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Bibliography
1. Volcanic ash, tuff, etc.—California. 2. Geology, Stratigraphic—Pliocene. 3. Geology, Stratigraphic—Pleistocene. I. Sarna-Wojcicki, Andrei M. II. Series.
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ABSTRACT

Eight widespread Pleistocene ash layers of east-central and southern California are characterized and correlated on the basis of chemical composition of volcanic glass (determined by neutron activation, electron probe, and energy-dispersive X-ray fluorescence analysis), stratigraphic criteria, and petrographic characteristics. In order of increasing age, these are the Lava Creek B ash bed (formerly referred to as the Pearlette type O ash bed; about 0.6 m.y.), the Bishop ash bed (0.73 m.y.), the Glass Mountain-D ash bed (estimated to be about 0.8-0.9 m.y.), the Glass Mountain-G ash bed (estimated to be about 1.0-1.1 m.y.), the Bailey ash (1.2 m.y.), the middle white ash of the Manix basin (estimated to be about 1.9 m.y.), the Huckleberry Ridge ash bed (formerly referred to as the Pearlette type B ash bed; about 1.9 m.y.), and the lowermost gray ash of the South Mountain area (Huckleberry Ridge? ash bed; estimated to be about 1.9 m.y.).

Three chemical types of the Bishop ash are recognized and assigned to an informal Bishop ash-bed group. The Friant Pumice Member (of the Turlock Lake Formation) of east-central San Joaquin Valley is one of the members of this group. The apparent 0.1-m.y. difference in K-Ar ages of the Friant Pumice Member (0.6 m.y.) and the Bishop Tuff (about 0.7 m.y.) may be due to factors other than differences in the true ages of these tephra units; alternatively, there may be two ash layers that have very similar glass chemistry and are here recognized as belonging to the Friant Pumice Member, but differ in age by as much as 0.1 m.y. The Huckleberry Ridge ash in the Manix basin is correlated with the same ash in Meade County, Kansas, over a distance of about 1,500 km.

Results of chemical analyses permit correlation of sedimentary strata deposited in diverse environments: marine, fluvial, and lacustrine. Chemical characteristics of ash layers also permit identification of source areas from which tephra was erupted; the main eruptive centers were the Long Valley-Glass Mountain area of east-central California, the Coso volcanic field of southeastern California, and the Yellowstone area of northwestern Wyoming and eastern Idaho. Systematic chemical depletion trends with time provide a possible independent method of estimating ages of ash layers of the Long Valley-Glass Mountain family.

INTRODUCTION

The Quaternary tephrochronology of east-central and southern California is summarized in this report. The purpose of the study is to help provide stratigraphic control for both site-specific and regional geologic studies, such as regional tectonic syntheses, determinations of ages, rates, and directions of crustal movements, calibration and evaluation of provincial and regional faunal, paleomagnetic, isotopic, and chemical age dating methods, and correlation of continental and marine faunal and isotopic stages.

Tephra layers (volcanic ashes and tuffs) are very useful in correlation of stratified sediments and rocks. Tephra produced by an explosive eruption can be spread over a large area within a matter of days or even hours (Sarna-Wojcicki and others, 1981b). Thus, tephra layers from past eruptions represent virtually instantaneous time horizons that can be used for correlating sedimentary and volcanic deposits. Tephra layers that have been carefully dated by isotopic or other methods at specific sites can be correlated with new exposures of tephra layers, allowing absolute as well as relative age correlations among separate basins of deposition.

An important application of tephrochronology is evaluation of existing radiometric and other types of age determinations. Radiocarbon, potassium-argon, and fission-track age determinations are subject to analytical and contamination errors that may be large for a wide range of Quaternary deposits; tephrochronologic correlations make it possible to cross-check age determinations from different localities of the same tephra unit and identify those ages that are determined on the best available materials, have the least possibility of contamination, have the lowest analytical error, or are in best agreement with other available stratigraphic or geochronologic data.

On the basis of chemical, petrographic, and isotopic-age analyses, we propose a number of new correlations and confirm or reject several previously suggested by others. The correlations presented here make it possible to assign relative and absolute ages to Quaternary deposits at a number of locations in the study area (fig. 1) and correlate deposits of diverse depositional environments—fluvial, glacio-fluvial, lacustrine, and marine (fig. 2). Owing to the ongoing nature of our work, some

[1]Lawrence Berkeley Laboratory, University of California, Berkeley, Calif.

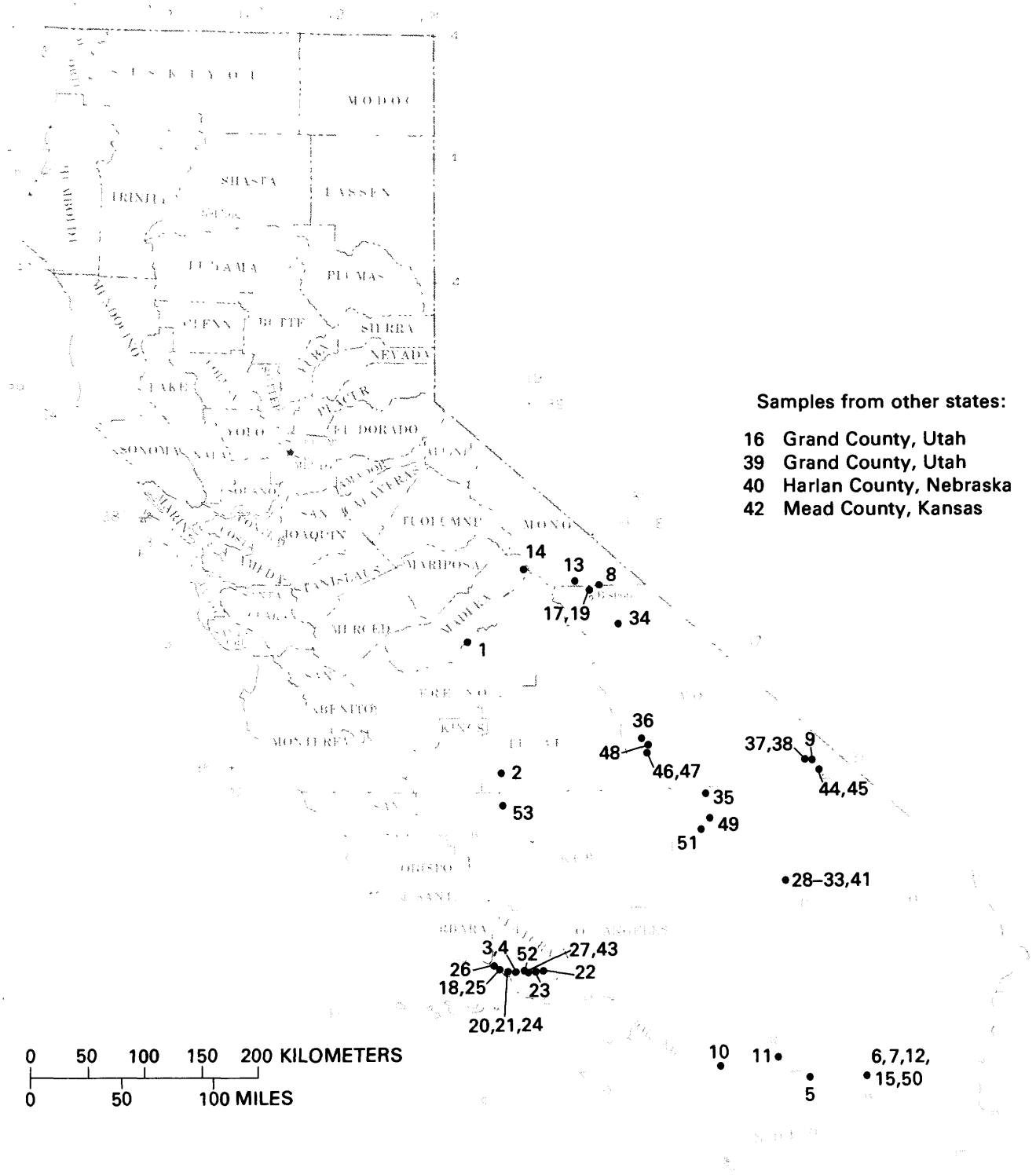


FIGURE 1.—Map showing generalized locations of tephra layers sampled for analysis. For more detailed information on location, see table 4.

correlations proposed here are made on the basis of preliminary analyses, and subsequent work may require revision of our conclusions.

ACKNOWLEDGMENTS

Many workers have contributed tephra samples or information, advice, or constructive suggestions to this study. Among these are C. R. Bacon, R. A. Bailey, P. C. Bateman, J. L. Bischoff, R. L. Christiansen, G. B. Dalrymple, W. A. Duffield, A. J. Gude, 3d, E. W. Hildreth, N. K. Huber, R. J. Janda, D. E. Marchand, R. V. Sharp, R. A. Sheppard, G. I. Smith, and R. E. Wilcox of the U.S. Geological Survey; G. A. Borchardt and M. P. Kennedy of the California Division of Mines and Geology; Robert Drake and R. L. Hay of the University of California, Berkeley; Richard Merriam of the University of Southern California; M. O. Woodburne of the University of California, Riverside; George Jefferson of the Los Angeles County Museum of Natural History; and R. S. Yeats of Oregon State University. Special thanks are given to G. A. Izett, C. W. Naeser, and R. E. Wilcox of the U.S. Geological Survey for providing samples and information on several key ash localities in the central region of the United States.

K. R. Lajoie and R. F. Yerkes of the U.S. Geological Survey contributed to our understanding of the structure and stratigraphy of the Ventura area and participated in field work related to this study. Lajoie and J. F. Wehmiller, University of Delaware, provided age calibration in the Ventura area through amino-acid racemization analysis of fossil mollusks. J. W. Hillhouse of the U.S. Geological Survey and J. C. Liddicoat, of the Lamont-Doherty Institute, N.Y., provided information on paleomagnetic stratigraphy of two key areas, the Lake Tecopa and Bishop areas, respectively. Both Hillhouse and Liddicoat provided preliminary information on paleomagnetic stratigraphy in the Ventura area.

Jose Rivera and Betsy Bradshaw separated and purified samples of volcanic glass for chemical analysis. The high quality of their work is reflected in the high precision of replicate analyses from individual tephra units.

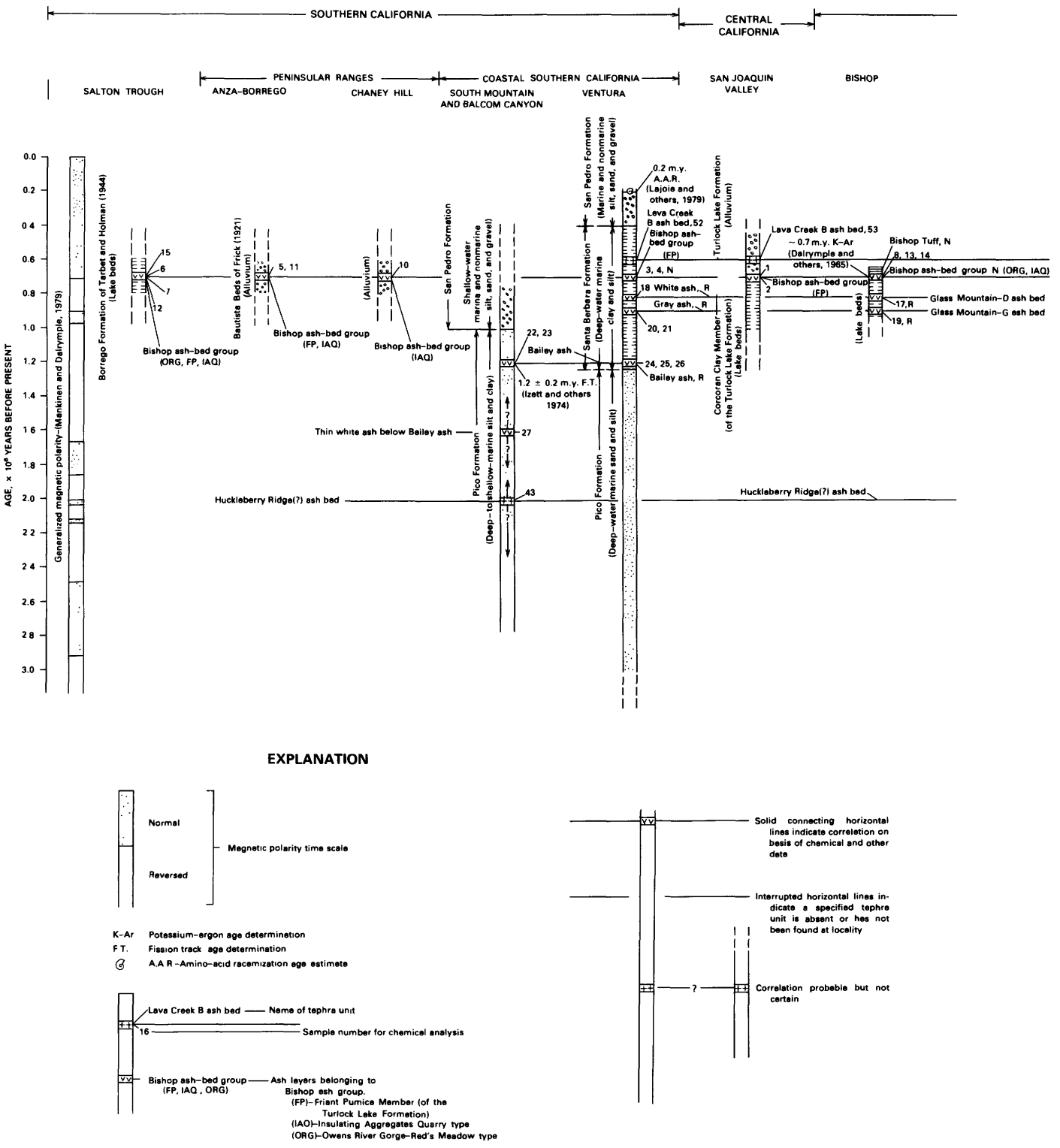
CRITERIA FOR CORRELATION OF TEPHRA

For a successful correlation, tephra layers must possess characteristics by which they can be uniquely identified. The principal method of correlation used in this study is chemical "fingerprinting" of volcanic glass from tephra. Pure glass separates are analyzed by neutron activation, electron microprobe, and energy-dispersive X-ray fluorescence, and samples with similar trace-element compositions are matched to establish correlations. These correlations are tested by petrographic analysis of tephra layers and, where available, by independent stratigraphic, biostratigraphic, and magnetostratigraphic control.

Previous studies (Jack and Carmichael, 1968; Sarna-Wojcicki, 1971, 1976; Sarna-Wojcicki and others, 1979, 1981a; Izett, 1981) suggest that the chemical composition of glass is one of the more distinctive characteristics by which tephra of specific volcanic eruptions can be identified. This is possible because a number of major, minor, and trace elements in volcanic glass can be analyzed with a high degree of precision, because silicic volcanic glass tends to be relatively homogeneous within tephra derived from the initial, explosive phase of silica- and volatile-rich magmatic eruptions (Sarna-Wojcicki and others, 1981a), and because tephra units erupted at different times from the same or different source areas are usually different enough in chemical composition to make identification possible. Tephra units erupted from different volcanic source areas are especially different in chemical composition (Sarna-Wojcicki, 1976; Sarna-Wojcicki and others, 1979; this report), more so than those erupted from the same source area; this makes it possible to identify volcanic source areas of distal tephra layers deposited at great distances from their eruptive vents, as well as to make specific correlations among tephra layers.

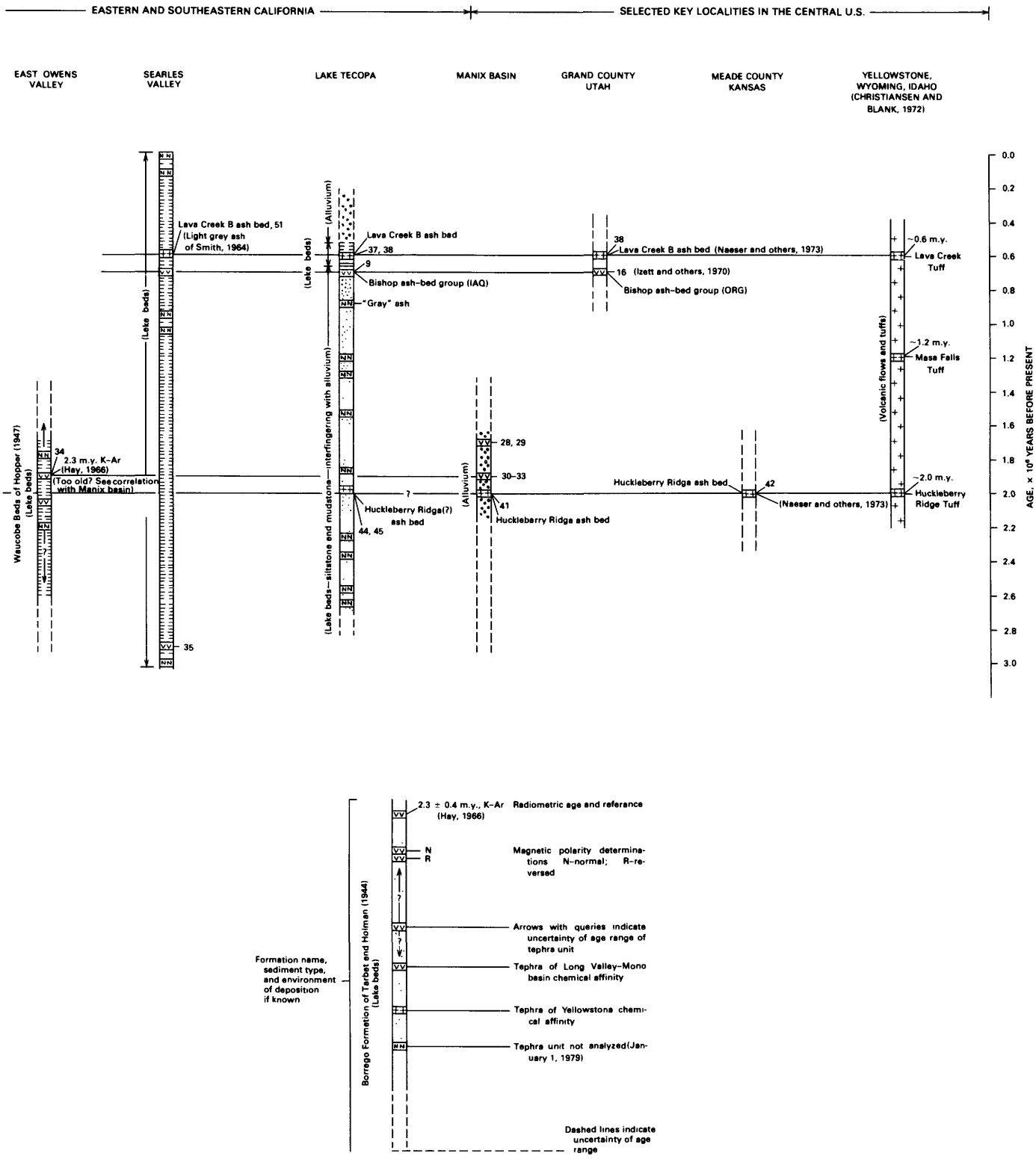
In the present study we assume that the chemical composition of volcanic glass from successive eruptions is not exactly duplicated. This is an assumption that cannot be proved conclusively because probably not all tephra units of the study area have been analyzed and chemically identified. A sufficient number of cases have been studied (Sarna-Wojcicki, 1976; Sarna-Wojcicki and others, 1981a; this report), however, in which stratigraphic positions, and consequently relative ages of tephra units, are known; in such instances, the chemical compositions of volcanic glasses are not repeated, except for very closely spaced tephra layers that represent multiple eruptions from one center during a single brief eruptive episode (Sarna-Wojcicki and others, 1981a). From these studies, we conclude that tephra units erupted over periods as short as several tens to several hundreds of years apart can be distinguished on the basis of composition.

This assumption of the compositional uniqueness of volcanic glass of tephras derived from individual eruptions seems reasonable in view of the many factors that probably affect magma generation and differentiation, and the complex manner in which these factors interact. Rocks are compositionally heterogeneous assemblages, and it is unlikely that any two batches of magma formed from the fusion of rocks would ever be exactly the same. Furthermore, magmatic differentiation and crystalliza-



EXPLANATION

FIGURE 2.—Correlation chart of upper Pliocene and Pleistocene tephra layers in east-central



California, southern California, and several key localities in the central United States.

tion proceed at different temperatures, pressures, and rates, resulting in formation of different kinds and amounts of crystals in the melt. Crystals take up varying amounts of elements from the magma, leaving variable concentrations of elements in the residual liquids. Furthermore, wall rocks, the "crucible" in which magma is contained, are not inert; they probably continually interact with the melt, resulting in continuous compositional changes through time. Thus, it can be assumed that all such variables cannot be exactly repeated in an identical sequence and at identical rates.

Zoning within magma chambers may present problems in identification of tephra layers if the range of chemical compositions of tephras erupted during a single eruption overlaps with the range of compositions of tephra erupted at different times from the same caldera or source area. Zoning has been well documented for some calderas (Hildreth, 1979; Smith, 1979), and the spectrum of compositions erupted during a single eruption or eruptive sequence can be quite wide. The silica- and volatile-rich early phase of explosive (plinian) eruptions from major calderas, however, probably makes up a small fraction of the total volume of a magma chamber (Smith, 1979) and thus probably represents a rather narrow compositional range. Some tephras are compositionally heterogeneous owing to mixing of magmas, as in the eruption of Katmai in 1912 (Curtis, 1968), and zoning in magma chambers, as in the eruption of Hekla in 1947 (Thorarinsson, 1949) and that of Mount Mazama about 7,000 yr B.P. (Williams, 1942; Smith, 1979). Mixing of compositionally different tephra layers can also occur as a result of surficial reworking after deposition (Cerling and others, 1978). Nevertheless, it is possible to test for effects of mixing or zoning, and as in the case of the 1947 eruption of Hekla (Thorarinsson, 1949), such effects may actually aid in the identification of ash layers, owing to their unique compositional or stratigraphic characteristics.

METHODS

We disaggregated and sieved tephra samples, separating the volcanic glass for chemical analysis and the mafic heavy minerals for petrographic analysis. Glass samples were analyzed by instrumental neutron activation for abundances of about 40 major, minor, and trace elements. About 16 to 20 elements were used in correlating tephra layers (see below). We also analyzed glass samples by electron microprobe for 12 elements: silicon, aluminum, iron, magnesium, manganese, calcium, barium, titanium, sodium, potassium, chlorine, and phosphorus. More recently, we have begun to analyze glass samples of tephra by energy-dispersive X-ray fluorescence analysis (XES). In general, this method is not as diagnostic as neutron activation, but more diagnostic than electron-probe analysis in chemical characterization of many tephra families. The advantage of the XES method is that it is rapid and relatively inexpensive compared to neutron-activation analysis but, unlike electron-probe analysis, requires careful separation of glass from other components of tephra. For a further description of sampling, sample preparation, and analyses, see the "Appendix."

SELECTION OF ELEMENTS FOR CORRELATION

For purposes of correlation, we selected elements on the basis of their natural variability within and among tephra layers of different age, as well as according to precisions attainable for each element in analysis. Analysis of samples from superposed tephra layers at several localities in the study area allows us to evaluate the internal and external variability of these layers and determine the resolution available for each element relative to independent age criteria. In other words, we can test whether the range of concentration of an element in glass of a single tephra layer overlaps with ranges determined for tephra layers at different stratigraphic levels, and we can determine the extent of overlap, if any exists.

On the basis of our experience in this and previous studies (Sarna-Wojcicki, 1976; Sarna-Wojcicki and others, 1979, 1981b), an element is useful in characterizing tephra if the mean of replicate analyses within a single tephra layer is different from that of another layer of demonstrably different age at a level of significance (alpha) equal to or less than about 0.05 (in other words, if we are 95 percent confident that the means are truly different). An element is useful in correlation if (1) it is relatively homogeneously distributed within the glass of a single tephra layer, (2) it usually differs in concentration in units of demonstrably different age, and (3) its full range of concentration can be accurately measured. In practice we use those elements for which analytical error is equal to or less than about 7 percent of their concentration in glass.

In neutron-activation analysis, from 16 to 20 major, minor, and trace elements are generally most useful for correlation of dacitic or rhyolitic tephra. These elements are, in order of increasing atomic number: scandium, manganese, iron, zinc, rubidium, cesium, barium, the rare-earth elements lanthanum, cerium, neodymium, samarium, europium, terbium, dysprosium, ytterbium, lutecium, and the heavy trace elements tantalum, hafnium, thorium, and uranium. In energy-dispersive X-ray fluorescence analysis the most useful elements are calcium, titanium, manganese, iron, rubidium, strontium, and zirconium. Potassium is only marginally useful

because it tends to be leached or enriched in volcanic glasses by postdepositional processes. Copper, zinc, yttrium, and niobium are also marginally useful because they occur in low concentrations in silicic glasses; consequently the analytical precision for these elements is relatively low. In electron microprobe analysis, we determined concentrations of sodium, aluminum, silicon, phosphorus, chlorine, potassium, calcium, titanium, manganese, iron, and barium. Of these, calcium and iron are the most useful. Sodium and potassium are strongly affected by postdepositional processes, aluminum and silicon tend to occur in about the same concentrations in silicic glasses of tephra layers derived from the same volcanic provinces, and the sensitivity for the remaining elements analyzed is often too low to adequately distinguish between tephra layers.

The utility of a certain element will vary from one volcanic source area to another and consequently among suites of tephra derived from different volcanic provinces. For instance, barium and europium are near minimum detection limits of neutron-activation analysis, and strontium is near the limit of X-ray fluorescence analysis, in tephra derived from highly differentiated silicic tephras of the Long Valley-Glass Mountain province of eastern California; the error in precision for these elements is as high or higher than compositional variations among tephra layers of different age erupted from this province. Thus, these elements cannot be used to discriminate among different tephra layers belonging to this tephra family. Strontium, barium, and europium can be used, however, to distinguish among tephra layers derived from other volcanic provinces (for instance, the Cascade Range) where the concentration in silicic glass is higher.

