the major lineament indices, and group assemblage OR6. All but the rock type indices repeated from Case 13 are transformed. The composition is summarized in Table 5.4-1. Likelihood ratios for this case are shown in Fig. 5.4-8 with the learning set hot springs again

R-39908a

Figure 5.4-7 Likelihood Ratio Map - Case 15

R-39909a

CODED AMPLITUDE LEVELS	
•	VALUE EQUAL TO MINIMUM
0	0.0 < VALUE < = 0.3
1	0.3 < VALUE < = 0.5
2	0.5 < VALUE < = 0.8
3	0.8 < VALUE < = 1.1
4	1.1 < VALUE < = 1.3
5	1.3 < VALUE < = 1.6
6	1.6 < VALUE < = 1.9
7	1.9 < VALUE < = 2.1
8	2.1 < VALUE < = 2.4
9	2.4 < VALUE < = 2.7
A	2.7 < VALUE < = 2.9
B	2.9 < VALUE < = 3.2
C	3.2 < VALUE < = 3.5
D	3.5 < VALUE < = 3.7
E	3.7 < VALUE < = 4.0
F	4.0 < VALUE < = 4.3
G	4.3 < VALUE < = 4.5
H	4.5 < VALUE < = 4.8
I	4.8 < VALUE < = 5.1
J	5.1 < VALUE

Figure 5.4-8 Likelihood Ratio Map - Case 16

located with circles. A gray scale representation of those ratios is presented in Fig. 5.4-9. It can be seen that Case 16 succeeds well in recovering most of the learning set hot springs and providing data of a useful character. Peaking of the ratios about the known hot springs is high, yet significant extensions of those areas and a small number of new regions, all potentially worthy of exploration, are indicated. The areas highlighted are a small fraction of the entire evaluation region, in keeping with the initial assumptions. Furthermore, the region of indicated high likelihood of geothermal resources is appropriate to the object of technique -- specifically, to determine areas of limited extent wherein more detailed geophysical surveys would be justified and could be concentrated.

Case 16 is not intended as the ultimate geothermal assessment achievable with these data sources. As previously noted this evaluation procedure is an iterative process dependent to some degree on a subjective assessment of data quality and on the geoscientist's ability to relate statistical inference to rational geologic mechanisms. Involvement of other geoscientists may have led the investigation in a somewhat different direction. The study was intended to serve in part as a working assessment of the geothermal resources of Nevada. More important, perhaps, it also served as a functional demonstration of the hypothesis testing technique.

5.5 SUMMARY

Eighty-nine indices developed from the major lineament and rock type data were merged into a common data base for further evaluation. One-dimensional statistics were then calculated for the individual hot spring locations. Using this information and the discriminant potential statistics discussed

R-39910

Figure 5.4-9 Gray Scale Representation of Likelihood Ratio Map - Case 16

in previous sections, a number of cases were defined for multi-dimensional studies. Eight of these cases involved only indices developed in this study. Another eight cases were defined to assess the value of the new indices when integrated with seven selected indices from the earlier USGS study. Evaluation of all sixteen cases was made through the use of covariance analysis and calculation of the likelihood ratios.

6.

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions can be drawn from the investigation described here:

- The hypothesis testing technique has been shown to be a viable method for the integration of diverse types of geophysical data in resource exploration. The method can readily be extended to many other types of information, such as geochemical data.
- The new indices studied appear to add appreciably to the information content in the search for geothermal energy. The major lineament indices are strong discriminants though they tend to average over a considerable area, not offering the local sensitivity that might be desired. Rock type indices also contain considerable information. The use of rock type assemblages to represent facies concepts offers significant potential for additional discriminant development.
- The objectivity of the technique has again been demonstrated. Several indices, generally thought closely correlated with geothermal energy, were found to have similar statistics throughout all of Nevada; the hot springs were not discriminated. Other indices, initially believed to have little discriminant potential, were found to be quite useful.
- The likelihood calculation is considerably more selective with the addition of new information introduced during this study. Further

reduction in the area assigned high likelihood values would be anticipated with the addition of new data.

- The likelihood calculation is computationally efficient. Though statistical in nature the method does not preclude involvement of the geoscientist. It does in fact require his participation, preferably in an iterative mode.
- Hypothesis testing as implemented here is a generalized technique. It would be capable of differentiating any defined subset from the total population, given an appropriate learning set and regional data.

6.2 RECOMMENDATIONS

Based on the efforts reported herein it is recommended that the following steps be taken to refine the hypothesis testing technique and its application to geothermal exploration in particular:

- Integrate additional types of data as they become available for the state of Nevada. The USGS has now digitized aeromagnetic data for the state and the NASA Heat Capacity Mapping Mission (HCMM) is now providing data. Other useful information might be derived from topographic data and satellite multispectral imagery.
- Calculate indices for and evaluate a smaller region, a two-degree quadrangle for instance, to assess the application of hypothesis testing for discrimination with finer spatial resolution. Limitation to a smaller region might also permit the integration of some types of data not generally available for an entire state.

