Current Concerns Regarding DOE/LANL Volcanism Geochemical Data
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Background

Current DOE/LANL models for the Lathrop Wells volcano of the Yucca Mountain Region (YMR) conclude that multiple eruptions have occurred at this volcano, separated at times by tens of thousands of years of inactivity (e.g., Crowe et al., 1995). This model is then used to conclude that the risk of igneous activity on the candidate repository site is reduced, because Lathrop Wells represents the current locus of igneous activity (e.g., Perry et al., 1994; Perry and Straub, 1994). Much of the evidence cited for recurring volcanism at Lathrop Wells is strongly dependent on geochemical differences between chronostratigraphic units. As part of the review of a preliminary draft status report (Crowe et al., 1995) and preparation for a technical exchange with the DOE on volcanism, CNWRA staff requested copies of Lathrop Wells geochemical data that were used to support conclusions in Crowe et al. (1993) and Perry and Crowe (1992). These data were obtained by the CNWRA from a Los Alamos print-out binder TWS-EES-13-LV-10-89-04 (POB), for activity 8.3.1.8.5.1.4. The NRC requested location and chronostratigraphic unit designations for these data in May 1993 and March 1994. For samples in the POB, 26 have complete X-ray Fluorescence (XRF) and Instrumental Neutron Activation Analysis (INAA); the remaining 50 samples only have INAA analyses.

As part of an ongoing NRC request for information to support the conclusions reached in Crowe et al. (1995) and other DOE volcanism activities, the NRC received a copy of Perry and Straub (1994) as an example of the types of data currently available from the DOE. Perry and Straub (1995) is a LANL-approved milestone that was submitted to the DOE on 9/28/94, and contains 118 XRF and 97 INAA geochemical analyses for Lathrop Wells volcano. Samples in Perry and Straub (1994) are located on a map of Lathrop Wells, and assigned to current chronostratigraphic units.

Problem 1

Sample numbers in Perry and Straub (1994) are identical to those in the 1993 POB. Trace element analyses produced through INAA also are identical for samples in Perry and Straub (1994) and the 1993 POB. However, major, minor, and trace element abundances determined by XRF are different for the same 26 samples listed in Perry and Straub (1994) and the 1993 POB. Appendix A is a comparison of samples common to these two data sets. These differences are not caused by different approached to normalizing for water content or in calculating ferric/ferrous ratios. Although some compositional differences are small, DOE/LANL has concluded that very small compositional differences are highly significant at Lathrop Wells (e.g., Crowe et al., 1995). Thus, the differences between these two data sets are important. Clearly, the XRF data have changed between the 1993 POB and Perry and Straub (1994). However, this comparison exists only for 26 samples.

It is likely that these earlier XRF analyses (1993 POB) were redone at a later date. However, it is not possible to tell if other samples in Perry and Straub (1994) were analyzed with the same, presumedly flawed, procedure as the 1993 POB samples, or if all samples were analyzed by a different technique. In addition, there is no discussion of this problem in Perry and Straub (1994) or Crowe et al. (1995). Models regarding the evolution of Lathrop Wells cannot be evaluated until it is clear which data are being used in different models. The relationship between the data in Perry and Straub (1994) and the 1993 POB need to be clarified before these evaluations can be made.

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LANL or DOE publications prior to Perry and Straub (1994) likely used Lathrop Wells geochemical data from the 1993 POB. Perry and Crowe (1992) clearly state these data were used to reach the main conclusions in that paper, and Crowe et al. (1992) also allude to using these data. Both of these papers are cited in Crowe et al. (1995). However, the conclusions in these papers are based, in part, on analyses that were subsequently redone. This questions whether the conclusions in these and allied documents are supportable during licensing, as the data used to support these conclusions have questionable validity.