The total error in replicate analyses of tephra samples from the same tephra layers, expressed as a percentage of concentration present in the glass, ranges from less than 1 to about 7 percent and averages about 3 to 4 percent for the elements used for correlation in neutron-activation analysis of glass. This error is a combination of both analytical and sampling errors. The latter is a function of the natural homogeneity of the glass and the purity of glass separations.

METHODS OF EVALUATING CHEMICAL DATA FOR CORRELATION

For the purpose of visual representation of element concentrations in glass, we calculated ratios of concentrations of elements of selected samples to concentrations of the same elements in U.S. Geological Survey (USGS) rock standard G-1. Histograms of these ratios are shown in figure 3. Suggested or recommended values and magnitudes (Fleisher, 1969) are used except for cesium, terbium, and ytterbium, for which values of 6, 1, and 2.5 ppm, respectively, were arbitrarily assigned in order to minimize high ratios. This graphic method was chosen because one can plot elements that vary in concentration by several orders of magnitude on a single scale. Differences between pairs of histograms have also been calculated and are shown adjacent to sample histograms (fig. 3).

Similarity coefficients (Borchardt and others, 1972) have been calculated for every sample pair in the study group (fig. 4). The similarity coefficient is an average of ratios of element concentrations in two glass samples. Ratios of individual elements are calculated by dividing the concentration in one sample by the concentration in another. Unless concentrations in samples are identical, the lower concentration is divided by the higher, so that the ratio is always less than or equal to 1. The coefficients are averaged for all elements in the comparison. The ideal value of this coefficient is 1 for a chemically identical sample pair. This coefficient is given by:

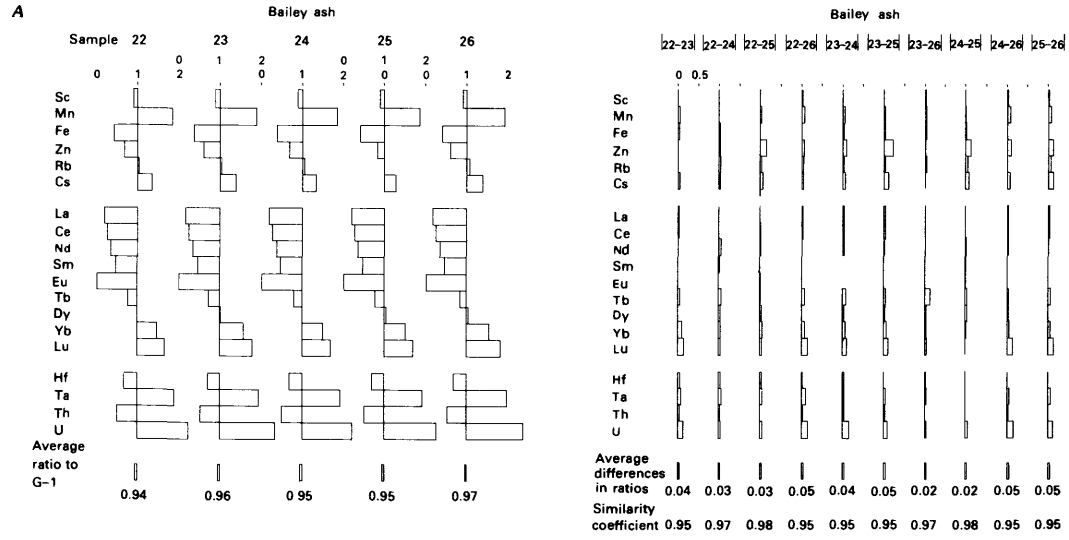
$$d_{(A,B)} = \frac{\sum_{i=1}^{n} R_i}{n},$$

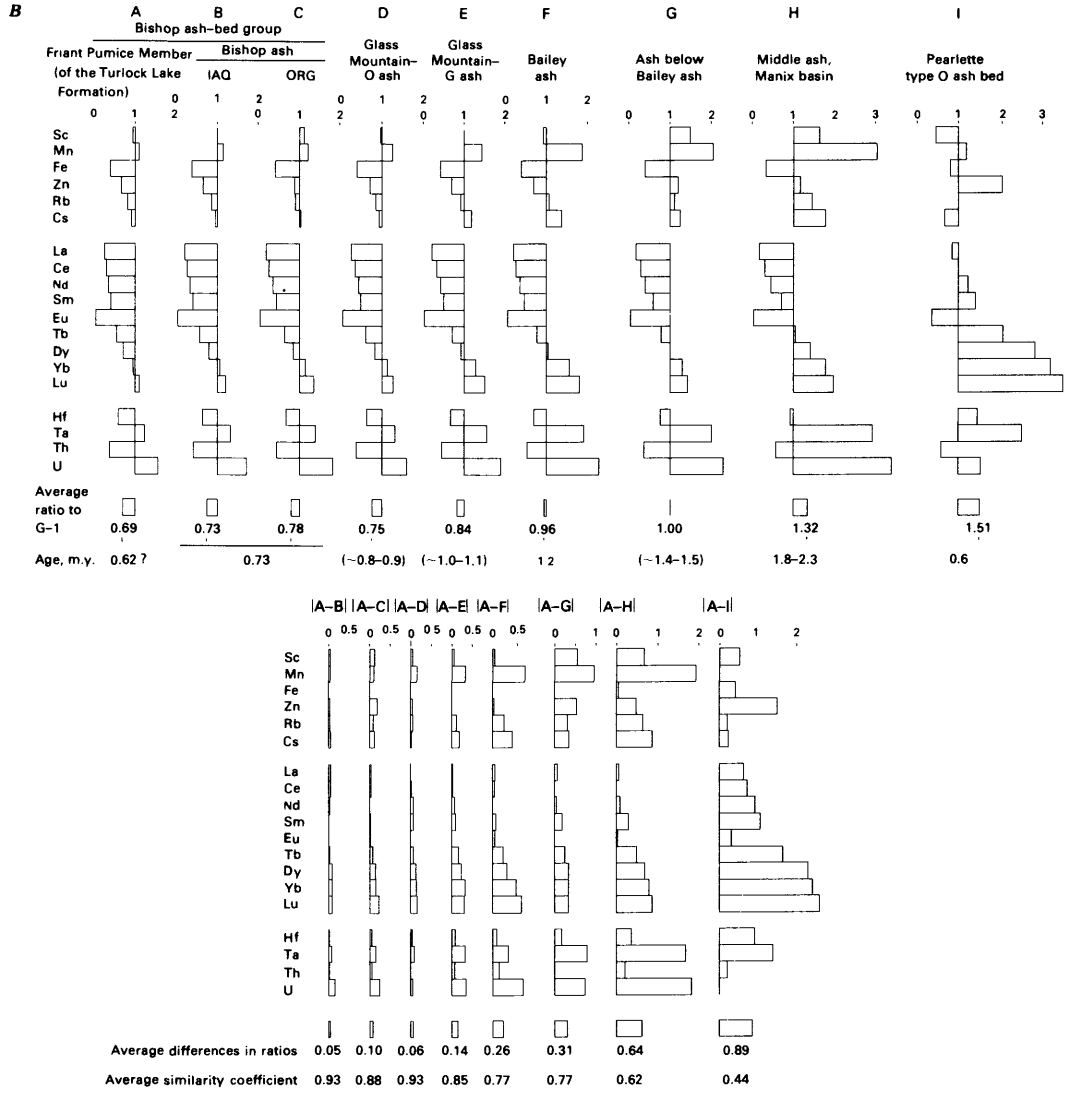
where

$d_{(A,B)} = d_{(B,A)}$ = similarity coefficient for comparison between sample A and sample B
i = element number,
n = number of elements,
$R_i = X_iA/X_iB$ if $X_iB \geq X_iA$; otherwise X_iB/X_iA,
X_iA = concentration of element i in sample A, and
X_iB = concentration of element i in sample B.

In practice, the values of the coefficient for replicate analyses of splits of the same sample, or of samples from a single emplacement unit, range from about 0.93 to 0.99 owing to inhomogeneities in the glass, variations in purity of glass separations, presence of microlites, or analytical errors. The actual range of values for replicate analyses within single emplacement units also varies to some extent depending on the elements selected for comparison and the volcanic source area from which the tephra suite has been erupted.

Values of similarity coefficients for tephra layers of demonstrably different age (for instance, tephra layers in stratigraphic order within an exposed continuous section) range from about 0.35 to about 0.94; the exact range depends on the variables mentioned above. Tephra layers derived from the Long Valley-Glass Mountain volcanic province are very similar in chemical


A
Bailey ash
Sample 22 23 24 25 26
Sc Mn Fe Zn Rb Cs
La Ce Nd Sm Eu Tb Dy Yb Lu
Hf Ta Th U
Average ratio to G-1
0.94 0.96 0.95 0.95 0.97
Bailey ash
22-23 22-24 22-25 22-26 23-24 23-25 23-26 24-25 24-26 25-26
Average differences in ratios 0.04 0.03 0.03 0.05 0.04 0.05 0.02 0.02 0.05 0.05
Similarity coefficient 0.95 0.97 0.98 0.95 0.95 0.95 0.97 0.98 0.95 0.95


B
A B C D E F G H I
Bishop ash-bed group
Friant Pumice Member (of the Turlock Lake Formation)
Bishop ash
lAQ ORG
Glass Mountain-O ash
Glass Mountain-G ash
Bailey ash
Ash below Bailey ash
Middle ash, Manix basin
Pearlette type O ash bed
Sc Mn Fe Zn Rb Cs
La Ce Nd Sm Eu Tb Dy Yb Lu
Hf Ta Th U
Average ratio to G-1
0.69 0.73 0.78 0.75 0.84 0.96 1.00 1.32 1.51
Age, m.y. 0.62 ? 0.73 (~0.8-0.9) (~1.0-1.1) 1.2 (~1.4-1.5) 1.8-2.3 0.6

A-B A-C A-D A-E A-F A-G A-H A-I
Sc Mn Fe Zn Rb Cs
La Ce Nd Sm Eu Tb Dy Yb Lu
Hf Ta Th U
Average differences in ratios 0.05 0.10 0.06 0.14 0.26 0.31 0.64 0.89
Average similarity coefficient 0.93 0.88 0.93 0.85 0.77 0.77 0.62 0.44

composition and are harder to distinguish than tephra layers from other provinces. Similarity coefficients for different tephra layers of this family are sometimes as high as 0.95. Consequently, the range of similarity coefficients from 0.93 to 0.95 represents an interval of uncertainty for this tephra family, and correlations based solely on similarity coefficients within this interval must be regarded as uncertain. This degree of uncertainty can be quantified and expressed in probabilistic terms by using a modification of the similarity coefficient, whereby the average ratio is calculated for sample pairs by dividing element concentrations in one sample by those of another, the concentrations of the first being in the denominator, those of the second in the numerator regardless of which is the greater. Because deviations from the ideal value of 1 for different elements of a sample pair in this instance may average out to give a misleadingly high average ratio, this modification is not as useful a guide to indicate correlation as the similarity coefficient; however, the standard deviation of the mean of these ratios for a population of variables (elements) is useful, because it measures the dispersion of values about 1, and the distribution of these values should be normal. Cluster analysis (Parks, 1970) of a data set similar to that presented here gives essentially the same groupings as those using the similarity coefficient (Sarna-Wojcicki, 1976).

Because ranges of similarity coefficients for replicate analyses of individual tephra layers generally do not overlap with those of tephra layers of different age, similarity coefficients can be used as quantitative guides to indicate correlation or its lack where stratigraphic or other types of age control are not available. The actual ranges of values for acceptance or rejection of correlation must be derived empirically for each suite of tephra erupted from a particular volcanic source area, calibrated and verified by replicate analyses of individual layers and multiple superposed layers at critical localities. For instance, the average analytical error on replicate analyses of glass samples by neutron activation of tephra layers derived from the Long Valley-Glass Mountain or Yellowstone tephra families averages about 3 to 4 percent for those elements used in correlation. Consequently, we expect that similarity coefficients of samples from a single tephra unit belonging to one of these families would average between 0.96 and 0.97.

A similarity coefficient matrix is given in figure 4 which compares all sample pairs in the group of 69 samples analyzed by neutron activation. Average values of the similarity coefficients and standard deviations of the averages for major groups have also been calculated and are given in figure 4. The matrix (fig. 4) is based on a comparison of 13 elements that were judged to be most reliable in distinguishing among the tephra samples: scandium, iron, rubidium, cesium, lanthanum, cerium, samarium, terbium, ytterbium, lutecium, hafnium, tantalum, and thorium. Elements excluded are manganese, dysprosium, and uranium, which were not determined for some samples, and zinc, neodymium, and europium, for which relative precision was low owing to low concentrations in glasses of some of the sample groups. A dendrogram (fig. 5) shows the relations among the samples and sample groups on the basis of the highest values of the similarity coefficient between individual sample pairs and the highest average values for the sample groups shown in the matrix (fig. 4).

FIGURE 3.—Chemical compositions of selected glass samples of tephra, shown as ratios to USGS rock standard G-1, and differences between histogram pairs. *A*, The left side of the figure shows glass compositions of five samples of the Bailey ash. The right side shows the absolute difference between samples. Thus, 22-23 is a histogram showing the absolute difference between samples 22 and 23. Sample numbers are the same as in other tables and figures. Method of plotting ratios is adapted from O'Keefe (1978). *B*, The upper part of the figure shows glass compositions of tephra units of the Long Valley-Glass Mountain family (A-H) and the Lava Creek B ash bed (I), as ratios to G-1. Average values of analyzed samples are used for each tephra unit. The lower part of the figure shows absolute differences between ratios of the Friant Pumice Member and ratios of each successive tephra unit to the right. Thus, A-B shows the absolute difference between the Friant Pumice Member and the Bishop ash, IAQ (Insulating Aggregates Quarry) type; A-C shows the absolute difference between the Friant Pumice Member and the Bishop ash, ORG (Owens River Gorge and Red's Meadow) type, and so on.

CORRELATION OF TEPHRA UNITS

Figure 2 summarizes correlations presented in this study and available isotopic age, stratigraphic, and paleomagnetic data. Correlations are made primarily on the basis of glass chemistry (table 1) and stratigraphic sequence, supported by petrographic, isotopic age, and magnetostratigraphic data.

It was not possible to resolve differences in glass chemistry for a number of tephra units on the basis of electron-microprobe analysis alone (table 2). This was particularly true for ashes of the Long Valley-Glass Mountain family situated in close stratigraphic proximity. Likewise, it was not possible to distinguish definitively among ashes derived from the Yellowstone area (Pearlette-like ashes) by this method. However, it is possible to distinguish individual tephra units of several other tephra families derived from other volcanic source areas, such as Crater Lake, Mount St. Helens, and Glacier Peak, by this method (Smith and others, 1977; Davis, 1978; Sarna-Wojcicki and others, 1981a). Attempts to differentiate among ashes of the Long Valley-

Similarity coefficients

Sample numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	a	b	c	18	19	20	21	a	b	c	d	22
Bishop ash-bed group: Friant Pumice Member (of the Turlock Lake Formation)	98	95	96	97	97	96	91	91	95	93	93	87	86	87	86	92	92	94	92	90	86	87	84	82	84	85	82	77
		94	96	97	98	95	90	90	93	92	92	87	86	86	85	91	92	94	91	90	86	87	84	82	84	85	82	77
			96	97	93	97	95	94	96	96	96	92	90	91	90	95	94	96	94	93	89	91	87	85	87	89	86	81
				97	96	96	92	92	96	94	94	88	88	89	87	93	93	95	93	91	86	88	85	82	84	86	83	78
					96	97	93	92	96	94	95	89	88	89	88	93	94	96	93	92	88	89	86	83	86	87	84	79
			96±1			94	89	89	93	91	91	86	85	85	85	91	91	93	91	89	84	86	83	80	82	84	81	76
							94	94	97	96	96	90	90	90	89	93	92	94	93	92	88	89	86	83	85	88	84	79
Bishop ash, IAQ type								97	95	97	96	96	94	95	94	94	92	93	93	93	91	92	88	86	88	91	87	83
									96	97	97	96	95	96	94	93	92	93	93	91	89	90	86	84	86	89	85	82
			93±2					97±1		97	98	92	91	92	91	93	93	95	93	92	87	88	85	83	85	88	84	81
											98	94	93	94	93	94	94	95	94	93	89	90	87	85	87	89	86	82
												93	93	93	92	94	93	95	94	92	89	90	86	84	86	89	85	82
Bishop ash, ORG type													97	97	96	92	90	91	92	92	92	92	89	86	89	91	88	84
													97±1	98	97	92	89	90	92	91	92	93	89	87	89	92	88	84
			88±2						94±1						98	92	89	91	92	91	91	92	88	86	88	90	87	83
																92	89	90	91	91	93	93	90	87	90	92	89	85
																	96	97	98	97	92	94	90	88	90	91	88	82
																		97	97	96	90	93	88	88	88	89	86	80
Glass Mountain-D ash bed			93±2						93±1					91±1			97±1			97	96	90	92	88	86	88	90	87	81
																				96	92	94	90	88	89	91	88	82
																					93	95	90	90	90	92	89	83
																						97	96	92	95	95	94	88
																							94	92	94	94	92	86
																								95	98	96	97	91
Glass Mountain-G ash bed			85±2						87±2					90±2				90±2				95±2			96	94	95	89
																										97	97	91
																											96	90
																												93
Bailey ash			77±2						81±2					84±2				80±2					87±3					
Ash below Bailey ash			77±2						80±1					83±1				81±1					86±1					
Upper white ash, Manix basin			88±2						91±1					91±1				91±1					88±1					
Middle white ash, Manix basin			62±1						65±1					68±1				65±1					71±2					
Ash in late Cenozoic lake beds of Searles Valley			92±1						92±1					91±0				94±1					89±2					
Unwelded, pumiceous ash-flow tuff in the Coso area			62±1						62±1					60±1				60±1					57±1					
Lava Creek B ash bed			44±1						45±1					46±1				47±1					49±1					
Mesa Falls ash bed			46±1						47±<1					48±1				49±1					52±1					
Huckleberry Ridge ash bed			45±1						45±1					46±1				47±1					50±1					
Huckleberry Ridge (?) ash bed			45±1						45±1					46±1				47±1					50±1					
Air-fall pumice of the Coso area			56±2						54±2					51±2				54±2					50±2					
Ash in Searles Valley			72±0						73±0					70±1				69±1					66±1					
Pumice overlying Cahuilla beds, Salton trough			55±1						52±1					51±1				55±1					51±1					

'Average similarity coefficient excluding sample 23a

Averages of coefficients for selected widespread tephra

FIGURE 4.—Similarity coefficient matrix comparing the chemical compositions of glass of tephra layers based on neutron-activation analysis. of similarity coefficients for sample pairs; the lower-left half gives averages

for sample pairs

a	23	a	b	c	d	24	a	b	c	25	26	a	27	28	29	30	31	32	33	34	35	36	37	38	39	40	A	41	42	43	44	a	45	46	47	48	A	49	50	Sample numbers
76	75	75	76	76	73	77	77	78	76	77	74	74	76	87	88	62	61	61	61	61	92	63	44	44	44	46	46	45	44	44	45	45	44	60	56	56	56	72	55	1
75	74	74	75	75	72	76	76	77	75	77	73	73	75	87	87	61	60	61	61	60	91	62	44	44	44	46	46	45	44	44	45	45	44	60	56	56	56	72	56	2
79	78	78	79	79	76	80	80	82	79	81	77	77	79	91	90	64	63	63	63	64	94	62	45	45	45	47	47	45	44	45	46	46	45	58	54	54	54	72	54	3
77	76	75	77	78	75	78	78	79	77	78	75	75	77	88	89	63	62	62	62	62	93	62	45	45	45	47	47	46	45	45	46	46	46	58	55	55	54	73	55	4
77	76	76	77	78	75	79	79	80	78	79	75	76	77	89	89	63	62	63	63	62	92	63	45	45	45	47	47	46	45	45	46	46	46	58	55	54	54	72	54	5
75	74	73	75	75	72	77	76	77	75	77	73	73	75	86	87	61	60	60	60	60	91	63	44	44	44	46	46	45	44	44	45	45	45	60	56	56	56	72	55	6
78	77	77	78	78	75	80	79	80	78	80	76	76	78	90	90	64	63	63	63	63	93	62	44	44	44	46	46	45	44	44	45	45	45	58	54	54	54	72	53	7
82	80	80	82	82	79	82	83	84	81	83	80	80	81	92	91	67	65	66	66	67	92	61	45	45	45	47	47	46	45	46	47	47	46	56	53	52	52	72	52	8
81	81	78	83	83	80	81	82	82	80	81	80	80	80	91	92	66	65	65	65	67	92	62	45	45	44	47	46	45	44	45	46	46	45	56	53	52	52	73	52	9
79	79	78	80	80	77	80	81	82	80	81	77	77	79	90	91	65	63	64	64	65	92	62	45	44	44	47	47	45	44	45	46	46	45	58	54	54	54	73	53	10
80	80	79	81	81	78	82	82	83	81	82	78	79	80	92	91	66	65	65	65	66	93	61	46	45	45	47	47	46	45	46	47	47	46	56	53	53	53	73	53	11
80	80	78	81	81	78	81	82	83	81	82	78	78	79	91	91	66	64	65	65	66	93	62	45	45	45	47	47	45	44	45	46	46	46	57	53	53	53	73	52	12
84	83	80	84	85	82	83	83	85	82	84	83	83	83	91	92	68	67	67	67	68	91	60	46	46	46	48	48	47	46	46	47	47	46	54	52	51	51	72	51	13
83	84	80	86	86	83	83	84	85	83	84	83	83	83	91	91	69	68	68	68	70	91	59	46	46	46	48	47	46	45	46	47	47	47	54	51	50	50	70	51	14
83	84	80	85	85	82	83	84	84	82	83	82	82	83	91	92	69	68	68	68	69	91	60	46	46	45	47	47	46	45	46	47	47	46	54	51	50	50	70	51	15
84	85	81	86	86	83	84	85	86	84	85	83	84	84	90	91	70	68	69	69	70	91	60	46	46	46	48	48	47	46	46	47	47	47	54	51	50	50	69	50	16
80	80	79	81	81	79	82	82	83	81	82	79	79	81	91	91	67	65	66	66	66	95	60	46	46	46	48	48	47	46	46	48	48	47	56	53	53	52	69	54	17
78	78	78	78	78	76	80	80	80	79	80	77	76	80	91	90	65	64	64	65	64	94	60	47	47	47	49	49	47	46	47	48	48	47	56	52	52	52	69	55	17a
79	78	78	80	80	77	81	81	82	80	81	77	77	80	91	89	65	64	65	65	64	95	61	46	46	46	48	48	46	45	46	47	47	46	56	53	53	53	70	55	17b
80	79	79	80	81	78	82	82	83	81	82	78	78	81	91	90	66	65	66	66	65	94	59	47	46	46	49	49	47	46	47	48	48	47	56	53	53	52	69	55	17c
81	79	79	79	80	78	82	81	82	80	83	79	79	81	91	90	66	65	65	65	65	94	59	47	47	47	50	49	48	47	47	49	48	48	56	53	53	52	70	54	18
85	84	84	85	85	82	87	87	88	85	88	84	83	86	91	90	71	70	70	70	70	91	58	49	48	49	51	51	49	49	48	49	49	48	53	50	50	49	67	52	19
84	83	83	83	83	81	85	85	86	84	86	82	82	83	91	90	69	68	68	68	68	92	58	49	48	48	51	50	49	48	48	49	49	48	53	51	50	49	67	52	20
88	87	87	87	88	85	90	89	91	88	91	87	86	87	88	87	73	71	72	72	72	89	57	50	49	50	52	52	50	50	49	50	50	50	52	50	49	48	66	50	21
87	85	87	86	86	83	88	87	88	86	89	85	85	85	86	84	72	71	72	72	71	86	55	50	50	50	52	52	51	50	51	52	52	51	51	49	48	47	64	52	21a
88	87	87	87	87	85	90	89	90	88	91	87	86	86	88	87	72	71	72	72	71	88	56	50	50	50	52	52	51	50	50	51	51	50	52	50	49	48	66	51	21b
87	86	85	86	86	84	88	88	89	87	89	85	85	85	90	89	71	70	70	70	70	90	57	49	49	48	51	51	49	48	49	50	50	50	53	51	50	49	67	52	21c
90	88	88	89	89	86	91	91	92	90	92	88	88	87	86	85	74	72	73	73	73	87	56	50	50	50	52	52	51	50	50	51	51	51	52	49	49	48	65	50	21d
97	95	93	94	95	93	97	97	96	96	98	95	94	86	82	81	77	75	76	76	77	81	57	52	51	52	54	54	52	51	52	53	52	52	50	48	48	47	65	46	22
	95	94	95	96	94	96	97	96	96	96	96	95	86	80	80	79	77	77	78	79	80	56	51	50	52	55	55	51	51	51	52	52	51	50	47	47	46	65	46	22a
		94	96	96	95	96	94	96	95	97	96	86	80	81	80	78	79	79	81	79	57	52	51	52	54	54	52	51	52	52	53	52	48	46	45	45	64	46	23
			91	93	94	95	95	94	95	94	94	93	88	80	79	83	81	81	81	82	79	55	53	52	54	56	56	53	52	53	54	54	53	47	45	45	44	62	47	23a
				98	94	94	96	95	94	94	95	95	86	80	81	78	77	77	78	79	80	58	51	50	51	53	53	50	50	50	52	51	51	49	46	45	45	65	46	23b
					96	95	96	95	95	94	96	95	86	80	81	79	77	77	78	79	81	57	51	50	52	54	54	51	50	51	52	52	51	49	47	46	45	65	46	23c
						93	94	93	96	93	96	97	86	79	79	82	81	81	81	82	78	56	52	51	53	56	55	52	52	52	52	52	52	47	45	44	44	63	45	23d
		95±1					97	97	97	98	95	94	88	83	82	79	77	78	78	78	81	57	52	51	53	55	55	52	52	52	53	53	52	49	47	46	45	64	46	24
								98	98	97	95	95	86	82	82	79	77	77	77	79	82	57	51	50	52	54	54	51	51	51	52	52	51	49	47	47	46	65	47	24a
					(96±1)[1]				96	97	94	94	86	83	82	78	76	76	77	77	82	57	52	50	52	54	53	51	51	51	52	52	51	50	48	47	46	65	47	24b
										97	96	95	87	81	81	80	78	79	79	80	80	56	52	51	53	55	55	52	52	52	52	52	52	49	47	46	45	64	46	24c
											95	94	87	83	82	78	76	76	77	78	81	56	53	51	53	55	55	52	52	52	53	53	52	50	48	47	46	65	47	25
												97	86	79	79	81	79	79	79	81	78	56	52	51	53	55	55	52	52	52	53	53	52	48	46	45	45	64	45	26
													86	79	79	80	78	79	79	81	78	57	52	51	53	55	55	52	52	52	52	53	52	48	46	45	45	64	45	26a
					86±1								86	85	80	79	79	79	80	81	56	48	47	49	52	51	47	47	47	47	48	47	47	45	45	44	61	49	27
					81±1							86±1		96	70	68	69	69	69	90	59	46	45	45	48	47	46	45	46	47	47	46	53	51	50	50	70	54	28
															69	68	69	69	69	90	60	45	45	45	47	47	46	45	45	46	46	45	54	51	51	50	69	53	29
																97	97	98	96	66	49	54	51	53	56	56	51	51	50	49	49	49	39	37	37	37	52	44	30
																	98	98	95	64	48	54	51	54	57	57	51	51	50	50	50	49	38	37	37	36	51	45	31
					79±2							79±1	69±1		97±1			98	96	65	48	54	51	53	56	56	51	51	50	50	50	49	39	37	37	36	51	45	32
																			96	65	49	54	51	53	56	56	50	50	49	49	49	49	38	37	37	36	51	44	33
																				65	50	53	50	53	56	56	50	50	49	49	49	48	40	38	38	37	53	43	34
					80±1									90±0		65±1					61	45	45	45	47	47	46	45	45	46	46	46	57	53	53	53	69	52	35
					57±1									60±1		65±1						34	32	34	35	35	34	34	33	34	34	33	51	48	50	50	49	38	36
																							92	97	91	90	90	90	85	84	84	85	39	36	35	34	40	61	37
					52±1							48±1	45±<1			53±1			45±0	33±1				93	86	87	95	94	92	90	91	91	39	36	35	34	38	60	38
																							94±3		91	91	90	91	86	85	85	86	39	37	36	35	39	61	39
					55±1							52±1	47±1			56±<1			47±0	35±0		89±2			98		87	87	84	83	83	84	38	35	34	34	43	58	40
																											87	87	85	83	84	84	38	35	34	33	43	58	40A
					52±1							47±<1	46±1			51±1			46±1	34±0		92±2		87±<1			97	94	92	92	94	38	34	33	33	39	62	41
																													94	92	93	94	38	35	34	33	38	60	42
																												96	97	98		39	35	35	34	38	59	43
					52±1							47±1	46±1			49±1			46±1	34±1		87±3		84±1		93±1		97±1		98	96	40	37	36	35	38	60	44
																															96	40	36	36	35	38	60	44a
																																38	35	34	33	38	61	45
																																	91	87	87	63	41	46
					48±2							45±1	51±1			37±1			37±1	52±3		36±2		35±2		35±2		36±2				91±4		93	92	61	39	47
																																			97	59	38	48
																																				59	37	48A
					64±1									70±1		52±1						39±1		43±0		39±1		38±0				61±2					45	49
					46±1									54±1		44±1						61±1		58±0		61±1		60±1				39±2						50

units and for tephra groups, plus or minus one standard deviation

Values given are in percent. A value of 100 percent represents a perfect match. The upper-right half of the matrix gives individual values of sample groups, plus or minus one standard deviation of the average.