- Investigate the value of weighting different forms of data to reflect their accuracy. Examine also the effect of scale factors on area data such as the rock type information. If the information is contained in higher (spatial) frequency components, it may be lost due to grid spacing or mask dimension.
- Develop methods for handling missing data and incompatible data. Various data smoothing or estimation techniques might be employed to enable the use of data from surveys with such problems.
- Improve the statistical basis for this study by examining more fully the nature of the hot springs of lower temperature. The quality of the learning set could be improved significantly by their use directly or with the implementation of a weighting scheme for all springs according to temperature.
- Employ the methodology described in this report to study the value of different kinds of measurements which are not available for most of Nevada. Many exploration measurements are too costly to obtain over large areas. The hypothesis testing method can, however, prove to be an extremely objective way of determining the relative value of different surveys.
- Subsequent to further refinement of the likelihood estimates through the addition of new data, provide for limited verification of the results in the field. Only through this step can the true viability and cost effectiveness of hypothesis testing for resource exploration be confirmed.

APPENDIX A
ROCK TYPE OCCURRENCE STATISTICS FOR NEVADA
REGIONAL PARTITIONS AND GEOTHERMAL AREAS

This appendix contains tables showing the statistical occurrence of the indicated rock types in selected partitions and geothermal areas of Nevada. These regions are indicated in Figs. 4.2-1 and 4.2-2. The rock type code is given in Table 4.1-1 and the rock groups are defined in Table 4.5-1. Format and definitions used in the tables of this appendix are analogous to those used in Tables 4.2-1(a) and 4.2-1(b). A minor variation is the inclusion of Cumulative Frequency and Cumulative Percent in the following tables.

TABLE A-1
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 1

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
EH	19	19	0.676	0.676
EPEQ	6	25	0.213	0.889
ET	11	36	0.391	1.280
JGB	9	45	0.320	1.600
JGR	18	63	0.640	2.240
JTRS	209	272	7.432	9.673
JTRV	1	273	0.036	9.708
KGR	112	385	3.983	13.691
KJD	16	401	0.569	14.260
KS	9	410	0.320	14.580
MSV	5	415	0.178	14.758
MZGR	77	492	2.738	17.496
NONE	32	524	1.138	18.634
OS	7	531	0.249	18.883
OSV	23	554	0.818	19.701
PMH	64	618	2.276	21.977
PPA	9	627	0.320	22.297
PPC	2	629	0.071	22.368
QA	608	1237	21.622	43.990
QLS	49	1286	1.743	45.733
QM	3	1289	0.107	45.839
QP	138	1427	4.908	50.747
QT8	30	1457	1.067	51.814
QTOA	43	1500	1.529	53.343
TA1	7	1507	0.249	53.592
TA2	34	1541	1.209	54.801
TA3	30	1571	1.067	55.868
T8	177	1748	6.294	62.162
TBA	224	1972	7.966	70.128
TGR	3	1975	0.107	70.235
TJGR	1	1976	0.036	70.270
TKS	1	1977	0.036	70.306
TMI	3	1980	0.107	70.413
TOB	5	1985	0.178	70.590
TRC	52	2037	1.849	72.440
TRK	37	2074	1.316	73.755
TRLG	7	2081	0.249	74.004
TRPV	49	2130	1.743	75.747
TRT	9	2139	0.320	76.067
TR1	16	2155	0.569	76.636
TR2	21	2176	0.747	77.383
TR3	208	2384	7.397	84.780
TS1	1	2385	0.036	84.815
TS3	122	2507	4.339	89.154
TTS	111	2618	3.947	93.101
TT2	57	2675	2.027	95.128
TT3	137	2812	4.872	100.000

TABLE A-2
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 2

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	78	78	2.155	2.156
DEC	11	89	0.304	2.461
DESV	19	108	0.525	2.986
DS	9	117	0.249	3.235
DSL	20	137	0.553	3.788
DT	9	146	0.249	4.036
EC	34	180	0.940	4.976
EH	6	186	0.166	5.142
EPEQ	25	211	0.691	5.834
ESC	4	215	0.111	5.944
ET	4	219	0.111	6.055
JGR	32	251	0.885	6.939
JTRA	3	254	0.083	7.022
JV	11	265	0.304	7.327
KGR	27	292	0.746	8.073
KJD	11	303	0.304	8.377
KJIM	30	333	0.829	9.207
KS	3	336	0.083	9.289
MC	1	337	0.028	9.317
MDMC	14	351	0.387	9.704
MDS	121	472	3.345	13.049
NONE	28	500	0.774	13.824
OC	70	570	1.935	15.759
OET	11	581	0.304	16.063
OS	81	662	2.239	18.302
OSV	95	757	2.626	20.929
OT	5	762	0.138	21.067
PC	105	867	2.903	23.970
PCD	3	870	0.083	24.053
PEQS	7	877	0.194	24.247
PMC	51	928	1.410	25.657
PMH	27	955	0.746	26.403
PNC	3	958	0.083	26.486
PPA	40	998	1.106	27.592
PPC	115	1113	3.179	30.771
PPCD	18	1131	0.498	31.269
PSC	105	1236	2.903	34.172
QA	643	1879	17.777	51.949
QLS	43	1922	1.189	53.138
QM	9	1931	0.249	53.387
QP	53	1984	1.465	54.852
QTB	3	1987	0.083	54.935
QTOA	59	2046	1.631	56.566
QTS	21	2067	0.581	57.147
SC	18	2085	0.498	57.644
SE	8	2093	0.221	57.866
SDC	28	2121	0.774	58.640
SS	6	2127	0.166	58.806
ST	24	2151	0.664	59.469
TA1	108	2259	2.986	62.455
TA2	28	2287	0.774	63.229
TA3	26	2313	0.719	63.948
TB	38	2351	1.051	64.999