Problem 2

Connor and Hill (1993) documented that 13 samples reported in Vaniman and Crowe (1981) and Vaniman et al. (1982) had different Rare Earth Element abundances than the same samples reported in Crowe et al. (1986). This problem also was discussed at the April 1993 technical exchange with DOE/LANL staff. It is likely that analyses in these publications will be used in licensing for many discussions of Miocene and possibly some Pliocene YMR volcanoes. The compositional differences between these data sources thus must be resolved.

Summary

Significant differences exist among reported DOE/LANL analyses of basaltic igneous rocks for the YMR. These differences likely are the result of reanalysis of samples with more precise or accurate techniques. However, it is not clear which data currently are regarded by DOE/LANL as accurate for the samples in question. In addition, it is not clear if other samples have been analyzed using older techniques that are currently regarded as inaccurate or imprecise. Upcoming QA and Vertical Slice activities will need to investigate the source of these problems, in addition to a rigorous evaluation of the various techniques used for geochemical analyses in the DOE program. Prior to these evaluations, there needs to be a clear documentation from the DOE on the following items:

- What geochemical abundances currently are regarded as the most precise and accurate for all YMR samples that will likely be used in licensing?

- Which older analyses (e.g., Vaniman et al., 1982; Crowe et al., 1986) are going to be reanalyzed before either submittal of the Volcanism high-level finding or the license application?

- What is the disposition of older analyses? Most importantly, what is the status of conclusions that were derived from the older data, when more recent analyses show relatively significant compositional differences? Are conclusions based on apparently imprecise or inaccurate data supportable during licensing?

References

Connor, C.B., and B.E. Hill. 1993. Volcanism Research. *NRC High–Level Radioactive Waste Research at CNWRA, July 1 Through December 31, 1992*. CNWRA 92–02S. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses. 10–1–10–31.

Crowe, B.M., K.H. Wohletz, D.T. Vaniman, E. Gladney, and N. Bower. 1986. *Status of Volcanic Hazard Studies for the Nevada Nuclear Waste Storage Investigations*. Los Alamos National Laboratory Report LA–9325–MS, Vol. II. Los Alamos, NM: Los Alamos National Laboratory.

Crowe, B., R. Morley, S. Wells, J. Geissman, E. McDonald, L. McFadden, F. Perry, M. Murrell, J. Poths, and S. Forman. 1992. The Lathrop Wells volcanic center: Status of field and geochronology studies. *Proceedings of the Third International High–Level Radioactive Waste Management Conference.* La Grange Park, IL: American Nuclear Society: 1,997–2,013.

Crowe, B.M., F.V. Perry, and G.A. Valentine. 1993. *Preliminary Draft: Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project.* Los Alamos National Laboratory Report: Los Alamos, NM: Los Alamos National Laboratory.

Crowe, B.M., F.V. Perry, J. Geissman, L. McFadden, S. Wells, M. Murrell, J. Poths, G.A. Valentine, L. Bowker, and K. Finnegan. 1995. *Status of Volcanic Hazard Studies for the Yucca Mountain Site Characterization Project.* Los Alamos National Laboratory Report LA–12908–MS. Los Alamos, NM: Los Alamos National Laboratory.

Perry, F.V., and Crowe, B.M., 1992. Geochemical evidence for waning magmatism and polycyclic volcanism at Crater Flat, Nevada. *Proceedings of Third International Conference on High–Level Radioactive Waste Management.* La Grange Park, IL: American Nuclear Society: 2356–2365.

Perry, F.V., and K.T. Straub. 1994. *Geochemistry of the Lathrop Wells Volcanic Center.* Los Alamos National Laboratory report, YMP milestone 3397. Los Alamos, NM: Los Alamos National Laboratory.

Perry, F.V., B.M. Crowe, S.G. Wells, and L.D. McFadden. 1994. *Field, Geochemical and Geochronologic Evidence for Polycyclic Volcanism at the Lathrop Wells Volcanic Center, Southwestern Nevada.* U.S. Geological Survey Circular 1107. Reston, VA: U.S. Geological Survey: 248.