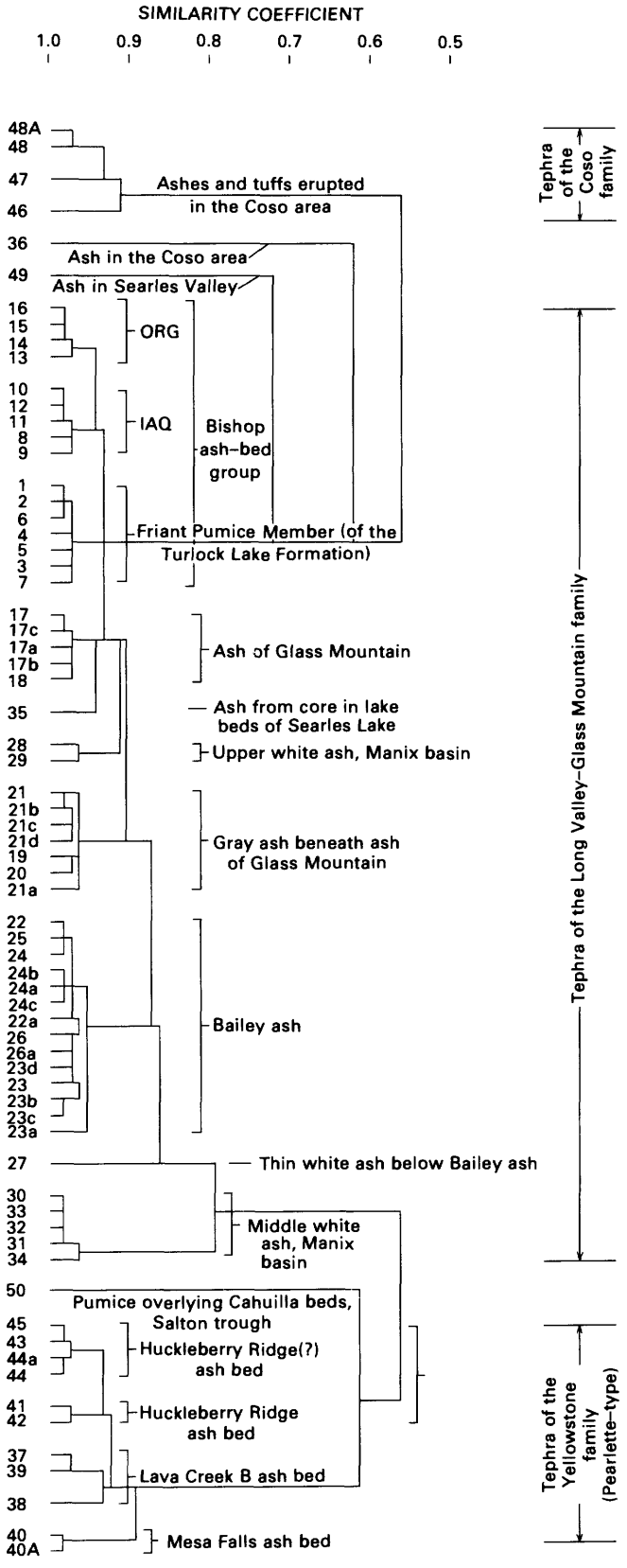


FIGURE 5.—Dendrogram showing relations between individual samples and sample groups, using similarity coefficients, based on neutron-activation analysis. Highest values of the similarity coefficient are used to link sample pairs, and highest average values of the coefficient are used to link sample groups. Values of the similarity coefficient at which linkages are made are shown by the horizontal scale at top.

Glass Mountain provenance by electron-microprobe analyses alone can result in misidentification.

DISCUSSION OF SPECIFIC CORRELATIONS

In the following discussion of specific correlations, we will be referring to samples analyzed in this study by locality numbers shown in figure 1. The same numbers are used in figure 2, the summary correlation chart, tables 1-3, which present chemical analyses, and table 4, which gives specific location information.

LAVA CREEK B ASH BED (FORMERLY THE PEARLETTE TYPE O ASH BED)

The Lava Creek B ash bed is the youngest of several widespread tephra units that are important stratigraphic markers in the central and western United States. This ash was erupted from volcanic sources in the Yellowstone area and is equivalent to the Lava Creek Tuff, dated at 0.6 m.y. (Christiansen and Blank, 1972). The age of the Lava Creek B ash bed has been dated independently at 0.6 m.y. by the fission-track method on zircons (Naeser and others, 1971, 1973; Izett and others, 1971). It was previously called the Pearlette type O ash bed but has since been informally renamed after the near-source formation, the Lava Creek Tuff, with which it is equivalent (Izett, 1981). Our chemical data confirm identification by Izett and others (1972) of the Lava Creek B ash bed in lake deposits of Pleistocene Lake Tecopa. Sample 37 (table 1), taken from the basal 7 cm of a 2.1-m-thick water-deposited ash (referred to as ash A by Sheppard and Gude, 1968) at the north end of Lake Tecopa, matches well with sample 39 (table 1) of the Lava Creek B ash bed from the locality at Onion Creek, Grand County, Utah (Izett and others, 1972). The similarity coefficient for this sample pair is 0.97 (fig. 4). Another sample of this ash at Lake Tecopa, taken at 91-106 cm above the base (sample 38; table 1), is somewhat different from the lower sample (37) and suggests that this tephra bed may represent more than one eruption, or that it was deposited from an eruption of a compositionally zoned magma. Alternatively, the chemical differences may represent postdepositional reworking of somewhat different ash compositions within the Lake Tecopa basin after eruption. The similarity coefficients

Table 1. Neutron-activation analysis of volcanic glass from late Cenozoic tephra of east-central and southern California.

[Concentrations in parts per million except for iron, which is in percent]

Sample[1] number	Sc	Mn	Fe	Zn[2]	Rb	Cs	La	Ce	Nd[2]	Sm	Eu[2]	Tb	Dy[2]	Yb	Lu	Hf	Ta	Th	U
ASHES HAVING CHEMICAL AFFINITY TO TEPHRA OF THE LONG VALLEY-GLASS MOUNTAIN AREA																			
Friant Pumice Member (of the Turlock Lake Formation) and correlative ashes																			
1[3]	2.83	252	0.52	32	171	5.4	24.1	50.8	20	3.57	0.04	0.53	3.42	2.39	0.30	3.64	1.91	19.4	6.08
2	2.89	252	.54	28	169	5.3	25.0	52.2	17	3.56	.06	.52	3.53	2.40	.31	3.56	1.91	19.0	6.08
3	2.87	254	.53	36	182	5.7	22.6	48.7	19	3.64	.04	.58	3.57	2.48	.37	3.57	2.00	19.5	6.38
4	2.75	258	.50	34	179	5.1	23.6	50.9	19	3.59	.04	.55	3.61	2.49	.35	3.46	1.96	19.2	6.18
5	2.80	258	.52	21	186	5.3	22.6	51.9	20	3.64	.05	.55	ND	2.40	.32	3.64	1.96	19.5	6.09
6	2.68	245	.52	31	170	5.3	25.2	51.9	20	3.53	.06	.52	3.28	2.29	.33	3.48	1.87	18.5	5.80
7	2.96	252	.52	25	178	5.6	21.6	48.6	18	3.61	.04	.55	3.70	2.54	.31	3.53	2.04	20.1	6.50
$\bar{x}$[4]	2.83	253	.52	30	176	5.4	23.5	50.7	19	3.59	.05	.54	3.52	2.43	.33	3.55	1.95	19.3	6.16
s[5]	.09	4	.01	5	7	.2	1.3	1.5	1	.04	.01	.02	.15	.08	.03	.07	.06	.5	.23
a.a.e.[6]	.02	2	.01	2	6	.1	.5	.6	2	.01	< .005	.03	.09	.03	.02	.06	.01	.2	.05
Bishop ash at the Insulating Aggregates quarry (8) and correlative ashes																			
8	3.06	265	0.54	30	187	6.0	19.4	47.1	20	3.74	0.04	0.56	4.10	2.70	0.37	3.74	2.15	21.0	6.69
9	2.99	254	.50	20	185	5.9	18.7	42.9	17	3.59	.04	.58	3.99	2.66	.36	3.79	2.10	21.0	7.44
10	2.85	262	.50	32	181	5.4	20.3	46.6	18	3.60	.03	.57	3.74	2.55	.34	3.67	2.04	19.8	6.53
11	2.95	266	.51	32	188	5.4	20.0	46.8	20	3.65	.04	.57	4.02	2.64	.37	3.60	2.10	20.8	6.70
12	2.92	266	.49	33	186	5.6	20.2	46.2	17	3.62	.04	.58	3.91	2.64	.35	3.67	2.08	20.2	6.68
$\bar{x}$	2.95	263	.51	29	185	5.7	19.7	45.9	18	3.64	.04	.57	3.95	2.64	.36	3.69	2.09	20.6	6.81
s	.08	5	.02	5	3	.3	.7	1.7	2	.06	< .005	.01	.14	.06	.01	.07	.04	.5	.36
a.a.e.	.02	3	.01	2	7	.1	.5	.7	1	.02	.01	.03	.10	.04	.02	.07	.01	.1	.06
Bishop ash at Owens River Gorge (13) and at Red's Meadow (14) and correlative ashes																			
13	3.17	281	0.55	66	200	6.1	18.5	42.2	20	3.89	0.04	0.60	4.21	2.84	0.37	3.92	2.18	21.4	7.13
14	3.22	274	.50	33	185	6.1	18.3	42.1	18	3.77	.03	.63	3.98	2.87	.41	3.99	2.25	21.9	7.19
15	3.20	272	.50	29	195	6.1	17.7	42.6	19	3.74	.03	.61	4.27	2.77	.39	3.84	2.25	21.9	7.22
16	3.16	279	.51	27	202	6.2	18.1	43.4	17	3.79	.03	.65	4.26	2.80	.42	3.74	2.27	22.0	7.20
$\bar{x}$	3.19	277	.52	39	196	6.1	18.0	42.6	19	3.78	0.03	0.62	4.18	2.82	.40	3.87	2.24	21.8	7.14
s	.03	4	.02	18	8	.1	.4	.6	1	.08	.01	.02	.14	.04	.02	.11	.04	.3	.08
a.a.e.	.03	3	.01	3	8	.2	.5	.7	1	.01	.01	.03	.08	.04	.02	.07	.01	.2	.06
Glass Mountain-D ash bed (17, 17a-c) and correlative ash, Ventura area (18)																			
17	2.91	276	0.50	29	189	5.7	24.0	53.2	22	4.15	0.02	0.63	3.98	2.74	0.38	3.76	2.09	19.7	6.55
17a[7]	2.91	ND	.52	34	186	5.3	24	58	26	4.6	.07	.59	ND	2.8	.36	3.6	2.11	19.0	ND
17b	2.90	ND	.51	26	184	5.3	23	53	22	4.0	.02	.58	ND	2.8	.38	3.6	1.98	19.2	6.1
17c	2.95	ND	.51	31	186	5.6	24	55	23	4.1	.12	.59	ND	2.9	.39	3.8	2.10	19.6	6.3
18	3.01	301	.58	39	186	5.4	22.7	54.9	22	4.34	.02	.64	4.22	2.77	.38	3.76	2.19	19.5	6.65
$\bar{x}$	2.94	289	.52	32	186	5.5	23.5	54.8	23	4.2	.05	.61	4.10	2.80	.38	3.7	2.09	19.4	6.4
s	.05	---	.03	5	2	.2	.6	2.0	2	.2	.04	.03	---	.06	.01	.1	.08	.3	.2
a.a.e.	.03	2	.01	1	5	.2	.3	.7	2	.04	.005	.02	.09	.05	.01	.1	.03	.2	.1
Glass Mountain-G ash bed (19) and correlative ash, Ventura area (20, 21, 21a-d)																			
19	3.09	313	0.54	36	211	6.0	22.2	52.6	21	4.48	0.03	0.71	4.51	3.00	0.42	4.04	2.31	22.0	7.27
20	3.00	316	.53	(111)	204	6.0	22.8	57.9	24	4.33	.02	.69	ND	2.90	.40	4.00	2.26	21.7	6.60
21	2.87	348	.54	27	210	6.6	22.3	52.3	23	4.50	.03	.75	4.68	3.21	.45	3.98	2.52	22.7	7.48
21a	2.98	ND	.57	37	188	6.9	23	60	28	5.0	.05	.73	ND	3.3	.49	4.2	2.52	23.5	ND
21b	2.87	ND	.55	29	201	6.5	22	53	22	4.5	.04	.73	ND	3.3	.46	4.0	2.56	23.1	8.2
21c	2.94	ND	.56	31	191	6.5	22	50	21	4.3	.04	.64	ND	3.3	.46	4.0	2.41	22.6	6.7
21d	2.96	ND	.56	31	203	7.1	22	52	22	4.4	.04	.75	ND	3.3	.47	3.9	2.76	23.8	9.0
$\bar{x}$	2.96	326	0.55	31	200	6.5	22.3	54.0	23	4.5	.04	0.71	4.60	3.19	0.45	4.02	2.47	22.8	7.5
s	.08	---	.01	4	9	.4	.4	3.6	2	.2	.01	.04	---	.17	.03	.09	.17	.8	.9
a.a.e.	.03	4	.01	2	5	.2	.3	.7	2	.04	.01	.03	.13	.06	.02	.06	.04	.2	.12

Table 1. Nuetron-activation analysis of volcanic glass from late Cenozoic tephra of east-central and southern California.--Continued

Sample[1] number	Sc	Mn	Fe	Zn[2]	Rb	Cs	La	Ce	Nd[2]	Sm	Eu[2]	Tb	Dy[2]	Yb	Lu	Hf	Ta	Th	U
Bailey ash, South Mountain (22, 22a, 23, 23a-d) and Ventura (24, 24a-c, 25, 26, and 26a) areas																			
22	2.68	426	0.57	30	227	8.1	20.2	45.8	19	4.36	0.04	0.77	5.14	3.71	0.50	4.01	3.02	26.7	8.95
22a	2.73	ND	.58	36	256	8.1	19	45	20	4.2	.08	.76	ND	3.8	.55	4.1	3.04	26.7	8.8
23	2.68	438	.50	27	229	8.4	17.2	42.6	19	4.36	.03	.73	5.14	3.95	.54	4.28	3.14	27.6	9.42
23a	2.82	ND	.53	30	244	8.5	20	49	17	(5.5)	(.21)	.81	ND	4.0	.56	4.3	3.05	27.8	ND
23b	2.67	ND	.48	29	233	7.7	17	41	19	4.0	.05	.75	ND	3.9	.55	4.1	2.87	26.1	8.2
23c	2.74	ND	.50	34	240	8.0	18	41	21	4.0	.06	.75	ND	3.9	.55	4.0	2.97	26.9	8.2
23d	2.78	ND	.50	34	249	8.8	18	42	18	4.3	.06	.79	ND	4.1	.58	4.2	3.27	28.4	10.4
24	2.68	426	.52	31	233	8.0	20.1	48.4	21	4.44	.04	.81	5.03	3.78	.51	4.14	3.08	26.7	8.86
24a	2.70	ND	.51	30	231	8.3	20	46	19	4.2	.05	.76	ND	3.8	.54	4.2	2.95	26.4	8.7
24b	2.70	ND	.53	29	222	8.0	20	47	21	4.1	.06	.79	ND	3.8	.53	4.2	2.79	26.0	8.5
24c	2.67	ND	.51	32	241	8.4	20	47	18	4.3	.06	.79	ND	3.8	.55	4.1	3.25	27.3	10.2
25	2.66	428	.55	37	223	7.7	20.0	47.1	20	4.35	.03	.78	5.27	3.81	.51	4.17	3.08	26.7	9.13
26	2.72	444	.55	27	237	8.4	17.4	42.4	19	4.35	.04	.85	5.23	3.90	.55	4.16	3.19	27.5	9.56
26a	2.79	ND	.57	31	233	8.8	17	42	19	4.1	.05	.80	ND	3.8	.57	4.2	3.19	27.9	9.6
$\bar{x}$	2.72	432	0.53	31	236	8.2	18.9	44.7	19	4.24	.05	.78	5.16	3.86	.54	4.15	3.06	27.1	9.1
s	.05	8	.03	3	10	.3	1.3	2.8	1	.15	.01	.03	.09	.10	.02	.09	.14	.7	.7
a.a.e.	.03	3	.01	2	6	.2	.3	.7	2	.03	.01	.03	.10	.06	.01	.08	.05	.3	.14
Thin white ash below the Bailey ash, South Mountain area																			
27	4.47	472	0.52	54	245	7.5	17.2	48.7	22	5.28	0.04	0.78	5.14	3.26	0.43	4.55	3.21	18.7	9.20
a.e.[8]	.03	3	.01	3	9	.2	.4	.6	1	.01	.01	.03	.07	.04	.02	.08	.01	.1	.05
Upper white ash, Manix basin, Mojave Desert																			
28	3.76	346	0.52	42	192	5.8	19.5	49.9	20	4.59	0.01	0.57	3.83	2.60	0.39	4.17	2.39	17.9	7.38
29	3.67	354	.50	36	197	5.8	18.4	48.8	22	4.47	.01	.61	4.03	2.50	.34	4.12	2.36	18.1	7.22
$\bar{x}$	3.72	350	0.51	39	192	5.8	19.0	49.4	21	4.53	.01	.59	3.93	2.56	0.37	4.15	2.38	18.0	7.30
a.a.e.	.02	3	.01	3	4	.2	.6	.6	1	.02	< .005	.03	.11	.03	.02	.07	.01	.2	.06
Middle white ash, Manix basin, Mojave Desert (30-33), and ash in the lacustrine Waucoba Beds of Hopper (1947), E. Owens Valley (34)																			
30	4.89	688	0.45	48	317	10.3	17.1	51.0	25	6.30	< 0.005	1.08	7.0	4.34	0.56	5.73	4.57	29.5	13.51
31	4.95	696	.44	51	315	10.8	17.3	51.5	21	6.44	< 0.005	1.00	6.7	4.46	.64	5.85	4.67	30.2	13.78
32	4.86	698	.46	52	327	11.1	17.5	52.3	27	6.33	.02	1.04	7.1	4.52	.60	5.81	4.71	29.7	13.49
33	4.92	701	.45	50	321	10.6	16.9	52.3	27	6.37	.03	1.04	7.2	4.38	.58	5.91	4.74	29.7	13.37
34	4.66	701	.46	61	323	10.7	16.0	45.3	24	6.00	.06	1.06	6.9	4.38	.58	5.53	4.61	30.5	13.24
$\bar{x}$	4.86	697	.45	52	318	10.7	17.0	50.5	25	6.29	.02	1.04	7.0	4.42	.59	5.77	4.66	29.9	13.48
s	.11	5	.01	5	9	.3	.6	2.9	2	.17	.02	.03	.2	.07	.03	.15	.07	.4	.20
a.a.e.	.03	5	.01	3	10	.2	.5	.7	1	.02	.01	.04	.1	.05	.03	.09	.02	.2	.10
Ash in late Cenozoic lake beds of Searles Valley																			
35	2.86	607	0.51	36	174	5.8	23.3	50.7	19	3.92	0.12	0.66	ND	2.86	0.36	3.51	2.23	17.0	4.84
a.e.[8]	.02	8	.01	2	6	.1	.5	.7	1	.01	.01	.03	---	.04	.02	.06	.01	.1	.04
Unwelded, pumiceous ash-flow tuff in the Coso area																			
36	2.48	484	0.36	23	228	10.7	6.2	15.8	7	0.99	0.09	0.16	1.34	1.67	0.26	3.60	1.59	16.5	7.75
a.e.	.02	4	.01	2	10	.2	.3	.5	1	.01	.01	.02	.11	.03	.01	.06	.01	.1	.05
ASHES HAVING CHEMICAL AFFINITY TO TEPHRA OF THE YELLOWSTONE AREA, WYOMING																			
Uppermost ash (ash A), Tecopa area (37, 38) and Lava Creek B ash bed (Pearlette-type O ash bed), Grand Co., Utah (39)																			
37	1.33	259	1.05	94	222	4.2	81	160	66	12.47	0.37	2.08	14.27	8.35	1.11	8.50	4.29	30.0	6.62
38	1.33	290	1.15	94	199	3.7	92	182	73	13.39	.59	2.10	13.89	7.91	1.00	9.26	3.84	29.2	5.77
39	1.29	270	1.05	90	235	4.0	83	161	63	12.60	.41	2.05	14.20	7.95	1.11	8.59	4.03	29.0	6.29
$\bar{x}$	1.32	273	1.08	93	219	4.0	84	168	67	12.63	0.46	2.08	14.25	8.07	1.06	8.78	4.05	29.4	6.13
a.a.e.	0.01	5	.01	7	8	.1	1	2	2	.09	.01	.09	.15	.08	.03	.10	.03	.2	.06

Table 1. Nuetron-activation analysis of volcanic glass from late Cenozoic tephra of east-central and southern California.--Continued