TABLE A-2 (Continued)
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 2

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
TBA	39	2390	1.078	66.077
TBG	93	2483	2.571	68.648
TBR	6	2489	0.166	68.814
TGR	18	2507	0.498	69.312
TJGR	31	2538	0.857	70.169
TMI	1	2539	0.028	70.196
TOB	8	2547	0.221	70.417
TRC	2	2549	0.055	70.473
TRCH	1	2550	0.028	70.500
TRI	1	2551	0.028	70.528
TRMT	41	2592	1.134	71.662
TRPS	3	2595	0.083	71.745
TR1	55	2650	1.521	73.265
TR2	6	2656	0.166	73.431
TR3	199	2855	5.502	78.933
TS1	50	2905	1.382	80.315
TS2	5	2910	0.138	80.453
TS3	375	3285	10.368	90.821
TS3	34	3319	0.940	91.761
TT1	91	3410	2.516	94.277
TT2	75	3485	2.074	96.351
TT3	132	3617	3.649	100.000

TABLE A-3
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 3

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	3	3	0.138	0.138
EPEQ	15	18	0.691	0.829
EPES	1	19	0.046	0.875
ET	8	27	0.368	1.243
JD	2	29	0.092	1.335
JGB	18	47	0.829	2.164
JGR	5	52	0.230	2.394
JPU	12	64	0.552	2.947
JTRS	86	150	3.959	6.906
JTRV	99	249	4.558	11.464
KGR	13	262	0.599	12.063
KJD	19	281	0.875	12.937
MZGR	137	418	6.308	19.245
NONE	34	452	1.565	20.810
OC	5	457	0.230	21.041
OET	11	468	0.506	21.547
OSV	13	481	0.599	22.145
PMH	21	502	0.967	23.112
PPA	3	505	0.138	23.250
PZSP	2	507	0.092	23.343
QA	501	1008	23.066	46.409
QLS	3	1011	0.138	46.547
QP	51	1062	2.348	48.895
QTA	3	1065	0.138	49.033
QTB	14	1079	0.645	49.678
QTOA	54	1133	2.486	52.164
QTR	4	1137	0.184	52.348
SC	3	1140	0.138	52.486
ST	6	1146	0.276	52.762
TA1	31	1177	1.427	54.190
TA2	29	1206	1.335	55.525
TA3	135	1341	6.215	61.740
TB	7	1348	0.322	62.063
TBA	192	1540	8.840	70.902
TGR	13	1553	0.599	71.501
TJGR	33	1586	1.519	73.020
TMI	15	1601	0.691	73.711
TRC	28	1629	1.289	75.000
TRK	7	1636	0.322	75.322
TRPD	6	1642	0.276	75.599
TRT	10	1652	0.460	76.059
TR1	33	1685	1.519	77.578
TR2	19	1704	0.875	78.453
TR3	14	1718	0.645	79.098
TS2	5	1723	0.230	79.328
TS3	145	1868	6.676	86.004
TTS	1	1869	0.046	86.050
TT2	299	2168	13.766	99.816
TT3	4	2172	0.184	100.000

TABLE A-4
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 4

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	241	241	8.234	8.234
DS	1	242	0.034	8.268
DSL	13	255	0.444	8.712
EC	103	358	3.519	12.231
EPEQ	67	425	2.289	14.520
ET	8	433	0.273	14.793
JGR	27	460	0.922	15.716
KGR	10	470	0.342	16.057
KJD	1	471	0.034	16.092
KS	8	479	0.273	16.365
MDS	189	668	6.457	22.822
NONE	28	696	0.957	23.779
OC	169	865	5.774	29.552
OET	13	878	0.444	29.997
OS	66	944	2.255	32.251
CSV	24	968	0.820	33.071
PC	39	1007	1.332	34.404
PCD	1	1008	0.034	34.438
PEQS	25	1033	0.854	35.292
PMC	2	1035	0.068	35.360
PMH	14	1049	0.478	35.839
PNC	17	1066	0.581	36.420
PPA	9	1075	0.307	36.727
PPC	180	1255	6.150	42.877
PPCD	5	1260	0.171	43.047
PSC	100	1360	3.416	46.464
QA	599	1959	20.465	66.929
QP	26	1985	0.888	67.817
QTCA	23	2008	0.786	68.603
QTS	6	2014	0.205	68.808
SC	51	2065	1.742	70.550
SOC	93	2158	3.177	73.727
ST	28	2186	0.957	74.684
TA1	136	2322	4.646	79.330
TA2	42	2364	1.435	80.765
TB	3	2367	0.102	80.868
TBA	13	2380	0.444	81.312
TBR	12	2392	0.410	81.722
TGR	21	2413	0.717	82.439
TJGR	13	2426	0.444	82.883
TKS	7	2433	0.239	83.123
TMI	3	2436	0.102	83.225
TRC	1	2437	0.034	83.259
TRMT	3	2440	0.102	83.362
TR1	96	2536	3.280	86.642
TR2	20	2556	0.683	87.325
TR3	17	2573	0.581	87.906
TS1	23	2596	0.786	88.691
TS2	17	2613	0.581	89.272
TS3	79	2692	2.699	91.971
TTS	1	2693	0.034	92.005
TT1	15	2708	0.512	92.518
TT2	218	2926	7.448	99.966
TT3	1	2927	0.034	100.000

