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Stratigraphic identification of middle Tertiary ash-flow tuffs using trace-element abundances, Worthington Mountains, Nevada

by

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ABSTRACT

The stratigraphic identities of 32 samples of middle Tertiary ash-flow tuff from the Worthington Mountains area of southern Nevada have been established by comparing their whole-rock trace-element abundances to those of nearby tuffs whose stratigraphic identity is well known. The inferred identities are confirmed by similar comparisons of petrographic attributes. Most (24 of 32 samples) of the ash-flow tuff in the Worthington Mountains area is correlative with stratigraphic units in the interval between the Hole-in-the-Wall and Baldhills Tuff Members of the Isom Formation. Of these 24 samples, two are composed of the tuff of Hancock Summit, nine are composed of the tuff of the Golden Gate Range, eight are composed of the intermediate cooling unit of the Shingle Pass Tuff, and five are composed of the lower cooling unit of the Shingle Pass Tuff; the remaining samples include a single sample of the Pahranagat Formation and seven samples of the Lund Formation. The work presented here confirms the utility of whole-rock trace-element abundances in stratigraphic correlation of ash-flow tuffs exposed in southern Nevada.

INTRODUCTION

The Worthington Mountains are about 195 km north-northwest of Las Vegas; Caliente, Nevada, about 100 km to the east, is the nearest population center (fig. 1). Warm Springs and Alamo, located about 65 km northwest and southeast, respectively, are nearby, though much smaller communities. The Worthington Mountains are a 25-km-long by 5-km-wide fault block range flanked by Sand Spring and Garden Valleys on the west and east sides, respectively.

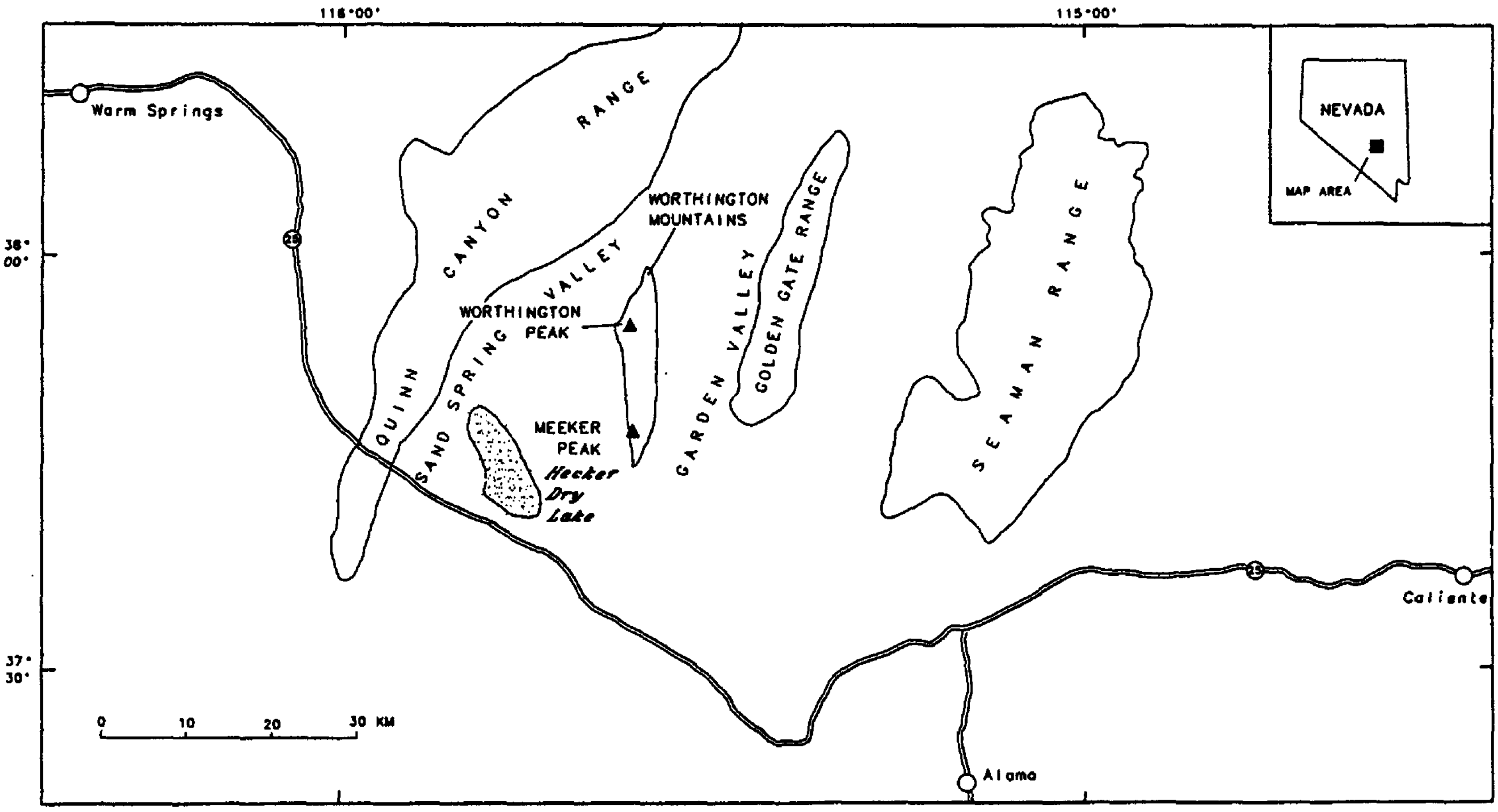

Figure 1. Map showing location of the Worthington Mountains and important geographic features in the region.