Sample[1] number	Sc	Mn	Fe	Zn[2]	Rb	Cs	La	Ce	Nd[2]	Sm	Eu[2]	Tb	Dy[2]	Yb	Lu	Hf	Ta	Th	U
Mesa Falls ash bed (Pearlette-type S ash bed), Harlan County, Nebraska[9]																			
40	1.70	240	0.99	69	264	4.6	81	161	58	11.41	0.40	1.92	13.00	7.53	1.09	7.11	3.79	33.9	7.25
40A[10]	1.74	244	1.03	69	268	4.6	83	161	60	11.50	.42	1.88	13.20	7.68	1.04	7.20	3.81	34.1	7.37
$\bar{x}$	1.72	242	1.01	69	266	4.6	79	161	59	11.01	0.41	1.90	13.20	7.61	1.03	7.16	3.80	34.0	7.03
a.a.e.	.02	3	.02	3	13	.1	1	2	2	.02	.01	.06	.17	0.08	.04	.10	.02	.2	.05
Lower gray ash, Manix basin (41), and Huckleberry Ridge ash bed (Pearlette-type B ash bed), Borchers locality, Meade County, Kansas (42)																			
41	1.77	287	1.21	106	201	3.7	92	181	73	13.78	0.69	2.20	13.9	7.93	1.08	9.51	3.53	29.9	6.24
42	1.68	281	1.20	103	211	3.5	96	187	74	13.95	.72	2.13	14.5	7.89	1.15	9.10	3.56	29.8	6.17
$\bar{x}$	1.73	284	1.21	105	206	3.6	92	184	74	13.54	0.71	2.17	14.38	7.91	1.09	9.31	3.55	29.9	6.21
a.a.e.	.02	3	.02	3	8	.1	1	2	2	.03	.01	.08	.17	.08	.04	.12	.02	.1	.06
Lowermost gray ash, South Mountain area (43), and gray ash (ash C)[11], Tecopa area (Huckleberry Ridge? ash bed) (44, 45)																			
43	1.74	301	1.24	122	196	3.0	104	203	78	14.45	0.82	1.98	13.91	7.62	1.03	9.39	3.30	28.6	5.70
44	1.75	305	1.25	120	189	2.8	102	189	78	14.29	.81	1.98	13.37	7.05	1.00	8.97	3.01	27.8	5.57
44a	1.71	ND	1.24	104	189	2.9	102	188	78	13.99	.81	1.98	ND	7.22	.98	9.25	3.13	27.5	5.25
45	1.80	310	1.28	125	192	3.2	102	202	80	14.28	.89	2.03	13.60	7.62	1.05	9.60	3.25	28.1	5.63
$\bar{x}$	1.75	305	1.25	118	192	3.0	103	196	79	14.25	0.83	1.99	13.63	7.38	1.02	9.30	3.17	28.0	5.54
s	.04	5	.02	9	3	.2	1	8	1	.19	.04	.03	.27	.29	.03	.26	.13	.5	.20
a.a.e.	.02	2	.02	3	8	.1	1	2	2	.05	.01	.05	.12	.07	.03	.11	.02	.2	.07
TEPHRA HAVING CHEMICAL AFFINITIES TO OTHER VOLCANIC PROVINCES																			
Air-fall pumice of the Coso area																			
46	1.41	251	1.02	48	111	2.9	25.1	44.4	16	2.31	0.49	0.20	1.60	1.03	0.17	3.74	0.66	7.95	2.49
a.e.	.02	3	.02	3	6	.1	0.6	.8	1	.01	.01	.02	.10	.03	.02	.07	.01	.06	.04
47	1.05	284	.95	42	105	2.6	24.1	44.1	14	1.97	.44	.20	1.48	.91	.12	3.91	.71	7.67	2.34
a.e.	.02	3	.02	3	5	.1	.6	.7	1	.01	.01	.02	.11	.03	.01	.08	.01	.06	.04
48	.91	281	.90	41	101	2.8	24.4	45.9	13	1.87	.41	.15	1.25	.85	.13	3.81	.74	8.19	2.48
48A	.87	283	.86	36	103	2.7	25.3	43.6	14	1.82	.41	.15	1.17	.86	.14	3.60	.72	8.16	2.44
$\bar{x}$	.89	282	.88	39	102	2.8	24.9	44.8	14	1.85	.41	.15	1.21	.86	.14	3.71	.73	8.18	2.46
a.a.e.	.02	3	.02	3	5	.1	.6	.7	1	.01	.01	.02	.10	.03	.01	.07	.01	.06	.04
Ash in Searles Valley																			
49	2.46	479	0.79	43	88	4.5	19.8	39.3	17	3.14	0.57	0.44	3.14	2.51	0.36	4.30	0.50	8.74	3.90
a.e.	.02	4	.02	2	4	0.1	.4	.6	1	.01	.01	.02	.12	.31	.02	.70	< .005	.06	.04
Pumice overlying the Cahuilla beds, Salton trough																			
50	3.88	403	1.90	68	137	4.0	45.9	107	51	12.18	1.76	0.40	16.7	12.1	1.72	12.8	1.75	19.1	5.40
a.e.	.03	3	.03	5	8	.1	.6	1	2	.02	.02	.05	.1	.1	.05	.2	.01	.2	.04

[1]Sample numbers are the same as in fig. 1.
[2]These elements were not used in calculation of the similarity coefficient and other statistical sample comparisons.
[3]Samples with a number designation only were analyzed at Lawrence Berkeley Laboratory, by H. W. Bowman, Frank Asaro, and Helen Michael.
[4]Average of sample group.
[5]Standard deviation of group.
[6]Average analytical error based on counting statistics. Generally taken as plus or minus one sigma of the mean.
[7]Samples with a number followed by a small letter designation are splits of single samples designated by number only, and were analyzed at the U.S. Geological Survey, Radiochemistry Laboratory, Reston, Va., by J. J. Rowe and P. A. Baedecker. Concentrations for these samples are predicted ($\hat{y}$) values from regression analysis of 22 sample pairs analyzed jointly by Lawrence Berkeley Laboratory (x) and the U.S. Geological Survey Radiochemistry Laboratory, Reston, Va. (y).
[8]Analytical error for a single analysis.
[9]Izett and others (1972).
[10]Samples with a number followed by a capital letter designation are splits of a single sample analyzed by Lawrence Berkeley Laboratory.
[11]Sheppard and Gude (1968).

Table 2. Electron microprobe analysis of volcanic glass from late Cenozoic tephra of east-central and southern California.

[Concentrations in oxide weight percent except for Cl and P, which are in atomic weight percent. Oxide concentrations are recalculated to totals of 100 percent. C. E. Meyer, analyst.]

Sample	SiO_2	Al_2O_3	Fe_2O_3[1]	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl	P	Total[2]	Total[3]
ASHES HAVING CHEMICAL AFFINITY TO TEPHRA OF THE LONG VALLEY-GLASS MOUNTAIN AREA														
Friant Pumice Member (of the Turlock Lake Formation) (1, 1A[4], 1B), and correlative ashes														
1	77.34	12.68	0.76	0.04	0.05	0.45	0.00	0.08	3.60	4.99	ND[5]	0.00	93.34	99.99
1A	77.90	12.45	.75	.03	.05	.45	.00	.06	3.53	4.77	ND	.01	96.44	100.00
1B	77.58	12.87	.77	.03	.02	.46	.00	.07	3.72	4.43	0.05	ND	94.58	100.00
2	77.18	12.89	.79	.06	.05	.48	.00	.06	3.92	4.51	.06	ND	93.44	100.00
3	77.81	12.22	.79	.04	.04	.47	.02	.05	3.72	4.80	ND	.04	94.29	100.00
4	77.28	12.88	.79	.04	.03	.49	.00	.07	3.84	4.53	.06	ND	93.75	100.01
5	78.00	11.71	.78	.03	.03	.47	.01	.07	3.47	5.39	.05	ND	92.08	100.01
6	77.49	12.97	.79	.04	.05	.46	.00	.07	4.48	3.60	.07	ND	93.07	100.02
$\bar{x}$[6]	77.57	12.58	.78	.04	.04	.47	.00	.07	3.79	4.63	.06	---	93.87	---
s[7]	0.30	0.44	.02	.01	.01	.01	.01	.01	0.32	0.52	.01	---	1.29	---
Bishop ash at Insulating Aggregates quarry (8) and correlative ashes														
8	77.37	12.72	0.75	0.04	0.04	0.45	0.00	0.06	3.34	5.22	ND	0.00	94.17	99.99
10	77.35	12.84	.78	.02	.03	.46	.00	.05	4.10	4.31	0.06	ND	92.93	100.01
11	78.15	11.87	.69	.02	.02	.44	.00	.07	4.11	4.58	.04	ND	89.02	99.99
12	77.31	12.81	.79	.04	.05	.47	.00	.05	4.58	3.84	.07	ND	92.66	100.01
$\bar{x}$	77.55	12.56	.75	.03	.04	.46	.00	.06	4.03	4.49	.06	---	92.20	---
s	0.40	0.46	.06	.01	.01	.01	.00	.01	0.51	0.58	---	---	2.22	---
Bishop ash at Red's Meadow (14) and ash at Onion Cr., Grand Co., Utah (16)														
14	77.33	12.86	0.77	0.04	0.02	0.47	0.00	0.05	4.10	4.28	0.04	ND	95.64	100.00
16	77.50	12.73	.77	.03	.05	.45	.01	.07	3.88	4.44	.07	ND	93.10	100.00
Glass Mountain-D ash bed (17) and correlative ash, Ventura area (18)														
17	77.91	12.24	0.74	0.03	0.05	0.41	0.00	0.06	3.53	5.00	ND	0.01	95.64	99.99
18	77.19	12.86	.80	.04	.05	.42	.01	.07	3.89	4.60	0.06	ND	93.11	99.99
Glass Mountain-G ash bed (19) and correlative ash, Ventura area (21)														
19	77.24	12.90	0.83	0.03	0.03	0.43	0.00	0.05	3.85	4.57	0.05	ND	94.56	100.00
21	77.12	12.66	.86	.04	.10	.43	.00	.07	3.55	5.16	ND	0.02	93.56	100.01
Bailey ash, South Mountain (22, 23) and Ventura (24, 25) areas														
22	77.32	12.32	0.83	0.03	0.05	0.51	0.00	0.06	3.83	5.03	ND	0.01	92.05	99.99
23	77.06	12.91	.81	.04	.05	.49	.02	.05	3.89	4.63	0.06	ND	93.42	100.01
24	77.23	12.92	.80	.03	.04	.48	.01	.06	3.83	4.55	.06	ND	93.20	100.01
25	76.98	12.99	.82	.03	.04	.47	.00	.05	3.88	4.67	.06	ND	93.43	99.99
$\bar{x}$	77.15	12.79	.82	.03	.05	.49	.01	.06	3.86	4.72	.06	---	93.03	---
s	0.16	0.31	.01	.01	.01	.02	.01	.01	0.03	0.21	---	---	0.66	---
Thin white ash below the Bailey ash, South Mountain area														
27	76.77	12.87	0.79	0.03	0.05	0.31	0.00	0.05	3.94	5.14	0.06	ND	94.03	100.01

Table 2. Electron microprobe analysis of volcanic glass from late Cenozoic tephra of east-central and southern California.--Continued

Sample number	SiO_2	Al_2O_3	Fe_2O_3[1]	MgO	MnO	CaO	BaO	TiO_2	Na_2O	K_2O	Cl	P	Total[2]	Total[3]
Middle white ash, Manix basin, Mojave Desert (33), and ash in the lacustrine Waucoba Beds of Hopper (1947), E. Owens Valley (34)														
33	78.33	11.99	0.71	0.02	0.09	0.34	0.01	0.07	4.68	3.72	0.03	ND	91.30	99.99
34	77.48	12.34	.68	.03	.09	.32	.01	.05	3.61	5.35	.04	ND	93.25	100.00
Ash in late Cenozoic lake beds of Searles Valley														
35	78.57	12.98	0.82	0.03	0.05	0.50	0.01	0.06	5.27	1.69	ND	0.01	90.71	99.99
Unwelded, pumiceous ash-flow tuff in Coso area														
36	77.04	12.66	0.56	0.02	0.07	0.74	0.00	0.04	3.07	5.79	0.00	ND	91.00	99.99
ASHES HAVING CHEMICAL AFFINITY TO TEPHRA OF THE YELLOWSTONE AREA, WYOMING														
Lava Creek B ash bed (Pearlette-type O ash bed), Grand Co., Utah[8] (39), and ash in Christmas Canyon Fm., Searles Valley (51)														
39	76.85	12.21	1.57	0.02	0.03	0.54	0.00	0.10	3.57	4.98	0.12	ND	94.02	99.99
51	77.00	11.76	1.75	.02	.03	.56	.02	.12	3.45	5.18	.11	ND	92.95	100.00
Mesa Falls ash bed (Pearlette type S ash bed), Harlan County, Nebraska[8]														
40	76.79	12.24	1.49	0.04	0.03	0.58	0.00	0.11	3.21	5.41	0.11	ND	94.14	100.00
Lowermost gray ash, Manix basin (41) and Huckleberry Ridge ash bed[8] (Pearlette type B ash bed), Borchers locality, Meade Co., Kansas[8] (42)														
41	75.97	12.95	1.69	0.03	0.03	0.61	0.02	0.13	4.06	4.36	0.15	ND	94.84	100.00
42	76.51	12.25	1.78	.02	.05	.58	.03	.12	3.34	5.21	.12	ND	93.98	100.01
Lowermost gray ash, South Mountain area, Huckleberry Ridge? ash bed (43), and ash (ash C)[9], Tecopa area (44, 45)														
43	76.52	12.11	1.90	0.02	0.05	0.60	0.05	0.10	3.63	5.01	ND	0.01	94.19	100.00
44	76.40	11.90	2.01	.03	.03	.64	.04	.14	2.85	5.94	ND	0.02	93.58	99.98
45	75.94	12.47	1.94	.02	.03	.64	.04	.12	3.45	5.23	0.12	ND	93.99	100.00
$\bar{x}$	76.28	12.16	1.95	.02	.04	.63	.04	.12	3.31	5.39	---	---	93.92	---
TEPHRA HAVING CHEMICAL AFFINITIES TO OTHER VOLCANIC PROVINCES														
Air-fall pumice of the Coso area														
46	75.65	13.17	1.43	0.23	0.06	1.23	0.14	0.14	3.42	4.49	0.05	ND	90.85	100.01
48	75.68	13.35	1.32	.19	.02	1.19	.12	.14	3.53	4.44	.03	ND	91.84	100.01
Ash in Searles Valley														
49	75.65	13.87	1.17	0.22	0.07	0.83	0.10	0.20	3.42	4.32	0.15	ND	95.42	100.00

[1] Total iron as Fe_2O_3
[2] Original totals. These are low due to presence of water as well as other volatiles, such as CO_2, in the glass.
[3] Totals recalculated to 100 percent.
[4] Samples 1A and 1B are replicate analyses of sample 1.
[5] ND--not determined.
[6] Group average.
[7] Standard deviation of group.
[8] Izett and others, 1973.
[9] Sheppard and Gude (1968).

Table 3. Energy-dispersive X-ray fluorescence analysis of volcanic glass of selected ash layers.
[Values given are normalized, integrated peak intensity counts, divided by total counts (peak plus background) in each of two spectral regions: 2.96 to 9.01 kev for elements Ca through Zn, and 12.32 through 17.00 kev for elements Rb through Nb. Resultant ratios are multiplied by 10,000 to give whole integers.]

Sample	Ca	Ti	Mn	Fe	Cu	Zn	Rb	Sr	Y	Zr	Nb	Sampled interval (cm above base)	Color
38h	33	92	118	948	41	192	1586	211	1109	2927	1073	185-196	light gray
38g	35	91	117	947	42	192	1675	203	1203	2772	1063	119-132	Do.
38f	33	92	121	943	42	187	1610	223	1157	2881	1043	99-107	Do.
38e	33	91	120	948	43	197	1618	217	1141	2912	1032	81-91	Do.
38d	33	92	117	948	43	190	1638	214	1151	2911	1041	56-66	Do.
38c	48	92	171	791	121	181	2225	338	980	1837	832	47-52	White
38b	34	91	117	951	44	193	1604	212	1175	2872	1104	33-43	light gray
38a	33	83	117	947	44	196	1729	198	1216	2963	1098	5-15	Do.
39	34	83	114	940	44	197	1582	201	1227	2657	1118	---	Do.
51	33	92	120	942	42	189	1760	212	1148	2937	1040	---	Do.
52	37	87	121	932	46	190	1661	216	1212	2773	1095	---	Do.
53	30	86	113	937	41	178	1608	220	1174	2725	1075	---	Do.
9a	50	88	181	789	67	158	2361	301	995	1717	851	---	White

38a through 38h - Samples of ash layers collected vertically in compound ash bed (ash A of Sheppard and Gude, 1968), in lake beds of Pleistocene Lake Tecopa.
39 - Lava Creek B ash bed, Grand Co., Utah
51 - Ash in pluvial lake beds of Searles Valley.
52 - Ash in marine San Pedro Formation, Ventura.
53 - Ash in lake beds of E-Clay zone, Wasco site (Davis and others, 1977), south San Joaquin Valley.
9a - Bishop ash bed (ash B of Sheppard and Gude, 1968), in pluvial lake deposits of Pleistocene Lake Tecopa.

between samples 37-38 and 38-39 are 0.92 and 0.93 (fig. 4), respectively, considerably lower than similarity coefficients for replicate analyses from a single emplacement unit of this type of tephra. Eight additional samples were collected subsequently from this tephra bed and analyzed by energy-dispersive X-ray fluorescence spectrometry to test whether multiple emplacement units are present. Examination of spectral data for these samples (fig. 6; table 3) suggests that at least two and perhaps three compositional types are present in this ash bed. Seven of these samples are very similar to each other (38a, b, and d through h) and to the Lava Creek B ash bed. The eighth sample (38c) was collected from a 5-cm-thick layer of white ash within this ash bed, 47 to 52 cm above the base. This layer contrasts with the light gray of the other layers in the bed. The chemical composition of glass of the white layer is quite different from that of the rest of the bed and is most similar to ashes of the Long Valley-Glass Mountain volcanic province, such as the Bishop ash-bed group. The presence of this ash in a bed correlated with the Lava Creek B ash bed suggests either that an eruption from Long Valley caldera occurred about 0.6 m.y. ago, at about the same time as the eruption of the Lava Creek B ash from the Yellowstone area, or that the Bishop ash has been reworked locally within the drainage basin tributary to Pleistocene Lake Tecopa. A thick bed of Bishop ash is present within the Tecopa lake beds of Sharp (1972),

Sample	h	g	f	e	d	c	b	a
h		97	98	98	99	76	98	95
g	5		96	97	97	76	98	97
f	3	5		99	99	77	98	95
e	2	4	1		99	76	98	95
d	2	4	2	1		76	98	95
c	34	32	32	33	33		75	75
b	2	3	3	3	3	34		96
a	7	4	7	7	6	32	5	

FIGURE 6.—Similarity coefficient matrix comparing chemical spectra of glass determined by energy-dispersive X-ray fluorescence of ash layers (samples 38a-h) collected from the compound ash bed in lake beds of Pleistocene Lake Tecopa (samples 38a-h) (ash A of Sheppard and Gude, 1968). Upper right-half of matrix shows similarity coefficients for sample pairs, in percent (100 represents a match of an identical sample pair). Lower-left half of matrix shows standard deviation of means of ratios for each sample pair. See text for discussion.

stratigraphically several meters beneath the Lava Creek B ash bed (see below). Consequently, Bishop ash from topographically higher parts of the drainage basin tributary to Lake Tecopa may have been periodically eroded and transported into the lake basin for some period of time after the eruption of the Bishop ash. The latter explanation is somewhat less probable than the former, because it requires that reworking take place during or shortly after deposition of the Lava Creek B ash bed, but not during deposition of texturally similar lake beds that overlie and underlie the Lava Creek B ash bed. The presence of this thin white ash layer within the compound Lava Creek B ash bed at the Tecopa locality adds a further degree of complexity to the problem of the age and correlation of the Friant Pumice Member of the Turlock Lake Formation and the Bishop ash-bed group (see below).

A sample of the ash (sample 38a) from the lower part of the Lava Creek B ash bed of the Tecopa area differs slightly from the other overlying samples (38b, and 38d through 38h). Similarity coefficients comparing the sample from the lower part of the ash bed with the six other overlying samples average 0.955, but coefficients comparing the upper six samples to each other range from 0.97 to 0.98 (fig. 6). One explanation is that the two lower samples (38a and 38b) represent two separate eruptions of Lava Creek B ash. The upper ashes (samples 38d through 38h) overlying the exotic layer of Long Valley-Glass Mountain provenance (sample 38c) may represent locally reworked material, mostly composed of ash similar in composition to sample 38b, with perhaps some small amounts of glass from layers represented by samples 38a and 38c.

In addition to the massive exposures in the Lake Tecopa beds, the Lava Creek B ash bed has also been identified from the following localities (fig. 1):

(1) In Searles Valley of southeastern California, about 100 km west-southwest of Lake Tecopa (G. A. Izett, written commun., 1979; this report, sample 51).

(2) In Pleistocene marine beds near the base of the San Pedro Formation, east of the town of Ventura, Calif. (sample 52). This is the first instance in which this ash has been found in marine deposits and also represents the westernmost locality reported for the Lava Creek B ash bed. Near Ventura, the ash is 850 m below the top of the San Pedro Formation, estimated to be about 0.2 m.y. old on the basis of amino-acid-racemization age estimates (Lajoie and others, 1979; Wehmiller and others, 1978), and 670 m above the Bishop ash bed (0.73 m.y. old; see below), in the upper part of the underlying marine Santa Barbara Formation. Identification of the Lava Creek B, Bishop, Bailey, and several other isotopically dated ashes in the Ventura basin (see below) has enabled calibration of existing marine faunal stages and estimation of sedimentation rates within the basin.

(3) In subsurface alluvium near Wasco, Calif. (sample 53; fig. 1). The ash sample was obtained from a core taken about 84 m below the surface of the southern San Joaquin Valley, in the "E-clay" unit correlated with the Corcoran Clay Member of the Tulare Formation (Davis and others, 1977). This ash has been previously identified as the "Bishop Tuff" (Davis and others, 1977), but we identify it as the Lava Creek B ash bed on the basis of energy-dispersive X-ray fluorescence of the glass (table 3), glass shard morphology, and color. Shards are dominantly solid-glass, bubble-wall and bubble-wall junction types typical of the Yellowstone tephra family, with very few pumiceous shards that are so typical of the Bishop ash-bed group. The color of this ash is light gray, like the Lava Creek B ash bed, and unlike the chalky white of the Bishop ash-bed group. All the mineral grains in ash at the Wasco locality lack glass selvages and are probably detrital. The rapid-scan X-ray fluorescence method used by Davis and others (1977) is not diagnostic for identification of many tephra families.

BISHOP ASH-BED GROUP

The Bishop ash-bed group is another important and widespread stratigraphic marker in the western and central United States (Izett and others, 1970). This ash was erupted from the Long Valley caldera east of the central Sierra Nevada in California (Gilbert, 1938; Bateman, 1965; Sheridan, 1965; Bailey and others, 1976; Hildreth, 1979). Near the source north of the town of Bishop, and at several localities in the vicinity of Long Valley, there are good exposures of a thick basal air-fall ash (sample localities 8, 13; fig. 1) that underlie the later ash flows of the Bishop Tuff. At locality 8, the air-fall ash has a minimum thickness of 4.5 m. Three chemical types of the Bishop ash, here collectively and informally termed the Bishop ash-bed group, are recognized on the basis of the chemical composition of the associated glass. These three types are referred to as (1) the Friant Pumice Member, (2) the Bishop ash at the Insulating Aggregates quarry (or Bishop ash, IAQ type), and (3) Bishop ash at Owens River Gorge and at Red's Meadow (or Bishop ash, ORG type). The three types are chemically very similar to each other. The small compositional differences among the three types may be due to zoning in the pre-eruption magma chamber, or tephra of somewhat variable composition may have been generated during one eruption or during several eruptions. At present we do not have a sufficient number of analyses to determine whether compositional variations among these three chemical types are continuous or discontinuous.

Table 4. Specific locality information.