Vaniman, D., and B. Crowe. 1981. *Geology and Petrology of the Basalts of Crater Flat: Applications to Volcanic Risk Assessment for the Nevada Nuclear Waste Storage Investigations.* Los Alamos National Laboratory Report LA–8845–MS. Los Alamos, NM: Los Alamos National Laboratory.

Vaniman, D.T., B.M. Crowe, and E.S. Gladney. 1982. Petrology and geochemistry of Hawaiite lavas from Crater Flat, Nevada. *Contributions to Mineralogy and Petrology* 80: 341–357.

Appendix A

Comparison of the geochemical analyses in the 1993 POB (courier font) with those for the same sample number in Perry and Straub (1994)(Helvetica bold font).

Sample	LW1	**LW01**	LW2	**LW02**	LW3	**LW03**	LW5	**LW05A**	LW6	**LW06**
Unit		**Qslr**		**QL3**		**Qs3**		**QL3**		**QL2a**
SiO2	48.42	**48.66**	48.71	**48.55**	48.73	**48.68**	48.82	**49.31**	48.69	**48.58**
TiO2	1.94	**1.97**	1.82	**1.83**	1.84	**1.83**	1.91	**1.91**	1.90	**1.90**
Al2O3	16.61	**16.77**	16.75	**16.96**	16.74	**16.87**	16.89	**16.76**	16.79	**16.92**
Fe2O3*	11.73	**11.78**	11.38	**11.25**	11.65	**11.50**	11.72	**11.59**	11.63	**11.45**
MnO	0.17	**0.17**	0.17	**0.17**	0.17	**0.18**	0.16	**0.17**	0.17	**0.17**
MgO	5.85	**5.84**	5.27	**5.22**	6.09	**5.67**	5.91	**5.95**	6.08	**5.86**
CaO	8.40	**8.41**	8.85	**8.83**	8.44	**8.52**	8.32	**8.84**	8.48	**8.50**
Na2O	3.08	**3.53**	3.10	**3.47**	3.17	**3.35**	3.34	**3.53**	3.24	**3.52**
K2O	1.72	**1.84**	1.65	**1.77**	1.67	**1.76**	1.76	**1.83**	1.70	**1.78**
P2O5	1.19	**1.24**	1.15	**1.21**	1.19	**1.18**	0.97	**1.19**	1.23	**1.21**
Total	99.09	**100.20**	98.82	**99.25**	99.66	**99.53**	99.80	**101.07**	99.89	**99.90**
Normalized 100% Anhydrous										
SiO2	48.86	**48.56**	49.29	**48.92**	48.89	**48.91**	48.92	**48.79**	48.74	**48.63**
TiO2	1.96	**1.97**	1.84	**1.84**	1.85	**1.84**	1.91	**1.89**	1.90	**1.90**
Al2O3	16.76	**16.74**	16.95	**17.09**	16.80	**16.95**	16.92	**16.58**	16.81	**16.94**
Fe2O3*	11.83	**11.76**	11.51	**11.34**	11.69	**11.55**	11.74	**11.47**	11.64	**11.46**
MnO	0.17	**0.17**	0.17	**0.17**	0.17	**0.18**	0.16	**0.17**	0.17	**0.17**
MgO	5.90	**5.83**	5.33	**5.26**	6.11	**5.70**	5.92	**5.89**	6.09	**5.87**
CaO	8.48	**8.39**	8.95	**8.90**	8.46	**8.56**	8.33	**8.75**	8.48	**8.51**
Na2O	3.10	**3.52**	3.13	**3.50**	3.18	**3.37**	3.34	**3.49**	3.24	**3.52**
K2O	1.73	**1.84**	1.66	**1.78**	1.67	**1.77**	1.76	**1.81**	1.70	**1.78**
P2O5	1.20	**1.24**	1.16	**1.22**	1.19	**1.19**	0.97	**1.18**	1.23	**1.21**
Mg# (85% FeO)	53.8	53.6	51.9	52.0	54.9	53.5	54.0	54.5	54.9	54.4
V	161	**187**	163	**181**		**178**	176	**182**	165	**181**
Cr	98	**116**	58	**63**		**107**	100	**113**	110	**129**
Ni	62	**52**	42	**33**		**42**	70	**52**	65	**52**
Zn	102	**134**	100	**125**		**132**	104	**128**	97	**124**
Rb	17	**17**	17	**22**		**18**	14	**21**	13	**17**
Sr	1338	**1516**	1316	**1470**		**1431**	1300	**1486**	1234	**1418**
Y	31	**26**	32	**34**		**29**	27	**26**	29	**25**
Zr	305	**381**	313	**371**		**373**	293	**356**	293	**375**
Nb		**37**		**27**		**30**		**27**		**26**
Ba	1430	**1428**	1410	**1433**	1410	**1419**		**1280**	1460	**1384**