TABLE A-5
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 5

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	371	371	5.184	5.184
DEC	31	402	0.433	5.617
DS	3	405	0.042	5.659
EC	277	682	3.870	9.529
EPEQ	105	787	1.467	10.996
EPES	91	878	1.271	12.268
ESS	19	897	0.265	12.533
ET	38	935	0.531	13.064
JD	23	958	0.321	13.385
JGR	28	986	0.391	13.777
JPU	3	989	0.042	13.819
JTRA	39	1028	0.545	14.364
JTRS	2	1030	0.028	14.392
JTRV	28	1058	0.391	14.783
KGR	30	1088	0.419	15.202
KJD	29	1117	0.405	15.607
KS	4	1121	0.056	15.663
MC	147	1268	2.054	17.717
MDS	145	1413	2.026	19.743
MZGR	94	1507	1.313	21.056
NONE	52	1559	0.727	21.783
OC	262	1821	3.661	25.444
DEC	44	1865	0.615	26.058
OET	15	1880	0.210	26.268
OS	42	1922	0.587	26.855
OSV	18	1940	0.252	27.106
PC	91	2031	1.271	28.378
PEGR	25	2056	0.349	28.727
PEM	82	2138	1.146	29.873
PEQS	25	2163	0.349	30.222
PES	23	2186	0.321	30.544
PMH	31	2217	0.433	30.977
PNC	6	2223	0.084	31.061
PPC	232	2455	3.242	34.302
PSC	68	2523	0.950	35.252
PZSP	1	2524	0.014	35.266
QA	1329	3853	18.569	53.835
QLS	17	3870	0.238	54.073
QM	1	3871	0.014	54.087
QP	148	4019	2.068	56.155
QTA	15	4034	0.210	56.364
QTB	105	4139	1.467	57.831
QTCA	75	4214	1.048	58.879
QTR	1	4215	0.014	58.893
QTS	11	4226	0.154	59.047
SC	174	4400	2.431	61.478
SOC	9	4409	0.126	61.604
ST	9	4418	0.126	61.730
TA2	192	4610	2.683	64.412
TA3	165	4775	2.305	66.718
TB	93	4868	1.299	68.017
TBA	139	5007	1.942	69.959
TBR	16	5023	0.224	70.183

TABLE A-5 (Continued)
ALL ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 5

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
TGR	23	5046	0.321	70.504
THS	48	5094	0.671	71.175
TI	35	5129	0.489	71.664
TJGR	1	5130	0.014	71.678
TKS	25	5155	0.349	72.027
TKSU	16	5171	0.224	72.251
TMI	27	5198	0.377	72.628
TOB	3	5201	0.042	72.670
TRC	23	5224	0.321	72.991
TRCH	31	5255	0.433	73.425
TRI	18	5273	0.252	73.676
TRMT	74	5347	1.034	74.710
TRPD	4	5351	0.056	74.766
TRPV	6	5357	0.084	74.850
TRT	21	5378	0.293	75.143
TR1	58	5436	0.810	75.954
TR2	118	5554	1.649	77.602
TR3	210	5764	2.934	80.537
TS1	4	5768	0.056	80.592
TS2	52	5820	0.727	81.319
TS3	310	6130	4.331	85.650
TT2	60	6190	0.838	86.489
TT2	592	6782	8.272	94.760
TT3	375	7157	5.240	100.000

TABLE A-6
ALL ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 1

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
JTRS	34	84	5.657	5.657
JTRV	1	85	0.067	5.724
KGR	52	137	3.502	9.226
KJD	15	152	1.010	10.236
KS	9	161	0.606	10.842
MZGR	53	214	3.569	14.411
NONE	18	232	1.212	15.623
QA	285	517	19.192	34.815
QLS	46	563	3.098	37.912
QM	2	565	0.135	38.047
QP	90	655	6.061	44.108
QTB	19	674	1.279	45.387
QTOA	20	694	1.347	46.734
TA1	4	698	0.269	47.003
TA2	26	724	1.751	48.754
TA3	14	738	0.943	49.697
TB	160	898	10.774	60.471
T8A	95	993	6.397	66.869
TMI	3	996	0.202	67.071
TQB	5	1001	0.337	67.407
TRC	7	1008	0.471	67.879
TRK	3	1011	0.202	68.081
TRPV	49	1060	3.300	71.380
TR1	5	1065	0.337	71.717
TR2	19	1084	1.279	72.997
TR3	140	1224	9.428	82.424
TS3	61	1285	4.108	86.532
TTS	103	1388	6.936	93.468
TT2	21	1409	1.414	94.882
TT3	76	1485	5.118	100.000