Sample number	State	County	Quadrangle	Quarter and Section	Township	Range	Lat (n)	Long (w)	Collector(s)	Field Number	Lab Number
Friant Pumice Member (of the Turlock Lake Formation) (1), and correlative ashes											
1	Calif.	Madera	Millerton Lake 15'	NE1/4 NE1/4, 1	10S	20E	N37°00'40"	W119°44'10"	R. J. Janda	63cj-26	N-ASW- 2
2	do.	Tulare	Alpaugh 7.5'	NW1/4 NE1/4, 16	23S	24E	N35°52'30"	W119°23'15"	Bureau of Reclamation	23-24-16B	do. 4
3	do.	Ventura	Ventura 7.5'	L.G.[1]	---	---	N34°17'56"	W119°16'58"	A. M. Sarna-Wojcicki	Pico-15	do. 58
4	do.	do.	do.	do.	---	---	N34°17'57"	W119°15'48"	do.	Pico-24	do. 69
5	do.	San Diego	Clark Lake 15'	NW1/4 NE1/4, 24	9S	5E	N33°22'50"	W116°24'35"	R. V. Sharp	ST-RT-3	do. 125
6	do.	Imperial	Durmid SE 7.5'	NW1/4 SW1/4, 19	do.	12E	N33°22'29"	W115°46'07"	A. M. Sarna-Wojcicki	Salton-2	do. 63
7	do.	do.	do.	do.	do.	do.	do.	do.	do	Salton-2A	do. 117
Bishop ash at Insulating Aggregates quarry (8), and correlative ashes											
8	Calif.	Inyo	Bishop 15'	NW1/4 NW1/4, 4	6S	33E	N37°27'40"	W118°21'55"	A. M. Sarna-Wojcicki, J. W. Hillhouse	BT-8	N-ASW-115
9	do.	do.	Shoshone 15'	SW1/4 NE1/4, 32	22N	7E	N35°58'02"	W116°14'52"	do.	Teco-5	do. 183
10	do.	Riverside	Murrietta 7.5'	SW1/4 NW1/4, 7	7S	3W	N33°34'52"	W117°14'25"	M. P. Kennedy, G. A. Borchardt	ELSI-1	do. 75
11	do.	do.	Idylwild 15'	SE1/4 SW1/4, 32	6S	3E	N33°36'00"	W116°41'44"	R. V. Sharp	ST-RT-2	do. 124
12	do.	Imperial	Durmid SE 7.5'	NW1/4 SW1/4, 19	9S	12E	N33°22'29"	W115°46'07"	A. M. Sarna-Wojcicki	Salton-5	do. 71
Bishop ash at Owens River Gorge (13), Bishop Tuff at Red's Meadow (14), and correlative ashes											
13	Calif.	Mono	Casa Diablo 15'	W1/2 NE1/4, 5	5S	31E	N37°32'47"	W118°35'26"	E. W. Hildreth	B-93	922K
14	do.	Madera	Devil's Postpile 15	N.F.[2]	---	---	N37°37'35"	W119°03'20"	R. J. Janda	J-328	N-ASW- 3
15	do.	Imperial	Durmid SE 7.5'	NW1/4 SW1/4, 19	9S	12E	N33°22'29"	W115°46'07"	A. M. Sarna-Wojcicki	Salton-1	do. 116
16	Utah	Grand	Polar Mesa 15'	SE1/4 NE1/4, 26	24S	24E	N38°41'25"	W109°14'11"	R. E. Wilcox	66W5	do. 149
Glass Mountain-D ash bed (17, 17a-c) and correlative ash, Ventura area (18)											
17	Calif.	Inyo	Bishop 15'	NE1/4 NE1/4, 23	6S	32E	N37°27'24"	W118°40'25"	A. M. Sarna-Wojcicki	BT-2	N-ASW- 55
18	do.	Ventura	Ventura 7.5'	L.G.	---	---	N34°19'05"	W119°20'43"	do.	Pico-23	do. 68
Glass Mountain-G ash bed (19) and correlative ashes, Ventura area (20, 21)											
19	Calif.	Inyo	Bishop 15'	NE1/4 NE1/4, 23	6S	32E	N37°27'24"	W118°40'25"	A. M. Sarna-Wojcicki	BT-1	N-ASW-101
20	do.	Ventura	Ventura 7.5'	L.G.	---	---	N34°18'10"	W119°16'14"	do.	Pico-27	do. 129
21	do.	do.	do.	do.	---	---	N34°18'05"	W119°18'14"	do.	Pico-14	do. 64
Bailey ash, South Mountain (22, 23), and Ventura (24, 25, 26)											
22	Calif.	Ventura	Moorpark 7.5'	NW1/4 SW1/4, 21	3N	20W	N34°19'41"	W118°58'37"	A. M. Sarna-Wojcicki	Pico-4	N-ASW- 56
23	do.	do.	do.	NE1/4 SW1/4, 20	do.	do.	N34°19'34"	W119°00'00"	do.	Pico-3	do. 54
24	do.	do.	Ventura 7.5'	L.G.	---	---	N34°18'10"	W119°18'15"	do.	Pico-5	do. 57
25	do.	do.	do.	do.	---	---	N34°18'13"	W119°20'48"	do.	Pico-21	do. 67
26	do.	do.	Pitas Point 7.5'	NW1/4 SE1/4, 16	3N	24W	N34°20'20"	W119°23'33"	do.	Pico-18	do. 65
Thin white ash below the Bailey ash, South Mountain											
27	Calif.	Ventura	Santa Paula 7.5'	NE1/4 NW1/4, 27	3N	21W	N34°19'00"	W119°04'24"	A. M. Sarna-Wojcicki	Pico-7	N-ASW- 66
Upper white ash, Manix basin, Mojave Desert											
28	Calif.	San Bernardino	Newberry 15'	NW1/4 SW1/4, 11	10N	4E	N34°58'23"	W116°32'12"	Richard Merriam, J. L. Bischoff	Manix-1	N-ASW- 41
29	do.	do.	do.	do. do.	do.	do.	do.		A. M. Sarna-Wojcicki & others	Manix-5	do. 113
Middle white ash, Manix basin, Mojave Desert (30-33), and ash in Pleistocene lake beds (Waucoba Beds of Hopper, 1947), E. Owens Valley (34)											
30	Calif.	San Bernardino	Newberry 15'	SW1/4 NW1/4, 11	10N	4E	N34°58'26"	W116°32'08"	A. M. Sarna-Wojcicki & others	Manix-4	N-ASW-112
31	do.	do.	do.	do.	do.	do.	do.	do.	Richard Merriam, J. L. Bischoff	Manix-2	do. 42
32	do.	do.	do.	NW1/4 NW1/4, 11	do.	do.	N34°58'44"	W116°32'06"	A. M. Sarna-Wojcicki & others	Manix-7	do. 120
33	do.	do.	do.	SW1/4 SW1/4, 2	do.	do.	N34°58'50"	W116°32'07"	do.	Manix-8	do. 121
34	do.	Inyo	Waucoba Mt. 15'	Section 18(?)	9S	34E	N37°10'	W118°12'	D. E. Marchand	W3A	do. 76

Table 4. Specific locality information--Continued

Sample number	State	County	Quadrangle	Quarter and Section	Township	Range	Lat (n)	Long(w)	Collector(s)	Field Number	Lab. Number
Ash from core in lake beds of Searles Valley											
35	Calif.	San Bernardino	Searles Lake 7.5'	Corner of 22, 23, 26, & 27	25S	43E	N35°44'15"	W117°19'30"	G. I. Smith	KM3A	N-ASW-126
Unwelded, pumiceous ash flow tuff in the Coso area											
36	Calif.	Inyo	Haiwee Reservoir 15'	NE1/4 NW1/4, 13	19S	37E	N36°11'55"	W117°55'17"	W. A. Duffield, C. R. Bacon	9-85-2A	
Uppermost ash (ash A), Tecopa area (37, 38), and Lava Creek B ash bed (Pearlette-type O ash bed), Grand Co., Utah (39)											
37	Calif.	Inyo	Shoshone 15'	NW1/4 NW1/4, 31	21N	6E	N35°58'16"	W116°16'28"	A. M. Sarna-Wojcicki, J. W. Hillhouse	Teco-3	N-ASW-181
38	do.	do.	do.	do. do.	do.	do.	do.	do.	do.	Teco-4	do. 182
39	Utah	Grand	Polar Mesa 15'	SE1/4 NE1/4, 26	24S	24E	N38°41'25"	W109°14'11"	R. E. Wilcox	67W104	do. 150
Mesa Falls ash bed (Pearlette-type S ash bed), Harlan County, Nebraska											
40	Nebr.	Harlan	Stamford 7.5'	SW1/4 NW1/4, 12	2N	2W	N40°09'19"	W99°32'30"	R. E. Wilcox	66W4	N-ASW-147
	do.	do.	do.	do.	do.	do.	do.	do.	do.	do.	do. 148
Lower gray ash, Manix basin (41) and Huckleberry Ridge ash bed (Pearlette type B ash bed), Borchers locality, Meade County, Kansas, (42)											
41	Calif.	San Bernardino	Newberry 15'	NW1/4 NW1/4, 11	10N	4E	N34°58'44"	W116°32'06"	A. M. Sarna-Wojcicki & others	Manix-6	N-ASW-114
42	Kansas	Meade	Irish Flats NE 7.5'	NW1/4 NE1/4, 21	33S	28W	N37°10'08"	W100°22'08"	R. E. Wilcox	68W98	do. 151
Huckleberry Ridge(?) ash bed; lowermost ash, South Mountain area (43), and ash (ash C), Tecopa area (44, 45)											
43	Calif.	Ventura	Santa Paula 7.5'	N1/2, 28	3N	21W	N34°18'50"	W119°05'13"	A. M. Sarna-Wojcicki	ASW-3-23 -75-1	N-ASW- 70
44	do.	Inyo	Tecopa 15'	SE1/4 SE1/4, 23	21N	7E	N35°54'	W116°11'	M. O. Woodburne	1; Teco-1	do. 73
45	do.	do.	do.	NE1/4 SE1/4, 23	do.	do.	do.	do.	do.	2; Teco-2	do. 74
Air-fall pumice of the Coso area											
46	Calif.	Inyo	Haiwee Reservoir 15'	SE1/4 NE1/4, 35	21S	38E	N36°03'57"	W117°50'22"	W. A. Duffield, C. R. Bacon	13-42-5	N-ASW-118
47	do.	do.	do.	do.	do.	do.	do.	do.	do.	13-42-4	do. 119
48	do.	do.	do.	NE1/4 NE1/4, 23	21S	38E	N36°05'58"	W117°50'04"	do.	9-8-11; Coso-1	do. 122
	do.	do.	do.	do. do.	do.	do.	do.	do.	do.	do.	123
Ash in Searles Valley											
49	Calif.	San Bernardino	Searles Lake 15'	N.R.[3]	---	---	N35°33'19"	W117°17'41"	G. I. Smith	AXL-30K-160-5	N-ASW-176
Pumice overlying Cahuilla beds, Salton trough											
50	Calif.	Imperial	Durmid 7.5'	SE1/4 NE1/4, 24	9S	11E	N33°22'50"	W115°46'05"	A. M. Sarna-Wojcicki	Salton-7	N-ASW- 72
Samples of Lava Creek B ash bed analyzed by energy-dispersive X-ray fluorescence only											
51	Calif.	San Bernardino	Searles Lake 15'	N.R.[3]	28S	43E	N35°31'12"	W117°22'56"	G. I. Smith	2V-198-4	---
52	do.	Ventura	Saticoy 7.5'	L.G.[4]	3N	22W	N34°17'54"	W119°13'44"	A. M. Sarna-Wojcicki	P-133	---
53	do.	Kern	Pond 7.5'	ND[4]	25S	25W	N35°40'	W119°20'	Paul Davis, James Smith	P5-23	---

[1]Land grant,
[2]National Forest, and
[3]Naval Reserve: no township and range coordinates on available maps.
[4]Not determined.

FRIANT PUMICE MEMBER (OF THE TURLOCK LAKE FORMATION)

Ash and pumice are exposed in quarries near the town of Friant in east-central San Joaquin Valley, about 110 km west-southwest of the Long Valley caldera. According to Janda (1965, p. 110),

> the pumiceous alluvium in the quarries of the California Industrial Minerals Company*** lies near the base of the alluvium deposited during the youngest aggradational cycle of the Turlock Lake Formation. In these quarries, 60 feet [18 m] of rhyolitic ash and pumice rest on a weathered surface that has 25 feet [8 m] of relief developed on sand and silt of an older part of this alluvial unit. The lower 10 to 30 feet [3 to 9 m] of the rhyolitic material consists of flat-lying, remarkably even beds of fine ash 1 to 30 mm thick. The rhyolitic alluvium is progressively coarser, more impure, and thicker-bedded upward in the section. Large scale fluviatile cross-bedding is present. The upper 30 feet [9 m] of the deposit commonly contains light-gray to grayish-pink pumice pebbles 25 to 50 mm in diameter.

Sample 1 (figs. 1, 2; table 1) is from pumice pebbles picked from the coarser, upper part of the gravelly alluvium (R. J. Janda, oral commun., 1972). Sample 2, a fine ash, is from a Bureau of Reclamation borehole some 120 km to the south, near the town of Alpaugh. At this locality, the ash is interbedded with lacustrine clays of the Corcoran Clay Member. Although the Turlock Lake Formation overlies the Corcoran Clay Member in the Friant area, the Turlock Lake Formation probably grades laterally into the Corcoran Clay Member to the south, in the vicinity of Alpaugh, because the tephra at these two localities is essentially identical. The similarity coefficient comparing samples 1 and 2 is 0.98 (fig. 4).

The age of the Friant Pumice Member is about 0.62 ± 0.02 m.y.[2], as determined by K-Ar analysis of sanidine separated from pumice cobbles at the quarry locality (Janda, 1965). As discussed below, pumice and associated ash of the Friant Pumice Member is chemically and petrographically very similar to the Bishop Tuff, dated at about 0.73 m.y. (Dalrymple and others, 1965). An Irvingtonian vertebrate fauna is found stratigraphically below the Friant Pumice Member (Janda, 1965; J. Firby-Durham, oral commun., 1974).

Other sites where ash chemically similar to that of the Friant Pumice Member has been found are:

(1) In the Salton trough, where it is interbedded in a 2-m-thick composite ash bed in the highly deformed lacustrine Borrego Formation of Tarbet and Holman (1944) east of the Salton Sea, adjacent to the San Andreas fault (samples 6 and 7; figs. 1, 2; table 1).

(2) In the Anza-Borrego area of the southern Peninsular Range, west of the Salton trough, where it is interbedded with fluvial sand, gravel, and lacustrine silt and clay of the Bautista Beds of Frick (1921) (sample 5; figs. 1, 2; table 1; R. V. Sharp, written commun., 1978).

(3) Near the town of Ventura in the western Transverse Ranges, in deformed, well-bedded marine silts and clays of the Santa Barbara Formation (samples 3, 4; figs. 1, 2; table 1). According to Natland (1952), the stratigraphic interval within which this ash bed is situated is close to the boundary between the Hallian and Wheelerian foraminiferal stages.

Similarity coefficients for the seven samples belonging to this chemical type (samples 1-7) range from 0.93 to 0.98, and average 0.96 ± 0.01 (fig. 4). Sample 7 appears to be transitional between the Friant Pumice Member (samples 1-6) and the Bishop ash, IAQ type (samples 8-12; see below). The average similarity coefficient (fig. 4) between sample 7 and the average of samples of the Friant Pumice Member is only slightly higher (0.96 ± 0.01) than between this sample and the Bishop ash, IAQ type (0.95 ± 0.01).

BISHOP ASH AT THE INSULATING AGGREGATES QUARRY (BISHOP ASH, IAQ TYPE)

Sample 8 (figs. 1, 2; table 1) is taken from a 4.6-m section of air-fall pumice lapilli ash that underlies the Bishop Tuff at the southeast margin of the volcanic tableland formed by the tuff, about 11 km north of the town of Bishop. The ash sample was taken about 1 m below the contact with the overlying unwelded phase of the ash-flow tuff. Dalrymple and others (1965) dated samples obtained from this locality, using sanidine separated from pumice lapilli. Ages of 0.76 ± 0.07 and 0.77 ± 0.08 m.y. were obtained by the K-Ar method on samples from this locality, with an average of 0.73 m.y. for all dated samples of the Bishop Tuff (Dalrymple and others, 1965). Tephra of this chemical type is also found at the following localities:

(1) In lake beds of Pleistocene Lake Tecopa in southeastern California (sample 9; figs. 1, 2; table 1; this ash is equivalent to ash B of Sheppard and Gude, 1968; also see Izett and others, 1970; Hildreth, 1979). At this locality, the ash (sample 9) is situated between 4 and 8 m below the Lava Creek B ash bed (samples 37, 38; figs. 1, 2; table 1).

(2) In deformed Pleistocene alluvium exposed at Chaney Hill, along the Elsinore fault zone in the Peninsular Range of southern California (sample 10; figs. 1, 2; table 1; M. P. Kennedy, written commun., 1976).

(3) In alluvium of the Bautista Beds of Frick (1921) (R. V. Sharp, written commun., 1979) of the Anza-Borrego area of the southeastern Peninsular Range, west of

[2]Janda (1965) cites a K-Ar age of 0.60 ± 0.02 m.y. for this pumice unit based on written communication with Dalrymple in 1963. We have multiplied this age by 1.0268 to correct for the new I.U.G.S. decay constants (Mankinen and Dalrymple, 1979), and all subsequent K-Ar ages cited in this report are corrected. Dalrymple (1980) cites two K-Ar ages (corrected) for the Friant Pumice Member: 0.618 ± 0.031 and 0.612 ± 0.031 m.y., both from sanidine separates.

the Salton trough (sample 11; figs. 1, 2; table 1).

(4) In the previously mentioned 2-m-thick bed in deformed lacustrine beds of the Borrego Formation in the Salton trough east of the Salton Sea, immediately west of the San Andreas fault (sample 12; figs. 1, 2; table 1). This ash underlies ash matched chemically with the Friant Pumice Member, samples 6 and 7, by, 1.32 and 1.17 m, respectively.

Similarity coefficients for Bishop ash of this chemical type (samples 8-12) range from 0.95 to 0.98 and average 0.97 ± 0.01 (fig. 4).

BISHOP ASH AT OWENS RIVER GORGE AND AT RED'S MEADOW (BISHOP ASH, ORG TYPE)

Fine- to medium-grained air-fall ash is exposed beneath unwelded ash-flow tuff of the Bishop Tuff in the west wall of the Owens River Gorge north of the town of Bishop in the Casa Diablo quadrangle (sample 13; figs. 1, 2; table 1; Hildreth, 1979) and at Red's Meadow, in the Devil's Postpile quadrangle, within the headwaters of the San Joaquin River drainage basin in east-central Sierra Nevada (sample 14; figs. 1, 2; table 1; R. J. Janda, oral commun., 1972). Air-fall pumice from this locality has been dated at 0.68 ± 0.02 m.y. by the K-Ar method (Huber and Rinehart, 1967).

This chemical type is present at two additional localities:

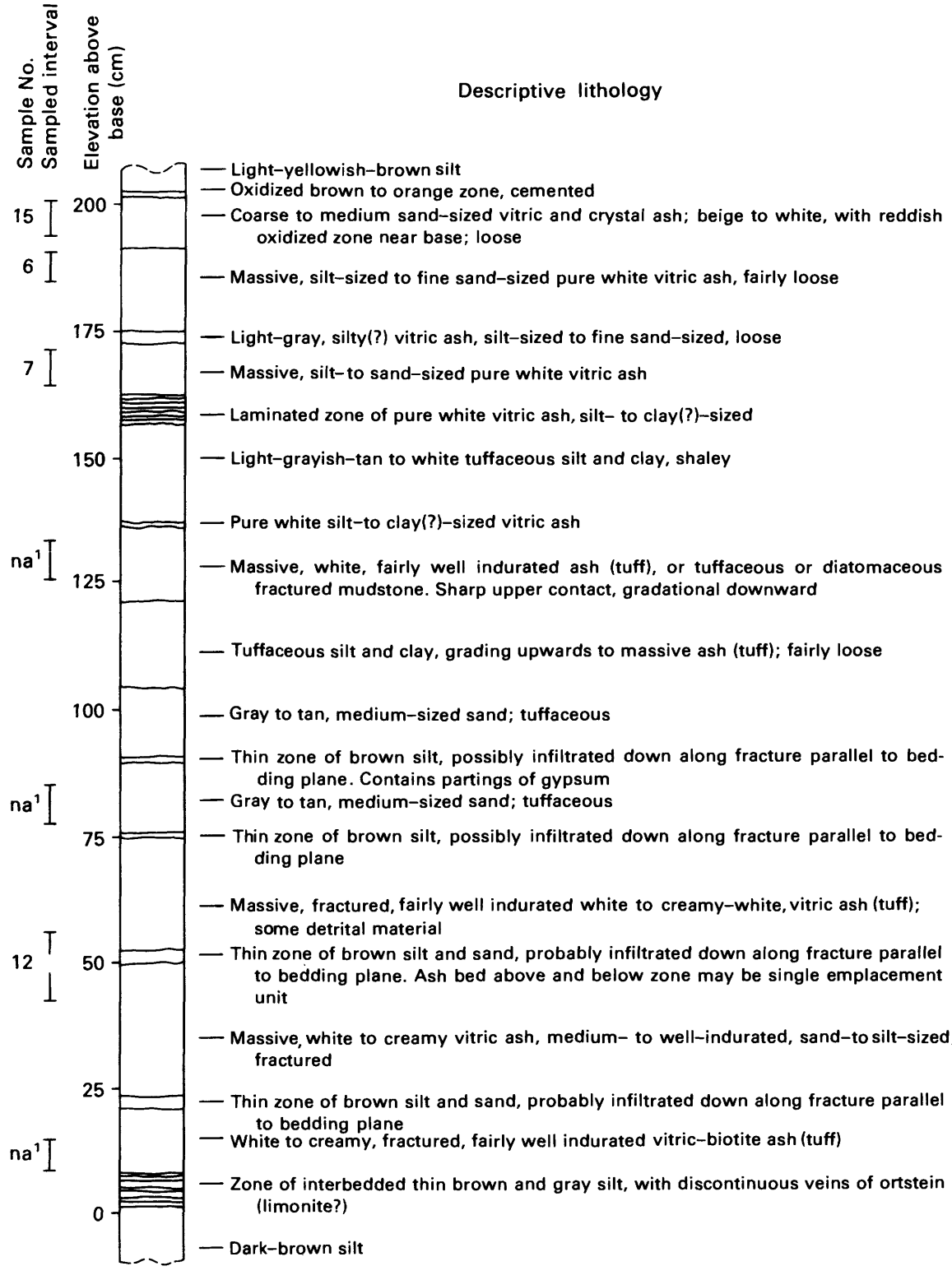
(1) At the previously mentioned locality in the Borrego Formation east of the Salton Sea (sample 15; fig. 1; table 1), where it overlies ash of the Friant Pumice Member, samples 6 and 7, by about 1 and 23 cm, respectively (figs. 2, 7).

(2) At Onion Creek, Grand County, Utah (sample 16; figs. 1, 2; table 1), where this ash again underlies the Lava Creek B ash bed (formerly called the Pearlette type O ash bed; sample 39; figs. 1, 2; table 1; Izett and others, 1972; G. A. Izett, written commun., 1978).

Similarity coefficients for Bishop ash of this chemical type range from 0.96 to 0.98 and average 0.97 ± 0.01 (fig. 4). Individual similarity coefficients among the three chemical types of the Bishop ash-bed group range from 0.85 to 0.97. Average coefficients among the three types are 0.88 ± 0.02 between the Friant Pumice Member and Bishop ash (ORG type), 0.93 ± 0.02 between the Friant Pumice Member and Bishop ash (IAQ type), and 0.94 ± 0.01 between the two latter Bishop ash types (fig. 4).

AGE AND STRATIGRAPHIC RELATIONS OF THE BISHOP ASH BED AND THE FRIANT PUMICE MEMBER (OF THE TURLOCK LAKE FORMATION)

The three chemical types composing the informally named Bishop ash-bed group are chemically very similar and were considered to be members of a single eruptive episode of short duration (Sarna-Wojcicki and others, 1980). The evidence for this assignment, however, is not entirely convincing, particularly in light of new stratigraphic and chemical data, as well as previous isotopic ages. Sarna-Wojcicki and others (1980) correlated the Friant Pumice Member at its type locality near Friant (Janda, 1965; sample 1), as well as at several other distal localities in southern California, with the Bishop ash bed for the following reasons: (1) Ash chemically matching the Friant Pumice Member at its type locality (sample 1, obtained from R. J. Janda, 1972) was found in a composite 2-m-thick ash bed in the Borrego Formation east of the Salton Sea (sample 6), interbedded with ash chemically matching the Bishop ash. The ash layer from which sample 6 was obtained overlies ash correlated with the Bishop ash (IAQ type; sample 12) by about 140 cm and underlies ash correlated with the Bishop ash (ORG type; sample 15) by about 5 cm (fig. 7). Thus, ash at the locality east of the Salton Sea, chemically correlated with the Friant Pumice Member, is sandwiched in between two ash layers correlated with Bishop ash on the basis of glass chemistry. Although the composite ash bed exposed east of the Salton Sea contains thin interbeds of tuffaceous silt and clay between some of the ash layers, the total time required for its deposition was probably not as long as the 0.1 m.y. represented by the difference in isotopic ages of the Friant Pumice Member and the Bishop Tuff. Although there is a possibility that the stratigraphic order of these ashes was reversed owing to local reworking within the depositional basin of the Salton trough, such reworking would probably take place within a short time after deposition. (2) Ash chemically matching the Friant Pumice Member (sample 1) at its type locality is found in the marine Santa Barbara Formation of the Ventura area (samples 3, 4), 530 m stratigraphically below ash identified as the Lava Creek B ash bed (see above). Because the age of the Lava Creek B ash bed is about 0.6 m.y. B.P. (Christiansen and Blank, 1972; Naeser and others, 1973), it seems improbable that an ash 530 m lower in the section would be about the same age as well. Estimates of sedimentation rates in the Ventura basin based on all available age control range from about 2.5 to 5.0 m/1,000 yr over the period from about 2.0 to 0.2 m.y. B.P. If the difference in ages between the Lava Creek B and Friant ashes in the Ventura area is indeed only about 0.02 m.y. (0.62 m.y., the K-Ar age of the Friant Pumice Member minus 0.60 m.y., the isotopic age of the Lava Creek B ash bed), then the sedimentation rate for the interval between these two ashes would have been an uncharacteristic 27 m/1,000 yr. The nature of the beds within this interval—well-bedded silt, clay, and mudstone, with



[1]Sample not analyzed, January 1, 1979

FIGURE 7.—Generalized stratigraphic section of composite ash bed in the Borrego Formation of Tarbet and Holman (1944) east of the Salton Sea.

only minor sand and gravel near the top—does not suggest that any such radical acceleration of sedimentation rates occurred.

We have not observed, nor seen any reference to, a widespread ash of Long Valley-Glass Mountain provenance that overlies the Bishop ash or Bishop Tuff with obvious stratigraphic separation that would represent an age difference of about 0.1 m.y., with the exception of the thin white ash layer found within the compound Lava Creek B ash bed in the lake beds of Pleistocene Lake Tecopa (see above). Bailey and others (1976) report no widespread, major post-caldera tephra eruption from the Long Valley caldera after the eruption of the Bishop Tuff. According to their isotopic age data, there is a period of inactivity between the early post-caldera rhyolites (about 0.73 to 0.65 m.y.) and the early moat rhyolites (about 0.52 to 0.48 m.y.). Moreover, it does not seem reasonable that one of the greatest climactic eruptions of Quaternary time, that of the Bishop Tuff, would not leave any trace of its products in the lower parts of a closely adjacent drainage basin (the ancestral upper San Joaquin River), while an eruption 100,000 years later (presumably that of the Friant Pumice Member) would deposit large volumes of pumice and ash within this basin, but not anywhere else nearby—particularly not within its probable source area. It would make much more sense if the Friant Pumice Member and the Bishop Tuff were part of the same eruptive sequence and about the same age. Lastly, if the ash and pumice at Friant represent only local reworking of an 0.6-m.y. tephra layer down the ancestral San Joaquin River, then we cannot explain the presence of chemically identical tephra at other locations in southern California (samples 3-7; figs. 1 and 2) in close association with the Bishop ash, unless there have been two or more separate eruptions of tephra of essentially identical composition, separated by over 100,000 years.

To compound the problem, if the age of the Friant Pumice Member is in fact about 0.6 m.y., it is difficult to understand why ash of a chemical composition identical to that of the Friant Pumice Member has not been found near the source area overlying the Bishop Tuff, at the Owens River Gorge locality, the Insulating Aggregates quarry, or at Red's Meadow. Alternatively, if the Friant Pumice Member is approximately coeval with the Bishop Tuff, why have we not found a chemically matching type in the proximal exposures of the Bishop Tuff? Perhaps this absence can be attributed to inadequate sampling at proximal localities—not all of the major lobes of the Bishop Tuff have been adequately sampled. Only at the distal Salton trough locality (samples 6, 7, 12, and 15) do we appear to have a complete compositional spectrum of the Bishop ash-bed group that includes the Friant Pumice Member.