Appendix A: Continued

Sample	LW8	LW08A	LW9	LW09	LW10	LW10A	LW11	LW11	LW12	LW12
Unit		Qs1u		Qs1u		Qs1u		QL1a		QL1a
SiO2	48.38	48.78	48.09	48.27	47.80	48.42	48.14	48.59	48.51	48.63
TiO2	1.98	2.00	1.98	1.97	2.00	1.98	1.98	1.98	1.98	1.97
Al2O3	16.37	16.65	16.45	16.57	16.39	16.52	16.59	16.80	16.55	16.95
Fe2O3*	11.86	11.80	11.85	11.67	11.86	11.68	11.85	11.78	11.93	11.82
MnO	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.18	0.17	0.17
MgO	5.69	5.79	6.16	5.86	6.08	5.67	6.06	5.89	6.25	5.93
CaO	8.19	8.66	8.55	8.58	8.50	8.69	8.26	8.29	8.41	8.41
Na2O	3.08	3.58	3.35	3.56	3.30	3.48	3.46	3.57	3.37	3.48
K2O	1.75	1.86	1.79	1.88	1.79	1.89	1.83	1.92	1.87	1.93
P2O5	0.97	1.23	1.20	1.26	1.19	1.25	1.26	1.24	1.28	1.25
Total	98.41	100.52	99.58	99.78	99.05	99.76	99.57	100.24	100.31	100.56
Normalized 100% Anhydrous										
SiO2	49.16	48.53	48.29	48.38	48.25	48.54	48.35	48.47	48.36	48.36
TiO2	2.01	1.99	1.99	1.97	2.01	1.98	1.99	1.98	1.97	1.96
Al2O3	16.63	16.56	16.52	16.61	16.54	16.56	16.66	16.76	16.49	16.86
Fe2O3*	12.05	11.74	11.89	11.70	11.97	11.71	11.90	11.75	11.89	11.75
MnO	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.18	0.17	0.17
MgO	5.78	5.76	6.19	5.87	6.13	5.68	6.09	5.88	6.23	5.90
CaO	8.32	8.62	8.58	8.60	8.58	8.71	8.29	8.27	8.38	8.36
Na2O	3.12	3.56	3.36	3.57	3.33	3.49	3.47	3.56	3.36	3.46
K2O	1.77	1.85	1.80	1.88	1.81	1.89	1.83	1.92	1.86	1.92
P2O5	0.99	1.22	1.21	1.26	1.20	1.25	1.27	1.24	1.28	1.24
Mg# (85% FeO)	52.8	53.3	54.8	53.9	54.4	53.1	54.4	53.8	55.0	53.9
V	153	185	171	180	168	177	171	179	177	180
Cr	115	122	115	117	103	116	105	113	112	115
Ni	66	59	76	57	77	51	73	60	68	61
Zn	103	142	109	136	109	142	101	129	100	125
Rb	19	20	14	19	19	18	17	19	16	20
Sr	1354	1525	1308	1522	1355	1541	1308	1490	1325	1488
Y	29	27	32	36	31	27	31	28	30	31
Zr	290	363	301	382	287	370	291	373	304	366
Nb		30		28		31		31		27
Ba		1292		1378		1272	1410	1373	1420	1391