TABLE A-7
ALL ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 2

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	7	7	0.631	0.631
DSL	20	27	1.802	2.432
DT	1	28	0.090	2.523
EC	2	30	0.180	2.703
EH	17	47	1.532	4.234
EPEQ	4	51	0.360	4.595
ESC	4	55	0.360	4.955
ET	11	66	0.991	5.946
JGB	3	69	0.270	6.216
JGR	30	99	2.703	8.919
JTRS	41	140	3.694	12.613
JV	7	147	0.631	13.243
KGR	10	157	0.901	14.144
KJD	2	159	0.180	14.324
KS	1	160	0.090	14.414
MSV	3	163	0.270	14.685
MZGR	1	164	0.090	14.775
NONE	17	181	1.532	16.306
OC	10	191	0.901	17.207
OS	31	222	2.793	20.000
OSV	65	287	5.856	25.856
PMH	68	355	6.126	31.982
PPA	28	383	2.523	34.505
PPC	2	385	0.180	34.685
QA	256	641	23.063	57.748
QLS	8	649	0.721	58.468
QP	6	655	0.541	59.009
QTB	14	669	1.261	60.270
QTOA	34	703	3.063	63.333
QTS	7	710	0.631	63.964
SC	4	714	0.360	64.324
SE	8	722	0.721	65.045
SS	2	724	0.180	65.225
ST	6	730	0.541	65.766
TA1	22	752	1.982	67.748
TA2	5	757	0.450	68.198
TA3	4	761	0.360	68.559
TB	9	770	0.811	69.369
TBA	61	831	5.495	74.865
TBR	2	833	0.180	75.045
TGR	9	842	0.811	75.856
TJGR	5	847	0.450	76.306
TKS	1	848	0.090	76.396
TRC	44	892	3.964	80.360
TRK	30	922	2.703	83.063
TRLG	5	927	0.450	83.514
TR1	8	935	0.721	84.234
TR2	1	936	0.090	84.324
TR3	34	970	3.063	87.387
TS1	7	977	0.631	88.018
TS3	59	1036	5.315	93.333
TTS	2	1038	0.180	93.514
TT2	62	1100	5.586	99.099
TT3	10	1110	0.901	100.000

TABLE A-8
ALL ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 3

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	55	55	2.647	2.647
DEC	11	66	0.529	3.176
DESV	19	85	0.914	4.090
DS	8	93	0.385	4.475
DT	7	100	0.337	4.812
EC	23	123	1.107	5.919
EPEQ	23	146	1.107	7.026
ET	1	147	0.048	7.074
JGR	19	166	0.914	7.988
JTRA	3	169	0.144	8.133
JV	4	173	0.192	8.325
KGR	6	179	0.289	8.614
KJD	8	187	0.385	8.999
KJIM	30	217	1.444	10.443
KS	2	219	0.096	10.539
MDMC	3	222	0.144	10.683
MDS	100	322	4.812	15.496
NONE	15	337	0.722	16.218
OC	47	384	2.262	18.479
OET	4	388	0.192	18.672
OS	43	431	2.069	20.741
OSV	36	467	1.732	22.474
OT	5	472	0.241	22.714
PC	89	561	4.283	26.997
PCD	3	564	0.144	27.141
PEQS	7	571	0.337	27.478
PMC	35	606	1.684	29.163
PMH	9	615	0.433	29.596
PPA	11	626	0.529	30.125
PPC	92	718	4.427	34.552

TABLE A-8 (Continued)
ALL ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 3

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
PPCD	18	736	0.866	35.419
PSC	79	815	3.802	39.220
QA	381	1196	18.335	57.555
QLS	16	1212	0.770	58.325
QM	5	1217	0.241	58.566
QP	38	1255	1.829	60.395
QTOA	8	1263	0.385	60.780
QTS	9	1272	0.433	61.213
SC	6	1278	0.289	61.501
SQC	23	1301	1.107	62.608
SS	4	1305	0.192	62.801
ST	16	1321	0.770	63.571
TA1	37	1358	1.781	65.351
TA2	17	1375	0.818	66.169
TA3	19	1394	0.914	67.084
TB	10	1404	0.481	67.565
TBA	5	1409	0.241	67.806
TBG	3	1412	0.144	67.950
TBR	3	1415	0.144	68.094
TGR	9	1424	0.433	68.527
TJGR	24	1448	1.155	69.682
THI	1	1449	0.048	69.731
TOB	1	1450	0.048	69.779
TRCH	1	1451	0.048	69.827
TRMT	33	1484	1.588	71.415
TRPS	3	1487	0.144	71.559
TR1	22	1509	1.059	72.618
TR2	2	1511	0.096	72.714
TR3	103	1614	4.957	77.671
TS1	39	1653	1.877	79.548
TS2	3	1656	0.144	79.692
TS3	279	1935	13.426	93.118
TT1	74	2009	3.561	96.679
TT2	25	2034	1.203	97.883
TT3	44	2078	2.117	100.000