With respect to the differences in isotopic ages of the Friant Pumice Member and the Bishop Tuff, two nearly identical K-Ar analyses of 0.61 and 0.62 m.y. (Dalrymple, 1980) were determined on sanidine separated from pumice pebbles of the Friant Pumice Member. K-Ar ages of the Bishop Tuff, by contrast, range from 0.66 to 0.77 m.y., with an associated error of about 0.07 to 0.08[3] for individual analyses (0.66 ± 0.07, 0.71 ± 0.06, 0.74 ± 0.07, 0.75 ± 0.07, 0.76 ± 0.07, and 0.77 ± 0.08 m.y.) (Dalrymple and others, 1965). In addition, an age of 0.68 ± 0.04 m.y. was obtained on ash-fall pumice underlying ash-flow tuff at Red's Meadow (Huber and Rinehart, 1967; Dalrymple, 1980). Within the error of K-Ar analyses, the age of the Friant Pumice Member is not significantly different from the age of the ash at Red's Meadow and the younger individual ages of the Bishop Tuff but is different from the average calculated age of the Bishop Tuff, 0.73 m.y., and its associated error of ± 0.04, one standard deviation away from the mean of the six individual determinations. The average ages of the Friant Pumice Member and the Bishop Tuff are not significantly different at two standard deviations from the mean (see Dalrymple, 1980, for a further discussion of the isotopic ages of the Friant Pumice Member and the Bishop Tuff).

The disparity in K-Ar ages of about 0.1 m.y. between the Friant Pumice Member and the Bishop Tuff may be due wholly or in part to reasons other than differences in the true ages of these units. Dalrymple and others (1965) have shown that certain early K-Ar analyses of samples containing xenolithic contamination have resulted in spuriously old ages for the Bishop Tuff, probably due to incomplete degassing of these accidental inclusions. Recent mineralogical work (P. C. Russell, A. M. Sarna-Wojcicki, unpub. data, 1983) on cleaned pumice lapilli separated from the Bishop ash collected at the south end of the volcanic tableland north of the town of Bishop indicates the presence of xenocrystic minerals within the lapilli. Heavy mineral separates from crushed, ultrasonically cleaned lapilli indicate the presence of epidote, sphene, clear mica (muscovite?), blue, light-green, and clear (metamorphic?) amphibole, and brown to green (plutonic?) hornblende—minerals that could not have crystallized from the parent magma of the Bishop ash (table 5; Hildreth, 1979). These minerals do not have glass coatings or jackets, with the rare exception of an occasional green hornblende. Fitch and others (1978) have reported older zircon crystals within cores of pumice clasts obtained from the KBS tuff in east Africa. These crystals must have been incorporated into the pumice before "consolidation of the lava froth," because no connecting vesicles were present in the

[3]Estimate of the precision of the analysis at the 95-percent confidence level.

clasts. The absence of glass jackets on most of the suspected xenocrysts in the Bishop ash is puzzling and argues for detrital rather than xenocrystic contamination. Alternatively, perhaps glass adheres only to those crystals that are thermally equilibrated with the magma and spalls from xenocrysts that are colder. These observations, considered together, suggest that the Bishop Tuff may be even younger than the weighted mean age of 0.73 m.y. Apparently, it cannot be much younger in view of the age of the post-Bishop Tuff early rhyolites (Bailey and others, 1976), if the K-Ar analyses on these flows reflect their true ages. Significantly, even among these flows there may be some contamination, because the oldest age obtained on these rhyolites is 0.75 m.y., and they clearly postdate the Bishop Tuff on the basis of field criteria (Bailey and others, 1976).

In summary, the uncertainty regarding the true ages and correlation of the Friant Pumice Member and the Bishop ash bed remains unresolved. This uncertainty may be resolved by further sampling and analyses—in particular, the mineralogy and chemistry of the pumice relative to the fine ash underlying it at Friant needs to be further investigated. We are hampered to some extent by an incompatible data base; many of the recent glass analyses are by rapid, but not entirely diagnostic, energy-dispersive X-ray fluorescence. Much of the earlier data base, as well as some of the continuing analytical work, is by the slower and more expensive but more definitive neutron-activation analysis. For the present, the preponderance of evidence, chemical as well as stratigraphic, suggests that what we have identified as distal ash layers of the Friant Pumice Member (samples 3, 4, 6, 7) should be essentially coeval with the Bishop Tuff. The possibility exists that tephra of the Friant Pumice Member at its type locality was erupted later than the Bishop Tuff, from some as yet undiscovered vent, perhaps in the upper reaches of the San Joaquin River basin (R. A. Bailey and N. K. Huber, written commun., 1979). If this is the case, and the true ages of these units (as suggested by Dalrymple, 1980) are indeed significantly different, then the correlation between the Friant Pumice Member and the distal ash layers (samples 2-7) proposed here would have to be considered spurious and coincidental; such a conclusion would also imply that tephras from two eruptions, separated in time by as much as about 0.1 m.y., have essentially the same chemical composition. Thus, for the present, correlation of distal ash layers (other than those of samples 3, 4, 6, 7) with the Friant Pumice Member by the chemical methods employed here entails an age uncertainty of about 0.1 m.y.

Correlations of the Bishop ash-bed group presented here confirm several correlations made by Merriam and Bischoff (1975) of the Bishop Tuff. Their ash sampling localities 1, 3, 4, and 6 are at or close to corresponding sample localities 6, 5, 11, and 10 of this study (figs. 1, 2; table 1), all of which have been correlated here with the Bishop ash-bed group (Friant Pumice Member and the Bishop ash, IAQ type). However, their samples 8, 9A, 9B, 10A, and 10B, collected from the Manix basin, and corresponding to our samples 28 through 34 (fig. 1; table 1), are not part of the Bishop ash-bed group, as can be seen from the large differences in a number of trace and minor elements (figs. 3, 4, 5). Ashes of the Manix basin are considerably older than the Bishop ash (see below). The wavelength-dispersive X-ray fluorescence rapid scan technique for rubidium, strontium, and zirconium used by Merriam and Bischoff (1975) is not sufficiently precise to resolve the small compositional differences that can be determined in tephra of the Long Valley-Glass Mountain family by neutron-activation or more precise energy- or wavelength-dispersive X-ray fluorescence analyses. We suggest that the rapid-scan technique should be used only for local correlation problems where contrasts in chemical composition of tephra layers are high, or for initial feasibility studies.

GLASS MOUNTAIN–D ASH BED

Several lenticular beds, 5 to 15 cm thick, of fine- to medium-grained water-deposited white vitric ash occur within a 2- to 2.5-m-thick zone of tuffaceous lacustrine sediment at the south end of the volcanic tableland, about 6.5 km north of the town of Bishop (samples 17, 17a-17c; figs. 1, 2; table 1). The ash underlies unwelded ash-flow tuff of the Bishop Tuff by about 17 m. The actual position of the Bishop ash in this section has not been located; it is either absent or covered by thick talus at the base of the Bishop Tuff, exposed in the upper half of the slope. The informally named Glass Mountain-D ash bed is situated 14 m below a magnetic reversal believed to be the Brunhes-Matuyama boundary (J. C. Liddicoat, written commun., 1978). This compound depositional or eruptive unit is referred to informally as the Glass Mountain-D ash bed because it contains small, angular accidental fragments of black obsidian believed to be derived from the obsidian of Glass Mountain, about 28 km to the north of the sampling locality. G. A. Izett (oral commun., 1978) has dated these obsidian fragments by the fission-track method, obtaining an age of 0.9 m.y. This age agrees with the 0.9-m.y. age of obsidian at Glass Mountain, dated by the K-Ar method by Gilbert and others (1968). Izett (1981), however, correlates this ash with the tuff of Taylor Canyon (Krauskopf and Bateman, 1977) on the basis of glass chemistry and field characteristics; he has dated the latter at 1.0 m.y.

Table 5. Mineral abundances in tephra samples

[Figures given represent line count of heavy mineral separates (2.85 specific gravity, unless otherwise noted) from the magnetic fraction (+ 0.6 amps). Size fraction used was 100-200 mesh (0.14-0.08 mm). P - present but not counted.]

Sample number	Biotite	Gr.-Br. Hblde	Br. Hblde	Clino-pyroxene	Hyper-sthene	Allanite	Zircon	Ilmenite	Sphene	Epidote group	Tremolite-actinolite	Bl.-Gr. Hblde	Clear mica	Oxy-hblde	Apatite	Opaque (unident.)	Other
1[1]	250	9	---	1?	2	---	---	---	---	---	---	---	---	---	---	---	---
1a[2]	272	82	1	1	12	6	6	---	---	8	---	---	---	4	---	178	---
2	6	30	7[3]	27	3	1?	1	---	3	22	7	---	5	---	1	12	5
3	23	72	---	8	---	---	12	---	29	163	3	---	5	3	1	118	2
6	301	---	---	---	P	P	---	---	---	2?	---	---	---	---	---	---	---
8[4]	3	48	---	5	---	126	35	50	4?	38	---	---	---	---	---	191	3
8a[5]	145	83	---	4	---	17	11	4	---	19	3	---	18	---	---	12	16
8b[6]	11	117	2	11	2	86	24	---	---	86	4	---	---	---	---	57	2
12	552	---	---	---	---	---	---	---	---	---	---	---	26	---	---	---	16
19	131	140	---	1	1	1	1	---	1	9	4	---	---	---	---	6	---
21	---	4	---	3	---	---	2	---	18	28	1	---	15	---	---	8	---
22	243	15	---	1	---	---	1	---	---	5	---	---	3	---	---	7	---
23	210	35	2	4	1	---	3	---	---	5	3	---	3	1	---	29	8
24	290	7	2	3	---	---	3	---	2	9	---	---	---	2	---	8	6
27	24	228	2	3	1	---	1	2	15	28	---	---	---	2	2	33	---
35	603	2	---	---	---	---	P	---	---	---	---	---	---	---	---	1	---
36	512	---	---	---	---	---	2	2	15	---	2	---	---	---	---	8	3
41	---	56	1	80	1[3]	38[3]	57[3]	135[3]	13	38	---	---	1	2	5	538	12
43	153	---	5	2	---	P[3]	P	2	---	30	3	48	31	1	---	9	5
45	---	P	---	P	---	P	P[3?]	P[1]	---	P	---	---	P	P	---	---	---
48	274[3]	396[3]	1	1	5	---	---	---	---	---	---	---	---	---	---	1	---
49	97	69	7	31	28	1?	2	4	6	3	6	---	10	2	---	50	1

[1]Minerals separated from pumice pebbles only, with specific gravity <2.85.
[2]Minerals separated from fine ash underlying unit which contains pumice pebbles; specific gravity <2.85.
[3]Mineral grains with adhering glass.
[4]Minerals separated from pumice lapilli only, with specific gravity <2.85.
[5]Minerals separated from pumice lapilli only, with specific gravity <2.65.
[6]Minerals separated from total sample, including matrix and pumice lapilli, with specific gravity <2.85.

by the K-Ar method. Because the obsidian fragments in this ash appear to be accidental rather than cogenetic, we believe they define a maximum age for this ash. This observation is supported in part by the reversely magnetized direction of the ash (J. C. Liddicoat, written commun., 1978). If the ash were 0.90 to 0.97 m.y. in age, it would be normally magnetized, because it would have been deposited during the Jaramillo normal polarity event (Mankinen and Dalrymple, 1979).

Chemical analyses of this ash (samples 17, 17a-17c; table 1) compare well with those of an ash in deep-water marine silt and clay of the Santa Barbara Formation exposed in the Ventura Avenue anticline west of the Ventura River (sample 18; figs. 1, 5; table 1). The ash in the Santa Barbara Formation is 9.5 mm thick, but only the lower 6.5 mm is pure and massive, water-laid, fine air-fall(?) vitric ash. The upper 3 mm is finely laminated tuffaceous clay. The stratigraphic position of this ash below the Bishop ash (correlative with the Friant Pumice Member) at Ventura is inferred from its stratigraphic position above the Glass Mountain-G ash bed and the Bailey ash (see below), and lateral projection into sections where the Bishop ash is locally exposed. Its relative position below the Bishop ash is also deduced from its correlation with the Glass Mountain-D ash bed at Bishop, which underlies the Bishop Tuff. In the Ventura area, the stratigraphic position of the Glass Mountain-D ash bed places it in the Wheelerian microfaunal stage of Natland (1952). Similarity coefficients for the five analyses of this ash from both localities range from 0.96 to 0.98 and average 0.97 ± 0.01 (fig. 4).

The Glass Mountain-D ash bed is similar in composition to the Bishop ash-bed group. Individual similarity coefficients among this ash and the three chemical types of the Bishop ash-bed group range from 0.89 to 0.96, with among-group averages equal to 0.93 ± 0.02, 0.93 ± 0.01, and 0.91 ± 0.01 (fig. 4). Student's two-sample t-tests show that despite several high individual similarity coefficients between the Bishop ash, IAQ type, and the Glass Mountain-D ash bed, these two sample groups are significantly different with respect to lanthanum, cerium, neodymium, samarium, ytterbium, and thorium (table 6).

GLASS MOUNTAIN-G ASH BED

A gray ash (sample 19) about 0.8 m thick underlies the Glass Mountain-D ash bed (sample 17) by about 6 m at the south end of the volcanic tableland (Chalk Bluffs), 6.5 km north of the town of Bishop (figs. 1, 2; table 1). This ash is also a compound depositional (or eruptive?) unit. It is correlated on the basis of its glass chemistry with a gray ash that crops out in the Ventura Avenue

Table 6. Two-sample t-test testing the hypothesis that means of concentrations of selected elements in the glass of the Bishop ash bed, IAQ type (1), and the "Glass Mountain-D ash" (2), are the same, versus the alternative hypothesis that the means are not the same. The null (first) hypothesis is rejected at significance levels (α) shown below

Ash	Element	n	Mean	St. dev.	t	α
1	La	5	19.72	0.67	-9.24	<0.0001
2		5	23.54	0.64		
1	Ce	5	45.92	1.72	-7.53	<0.0001
2		5	54.82	2.01		
1	Nd	5	18.40	1.52	-4.47	0.0029
2		5	23.00	1.73		
1	Sm	5	3.64	0.06	-5.47	0.0055
2		5	4.24	0.24		
1	Yb	5	2.64	0.06	-4.50	<0.0001
2		5	2.80	0.06		
1	Th	5	20.56	0.54	4.23	0.0054
2		5	19.40	0.29		

anticline near the town of Ventura (samples 20, 21, 21a-21d; figs. 1, 2; table 1). Similarity coefficients for this ash range from 0.92 to 0.97, with an average of 0.95 ± 0.02 (fig. 4). The lower average value of the similarity coefficient and the somewhat greater spread of these values indicate that, like the Bishop ash-bed group, the informally named Glass Mountain-G ash bed may also be a compound unit and represent several closely spaced eruptions, although there is not a sufficient number of analyses to determine whether this is the case.

The Glass Mountain-G ash bed in the Ventura area is about 2.5 cm thick, fine, vitric, and generally uniform in thickness. Stratigraphic separation between this ash and the underlying Bailey ash on the south limb of the doubly plunging Ventura Avenue anticline north of the town of Ventura is about 120 m (samples 20, 21). The Glass Mountain-G ash bed is situated within the Wheelerian microfaunal stage of Natland (1952). The age of the ash is unknown, but its paleomagnetic orientation is reversed (J. C. Liddicoat, written commun., 1978). Because this ash underlies the Glass Mountain-D ash bed by only 6 m near Bishop, its age probably lies somewhere between 0.97 m.y., the end of the Jaramillo normal magnetic event, and 1.2 m.y., the age of the Bailey ash. An alternative interpretation is that the age of both the Glass Mountain-D and -G ash beds lies within the reversed polarity period between 0.73 and 0.91 m.y. This seems less likely, because within the Ventura Avenue anticline, the Glass Mountain-G ash bed is situated stratigraphically much closer to the Bailey ash, dated at 1.2 m.y. (see below), than it is to the Bishop ash. Thus, it is more likely that the Glass Mountain-G ash bed was deposited before, while the Glass Mountain-D ash bed was deposited after, the Jaramillo normal polarity event. According to J. C. Liddicoat (written commun., 1979), however, the entire section exposed at Chalk Bluffs near Bishop is reversely magnetized below the Brunhes-Matuyama boundary, including the Glass Mountain-D ash bed and Glass Mountain-G ash bed below it. The Jaramillo event has not been found there, although it may be situated within a sandy interval within this section, or normally magnetized sediments of this age may have been eroded away. Pending further paleomagnetic work and direct age determination by the fission-track method, we tentatively consider the Glass Mountain-G ash bed to be about 1 m.y. old (± 0.1 m.y.). Current work by G. A. Izett and A. M. Sarna-Wojcicki on the tuff of Taylor Canyon (Krauskopf and Bateman, 1977), a thick, compound unit that in its upper part is probably about the same age as Glass Mountain-D and -G ash beds, may shed more light on the ages and correlations of these units.

BAILEY ASH

The informally named Bailey ash (Yeats and others, 1967; Izett and others, 1974) has been recognized to date only within the South Mountain-Balcom Canyon and Ventura areas of coastal southern California (samples 22-26a). Its glass chemistry strongly indicates that it belongs to the Long Valley-Glass Mountain family of ashes erupted from sources east of the central Sierra Nevada (figs. 1, 2, 3; table 1). The Bailey ash may be covered at its inferred source area by younger volcanic rocks, such as the Bishop Tuff or younger alluvium. The Bailey ash is the thickest of nine ashes presently recognized in the Balcom Canyon-South Mountain-Ventura area and consequently represents a sizable eruption. In some exposures, such as the one west of the Ventura River, the ash is about 20 cm thick, but only the lowermost 3 cm is air-fall ash. The lower part consists of creamy to chalky white fine vitric ash (fig. 8). The upper part consists of fine layers and laminae of silty to clayey ash, alternating with partings of silt and clay.

We have mapped the Bailey ash in the Balcom Canyon-South Mountain area, where it is situated wholly within the Pico Formation (as mapped by Weber and others, 1973). To the west, in the foothills north of the town of Ventura, the ash is situated near the contact between the Santa Barbara and the underlying Pico Formations, and we have mapped it both above and below this contact. We have also mapped this ash over a distance of about 23 km, on both the south and north flanks of the Ventura Avenue anticline, and it is a useful stratigraphic marker. No exposures exist between the Ven-

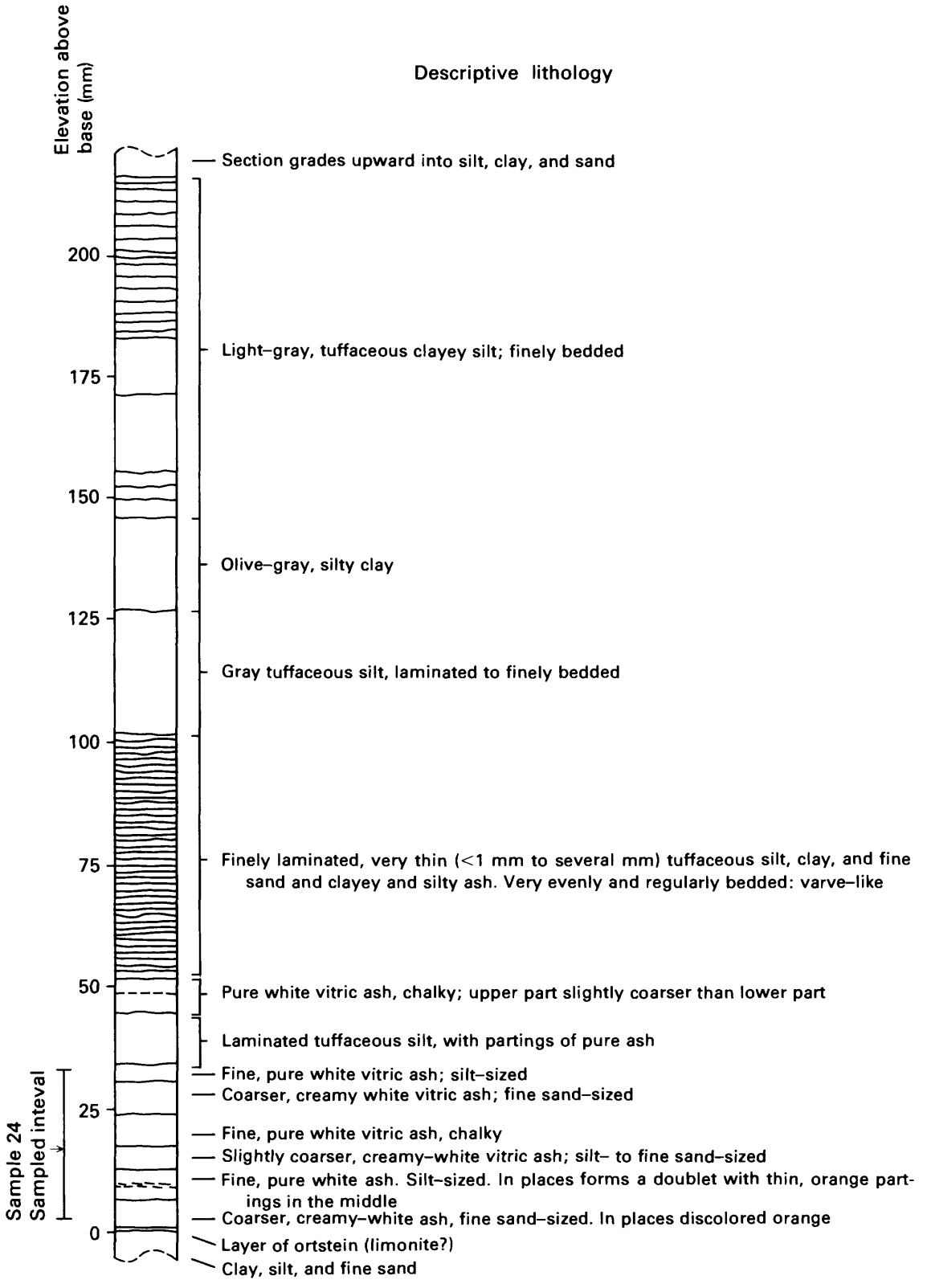


FIGURE 8.—Generalized stratigraphic section of the Bailey ash in the uppermost part of the Pico Formation, Ventura area.

Table 7. Comparison of average compositions of seven samples of the Bailey ash from the South Mountain-Balcom Canyon area with seven samples from the Ventura area

[Similarity coefficient comparing the averages of the two groups is 0.98. Concentrations in parts per million except for iron, which is in percent. Manganese and dysprosium were analyzed from only a few samples in each group.]

	Sc	Mn	Fe	Zn	Rb	Cs	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Hf	Ta	Th	U
South Mountain-Balcom Canyon area (Avg. 7)	2.73	(432)	0.52	31	240	8.2	18.5	43.8	19	4.2	0.05	0.77	(5.14)	3.91	0.55	4.14	3.05	27.2	9.00
s[1]	±0.06		±0.04	±3	±11	±0.4	±1.3	±3.0	±1	±0.2	±0.02	±0.03		±0.13	±0.02	±0.12	±0.13	±0.8	±0.83
Ventura area (Avg. 7)	2.70	(436)	0.53	31	231	8.3	19.2	45.7	20	4.3	0.05	0.80	(5.18)	3.81	0.54	4.16	3.08	26.9	9.22
s	±0.04		±0.02	±3	±7	±0.4	±1.4	±2.5	±1	±0.1	±0.01	±0.03		±0.04	±0.02	±0.04	±0.16	±0.7	±0.60

[1]Sample standard deviation.

tura and Balcom Canyon-South Mountain areas, because the section between these two areas is down-dropped between two antithetical, high-angle reverse faults, the Oak Ridge and the Ventura-Pitas Point faults. The presence of this ash in the intervening area is inferred from subsurface magnetostratigraphic and biostratigraphic data by Blackie and Yeats (1976).

Seven chemical analyses of the Bailey ash from the Balcom Canyon-South Mountain area correlate well with seven analyses of the ash from the Ventura area (table 7). The similarity coefficient comparing averages of the two groups is 0.98 (fig. 4), demonstrating quite convincingly that this ash can be correlated across the intervening structures.

Similarity coefficients for all 14 analyses of this ash range from 0.91 to 0.98 and average 0.95 ± 0.01. If analyses of sample 23a are not included (this analysis, a replicate of sample 23, is suspect; it deviates sharply from the average of the four other replicates, samples 23, 23b, c, and d; fig. 4), the similarity coefficients range from 0.93 to 0.98 and average 0.96 ± 0.01.

The Bailey ash has been dated by both the K-Ar and fission-track methods (fig. 9), but only the latter method appears reliable in view of the fine-grained and water-deposited nature of the ash. Early K-Ar ages (fig. 9) are too old to be consistent with stratigraphic evidence and correlated ages of other ashes, such as the overlying Glass Mountain-G and -D ash beds and the underlying lowermost gray ash (Huckleberry Ridge? ash bed) (see below). The older ages would also be inconsistent with the Wheelerian microfaunal stage assigned to the stratigraphic interval within which this ash is situated (Natland, 1952; Van Eysinga, 1975). According to Izett and others (1974), some of the earlier age analyses are probably too old owing to detrital contamination. The age of 1.2 ± 0.2 m.y. on a sample of this ash collected from the Balcom Canyon locality (our sample locality 22; figs. 1, 2; Izett and others, 1974) and an age of about 1.2 ± 0.3 m.y. obtained by the fission-track method on glass (Boellstorff and Steineck, 1975) are most compatible with other available ages, and stratigraphic and biostratigraphic information.