Appendix A: Continued

Sample	LW12	LW12	LW14	LW14	LW15	LW15	LW16	LW16	LW19	LW19
Unit		QL1a		Qs4c		Qs4b		Qs4c		QL2a
SiO2	48.51	48.63	49.29	49.13	48.41	48.20	49.22	48.65	48.88	48.96
TiO2	1.98	1.97	1.84	1.88	1.79	1.81	1.80	1.80	1.84	1.86
Al2O3	16.55	16.95	16.97	16.82	15.96	16.07	16.16	16.24	16.64	16.69
Fe2O3*	11.93	11.82	11.66	11.61	12.10	12.05	12.19	12.13	11.54	11.40
MnO	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.17	0.18
MgO	6.25	5.93	5.76	5.71	7.19	7.09	7.22	7.14	6.09	5.79
CaO	8.41	8.41	7.99	7.98	8.18	8.20	8.20	8.18	8.61	8.61
Na2O	3.37	3.48	2.49	3.06	2.52	3.18	2.58	3.17	3.19	3.43
K2O	1.87	1.93	1.56	1.67	1.51	1.64	1.53	1.63	1.73	1.79
P2O5	1.28	1.25	1.01	1.07	1.10	1.17	1.11	1.18	1.24	1.25
Total	100.31	100.56	98.72	99.09	98.92	99.57	100.17	100.30	99.90	99.94
Normalized 100% Anhydrous										
SiO2	48.36	48.36	49.93	49.58	48.94	48.41	49.14	48.50	48.92	48.99
TiO2	1.97	1.96	1.86	1.90	1.80	1.82	1.80	1.79	1.84	1.86
Al2O3	16.49	16.86	17.19	16.97	16.13	16.14	16.13	16.19	16.65	16.70
Fe2O3*	11.89	11.75	11.81	11.72	12.23	12.10	12.16	12.09	11.55	11.41
MnO	0.17	0.17	0.17	0.17	0.18	0.18	0.17	0.18	0.17	0.18
MgO	6.23	5.90	5.83	5.76	7.27	7.12	7.20	7.12	6.10	5.79
CaO	8.38	8.36	8.09	8.05	8.27	8.24	8.19	8.16	8.61	8.62
Na2O	3.36	3.46	2.52	3.09	2.54	3.19	2.58	3.16	3.19	3.43
K2O	1.86	1.92	1.58	1.69	1.53	1.65	1.52	1.63	1.73	1.79
P2O5	1.28	1.24	1.02	1.08	1.11	1.18	1.10	1.18	1.24	1.25
Mg# (85% FeO)	55.0	53.9	53.5	53.4	58.1	57.8	58.0	57.8	55.2	54.2
V	177	180	136		154	169	164	162	165	177
Cr	112	115	89	106	157	187	160	193	87	100
Ni	68	61	65	58	101	110	102	107	63	57
Zn	100	125	83	101	75	94	78	99	98	127
Rb	16	20	14	17	17	17	14	16	17	19
Sr	1325	1488	1273	1414	1218	1372	1234	1380	1238	1451
Y	30	31	28	32	31	18	29	25	33	25
Zr	304	366	312	368	285	352	285	357	287	382
Nb		27		30		31		27		31
Ba	1420	1391	1390	1383	1350	1334	1310	1317		1393