TABLE A-9
ALL ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 4

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	3	3	0.162	0.162
EPEQ	13	16	0.702	0.863
ET	8	24	0.432	1.295
JD	1	25	0.054	1.349
JGB	18	43	0.971	2.321
JGR	5	48	0.270	2.590
JPU	8	56	0.432	3.022
JTRS	85	141	4.587	7.609
JTRV	69	210	3.724	11.333
KGR	13	223	0.702	12.035
KJD	11	234	0.594	12.628
MZGR	102	336	5.505	18.133
NCNE	34	370	1.835	19.968
OC	5	375	0.270	20.237
OET	6	381	0.324	20.561
OSV	13	394	0.702	21.263
PMH	18	412	0.971	22.234
PPA	3	415	0.162	22.396
PZSP	2	417	0.108	22.504
QA	439	856	23.691	46.195
QLS	3	859	0.162	46.357
QP	51	910	2.752	49.110
QTA	3	913	0.162	49.271
QTB	14	927	0.756	50.027
QTC	50	977	2.698	52.725
QTR	4	981	0.216	52.941
SC	3	984	0.162	53.103
ST	5	989	0.270	53.373
TA1	23	1012	1.241	54.614
TA2	22	1034	1.187	55.801
TA3	105	1139	5.666	61.468
TB	7	1146	0.378	61.846
TBA	172	1318	9.282	71.128
TGR	11	1329	0.594	71.722
TJGR	30	1359	1.619	73.341
TMI	13	1372	0.702	74.042
TRC	25	1397	1.349	75.391
TRK	7	1404	0.378	75.769
TRPD	2	1406	0.108	75.877
TRT	10	1416	0.540	76.417
TR1	28	1444	1.511	77.928
TR2	12	1456	0.648	78.575
TR3	11	1467	0.594	79.169
TS2	5	1472	0.270	79.439
TS3	118	1590	6.368	85.807
TTS	1	1591	0.054	85.861
TT2	258	1849	13.923	99.784
TT3	4	1853	0.216	100.000

TABLE A-10
DOMINANT ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 1

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
EH	10	10	1.209	1.209
EPEQ	2	12	0.242	1.451
ET	2	14	0.242	1.693
JGB	5	19	0.605	2.297
JGR	2	21	0.242	2.539
JTRS	119	140	14.389	16.929
KGR	51	191	6.167	23.096
KJD	2	193	0.242	23.337
MSV	3	196	0.363	23.700
MZGR	27	223	3.265	26.965
OS	3	226	0.363	27.328
OSV	6	232	0.726	28.053
PMH	42	274	5.079	33.132
PPA	1	275	0.121	33.253
QTB	12	287	1.451	34.704
TA1	2	289	0.242	34.946
TA2	21	310	2.539	37.485
TA3	4	314	0.484	37.969
TB	116	430	14.027	51.995
TBA	89	519	10.762	62.757
TMI	1	520	0.121	62.878
TDB	1	521	0.121	62.999
TRC	15	536	1.814	64.813
TRK	13	549	1.572	66.385
TRLG	4	553	0.484	66.868
TRPV	25	578	3.023	69.891
TRT	2	580	0.242	70.133
TR2	15	595	1.814	71.947
TR3	105	700	12.696	84.643
TS3	35	735	4.232	88.875
TTS	23	758	2.781	91.657
TT2	19	777	2.297	93.954
TT3	50	827	6.046	100.000

TABLE A-11
DOMINANT ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 2

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	21	21	2.236	2.236
DEC	7	28	0.745	2.982
DESV	4	32	0.426	3.408
DSL	4	36	0.426	3.834
DT	2	38	0.213	4.047
EC	9	47	0.958	5.005
EH	3	50	0.319	5.325
EPEQ	6	56	0.639	5.964
ET	1	57	0.106	6.070
JGR	19	76	2.023	8.094
JV	10	86	1.065	9.159
KGR	7	93	0.745	9.904
KJIM	28	121	2.982	12.886
MDMC	3	124	0.319	13.206
MDS	29	153	3.088	16.294
DC	15	168	1.597	17.891
DET	1	169	0.106	17.998
OS	18	187	1.917	19.915
OSV	37	224	3.940	23.855
PC	29	253	3.088	26.944
PEQS	3	256	0.319	27.263
PMC	7	263	0.745	28.009
PMH	8	271	0.852	28.860
PPA	3	274	0.319	29.180
PPC	26	300	2.769	31.949
PPCD	3	303	0.319	32.268
PSC	34	337	3.621	35.889
QTB	6	343	0.639	36.528
QTS	13	356	1.384	37.913
SE	1	357	0.106	38.019
SCC	2	359	0.213	38.232
SS	1	360	0.106	38.339
TA1	30	390	3.195	41.534
TA2	4	394	0.426	41.960
TA3	1	395	0.106	42.066
TB	13	408	1.384	43.450
TBA	23	431	2.449	45.900
TBG	76	507	8.094	53.994
TGR	5	512	0.532	54.526
TJGR	5	517	0.532	55.059
TOB	1	518	0.106	55.165
TRC	1	519	0.106	55.272
TRMT	5	524	0.532	55.804
TR1	21	545	2.236	58.040
TR3	104	649	11.076	69.116
TS1	9	658	0.958	70.075
TS2	2	660	0.213	70.288
TS3	185	845	19.702	89.989
TTS	10	855	1.065	91.054
TT1	24	879	2.556	93.610
TT2	15	894	1.597	95.208
TT3	45	939	4.792	100.000