The Worthington Mountains are underlain by a homoclinal section of sedimentary rocks in which the rocks are oldest at the north end of the range and youngest at its south end. The Ordovician Eureka Quartzite occurs stratigraphically above Ordovician Pogonip Group limestone, the oldest rock exposed in the area. A thick section of Ordovician and Devonian dolomite crops out above the Eureka Quartzite and gives way stratigraphically to Devonian, Mississippian, and Pennsylvanian limestone. Two small granitoid stocks of indeterminate age, probably Cretaceous or Tertiary, intrude carbonate rocks at the north end of the range.

In the Worthington Mountains area, Tertiary ash-flow tuffs, the focus of this report, are of rhyolitic to dacitic composition; these tuffs unconformably onlap Paleozoic sedimentary rocks at the north and south ends of the range. These volcanic rocks were probably derived from several Tertiary volcanic centers. The nearby Quinn Canyon Range is a hypothesized volcanic edifice (Ekren and others, 1977) and is a possible source for some of the ash-flow tuffs. Tuffs exposed along the flanks of the Worthington Mountains are part of an areally extensive ignimbrite field that occurs throughout much of southern Nevada and southwestern Utah.

The geology of the Worthington Mountains was most recently mapped, in reconnaissance fashion, by du Bray and others (1986). At that time, the stratigraphy of middle Tertiary ash-flow tuffs in this area, summarized on the geologic map of Tertiary volcanic rocks in Lincoln County (Ekren and others, 1977), was very poorly known. Ash-flow tuffs in the Worthington Mountains were assigned to one of two units: (1) Miocene, Unit 3 of Ekren and others (1977) or (2) Oligocene, Unit 2 of Ekren and others (1977). Even as reconnaissance mapping was underway, it was obvious that these map units were in fact composed of multiple, petrographically distinct ash-flow tuffs. However, the reconnaissance nature of that work and the lack of well-defined stratigraphic nomenclature for these rocks precluded more detailed unit identification and delineation.

During the last 10 years, considerable additional geologic mapping and stratigraphic study in this region have allowed synthesis of a reasonably complete stratigraphic framework for ash-flow tuffs in this region. The best overall summary concerning petrographic, geochemical, geochronologic, and paleomagnetic characteristics of these rocks is presented by Best and others (1989). In addition, the geology of the nearby Seaman Range was mapped by du Bray and Hurtubise (1994). During the course of that mapping, the stratigraphic identity and diagnostic characteristics of numerous middle Tertiary ash-flow tuffs became firmly established (Hurtubise and du Bray, 1992; du Bray, 1995). In this report, an attempt is made to apply recent improvements in the understanding of middle Tertiary ash-flow tuff stratigraphy in southern Nevada to retrospectively make more definitive identifications of ash-flow tuff units present in the Worthington Mountains area.

METHODS

During the course of geologic mapping in the Worthington Mountains area (du Bray and others, 1986), 32 samples of middle Tertiary ash-flow tuff were collected at representative sample sites (fig. 2). These samples were collected to enable geochemical and petrographic characterization of rocks present in the area. Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, and FeO* (total iron as FeO) abundances were determined (by E.A. du Bray) by energy-dispersive X-ray fluorescence spectroscopy (Elsass and du Bray, 1982; Yager and Quick, 1992) using ^{109}Cd and ^{241}Am radioisotope excitation sources (table 1). All geochemical analyses were performed in analytical