THIN WHITE ASH BELOW THE BAILEY ASH

A thin fine-grained white vitric ash about 6 mm thick (sample 27; figs. 1, 2; table 1) crops out in silty tuffaceous beds of the Pico Formation where this formation butts against strongly deformed beds of the Modelo Formation, west of South Mountain (the "sea knoll" of Yeats, 1965), about 4.5 km south of the town of Santa Paula. This ash is about 245 m stratigraphically below

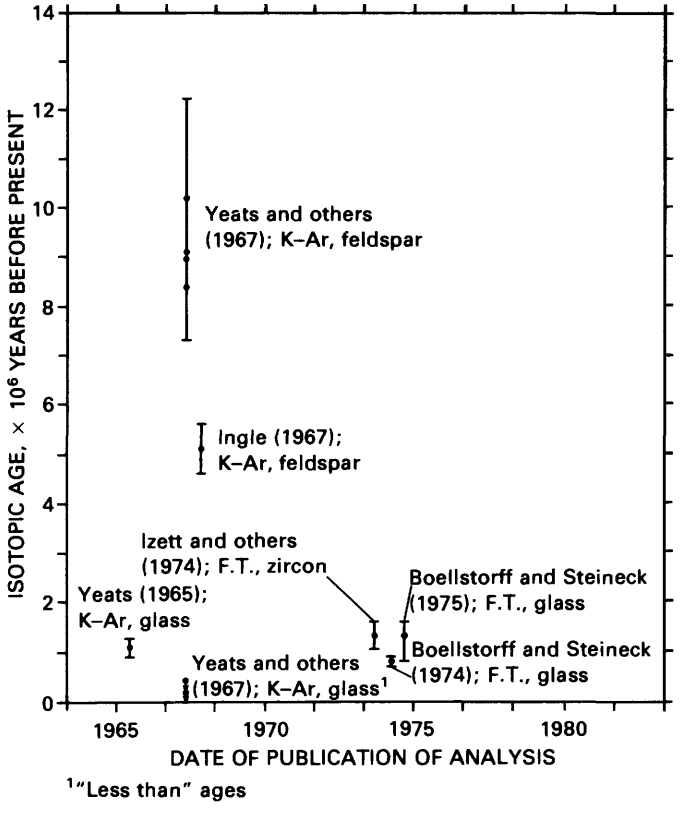


FIGURE 9.—Isotopic ages of the Bailey ash plotted against publication dates of analyses. Analytical methods and material analysed are shown adjacent to each reference. K-Ar, potassium-argon dates; F.T., fission-track dates.

the Bailey ash. It is chemically similar to the Long Valley-Glass Mountain family of ashes and probably represents a minor eruption from that source, although the ash has been found only in the South Mountain area. No direct isotopic age has been determined for this ash, but it must be older than the 1.2-m.y. age of the Bailey ash higher in the section and probably younger than about 2 m.y., an age estimated for the lowermost gray ash (Huckleberry Ridge? ash bed) lower in the section. We can estimate the age of this ash by calculating the average sedimentation rate between the Bishop ash bed (0.7 m.y.) and the Bailey (1.2 m.y.) ash over the 245-m stratigraphic interval that separates them and extrapolate this rate down to the stratigraphic position of the thin white ash. This calculation gives us about 1.5 m.y. for the thin white ash below the Bailey ash. We can also estimate the age of this ash by interpolating between the Bailey ash, above, and the lowermost gray ash, below, again on the basis of stratigraphic position of the three, assuming a 2-m.y. age for the lowermost ash (Huckleberry Ridge? ash bed, see below). Again, we estimate an age of about 1.5 m.y. for the thin white ash below the Bailey ash. Such estimates are subject to considerable error because sedimentation rates most likely have not been constant during these time intervals and also probably differed from site to site within the basin. An independent age estimate made on the basis of systematic compositional trends discussed below gives us an age of about 1.4 m.y.

The thin white ash below the Bailey ash is chemically most similar to the Bailey ash (samples 22 through 26a; average similarity coefficient of 0.86 ± 0.01; fig. 4) and to the upper, white ash in the Manix basin of the Mojave Desert (samples 28, 29; average similarity coefficient of 0.86 ± 0.01; fig. 4).

LOWERMOST GRAY ASH, SOUTH MOUNTAIN AREA (HUCKLEBERRY RIDGE? ASH BED)

A 2.5-cm-thick fine gray vitric ash is interbedded with sand and silt beds of the Pico Formation where they are buttressed against deformed Modelo Formation a few meters above the Pico-Modelo contact, west of South Mountain (sample 43; figs. 1, 2; table 1). This ash is about 670 m below the stratigraphic level of the Bailey ash.

Glass in this ash contrasts sharply with glass in ashes of the Long Valley-Glass Mountain family in chemical composition but is very similar to tephra erupted from the Yellowstone area (Pearlette tephra family). The ash correlates well with a gray 40-cm-thick ash interbedded with lake beds of Pleistocene Lake Tecopa (ash C of Sheppard and Gude, 1968; our samples 44, 44a, and 45; figs. 1, 2; table 1). The similarity coefficient among these samples ranges from 0.96 to 0.98 and averages 0.97 ± 0.01 (fig. 4).

The age of this ash at this locality has not been determined. If we assume a constant sedimentation rate for the stratigraphic interval containing the Bishop, Bailey, and lowermost gray ashes in the Ventura Avenue anticline and South Mountain sections near Ventura, the age of the lowermost gray ash would be 2 to 2.1 m.y. Again, the same cautions apply regarding uniformity of sedimentation rates and variation in rates from site to site in the basin.

The lowermost gray ash in the South Mountain area and its correlative in the Tecopa lake beds are chemically very similar to the Huckleberry Ridge ash bed (formerly the Pearlette type B ash bed), dated at about 1.9 m.y. by the fission-track method (Naeser and others, 1971) and equivalent to the proximal Huckleberry Ridge Tuff in the Yellowstone area of Wyoming, where it has also been dated at 1.9 m.y. by the K-Ar method (Christiansen and Blank, 1972). The lowermost gray ash in the South Mountain area is not similar enough to the Huckleberry Ridge ash bed to be considered correlative on the basis of chemical analyses of glass alone (similarity coefficients of 0.92 to 0.94, with an average of 0.93 ± 0.01; fig. 4). Christiansen and Blank (1972) report, however, that the Huckleberry Ridge Tuff is a composite emplacement unit produced by several eruptions. Perhaps here again we see the effect of multiple eruptions produced by an eruptive episode of short duration, which may account for small chemical differences in distal tephra units. Further work on this problem is currently underway. Identification of two Yellowstone-type ashes in the Ventura-South Mountain area of southwestern California (the Lava Creek B and Huckleberry Ridge? ash beds) marks the first time that these ashes have been found in marine strata, the westernmost exposures of these ashes, and important time horizons for reconciling continental and marine faunal chronologies.

ASHES OF THE MANIX BASIN, MOJAVE DESERT

Four ash beds crop out in pluvial lake beds and deformed older alluvium of the Manix basin in the Mojave Desert, about 40 km east of Barstow. The uppermost ash, in pluvial lake beds, was not analyzed, because glass in the sample was devitrified. Since our study, outcrops of this ash have been found that contain fresh glass, and the ash has been correlated (Izett, 1981) with his Long Canyon ash, K-Ar dated at 0.185 m.y. on tephra near the source area in Long Canyon (Bacon and Duffield, 1981). The three other ashes, interbedded with older fluvial deposits in the basin and separated from the overlying pluvial lake beds by an angular uncon-

formity, had fresh glass and were analyzed. We refer to these ashes as the upper white ash, the middle white ash, and the Huckleberry Ridge ash bed (lowermost gray ash of Manix basin).

UPPER WHITE ASH

A fine white vitric ash about 8 cm thick crops out in low cliffs on the south side of the Mojave River (samples 28, 29; figs. 1, 2; table 1). Only the basal 2 to 2.5 cm is massive pure air-fall(?) ash, the upper part being finely bedded water-laid tephra, probably locally reworked. This ash does not correlate with any other ash analyzed to date. It is most similar to ashes of Long Valley-Glass Mountain provenance and was probably erupted from that volcanic province. Although correlated with the Bishop Tuff on the basis of rapid-scan X-ray fluorescence analysis for rubidium, strontium, and zirconium by Merriam and Bischoff (1975), this ash is chemically different from the Bishop ash-bed group, particularly with respect to scandium, manganese, samarium, hafnium, tantalum, and thorium (table 1). Average similarity coefficients between this ash and the three chemical types of the Bishop ash-bed group are 0.88 ± 0.02, 0.91 ± 0.01, and 0.91 ± 0.01 (fig. 4).

MIDDLE WHITE ASH

A fine white vitric ash about 3 to 4 cm thick (samples 30-33; figs. 1, 2; table 1) underlies the upper white ash by about 12 to 15 m. Pure white ash, about 1.3 cm thick near the base, rests with sharp contact on alluvial silt and sand and grades upward into pinkish tuffaceous silt. The upper 2 to 3 cm consists of well-bedded or laminated water-laid ash. Samples 30 and 31 were collected on the south side of the Mojave River; samples 32 and 33 were collected on the north side, about 0.8 km north of localities 30 and 31. Our chemical analyses correlate this ash over this short distance, across the river. This ash also correlates well with an ash, the second from the top of a sequence of four ashes interbedded with the late Cenozoic lacustrine Waucoba Beds of Hopper (1947) in eastern Owens Valley, about 270 km to the north of the Manix basin (sample 34; figs. 1, 2; table 1). The range of similarity coefficients for ashes of these two localities is from 0.95 to 0.96, with an average of 0.96 ± 0.01 (fig. 4). The range of similarity coefficients for the entire group of five samples is from 0.95 to 0.98, with an average of 0.97 ± 0.01 (fig. 4).

There is no direct isotopic age available for this ash at the Manix basin localities, but a K-Ar age of 2.3 m.y. was obtained on the ash in the Waucoba Beds of Owens Valley (Hay, 1966; our sample locality 34). This age appears to be somewhat too old, because the middle white ash locally overlies the Huckleberry Ridge ash bed in the Manix basin (see below).

Although Merriam and Bischoff (1975) correlated this ash with the Bishop Tuff on the basis of rapid-scan X-ray fluorescence analysis for rubidium, strontium, and zirconium, neutron-activation analyses for trace and minor elements reveal large differences between these tephra units, particularly for scandium, manganese, iron, rubidium, cesium, samarium, terbium, dysprosium, ytterbium, lutecium, hafnium, tantalum, thorium, and uranium (fig. 3; table 1). Average similarity coefficients between the middle white ash and the chemical types of the Bishop ash-bed group are low: 0.62 ± 0.01, 0.65 ± 0.01, and 0.68 ± 0.01. Furthermore, the ash correlates well with an older, late Cenozoic ash in the Waucoba Beds (see above) and is underlain by the Huckleberry Ridge ash bed dated by others at about 2 m.y. (see below).

Despite the large differences in glass chemistry between the middle white ash at Manix basin and the Bishop ash-bed group, the middle white ash belongs to the Long Valley-Glass Mountain family of ashes, as can be seen in gross chemical similarities to other tephra units belonging to this group, as well as in systematic age-related elemental depletion trends that are a characteristic of this tephra family (figs. 3, 5, 10).

HUCKLEBERRY RIDGE ASH BED (LOWERMOST GRAY ASH)

A fine gray vitric ash 3 cm thick (sample 41) underlies the middle white ash (sample 32) by about 2 to 3 m in low hills on the north side of the Mojave River in the Manix basin (figs. 1, 2; table 1). This ash correlates very well on the basis of its glass composition with a sample of the Huckleberry Ridge ash bed (formerly called the Pearlette type B ash bed; sample 42; figs. 1, 2) from the Borchers faunal locality, Meade County, Kansas (table 1; also see Izett and others, 1972). The similarity coefficient between these two samples is 0.97 (fig. 4). Furthermore, the Manix basin gray ash contains crystals of green to brown hornblende, clinopyroxene, allanite, zircon, apatite, ilmenite, and magnetite, minerals typical of the tephra of the Yellowstone family (Izett and others, 1970). These data correlate a single tephra unit over a distance of about 1,500 km between sample localities and over a distance of about 1,200 km between the source area in Yellowstone National Park, Wyoming, and the Manix basin.

The similarity coefficient comparing analyses of the Manix basin gray ash (sample 41) with an analysis of the upper part of the Lava Creek B ash bed at Lake Tecopa (sample 38) is also high (0.95; fig. 4), but not as high as the coefficient comparing the former ash with the Huckleberry Ridge ash bed (0.97; fig. 4). Furthermore,

isotopic age and stratigraphic control (fig. 2) independent of glass chemistry supports correlation of the lower gray ash in the Manix basin with the Huckleberry Ridge ash bed.

The lower gray ash at Manix basin (sample 41), the lower gray ash in the South Mountain area (sample 43), the gray ash (ash C of Sheppard and Gude, 1968) in the Lake Tecopa area (samples 44, 45), and the Huckleberry Ridge ash bed from Kansas (sample 42) may all have been derived from a single eruptive episode of short duration and be equivalent to near-source tephra in the Yellowstone area represented by the compound Huckleberry Ridge Tuff, dated at about 2 m.y. (figs. 1, 2; table 1; Christiansen and Blank, 1972).

OTHER TEPHRA UNITS OF LIMITED AREAL EXTENT OR RECOGNITION

The glass samples from a number of tephra units that have been analyzed in the present study are found at single localities only or are exposed over small areas. These units may have been produced by minor local eruptions, or they may be products of larger eruptions that have not yet been widely recognized. Alternatively, some of these samples may also be tephra whose original composition has been somewhat masked or altered by postdepositional diagenetic processes, but the glass of which is still optically isotropic.

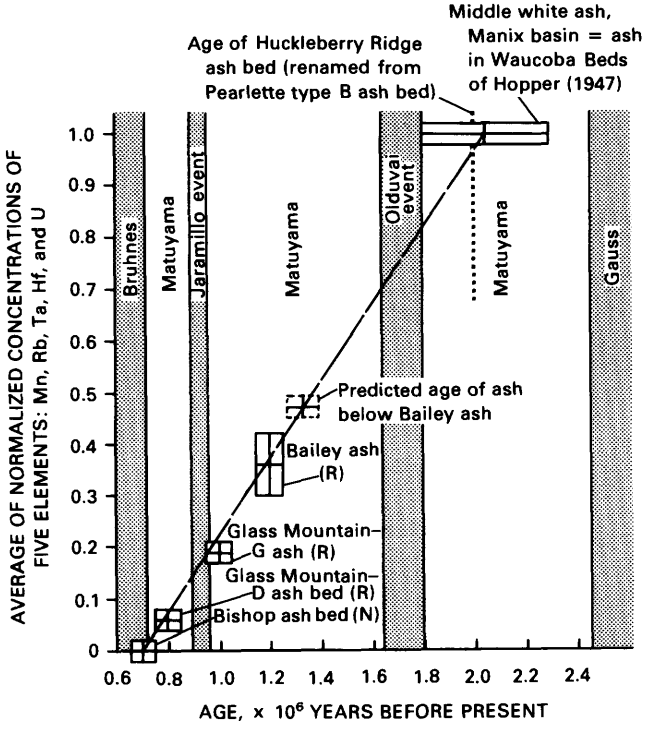


FIGURE 10.—Systematic depletion trends versus time in ash layers of the Long Valley-Glass Mountain tephra family. Average of normalized concentrations of five elements (manganese, rubidium, tantalum, hafnium, and uranium) in glasses of five ash layers are plotted against their ages. The age of a sixth ash layer, the thin white layer below the Bailey ash near South Mountain, is estimated on the basis of its normalized composition and the linear relation between composition and age of this tephra family. N, polarity normal; R, polarity reversed.

ASH IN LATE CENOZOIC LAKE BEDS OF SEARLES VALLEY

A sample of a fine white vitric ash interbedded with upper Pliocene lake beds was obtained from a borehole in Searles Lake (sample 35; figs. 1, 2; table 1; Smith, 1978). This ash does not match well with any other ash we have analyzed, although it is most similar to ashes of the Long Valley-Glass Mountain family (similarity coefficients of 0.65 to 0.95; fig. 4). The ash is most similar to the Glass Mountain-D ash bed (average similarity coefficient of 0.94 ± 0.01; fig. 4), but it is most likely much older than that, probably about 3 m.y., according to stratigraphic and paleomagnetic data (Liddicoat and Smith, 1979). Although glass separated from this ash was optically clear for the most part, there is a possibility that its deposition in a saline lake may have changed its glass chemistry so that it can no longer be matched with unaltered glass of the same tephra unit.

TUFFS OF THE COSO AREA

Glass from an unwelded pumiceous ash-flow collected by W. A. Duffield (oral commun., 1977) in the Coso area east of the southern Sierra Nevada (sample 36; figs. 1, 2) does not correlate with any other analyzed tephra unit on the basis of glass chemistry (fig. 4; table 1), not even with the other analyzed tuffs of the Coso area. This ash has an unusual composition compared to other tephra samples. It has very low concentrations of iron and the rare-earth elements lanthanum, cerium, neodymium, samarium, terbium, dysprosium, ytterbium, and lutecium (table 1). Perhaps this ash also has been affected by postdepositional processes.

Pumice from a distinctive air-fall pyroclastic unit of the Coso volcanic field (Duffield and Bacon, 1977) has been analyzed in this study (samples 46-48 and 48a; figs. 1, 2; table 1). This unit yields a weighted mean K-Ar age of 2.99 ± 0.20 m.y. (Duffield and others, 1980), and 2.98 ± 0.28 and 2.91 ± 0.20 according to fission-track ages determined in this study (table 8). Sample 46 overlies sample 47 at the locality where they were collected, but exact stratigraphic relations of sample 48, from another locality, are unknown. Analyses of samples 48 and 48a were run on coarse-grained and fine-grained glass, respectively, separated from the same sample. These two separates were run to determine the effect of phenocrysts and microlites on glass composition. The

Table 8. Analytical data on fission-track ages of zircon crystals from an ash flow tuff in the Coso area (sample 48)

Analyst	Spontaneous tracks No. Counted	Spontaneous tracks Density[1]	Induced tracks No. Counted	Induced tracks Density[1]	Neutron flux[2]	Age (m.y.)
C. E. Meyer	217	7.1×10^5	2088	1.4×10^7	9.59×10^{14}	2.98±0.28
M. J. Woodward	390	5.3×10^5	3754	1.1×10^7	9.59×10^{14}	2.91±0.20

[1]Tracks per cm^2.
[2]Neutrons per cm^2.

coarser fraction would be expected to contain a higher proportion of compound shards containing phenocrysts and microphenocrysts. As can be seen from table 1, there is very little difference between the two analyses within the limits of analytical precision of the neutron-activation method; consequently there is little or no sampling error in the analyses due to differences in degree of separation of phenocrysts from the glass.

ASH IN SEARLES VALLEY

An ash collected by G. I. Smith (oral commun., 1976; sample 49; figs. 1, 2; table 1) from late Cenozoic lacustrine deposits exposed on the southeast side of Searles Valley does not correlate specifically with any tephra unit analyzed in this study. Glass of this ash is most similar to tephra units erupted from the southern Cascade Range of northern California, specifically the Nomlaki Tuff Member of the Tehama and Tuscan Formations, 3.4 m.y. old (Evernden and others, 1964), the Ishi Tuff Member of the Tuscan Formation, between 2.5 and 3.5 m.y. old (Harwood and others, 1981), and the ash in the Merced Formation, about 0.45 m.y. old (Meyer and others, 1980).

PUMICE OVERLYING THE CAHUILLA BEDS, SALTON TROUGH

Large pumice cobbles up to 20 cm in diameter overlie the informally named Cahuilla beds of the Salton trough. The Cahuilla beds, in turn, overlie the strongly deformed Borrego Formation with marked angular unconformity. The pumice was most likely derived by erosion of young pumice domes of late Pleistocene (Muffler and White, 1969) or Holocene (Friedman and Obradovich, 1981) age situated at the south shore of the Salton Sea; the cobbles then floated northward along the shore. The highest extent of these cobbles probably defines a former high stand of the lake in this area. Glass from one of these cobbles (sample 50; fig. 1; table 1) was analyzed. The chemical composition of this glass is quite distinct from that of the Bishop ash-bed group in the Borrego Formation, especially with respect to iron, rubidium, cesium, the rare-earth elements, and hafnium, indicating that there is no genetic relation between the ashes in the Borrego Formation and the local pumice domes, despite their close geographic proximity. This pumice is also easily distinguished from other tephra families on the basis of its chemical composition (figs. 4, 5; table 1).

PROVINCIAL RELATIONS OF TEPHRA OF THE LONG VALLEY-GLASS MOUNTAIN FAMILY

The Long Valley-Glass Mountain family of tephra is defined on the basis of gross chemical similarities that distinguish these tephra units from tephra of other families. The Bishop ash-bed group, Glass Mountain-D ash bed, and Glass Mountain-G ash bed beneath it were all erupted from sources just east of the central Sierra Nevada, as indicated by thickness and clast-size gradients of these units. Because of chemical similarities (figs. 3, 4, 5), the Bailey ash and the thin white ash below it are also presumed to have been erupted from this general area, although no near-source outcrops of these ashes have been found. The younger, voluminous deposits of the Bishop Tuff and younger deposits in the down-faulted Long Valley caldera and other basins east of the Sierra Nevada may cover near-source correlatives of the older ashes. The upper white ash and middle white ash of the Manix basin and the subsurface ash obtained from lake beds of Searles Valley also belong to this family (figs. 4, 5).

In general, greatest similarity is observed between tephra units of this family that are close in age or stratigraphic position to each other, while greater differences are observed between units that are farther separated in time and space (fig. 3). These relations

suggest that there is a systematic compositional variation in this tephra family that is related to time. Isotopic or relative ages of six of these units (the Bishop ash-bed group, Glass Mountain-D ash bed, Glass Mountain-G ash bed, the Bailey ash, the thin ash beneath the Bailey, and the middle white ash of the Manix basin) are known. These six units show systematic elemental depletion with decreasing time for a number of elements (fig. 3). Five elements, manganese, rubidium, tantalum, hafnium, and uranium, show the most consistent depletion trends with decreasing age (fig. 10). Isotopic ages of three of these ashes, the Bishop, the Bailey, and the ash in the Waucoba Beds (equivalent to the middle white ash of the Manix basin), have been determined, while ages of two others, the Glass Mountain-D ash bed and Glass Mountain-G ash bed, can be fairly closely bracketed at between about 0.8-0.9 and 1.0-1.1 m.y., respectively, from stratigraphic relations to the other ashes and magnetic polarity (fig. 10). As mentioned above, the 2.3-m.y. age of the ash in the Waucoba Beds is considered to be somewhat too old, because this ash closely overlies the 1.9-m.y.-old Huckleberry Ridge ash bed. Normalized values of the five elements plotted against their ages have a nearly linear trend. A straight-line extrapolation of the age-composition trend between the Bishop and the Bailey ashes (fig. 10) would intersect the normalized composition of the middle white ash of the Manix basin (equivalent to the ash in the Waucoba Beds) at about 2 m.y. Using this linear relation, we can estimate the age of the thin ash below the Bailey ash at about 1.4 m.y. (fig. 10). Estimates of the age of this ash based on extrapolation and interpolation between dated ash horizons in the Ventura-South Mountain area, assuming uniform sedimentation rates (see above), both gives similar results of about 1.5 m.y.

Two ashes of this tephra family, the upper white ash of the Manix basin and the ash obtained from the subsurface in Searles Valley, do not appear to fall on this age-composition trend, but isotopic ages have not been determined for them. The upper white ash of the Manix basin (samples 28, 29; figs. 1, 2; table 1) is younger than the middle white ash at that locality and older than the uppermost white ash in pluvial lake beds of the Manix basin. The age of this uppermost ash has not been determined directly, although it has been correlated (Izett, 1981) with a young dome dated from K-Ar at about 185,000 yr B.P. in Long Canyon west of the Coso volcanic field (Bacon and others, 1981). The age of the ash in the subsurface from Searles Lake (sample 35; figs. 1, 2; table 1) is also not known but is estimated to be about 3 m.y. from stratigraphic and paleomagnetic data (Liddicoat and Smith, 1979).

The younger ashes, such as the Bishop ash-bed group and Glass Mountain-D ash bed, are associated with roughly coeval pyroclastic and flow rocks of widely ranging compositions. The ash-flow phases of the Bishop Tuff itself have chemical variations that are much greater than the variations in the air-fall ash (Hildreth, 1979) and encompass the range of several plinian tephras derived from the Long Valley-Glass Mountain province. For this reason, we believe that each of the six tephra units shown in figure 10 may represent initial plinian eruptions from about the same source area, each a culmination of a relatively short-term differentiation cycle. Thus, these widespread air-fall ashes were probably derived from the uppermost, highly differentiated parts of one magma chamber or a succession of spatially and genetically related magma chambers within the same volcanic province. The long-term, roughly linear depletion trend may represent an envelope curve for some long-term magmatic evolution process superimposed on shorter term cyclic eruptive episodes, such as that represented by the Bishop Tuff and associated volcanic rocks of approximately coeval age. Similar cyclic variations in trace-element chemistry of tephra and associated flows have been documented by Smith (1979) for the Valles caldera complex of the Jemez Mountains, New Mexico. Depletion trends such as those observed for the Long Valley-Glass Mountain tephra family could be used as an independent method of estimating or cross-checking ages of tephra erupted from this volcanic province, but because reversals with time in such trends have been noted for other volcanic provinces (Smith, 1979) and because not all tephra layers of this family fall on the age-composition trend, this method should be viewed with skepticism pending further testing.

RECOGNITION OF PROVINCIAL CHARACTERISTICS OF TEPHRA

Because of gross chemical similarities in trace- and minor-element glass composition, eruptive source areas of individual tephra layers can be recognized. For instance, average similarity coefficients within the Long Valley-Glass Mountain tephra family among tephra layers of different age range from 0.62 to 0.94. Average similarity coefficients among tephra layers of the Yellowstone family range from 0.84 to 0.93, whereas average similarity coefficients between tephra layers of these two families are much lower, from 0.44 to 0.56, demonstrating the large compositional contrast among tephra layers from different source areas (figs. 3, 4, 5).

In this study, three main tephra families have been recognized on the basis of trace- and minor-element composition of the volcanic glass: the Long Valley-Glass Mountain, the Yellowstone (Pearlette), and the Coso. Sample 50, correlated with the pumice domes at the south shore of the Salton Sea, represents a fourth vol-

canic province (although no tephra unit is associated with this source), while sample 49, from Searles Valley, probably represents a fifth, south Cascade Range province. In other studies (Izett and others, 1972; Sarna-Wojcicki and others, 1979) six other major late Cenozoic tephra families have been identified in the western conterminous United States on the basis of chemical composition of volcanic glass. Each of these families is associated with a specific source area. Within several tephra families, subgroups can be distinguished, while several families (for instance, those of Cascade Range volcanic sources) can be grouped into larger supergroups on the basis of gross similarities.

The unique chemical characteristics associated with each eruptive source area are undoubtedly related to the parent materials from which magma was formed and the magmatic differentiation processes that operate within these source areas. These, in turn, are probably related to the tectonic setting of the source area itself.