TABLE A-12
 DOMINANT ROCK OCCURRENCES IN NEVADA
 REGIONAL PARTITION 3

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
EPEQ	3	3	0.499	0.499
ET	3	6	0.499	0.998
JGB	10	16	1.664	2.662
JTRS	24	40	3.993	6.656
JTRV	26	66	4.326	10.982
KGR	5	71	0.832	11.814
KJD	2	73	0.333	12.146
MZGR	56	129	9.318	21.464
OET	2	131	0.333	21.797
CSV	8	139	1.331	23.128
PMH	2	141	0.333	23.461
QTA	1	142	0.166	23.627
QTB	9	151	1.498	25.125
TA1	1	152	0.166	25.291
TA2	9	161	1.498	26.789
TA3	57	218	9.484	36.273
TB	2	220	0.333	36.606
TBA	108	328	17.970	54.576
TGR	3	331	0.499	55.075
TJGR	9	340	1.498	56.572
TMI	1	341	0.166	56.739
TRC	14	355	2.329	59.068
TRT	1	356	0.166	59.235
TR1	2	358	0.333	59.567
TR2	2	360	0.333	59.900
TR3	1	361	0.166	60.067
TS3	51	412	8.486	68.552
TT2	189	601	31.448	100.000

TABLE A-13
DOMINANT ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 4

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	76	76	11.515	11.515
DSL	6	82	0.909	12.424
EC	40	122	6.061	18.485
EPEQ	32	154	4.848	23.333
ET	1	155	0.152	23.485
JGR	7	162	1.061	24.545
KGR	4	166	0.606	25.152
KS	4	170	0.606	25.758
MDS	44	214	6.667	32.424
QC	28	242	4.242	36.667
CET	3	245	0.455	37.121
OS	24	269	3.636	40.758
OSV	5	274	0.758	41.515
PC	5	279	0.758	42.273
PEQS	12	291	1.818	44.091
PMH	4	295	0.606	44.697
PPC	27	322	4.091	48.788
PPCD	5	327	0.758	49.545
PSC	39	366	5.909	55.455
SC	6	372	0.909	56.364
SOC	2	374	0.303	56.667
TA1	47	421	7.121	63.788
TA2	20	441	3.030	66.818
TBA	2	443	0.303	67.121
TGR	1	444	0.152	67.273
TJGR	6	450	0.909	68.182
TR1	46	496	6.970	75.152
TR2	3	499	0.455	75.606
TR3	4	503	0.606	76.212
TS1	2	505	0.303	76.515
TS2	1	506	0.152	76.667
TS3	28	534	4.242	80.909
TT2	126	660	19.091	100.000

TABLE A-14
DOMINANT ROCK OCCURRENCES IN NEVADA
REGIONAL PARTITION 5

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	84	84	5.512	5.512
DEC	15	99	0.984	6.496
EC	71	170	4.659	11.155
EPEQ	34	204	2.231	13.386
EPES	23	227	1.509	14.895
ET	3	230	0.197	15.092
JD	1	231	0.066	15.157
JGR	12	243	0.787	15.945
JTRA	7	250	0.459	16.404
JTRV	7	257	0.459	16.864
KGR	11	268	0.722	17.585
MC	14	282	0.919	18.504
MDS	13	295	0.853	19.357
MZGR	24	319	1.575	20.932
OC	65	384	4.265	25.197
OEC	5	389	0.328	25.525
CET	5	394	0.328	25.853
OS	4	398	0.262	26.115
OSV	3	401	0.197	26.312
PC	10	411	0.656	26.969
PEGR	7	418	0.459	27.428
PEM	29	447	1.903	29.331
PEQS	3	450	0.197	29.528
PES	3	453	0.197	29.724
PMH	7	460	0.459	30.184
PNC	1	461	0.066	30.249
PPC	74	535	4.856	35.105
PSC	4	539	0.262	35.367
QTA	6	545	0.394	35.761
QTB	28	573	1.837	37.598
QTS	2	575	0.131	37.730
SC	5	580	0.328	38.058
TA2	36	616	2.362	40.420
TA3	43	659	2.822	43.241
TB	8	667	0.525	43.766
TBA	50	717	3.281	47.047
TBR	2	719	0.131	47.178
TGR	3	722	0.197	47.375
THS	8	730	0.525	47.900
TI	20	750	1.312	49.213
TKS	5	755	0.328	49.541
TKSU	12	767	0.787	50.328
TMI	1	768	0.066	50.394
TRC	7	775	0.459	50.853
TRCH	1	776	0.066	50.919
TRMT	7	783	0.459	51.378
TRPD	1	784	0.066	51.444
TRPV	1	785	0.066	51.509
TRT	11	796	0.722	52.231
TR1	3	799	0.197	52.428
TR2	17	816	1.115	53.543
TR3	47	863	3.084	56.627
TS2	4	867	0.262	56.890
TS3	140	1007	9.186	66.076
TTS	8	1015	0.525	66.601
TT2	352	1367	23.097	89.698
TT3	157	1524	10.302	100.000