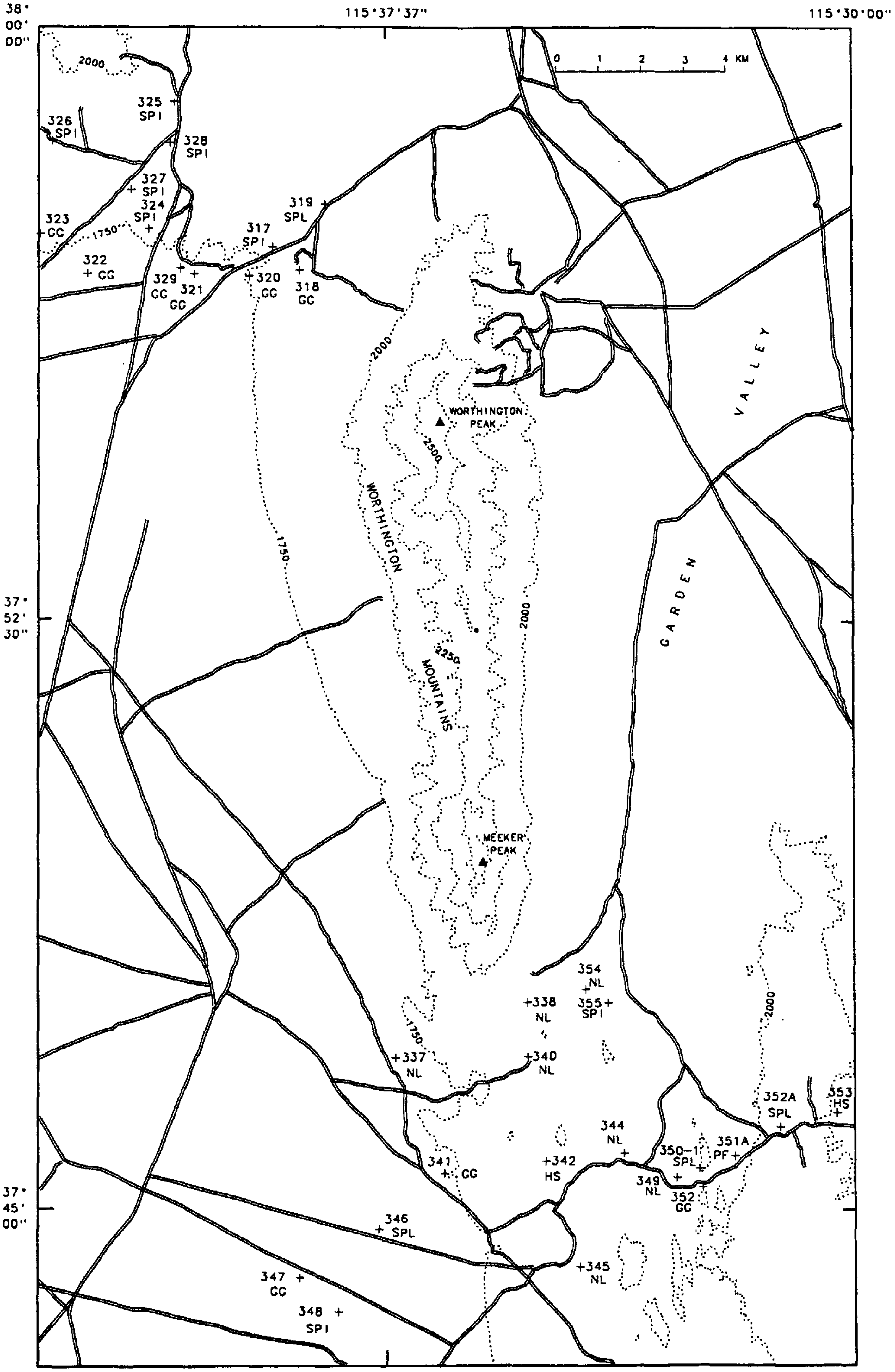

Figure 2. Map showing sample sites for 32 ash-flow tuff samples from the Worthington Mountains area. All sample numbers are prefixed by 201. The stratigraphic identity of each sample is indicated by the following codes: NL, Lund Formation; SPL and SPI, lower and intermediate cooling units, respectively, of the Shingle Pass Tuff; GG, tuff of the Golden Gate Range; HS, tuff of Hancock Summit; and PF, Pahranagat Formation. Contour interval, 250 m.

Table. 1--Trace-element abundances, in parts per million, in middle Tertiary ash-flow tuff samples from the Worthington Mountains, Nevada.

[NL, Lund Formation; SPL and SPI, lower and intermediate cooling units, respectively, of the Shingle Pass Tuff; GG, tuff of the Golden Gate Range; HS, tuff of Hancock Summit; PF, Pahranagat Formation.]

Sample	201317	201318	201319	201320	201321	201322	201323	201324	201325	201326	201327
Unit	SPI	GG	SPL	GG	GG	GG	GG	SPI	SPI	SPI	SPI
Rb	221	238	221	228	169	225	245	203	144	236	186
Sr	177	56	108	68	151	65	54	226	88	86	245
Y	29	22	13	24	24	25	20	29	28	18	22
Zr	270	127	181	118	161	117	115	225	254	250	233
Nb	18	19	12	21	14	18	26	22	14	12	23
Ba	1473	267	1018	187	487	163	146	1661	1476	1146	1712
La	70	34	46	35	55	44	39	62	65	67	66
Ce	117	84	100	81	119	89	75	123	124	119	101
Nd	35	24	47	32	45	53	30	41	91	51	52

Sample	201328	201329	201337	201338	201340	201341	201342	201344	201345	201346	201347
Unit	SPI	GG	NL	NL	NL	GG	HS	NL	NL	SPL	GG
Rb	152	163	140	156	175	198	142	129	135	218	188
Sr	135	186	500	486	330	127	451	519	505	153	69
Y	18	16	9	23	9	22	25	21	16	26	16
Zr	164	166	173	203	171	117	243	184	185	225	114
Nb	17	8	9	13	10	11	12	6	12	15	20
Ba	1418	490	925	902	891	566	2219	933	955	1172	131
La	67	73	41	34	51	42	117	56	29	81	48
Ce	82	122	100	82	91	77	155	84	88	122	83
Nd	51	42	27	21	34	43	76	39	40	55	47