CONCLUSIONS

Tephra correlation and age data provide five categories of information that are useful in resolution of problems relating to the Quaternary geology of southern California, as well as in other areas:

(1) Recognition of a tephra layer at a specific locality provides age data for the tephra layer and stratigraphically associated deposits. For example, recognition of the Lava Creek B ash bed in the marine San Pedro Formation within the Ventura area dates stratigraphically associated sediments at about 0.6 m.y.

(2) Correlation of a particular tephra layer at two or more localities documents the temporal equivalence of deposits at these locations and permits correlation of diverse depositional environments such as marine and continental. For example, the identification of the Lava Creek B ash bed within the deposits of the Ventura Basin and Pleistocene Lake Tecopa enables temporal correlation of marine with lacustrine sediments. Alternatively, correlation of a single ash layer among several separate basins can document synchroneity of depositional conditions. For instance, pluvial conditions must have existed about 0.6 m.y. ago in the Lake Tecopa basin, Searles Valley basin, and southern San Joaquin Valley, because Lava Creek B ash is found in lake beds in all three areas.

(3) Identification of an ash sequence within a continuous stratigraphic section makes it possible to bracket specific intervals within stratigraphic sections, provides information on deposition rates and rates of organic evolution and migration, and makes it possible to estimate durations of unconformities. For instance, within the Ventura basin, nine ashes have been identified within a composite stratigraphic section that represents continuous deposition spanning an age range of 0.6 to 1.9 m.y. The age of the uppermost beds in this section have been estimated at 0.2 m.y. by amino-acid stereochemistry on marine mollusks (Wehmiller and others, 1977; Lajoie and others, 1978). These age data enable us to calculate depositional rates and to bracket marine faunal stages previously developed within this basin (Yerkes and others, 1983).

(4) Correlation of ash sequences between basins makes it possible to compare depositional rates between different tectonic provinces, as well as to reconcile marine and continental faunal chronologies. For example, the stratigraphic separation between the Lava Creek B and Huckleberry Ridge? ash beds in the marine Ventura basin is about 2,800 m. The stratigraphic separation between these same two ashes in the lacustrine Lake Tecopa section is about 30 m (J. W. Hillhouse, written commun., 1981). Calculated net sedimentation rates in the two areas are thus 2.2 mm/yr and 0.02 mm/yr, a difference of about two orders of magnitude. Correlation of the two sequences, furthermore, permits comparison on the basis of planktic foraminifers (Natland, 1952; Ingle, 1967; Yerkes and others, 1983) of marine faunal stages with land vertebrate stages (for instance, with the recently developed faunal chronology based on rapidly evolving microtine rodents (C. R. Repenning, oral commun., 1981).

(5) Dated tephra layers provide time horizons by which directions and rates of crustal motion can be measured. An extensive tephra layer defines a paleosurface of a portion of the Earth. By determining the displacement of this surface from its original position relative to a reference point, line, or surface (for instance, sea level), we can determine amounts of crustal uplift, subsidence, horizontal translation, or complex differential deformation such as faulting and folding. For instance, the presence of the Bailey ash on both flanks of the west-trending Ventura Avenue anticline of the Ventura basin and of the South Mountain anticline makes it possible to determine a minimum rate of north-south crustal shortening within this tectonic province over the last 1.2 m.y. Combined with paleobathymetric data obtained from paleontological evidence, the relative uplift or subsidence of any particular site where this ash is found can also be determined.

REFERENCES

Bacon, C. R., and Duffield, W. A., 1981, Late Cenozoic rhyolites from the Kern Plateau, southern Sierra Nevada, California: American Journal of Science, v. 281, p. 1-34.

Bailey, R. A., Dalrymple, G. B., and Lanphere, M. A., 1976, Volcanism, structure, and geochronology of Long Valley Caldera, Mono County, California: Journal of Geophysical Research, v. 81, no. 5, p. 725-744.

Bateman, P. C., 1965, Geology and tungsten mineralization of the Bishop district, California: U.S. Geological Survey Professional Paper 470, 208 p.

Blackie, G. W., and Yeats, R. S., 1976, Magnetic-reversal stratigraphy of Pliocene-Pleistocene producing section of Saticoy oil field, Ventura basin, California: American Association of Petroleum Geologists Bulletin, v. 60, no. 11, p. 1985-1991.

Boellstorff, J. D., and Steineck, P. L., 1974, Fission-track absolute age of Plio-Pleistocene volcanic ashes, California [abs]: Geological Society of America, Annual Meeting, Abstracts with Programs, p. 660-661.

———1975, The stratigraphic significance of fission-track ages on volcanic ashes in the marine late Cenozoic of southern California: Earth and Planetary Science Letters, v. 27, p. 143-154.

Borchardt, G. A., Aruscavage, P. J., and Millard, H. T., Jr., 1972, Correlation of the Bishop ash, a Pleistocene marker bed, using instrumental neutron activation analysis: Journal of Sedimentary Petrology, v. 42, no. 2, p. 301-306.

Bowman, H. R., Asaro, Frank, and Pearlman, Isidore, 1973, On the uniformity of composition in obsidians and evidence for magmatic mixing: Journal of Geology, v. 81, p. 312-327.

Cerling, T. E., Cerling, B. W., Curtis, G. H., Drake, R. E., and Brown, F. H., 1978, Correlation of reworked ash deposits: the KBS tuff, northern Kenya, *in* Zartman, R. E., Short papers of the Fourth International Conference, Geochronology, Cosmochronology, Isotope Geology: U.S. Geological Survey Open-File Report 78-701, p. 61-63.

Christiansen, R. L., and Blank, H. R., Jr., 1972, Volcanic stratigraphy of the Quaternary rhyolite plateau in Yellowstone National Park: U.S. Geological Survey Professional Paper 729-B, 18 p.

Curtis, G. H., 1968, The stratigraphy of the ejecta from the 1912 eruption of Mount Katmai and Novarupta, Alaska, *in* Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geological Society of America Memoir 116, p. 153-210.

Dalrymple, G. B., 1980, K-Ar ages of the Friant Pumice Member of the Turlock Lake Formation, the Bishop Tuff, and the tuff of Red's Meadow, central California: Isochron/West, no. 28, p. 3-5.

Dalrymple, G. B., Cox, Allan, and Doell, R. R., 1965, Potassium-argon age and paleomagnetism of the Bishop Tuff, California: Geological Society of America Bulletin, v. 76, p. 665-674.

Davis, J. O., 1978, Tephrochronology of the Lake Lahontan area, Nevada and California: Nevada Archaeological Research Paper 7, 137 p.

Davis, Paul, Smith, James, Kukla, G. J., and Opdyke, N. D., 1977, Paleomagnetic study at a nuclear power plant site near Bakersfield, California: Quaternary Research, v. 7, p. 380-397.

Duffield, W. A., and Bacon, C. R., 1977, Preliminary geologic map of the Coso volcanic field and adjacent areas, Inyo County, California: U.S. Geological Survey Open-File Map 77-311, scale 1:50,000, 2 sheets.

Duffield, W. A., Bacon, C. R., and Dalrymple, G. B., 1980, Late Cenozoic volcanism, geochronology, and structure of the Coso Range, Inyo County, California: Journal of Geophysical Research, v. 85, p. 2381-2404.

Evernden, J. F., Savage, D. E., Curtis, G. H., and James, G. T., 1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, p. 145-198.

Fitch, F. J., Hurford, A. J., Hooker, P. J., Miller, J. A., 1978, The KBS tuff problem, *in* Zartmann, R. E., ed., Short Papers of the Fourth International Conference, Geochronology, Cosmochronology, Isotope Geology: U.S. Geological Survey Open-File Report 78-701, p. 114-117.

Fleisher, Michael, 1969, U.S. Geological Survey Standards—I, additional data on rocks G-1 and W-1, 1965-1967: Geochimica et Cosmochimica Acta, v. 33, p. 65-79.

Frick, Childs, 1921, Extinct vertebrate faunas of the badlands of Bautista Creek and San Timoteo Canon, southern California: University of California Publications in Geological Sciences Bulletin, v. 12, p. 277-424.

Friedman, Irving, and Obradovich, J. D., 1981, Obsidian hydration dating of volcanic events: Quaternary Research, v. 16, p. 37-47.

Gilbert, C. M., 1938, The Cenozoic geology of the region southeast of Mono Lake, California: Berkeley, University of California, Ph.D. thesis, 200 p.

Gilbert, C. M., Christensen, M. N., Al-Rawi, Yehya, and Lajoie, K. R., 1968, Structural and volcanic history of Mono Basin, California-Nevada, *in* Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geological Society of America Memoir 116, p. 275-329.

Harwood, D. S., Helley, E. J., and Doukas, M. P., 1981, Geologic map of the Chico monocline and northeastern part of the Sacramento Valley, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1238, scale of 1:62,500.

Hay, R. L., 1966, Zeolites and zeolitic reactions in sedimentary rocks: Geological Society of America Special Paper 85, 130 p.

Hildreth, E. W., 1979, The Bishop Tuff: Evidence for the origin of compositional zonation in silicic magma chambers, *in* Chapin, C. E., and Wolfgang, E. E., eds., Ash Flow Tuffs: Geological Society of America Special Paper 180, p. 43-72.

Hopper, R. H., 1947, Geologic section from the Sierra Nevada to Death Valley, California: Geological Society of America Bulletin, v. 58, no. 5, p. 393-432.

Huber, N. K., and Rinehart, C. D., 1967, Cenozoic volcanic rocks of the Devils Postpile Quadrangle, eastern Sierra Nevada, California: U.S. Geological Survey Professional Paper 554-D, 21 p.

Ingle, J. C., 1967, Foraminiferal biofacies variation and the Miocene-Pliocene boundary in southern California: Bulletin of American Paleontology, v. 52, no. 238, p. 218-394.

Izett, G. A., 1981, Volcanic ash beds: Recorders of upper Cenozoic silicic pyroclastic volcanism in the western United States: Journal of Geophysical Research, v. 86, no. B11, p. 10,200-10,222.

Izett, G. A., Naeser, C. W., and Obradovich, J. D., 1974, Fission-track age of zircons from an ash bed in the Pico Formation (Pliocene and Pleistocene) near Ventura, California [abs.]: Geological Society of America, Annual Meeting, Cordilleran Section, Abstracts with Programs, p. 197.

Izett, G. A., Wilcox, R. E., and Borchardt, G. A., 1972, Correlation of a volcanic ash bed in Pleistocene deposits near Mount Blanco, Texas, with the Guaje pumice bed of the Jemez Mountains, New Mexico: Quaternary Research, v. 2, no. 4, p. 554-578.

Izett, G. A., Wilcox, R. E., Obradovich, J. D., and Reynolds, R. L., 1971, Evidence for two Pearlette-like beds in Nebraska and adjoining areas [abs.]: Geological Society of America, Annual Meeting, Abstracts with Programs, p. 610.

Izett, G. A., Wilcox, R. E., Powers, H. A., and Desborough, G. A., 1970, The Bishop ash bed, a Pleistocene marker bed in the western United States: Quaternary Research, v. 1, p. 121-132.

Jack, R. N., and Carmichael, I. S. E., 1968, The chemical "fingerprinting" of acid volcanic rocks: California Division of Mines and Geology Special Report 100, p. 17-32.

Janda, R. J., 1965, Quaternary alluvium near Friant, California, *in* Guidebook for Field Conference I, northern Great Basin and California, International Association Quaternary Research, 7th Cong., U.S.A. 1965: Lincoln, Nebraska, Nebraska Academy Science, p. 128-133.

Krauskopf, K. B., and Bateman, P. C., 1977, Geologic map of the Glass Mountain quadrangle, Mono County, California, and Mineral County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1099, scale 1:62,500.

Lajoie, K. R., Kern, J. P., Wehmiller, J. F., Kennedy, G. L., Mathieson, S. A., Sarna-Wojcicki, A. M., Yerkes, R. F., and McCrory, P. F., 1979, Quaternary marine shorelines and crustal deformation, San Diego to Santa Barbara, California, *in* Abbott, P. L., ed., Geological excursions in the southern California area: Geological Society of America, Annual Meeting, San Diego State University, Department of Geology, p. 3-15.

Liddicoat, J. C., and Smith, G. I., 1979, Lithology and paleomagnetic dating of late Cenozoic sediments in a 930-meter core from Searles Valley, California [abs.]: Geological Society of America, Annual Meeting, Abstracts with Programs, p. 466.

Mankinen, E. A., and Dalrymple, G. B., 1979, Revised geomagnetic polarity time scale for the interval 0-5 m.y. B.P.: Journal of Geophysical Research, v. 84, no. B2, p. 615-626.

Merriam, Richard, and Bischoff, J. L., 1975, Bishop ash: a widespread volcanic ash extended to southern California: Journal of Sedimentary Petrology, v. 45, no. 1, p. 207-211.

Meyer, C. E., Woodward, M. J., Sarna-Wojcicki, A. M., and Naeser, C. W., 1980, Zircon fission-track age of 0.45 million years on ash in the type section of the Merced Formation west-central California: U.S. Geological Survey Open-File Report 80-1071, 6 p.

Muffler, L. J. P., and White, D. E., 1969, Active metamorphism of upper Cenozoic sediments in the Salton Sea geothermal field and the Salton trough, southeastern California: Geological Society of America Bulletin, v. 80, p. 157-182.

Naeser, C. W., Izett, G. A., and Wilcox, R. E., 1971, Zircon fission-track ages of Pearlette-like volcanic ash beds in the Great Plains [abs]: Geological Society of America, Annual Meeting, Abstracts with Programs, p. 657.

———1973, Zircon fission-track ages of Pearlette family ash beds in Meade County, Kansas: Geology, v. 1, no. 4, p. 187-189.

Natland, M. L., 1952, Pleistocene and Pliocene stratigraphy of southern California: Los Angeles, University of California, Ph.D. thesis, 165 p.

O'Keefe, J. A., 1978, The tectite problem: Scientific American, v. 239, no. 2, p. 116-125.

Parks, J. M., 1970, Fortran IV program for Q-mode cluster analysis on distance function with printed dendrogram: State Geological Survey and Kansas University, Lawrence, Computer Contribution 46, 32 p.

Sarna-Wojcicki, A. M., 1971, Correlation of late Cenozoic pyroclastic deposits in the central Coast Ranges of California: Berkeley, University of California, Ph.D. thesis, 173 p.

———1976, Correlation of late Cenozoic tuffs in the central Coast Ranges of California by means of trace- and minor-element chemistry: U.S. Geological Survey Professional Paper 972, 30 p.

Sarna-Wojcicki, A. M., Bowman, H. R., Meyer, C. E., Russell, P. C., Asaro, Frank, Michael, Helen, Rowe, J. J., Jr., Baedecker, P. A., and McCoy, Gail, 1980, Chemical analyses, correlations and ages of late Cenozoic tephra units of east-central and southern California: U.S. Geological Survey Open-file Report 80-231, 53 p.

Sarna-Wojcicki, A. M., Bowman, H. R., and Russell, P. C., 1979, Chemical correlation of some late Cenozoic tuffs of northern and central California by neutron-activation analysis of glass and comparison with X-ray fluorescence analysis: U.S. Geological Survey Professional Paper 1147, 15 p.

Sarna-Wojcicki, A. M., Meyer, C. E., Woodward, M. J., Lamothe, P. J., 1981a, Composition of air-fall ash erupted on May 18, May 25, June 12, July 22, and August 7, *in* Lipman, P. W., and Mullineaux, D. R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 667-682.

Sarna-Wojcicki, A. M., Shipley, Susan, Waitt, R. B., Jr., Dzurisin, Daniel, and Wood, S. H., 1981b, Areal distribution, thickness, mass, volume, and grain size of air-fall ash from the six major eruptions of 1980, *in* Lipman, P. W., and Mullineaux, D. R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 577-600.

Sharp, R. P., 1972, Geology field guide to southern California: California Institute of Technology, Regional Geology Series, 181 p.

Sheppard, R. A., and Gude, A. J., 3d., 1968, Distribution and genesis of authigenic silicate minerals in tuffs of Pleistocene Lake Tecopa, Inyo County, California: U.S. Geological Survey Professional Paper 597, 37 p.

Sheridan, M. F., 1965, The mineralogy and petrology of the Bishop Tuff: Stanford, Calif., Stanford University, Ph.D. thesis, 165 p.

Smith, G. I., 1964, Geology and volcanic petrology of the Lava Mountains, San Bernardino County, California: U.S. Geological Survey Professional Paper 457, 97 p.

———1978, A 3,000,000-year record of continental evaporite deposition in Searles Lake, California [abs]: Tenth International Congress on Sedimentology, Jerusalem, v. II, p. 620.

Smith, H. W., Okazaki, Rose, Knowles, C. R., 1977, Electron microprobe data for tephra attributed to Glacier Peak, Washington: Quaternary Research, v. 7, p. 197-206.

Smith, R. L., 1979, Ash-flow magmatism, *in* Chapin, C. E., and Wolfgang, E. E., eds., Ash flow tuffs: Geological Society of America Special Paper 180, p. 5-25.

Tarbet, L. A., and Holman, W. H., 1944, Stratigraphy and micropaleontology of the west side of Imperial Valley, California [abs.]: American Association of Petroleum Geologists Bulletin, v. 28, no. 12, p. 1782.

Thorarinsson, Sigurdur, 1949, The eruption of Mt. Hekla: Bulletin Volcanologique, v. 9, ser. 2, p. 157-168.

Van Eysinga, F. W. B., 1975, Geological Time Table: Amsterdam, Elsevier Scientific Publishing Co.

Weber, F. H., Jr., Cleveland, G. B., Kahle, J. E., Kiessling, E. F., Miller, R. V., Mills, M. F., Morton, D. M., and Cilweck, B. A., 1973, Geology and mineral resources study of southern Ventura County, California: California Division of Mines and Geology, Preliminary Report 14, 102 p.

Wehmiller, J. F., Lajoie, K. R., Sarna-Wojcicki, A. M., Yerkes, R. F., Kennedy, G. L., Stephens, T. A., and Kohl, R. F., 1978, Amino acid racemization dating of Quaternary mollusks, Pacific Coast United States: U.S. Geological Survey Open-File Report 78-701, 4 p.

Williams, Howel, 1942, The geology of Crater Lake National Park, Oregon: Washington D. C., Carnegie Institute of Washington, Publication 540, 162 p.

Yakowitz, Harvey, Myklebrust, R. L., and Heinrich, K. F. J., 1973, FRAME—an on line correction procedure for quantitative electron microprobe microanalysis: National Bureau of Standards Technical Note 796, 46 p.

Yeats, R. S., 1965, Pliocene seaknoll at South Mountain, Ventura basin, California: American Association of Petroleum Geologists Bulletin, v. 49, no. 5, p. 526-546.

Yeats, R. S., McLaughlin, W. A., and Edwards, George, 1967, K-Ar mineral age of ash bed in Pico Formation, Ventura basin, California: American Association of Petroleum Geologists Bulletin, v. 51, no. 3, p. 486.

Yerkes, R. F., Sarna-Wojcicki, A. M., and Lajoie, K. R., 1983, Geology and Quaternary deformation of the Ventura area, Ventura County, California: U.S. Geological Survey Professional Paper [in press].

APPENDIX

SAMPLING METHODS

We examined ash and tuff outcrops at collecting localities and sampled the purest or least contaminated layers or zones. For air-fall or water-deposited tephra, these layers or zones are usually situated at or near the base of the tephra units. We "high-graded" the least contaminated material from the exposures, obtaining between several hundred grams and several kilograms, depending on the thickness of the tephra unit, the ease of obtaining the purest available material, and the type of analyses planned for each sample. Samples of 0.5 to 2 kg were collected for chemical and petrographic analyses. At several localities, we collected larger samples of 10-20 kg for fission-track age determinations. At some outcrops, we took multiple samples vertically where the presence of multiple emplacement units was suspected, or to determine vertical variability within each tephra unit. In a number of instances, we took replicate samples laterally within individual emplacement units to determine their lateral variability.

SAMPLE PREPARATION

Previous experience (Sarna-Wojcicki, 1971, 1976; Sarna-Wojcicki and others, 1979) indicates that purity of glass separations is reflected favorably in the quality of analytical results and facilitates data interpretation. For this reason, special care was exercised in glass separations for chemical analyses.

We disaggregated samples by hand or crushed them in a mullite mortar and sieved them in plastic sieves fitted with nylon filament screens to avoid contamination with metals. We treated the 100-200 mesh size fraction (0.14-0.08 mm) with 10 percent reagent grade HCl for about 1 minute, rinsed several times in distilled water, treated it with 8 percent reagent-grade HF for about 30 seconds, rinsed it several times again, vibrated it in an ultrasonic cleaner, wet-sieved it again, and then dried it. We then separated the glass from other components of tephra in a Frantz magnetic separator and in acetone-bromoform and acetone-methylene iodide liquid solutions using a density- gradient column.

ANALYTICAL METHODS

NEUTRON-ACTIVATION ANALYSIS

Bowman and others (1973) and Sarna-Wojcicki and others (1979) describe the analytical methods for neutron-activation analysis. In this study, neutron-activation analyses of glass samples were done by two laboratories, Lawrence Berkeley Laboratory of the University of California at Berkeley and the Radiochemistry Laboratory of the U.S. Geological Survey at Reston, Virginia. To correct for standardization and instrumental differences between the laboratories, we calculated conversion factors by least-square fits for 22 samples split and analyzed by both laboratories. Elemental concentrations determined by the U.S. Geological Survey laboratory (tables 1, 9) are predicted y values from regression analysis.

Table 9. Equations derived from linear regression analysis of split samples analyzed by two laboratories

[The USGS Radiochemistry Laboratory, Reston, Va. and the Lawrence Berkeley Laboratory, University of California, Berkeley analyzed splits of 22 samples. Equations in (1) give predicted y values for converting LBL to USGS analyses; in (2), predicted y values for converting USGS to LBL analyses.]

Parameter	Sc	Fe	Zn	Rb	Cs	Ba[1]	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Th	U
(1)																		
a[2]	-0.035	0.012	4.849	0.571	0.258	-108.901	0.443	-1.758	0.635	-0.271	0.002	-0.018	-0.091	0.032	-0.051	-0.002	-0.154	0.129
b[3]	0.935	0.998	0.785	0.946	0.882	1.136	1.113	1.018	1.030	1.150	0.981	1.113	1.037	0.953	0.934	1.189	1.011	1.102
r^2[4]	0.999	0.999	0.958	0.980	0.985	0.976	0.999	0.997	0.993	0.994	0.991	0.993	0.998	0.993	0.997	0.997	0.996	0.973
(2)																		
a	0.042	-0.011	-4.190	2.202	-0.183	115.07	-0.367	1.912	-0.416	0.256	0.002	0.023	0.094	-0.030	0.069	0.008	0.196	0.037
b	1.068	1.001	1.219	1.036	1.117	0.859	0.898	0.981	0.970	0.869	1.011	0.892	0.963	1.043	1.068	0.8382	0.987	0.883
r^2	0.998	0.999	0.964	0.980	0.985	0.976	0.999	0.997	0.992	0.996	0.991	0.993	0.998	0.993	0.997	0.997	0.996	0.973

[1]based on 16 sample pairs only
[2]y intercept
[3]slope of line
[4]correlation coefficient

ELECTRON MICROPROBE ANALYSIS

We determined major- and minor-element concentrations of 12 elements in glass of tephra samples by means of an electron microprobe using a 15-kv excitation potential, a 0.010 nm specimen current, and a 1-μm beam diameter. When possible, the beam was swept over a 10 by 10 μm area to minimize volatilization of sodium and water. As standards, we used natural glasses and silicate minerals that were analyzed by conventional wet-chemical methods. We took X-ray counts on a total population of 60 to 80 shards per sample to evaluate homogeneity. Each glass shard selected for analysis was inspected visually to avoid vesicles, crystalline material, or abnormally fluorescent areas under the beam. We made corrections for background, atomic number, absorption, and fluorescence using a modified on-line data reduction program (Yakowitz and others, 1973). We give results of electron microprobe analyses in table 2.

ENERGY-DISPERSIVE X-RAY FLUORESCENCE ANALYSIS

Powdered glass separated from tephra samples was analyzed by means of an energy-dispersive X-ray fluorescence spectrometer. Integrated peak intensities within two spectral regions were determined for potassium, calcium, titanium, manganese, iron, copper, and zinc (for the spectral region between 2.96 and 9.01 keV) and for rubidium, strontium, yttrium, zirconium, and niobium (for the spectral region between 12.32 and 17.00 keV). Peak intensities for each element were normalized by dividing by total number of counts (peak intensities plus background) for each of the two spectral regions studied and were multiplied by 10,000 to convert normalized counts to whole integers. Standards were not run for this type of analysis; consequently, we did not obtain information on elemental concentrations in the glass, only relative peak intensity data. These data, however, are sufficiently precise to distinguish among most of the tephra units we have studied. By using spectral intensity data alone to compare tephra samples, we avoided an extra step and its associated error in the analytical procedure.

PETROGRAPHIC ANALYSIS

Sized separates of the 100-200 mesh (0.14-0.08 mm) fractions and the 200-325 mesh (0.08-0.03 mm) fractions for fine tephra beds were separated in a magnetic separator at high- and low-amperage settings. We further processed the intermediate magnetic fraction, containing mostly magnetic glass, for separation of volcanic glass (see above). We separated the magnetic fraction, containing the bulk of minerals rich in transition elements, in heavy liquid solutions having a specific gravity of approximately 2.85, and examined the heavy separate in optic oils under a petrographic microscope. We recorded the presence of transparent mineral species for each sample and calculated relative frequencies of the various species present from line counts using a mechanical stage (table 5). We also noted presence of glass coatings on specific minerals. We consider glass-coated minerals to be cogenetic; that is, they were probably contained in the magma chamber from which the tephra unit was erupted, and they usually help distinguish such minerals from other minerals present in the tephra owing to detrital or accidental contamination.

Many of the tephra layers found in the southern and southwestern parts of California were undoubtedly situated at great distances from their sources because they are very thin and fine grained. In such layers the characteristic heavy minerals are usually very small or absent owing to winnowing by wind. Heavy-mineral separates from such units consist mostly of detrital minerals. In such instances, we have relied on the chemistry of volcanic glasses and stratigraphic data to determine correlations.

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