TABLE A-15
DOMINANT ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 1

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
JTRS	42	42	9.396	9.396
KGR	30	72	6.711	16.107
KJD	2	74	0.447	16.555
MZGR	21	95	4.698	21.253
QTB	9	104	2.013	23.266
TA1	2	106	0.447	23.714
TA2	17	123	3.803	27.517
TA3	1	124	0.224	27.740
TB	104	228	23.266	51.007
TBA	36	264	8.054	59.060
TMI	1	265	0.224	59.284
T0B	1	266	0.224	59.508
TRC	3	269	0.671	60.179
TRK	3	272	0.671	60.850
TRPV	25	297	5.593	66.443
TR2	15	312	3.356	69.799
TR3	69	381	15.436	85.235
TS3	27	408	6.040	91.275
TTS	19	427	4.251	95.526
TT3	20	447	4.474	100.000

TABLE A-16
DOMINANT ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 2

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	1	1	0.333	0.333
DSL	4	5	1.333	1.667
EH	7	12	2.333	4.000
EPEQ	2	14	0.667	4.667
ET	2	16	0.667	5.333
JGB	1	17	0.333	5.667
JGR	9	26	3.000	8.667
JTRS	23	49	7.667	16.333
JV	6	55	2.000	18.333
MSV	3	58	1.000	19.333
OS	17	75	5.667	25.000
OSV	33	108	11.000	36.000
PMH	44	152	14.667	50.667
PPA	1	153	0.333	51.000
QTB	9	162	3.000	54.000
QTS	4	166	1.333	55.333
SE	1	167	0.333	55.667
SS	1	168	0.333	56.000
TA1	5	173	1.667	57.667
TA2	3	176	1.000	58.667
TB	7	183	2.333	61.000
TBA	32	215	10.667	71.667
TRC	12	227	4.000	75.667
TRK	6	233	2.000	77.667
TRLG	4	237	1.333	79.000
TR1	2	239	0.667	79.667
TR3	14	253	4.667	84.333
TS1	2	255	0.667	85.000
TS3	12	267	4.000	89.000
TT2	31	298	10.333	99.333
TT3	2	300	0.667	100.000

TABLE A-17
DOMINANT ROCK OCCURRENCES IN NEVADA
GEOTHERMAL AREA 3

ROCK TYPE	FREQUENCY	CUMULATIVE FREQUENCY	PERCENT	CUMULATIVE PERCENT
DC	13	13	2.510	2.510
DEC	7	20	1.351	3.861
DESV	4	24	0.772	4.633
DT	2	26	0.386	5.019
EC	6	32	1.158	6.178
EPEQ	6	38	1.158	7.336
JGR	12	50	2.317	9.653
JV	4	54	0.772	10.425
KGR	2	56	0.386	10.811
KJIM	28	84	5.405	16.216
MDS	25	109	4.826	21.042
OC	12	121	2.317	23.359
OET	1	122	0.193	23.552
OS	3	125	0.579	24.131
OSV	10	135	1.931	26.062
PC	28	163	5.405	31.467
PEQS	3	166	0.579	32.046
PMC	5	171	0.965	33.012
PMH	3	174	0.579	33.591
PPC	20	194	3.861	37.452
PPCD	3	197	0.579	38.031
PSC	23	220	4.440	42.471
QTS	4	224	0.772	43.243
SOC	2	226	0.386	43.629
TA1	7	233	1.351	44.981
TA2	3	236	0.579	45.560
TA3	1	237	0.193	45.753
TB	1	238	0.193	45.946
TBG	1	239	0.193	46.139
TGR	5	244	0.965	47.104
TJGR	5	249	0.965	48.069
TRMT	4	253	0.772	48.842
TR1	10	263	1.931	50.772
TR3	61	324	11.776	62.548
TS1	7	331	1.351	63.900
TS2	2	333	0.386	64.286
TS3	162	495	31.274	95.560
TT1	18	513	3.475	99.035
TT3	5	518	0.965	100.000

APPENDIX B
MAPS OF SELECTED ROCK TYPE OCCURRENCE IN NEVADA

This appendix contains maps indicating the occurrence of selected rock types in Nevada. Each point indicates the occurrence or non-occurrence of that rock unit or group assemblage within six kilometers of the mapped point. The source map and rock type/group definition are discussed in Chapter 4.

Map Explanation

- * Selected rock type/group occurs within six kilometers of designated grid point
- . Selected rock type/group does not occur within six kilometers of designated grid point
- H Location of learning set hot spring, non-coincident with occurrence of designated rock type/group
- K Location of learning set hot spring, coincident with occurrence of designated rock type/group

Figure B-1 Occurrences of Rock Type JGR

Figure B-2 Occurrences of Rock Type JTRS

Figure B-3 Occurrences of Rock Type JTRV

Figure B-4 Occurrences of Rock Type KGR

Figure B-5 Occurrences of Rock Type MZGR

Figure B-6 Occurrences of Rock Type PMH

Figure B-7 Occurrences of Rock Type TA3

Figure B-8 Occurrences of Rock Type TBA

B-10

Figure B-10 Occurrences of Dominant Rock Type EC

Figure B-11 Occurrences of Dominant Rock Type JTRS

Figure B-12 Occurrences of Rock Group OR6

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