Sample	201348	201349	201350	201351	201351A	201352	201352A	201353	201354	201355
Unit	SPI	NL	SPL	SPL	PF	GG	SPL	HS	NL	SPI
Rb	214	155	217	222	182	173	237	198	138	218
Sr	186	514	146	148	153	142	129	373	526	184
Y	29	14	35	22	18	21	32	25	20	31
Zr	257	185	219	234	123	135	220	301	196	216
Nb	19	12	17	15	17	7	15	11	8	12
Ba	1345	1011	1085	1015	284	692	925	1591	922	1343
La	56	40	91	58	41	36	83	62	41	89
Ce	118	73	146	117	81	86	117	108	72	151
Nd	46	32	60	52	34	35	73	59	34	52

laboratories of the U.S. Geological Survey in Denver, Colorado. Petrographic characteristics of each analyzed sample were established by binocular microscopic examination.

The geochemical composition versus stratigraphic-unit-correlation-key developed by du Bray (1995) for Oligocene through Miocene ash-flow tuffs in the nearby Seaman Range (fig. 1) was applied to tuffs exposed in the Worthington Mountains area. The key consists of a number of plots (fig. 3), one per element/oxide, on which the compositional ranges of ash-flow tuff units are arranged in stratigraphic order. On the vertical axis of these plots, the ash-flow tuffs exposed in the Seaman Range are evenly spaced in stratigraphic order. In the horizontal dimension of these plots, the compositional range for each tuff is portrayed by a horizontal line that depicts the abundances of a particular element or oxide for a series of samples of each tuff. These horizontal arrays depict the element/oxide compositional range characteristic of each ash-flow tuff stratigraphic unit.

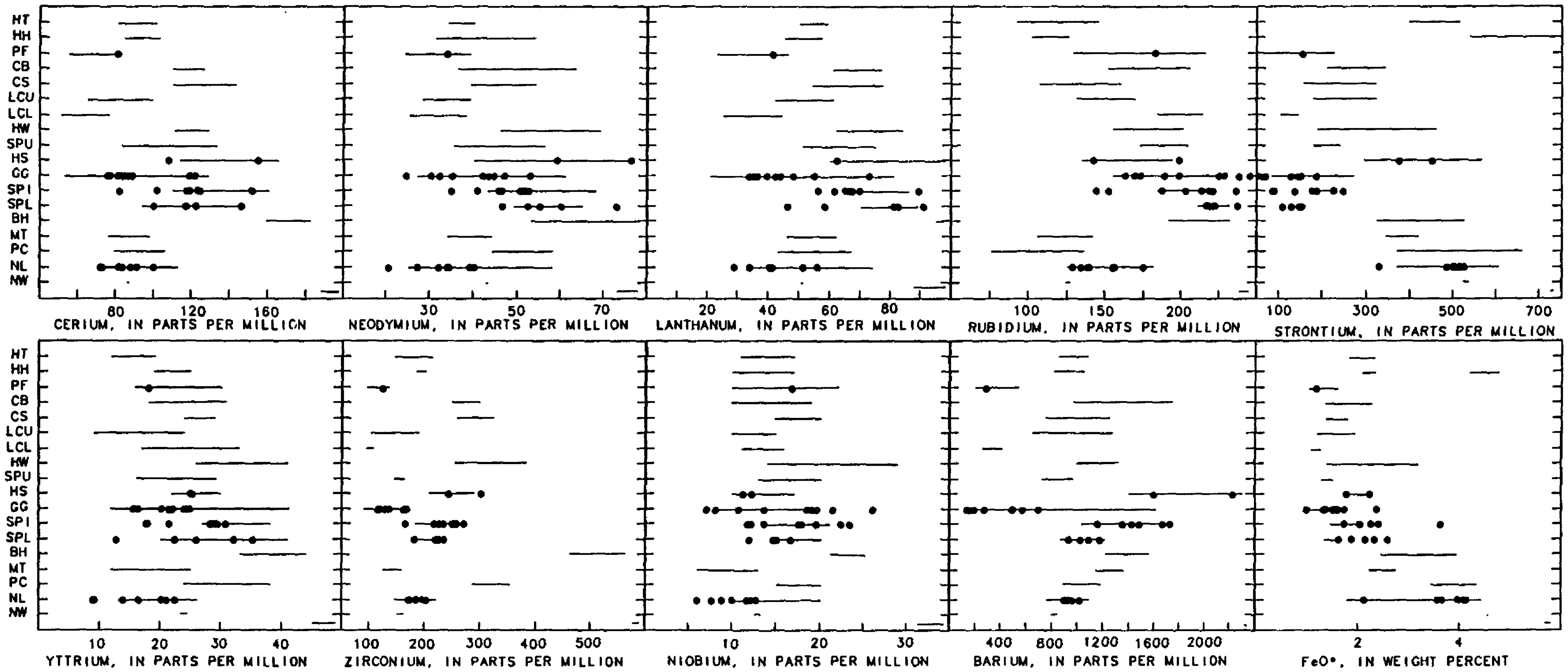

Figure 3. Stratigraphic compositional variation of ash-flow tuffs in southern Nevada (du Bray, 1995). Units arranged from oldest (bottom) to youngest (top) in each plot: NW, Wah Wah Springs Formation; NL, Lund Formation; PC, Petroglyph Cliff Ignimbrite; MT, Monotony Tuff; BH, Baldhills Tuff Member of the Isom Formation; SPL and SPI, lower and intermediate cooling units, respectively, of the Shingle Pass Tuff; GG, tuff of the Golden Gate Range; HS, tuff of Hancock Summit; SPU, upper cooling unit of the Shingle Pass Tuff; HW, Hole-in-the-Wall Member of the Isom Formation; LCL, Leach Canyon Formation, lower cooling unit; LCU, Leach Canyon Formation, upper cooling unit; CS, Swett Tuff Member of Condor Canyon Formation; CB, Bauers Tuff Member of Condor Canyon Formation; PF, Pahranagat Formation; HH, Harmony Hills Tuff; HT, Hiko Tuff. Dots represent data for samples collected in the Worthington Mountains area. Analytical uncertainty (for a single analysis) for oxide or element is shown by error bar in bottom right corner of each plot.

The abundance ranges of single elements/oxides do not uniquely define stratigraphic identity, but considered in various combinations the abundances of groups of elements/oxides do allow stratigraphic identification of ash-flow tuff samples using their geochemical composition. The ranges of zirconium abundances in individual stratigraphic units are the most diagnostic of any element/oxide whose variation was studied. The ranges of zirconium abundances in each stratigraphic ash-flow tuff unit are relatively narrow and most nearly nonoverlapping; in addition, analytical precision for zirconium abundances in single samples is very good (fig. 3).

The zirconium abundances of single samples, whose stratigraphic identity was uncertain, were used as the initial filter in the stratigraphic keying process. To begin determination of the stratigraphic identities of ash-flow tuffs from the Worthington Mountains area, vertical lines corresponding to their determined zirconium abundances were drawn on the stratigraphic unit versus zirconium plot (fig. 3). Intersections between these lines and horizontal compositional lines that depict the abundances of zirconium in particular stratigraphic tuff units of the Seaman Range provide a series of possible stratigraphic identities for each of the unknown tuffs. Successively constructing similar vertical lines for other elements/oxides (corresponding to abundances of other trace elements in tuff samples of unknown stratigraphic identity) on the stratigraphic unit versus composition plots allowed progressive refinement of the potential stratigraphic identity of each unknown tuff sample. This process resulted in unique identification of all 32 ash-flow tuff samples. In most cases (considering the analytical uncertainty associated with single unknown tuff sample analyses), trace element/oxide abundances of the 32 unknown ash-flow tuffs plot within the composition ranges of their inferred correlatives in the Seaman Range (fig. 3), thereby confirming the inferred identity of each unknown tuff sample. Deviations from this generalization are discussed below.

DISCUSSION

Of the 32 ash-flow tuff samples from the Worthington Mountains area one is from the Pahranagat Formation, two are from the tuff of Hancock Summit, nine are from the tuff of the Golden Gate Range, eight are from the intermediate cooling unit of the Shingle Pass Tuff, five are from the lower cooling unit of the Shingle Pass Tuff, and seven are from the Lund Formation. Each of the ash-flow tuff stratigraphic units in the Worthington Mountains appears to be correlative with one of those exposed in the Seaman Range; in contrast, eleven of the ash-flow tuff units exposed in the Seaman Range appear to be absent in the Worthington Mountains area. The majority of ash-flow tuff in the Worthington Mountains area represents the relatively narrow stratigraphic interval between and including the lower cooling unit of the Shingle Pass Tuff and the tuff of Hancock Summit. The Lund Formation, well represented in the Worthington Mountains area, is the oldest tuff exposed in this area.

To further evaluate stratigraphic correlations inferred from the stratigraphic unit-composition plots (fig. 3) in the stratigraphic interval between the Monotony Tuff and the Leach Canyon Formation, variation diagrams utilized by du Bray (1995) to refine identification of these units were applied to composition data for ash-flow tuffs in the Worthington Mountains area (fig. 4). Compositions of the two samples of the tuff of Hancock Summit from the Worthington Mountains area plot within the fields (on the variation diagrams described above) previously defined by du Bray (1995). Similarly, the five samples of the lower cooling unit of the Shingle Pass Tuff from the Worthington Mountains area plot within, or very near, previously defined

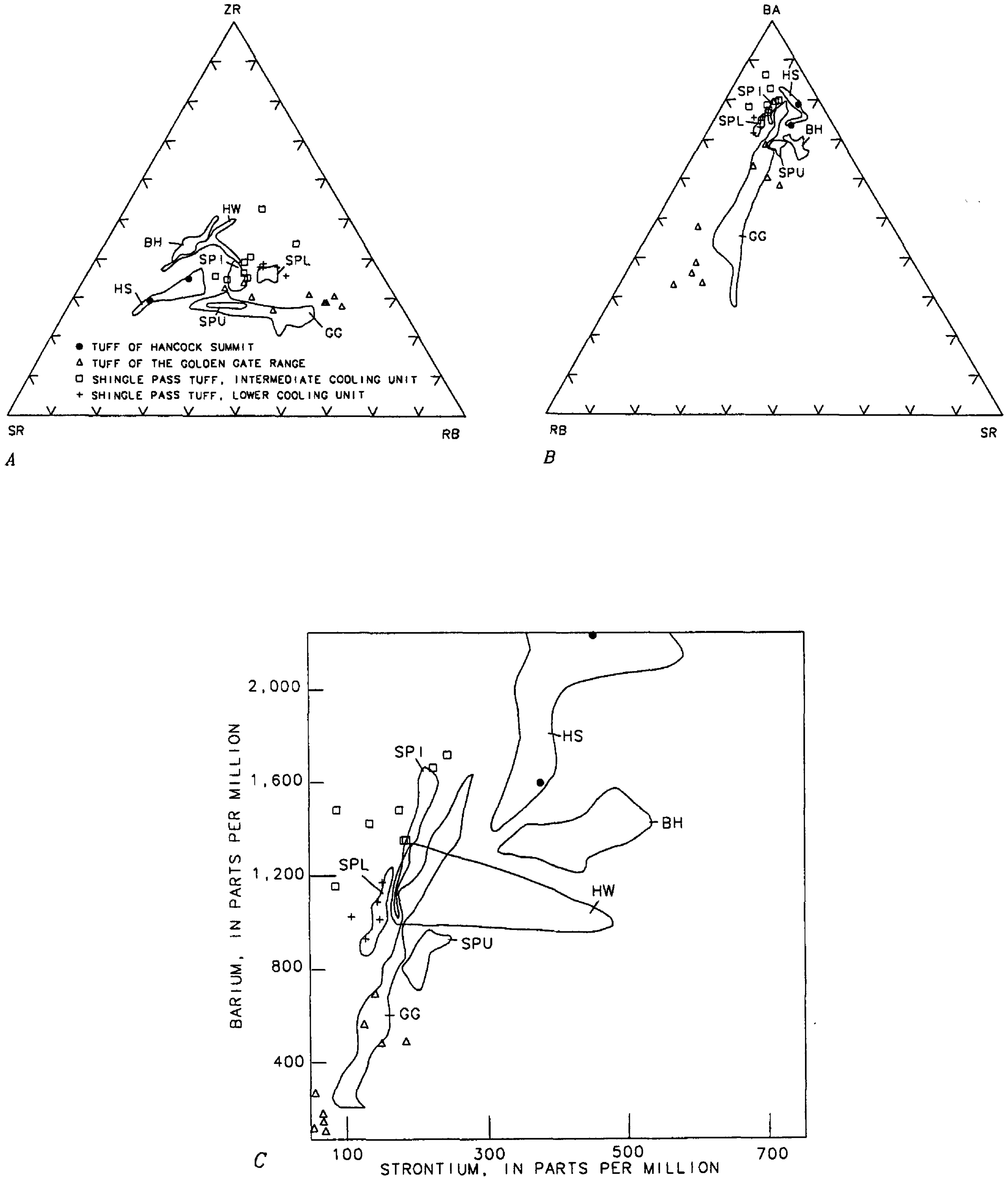

Figure 4. Variation diagrams showing compositions of samples in the stratigraphic interval between the Monotony Tuff and the Leach Canyon Formation, including: BH, Baldhills Tuff Member of the Isom Formation; SPL and SPI, lower and intermediate cooling units, respectively, of the Shingle Pass Tuff; GG, tuff of the Golden Gate Range; HS, tuff of Hancock Summit; SPU, upper cooling unit of the Shingle Pass Tuff; HW, Hole-in-the-Wall Member of the Isom Formation. *A*, Strontium-zirconium-rubidium. *B*, Rubidium-barium-strontium. *C*, Barium versus strontium.

fields. Compositions of the tuff of the Golden Gate Range samples from the Worthington Mountains area plot in and near the previously defined fields but also extend the compositional fields of this unit. In particular, these samples extend these fields to lower barium and strontium abundances and to higher rubidium and zirconium abundances; these composition field extensions do not overlap fields of the other units in the stratigraphic interval between the Monotony Tuff and the Leach Canyon Formation. Five of eight samples from the intermediate cooling unit of the Shingle Pass Tuff plot in or near the previously defined composition fields for this unit.

Three samples (201325, 201326, and 201328) of the intermediate cooling unit of the Shingle Pass Tuff plot significantly outside their previously defined composition fields (fig. 4). In addition, abundances of several trace elements in these three samples are beyond the ranges normally characteristic of the intermediate cooling unit of the Shingle Pass Tuff (fig. 3). Petrographic examination of these samples indicates that they are considerably altered. These three samples are from an area noted by Ekren and others (1977) of moderate to intense hydrothermal alteration. The somewhat unusual, but still recognizable, composition of these samples probably reflects mobilization and redistribution of some trace elements during hydrothermal alteration and not primary compositional features.

PETROGRAPHIC OBSERVATIONS

In order to provide additional, independent confirmation of the geochemical-composition-based stratigraphic assignments made for the 32 ash-flow tuff samples from the Worthington Mountains area, the petrographic attributes of each sample were compared to those compiled for samples of correlative ash-flow tuff units exposed in the Seaman Range (table 2, du Bray, 1995). Petrographic attributes of the 32 samples are summarized below (phenocrysts listed in order of decreasing abundance).

201317: Pale red; 10-15 percent crystals, including sanidine, plagioclase, biotite, and trace hornblende and quartz; in a densely welded groundmass; low lithic and pumice contents.
201318: Pale red; 20-25 percent crystals, including sanidine, quartz, plagioclase, and biotite in a densely welded groundmass; low lithic and pumice contents.
201319: Grayish pink; 5-10 percent crystals, including sanidine, plagioclase, and trace biotite in a densely welded groundmass; minor lithic and pumice contents. Sample moderately altered; feldspars replaced by clay, secondary silica in vugs.
201320 Pale pinkish gray; 25-30 percent crystals, including smoky quartz, sanidine, plagioclase, and biotite in a moderately welded groundmass; minor lithic content. Contains moderate abundance of small pumice fragments.
201321: Grayish pink; 25-30 percent crystals, including sanidine, quartz, plagioclase, and biotite in a moderately welded groundmass; minor lithic and pumice contents.
201322: Pale red; 30-35 percent crystals, including sanidine, quartz, plagioclase, biotite, and trace hornblende in a densely welded groundmass; minor lithic and pumice contents.
201323: Pale red; 25-30 percent crystals, including quartz, sanidine, plagioclase, biotite in a densely welded groundmass; minor lithic and pumice contents.
201324: Medium-gray vitrophyre; 10-15 percent crystals, including plagioclase, sanidine, and biotite in a densely welded groundmass; minor lithic and pumice contents.
201325: Light gray; 10-15 percent crystals, including plagioclase, sanidine, biotite and trace

quartz in a moderately welded groundmass; minor lithic content. Contains abundant small pumice fragments. Moderately to intensely altered; all feldspar replaced by clay minerals.

201326: Very light gray; 10-15 percent crystals, including feldspars and trace quartz in a silicified groundmass; minor lithic and pumice contents. Intensely altered; all feldspars replaced by clay minerals; mafic silicates obliterated.

201327: Medium-gray vitrophyre; 10-15 percent crystals, including plagioclase, sanidine, and biotite in a densely welded groundmass; minor lithic and pumice contents.

201328: Light gray; 5-10 percent crystals, including plagioclase and biotite in a weakly welded groundmass; minor lithic content. Contains abundant unflattened pumice fragments. Moderately altered; plagioclase replaced by clay minerals.

201329: Grayish pink; 20-25 percent crystals, including sanidine, quartz, plagioclase, and biotite in a densely welded groundmass; minor lithic content. Contains moderate amount of small, partially flattened pumice fragments.

201337: Pale red; 25-30 percent crystals, including plagioclase, quartz, biotite, and sanidine in a moderately welded groundmass; minor lithic and pumice contents. Weakly stained by secondary, reddish iron oxides.

201338: Pale red; 25-30 percent crystals, including plagioclase, quartz, biotite, sanidine, and hornblende in a moderately welded groundmass; minor lithic and pumice contents.

201340: Pinkish gray; 25-30 percent crystals, including plagioclase, quartz, biotite, and sanidine in a moderately welded groundmass; minor lithic and pumice contents.

201341: Pale red; 30-35 percent crystals, including sanidine, smoky quartz, plagioclase, and trace biotite in a densely welded groundmass; minor lithic and pumice contents.

201342: Pinkish gray; 20-25 percent crystals, including plagioclase, sanidine, quartz, biotite and trace hornblende in a densely welded groundmass; minor lithic and pumice contents.

201344: Pale red; 30-35 percent crystals, including plagioclase, quartz, biotite, sanidine, and trace hornblende in a moderately welded groundmass; minor lithic and pumice contents.

201345: Pale red; 35-40 percent crystals, including plagioclase, quartz, biotite, sanidine, and trace hornblende in a densely welded groundmass; minor lithic and pumice contents.

201346: Pale red; 5-10 percent crystals, including plagioclase, sanidine, biotite, and trace hornblende in a densely welded groundmass; minor lithic content. Contains moderate amount of completely flattened, streaky pumice fragments.

201347: Pale red; 30-35 percent crystals, including sanidine, quartz, plagioclase, and biotite in a densely welded groundmass; minor lithic and pumice contents.

201348: Pale red; 5-10 percent crystals, including plagioclase, sanidine, and biotite in a densely welded groundmass; minor lithic and pumice contents.

201349: Grayish pink; 25-30 percent crystals, including plagioclase, quartz, biotite, sanidine and trace hornblende in a densely welded groundmass; minor lithic and pumice contents. Weakly stained by secondary, reddish iron oxides.

201350: Medium-dark-gray vitrophyre; 5-10 percent crystals, including sanidine, plagioclase, and trace clinopyroxene in a densely welded groundmass; minor lithic and pumice contents.

201351: Pale red; 10-15 percent crystals, including plagioclase and sanidine in a densely welded groundmass; minor lithic and pumice contents.

201351A: Pale pinkish gray; 15-20 percent crystals, including sanidine, quartz, plagioclase, and biotite in a weakly welded groundmass; minor lithic content. Contains a moderate abundance of

distinctly unflattened pumice fragments.
201352: Grayish orange pink; 30-35 percent crystals, including sanidine, quartz, plagioclase, and trace biotite in a moderately welded groundmass; minor lithic and pumice contents.
201352A: Very pale red purple; 5-10 percent crystals, including sanidine, plagioclase, and trace quartz and biotite in a densely welded groundmass; minor lithic and pumice contents.
201353: Grayish pink; 15-20 percent crystals, including plagioclase, sanidine, biotite, and trace quartz in a densely welded groundmass; minor lithic and pumice contents.
201354: Light brownish gray; 35-40 percent crystals, including plagioclase, quartz, biotite, sanidine, and trace hornblende in a densely welded groundmass; minor lithic and pumice contents.
201355: Pale red; 10-15 percent crystals, including sanidine, plagioclase, and trace quartz and biotite in a densely welded groundmass; minor lithic and pumice contents.

The petrographic character of the 32 ash-flow tuff samples from the Worthington Mountains area and that of the units (exposed in the Seaman Range) with which they were correlated on the basis of geochemical compositions are remarkably similar. This independent indicator of stratigraphic identity confirms the utility of geochemical composition as a tool of stratigraphic ash-flow tuff correlation.

CONCLUSIONS

Successful determination of the stratigraphic identity of 32 ash-flow samples from the Worthington Mountains using stratigraphic unit versus geochemical composition plots demonstrates the utility of this technique in stratigraphic correlation. This technique joins already established correlation methods, including petrography, geochronology, and paleomagnetism, that are useful in establishing the stratigraphic identity of ash-flow tuffs that are, for any number of reasons, uncertain.

A derivative benefit of this study is the expansion of compositional envelopes for several of the ash-flow tuffs. Because of the dynamics of ash-flow emplacement, pre-eruptive compositional variation in source magma reservoirs is unlikely to be completely preserved in single stratigraphic sections. Ash-flow emplacement occurs in discrete depositional lobes that are, at least in part, controlled by pre-emplacement topography. Consequently, in order to document as completely as possible the compositional variation characteristic of a stratigraphic ash-flow tuff unit, a representative subset of its depositional lobes must be sampled and analyzed. Sampling and analysis of ash-flow tuffs in the Worthington Mountains area confirm and slightly extend the compositional fields for several of the southern Nevada ash-flow tuff units.

A number of recent petrologic studies (Hildreth, 1981; Fridrich and Mahood, 1987) of ash-flow tuffs have relied primarily on analyses of pumice fragments because these samples are considered to represent uncontaminated, intact samples of their source magma reservoirs. The study of ash-flow tuff compositional variation by du Bray (1995) suggests that, at least in some cases, analyses of whole-rock samples can be as useful as pumice analyses in establishing the stratigraphic identity of ash-flow tuffs and in studying their compositional zonation. The principal risks in using whole-rock samples for these purposes relate to the dynamics of ash-flow tuff emplacement. Elutriation of very fine glass shards from, and mechanical concentration of crystals in pyroclastic material during flowage can cause the composition of ash-flow tuffs, as deduced from whole-rock analyses, to be strongly modified. In addition, pyroclastic flows have the ability to entrain exotic material during flowage and emplacement. These factors must be carefully considered when attempting to use analyses of whole-rock samples for stratigraphic correlation or in zonation studies. The work presented here, however, confirms the utility of whole-rock samples for stratigraphic correlation of ash-flow tuffs exposed in southern Nevada.

The utility of whole rock samples such as these is fortunate because collecting pumice from moderately to densely welded tuffs (in which pumice blocks are flattened to very thin, uncollectible discoid masses) that are completely indurated (such as is the case with most Tertiary or older tuffs) may be impractical. In addition, as demonstrated by Lipman (1965), hydration and devitrification processes that affect vitric material, including pumice fragments, in ash-flow tuffs can cause their compositions to be significantly modified. Consequently, the utility of pumice compositions for stratigraphic correlation or in zonation studies may itself be uncertain.

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