Appendix A: Continued

Sample	LW20	LW20	LW21	LW21	LW22	LW22	LW23	LW23	LW25-B	LW25
Unit		QL1d		QL1d		QL1d		QL1d		QL2b
SiO2	48.17	48.58	46.89	46.53	47.63	47.43	47.87	47.74	47.88	48.26
TiO2	2.04	2.04	2.02	1.98	2.09	2.06	2.04	2.03	1.91	1.93
Al2O3	16.67	16.69	16.23	16.06	16.65	16.60	16.46	16.39	16.84	16.96
Fe2O3*	12.13	12.02	12.10	11.88	12.39	12.15	12.17	12.02	12.08	11.90
MnO	0.17	0.18	0.17	0.18	0.18	0.18	0.17	0.17	0.16	0.18
MgO	6.18	6.03	6.16	5.83	6.36	6.13	6.36	5.98	5.79	5.81
CaO	8.57	8.53	9.12	9.12	8.38	8.40	8.60	8.61	8.32	8.38
Na2O	3.29	3.61	3.22	3.51	3.26	3.55	3.32	3.58	2.98	3.54
K2O	1.80	1.88	1.76	1.82	1.74	1.80	1.78	1.85	1.75	1.86
P2O5	1.28	1.29	1.24	1.26	1.30	1.31	1.28	1.24	1.16	1.23
Total	100.30	100.85	98.87	98.15	99.96	99.60	100.03	99.61	98.87	100.03
Normalized Anhydrodous			100%							
SiO2	48.03	48.17	47.43	47.41	47.65	47.62	47.85	47.93	48.43	48.25
TiO2	2.03	2.02	2.04	2.02	2.09	2.07	2.03	2.04	1.93	1.93
Al2O3	16.62	16.55	16.41	16.36	16.66	16.67	16.46	16.45	17.03	16.95
Fe2O3*	12.09	11.92	12.23	12.10	12.39	12.20	12.16	12.07	12.22	11.90
MnO	0.17	0.18	0.17	0.18	0.18	0.18	0.17	0.17	0.16	0.18
MgO	6.16	5.98	6.23	5.94	6.36	6.15	6.36	6.00	5.86	5.81
CaO	8.54	8.46	9.22	9.29	8.38	8.43	8.60	8.64	8.42	8.38
Na2O	3.28	3.58	3.26	3.58	3.26	3.56	3.31	3.59	3.01	3.54
K2O	1.79	1.86	1.78	1.85	1.74	1.81	1.78	1.86	1.77	1.86
P2O5	1.28	1.28	1.25	1.28	1.30	1.32	1.28	1.24	1.17	1.23
Mg# (85% FeO)	54.3	53.9	54.3	53.4	54.5	54.0	54.9	53.7	52.8	53.2
V	166	173	167	181	160	185	165	186	157	175
Cr	87	104	99	120	98	106	100	109	114	116
Ni	75	62	69	61	81	62	81	67	68	63
Zn	105	133	104	131	95	123	104	136	109	127
Rb	14	15	15	19	13	14	12	14	19	18
Sr	1356	1552	1355	1533	1378	1556	1335	1547	1349	1456
Y	30	31	31	30	31	24	30	26	23	32
Zr	299	382	295	367	311	382	286	379	291	379
Nb		27		27		29		34		39
Ba	1370	1326	1320	1318	1350	1315	1330	1280	1420	1450

Appendix A: Continued

Sample	LW26	LW26	LW27	LW27	LW28	LW28	LW29	LW29	LW30	LW30
Unit		QL2b		QL2b		QL2b		QL2b		QL1c
SiO2	48.32	48.26	48.79	48.87	48.71	48.62	48.66	48.66	48.08	47.55
TiO2	1.89	1.93	1.95	1.96	1.85	1.86	1.96	1.97	1.89	1.89
Al2O3	16.67	16.68	16.82	16.78	16.76	16.74	16.80	16.73	16.43	16.26
Fe2O3*	11.65	11.56	11.79	11.74	11.67	11.40	11.85	11.72	11.70	11.36
MnO	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.17	0.16	0.17
MgO	5.83	5.83	6.18	5.88	6.07	5.86	5.96	5.89	6.10	5.84
CaO	8.65	8.62	8.46	8.51	8.61	8.67	8.35	8.38	9.42	9.36
Na2O	2.84	3.47	3.42	3.60	3.07	3.44	2.92	3.61	3.08	3.44
K2O	1.71	1.80	1.76	1.85	1.75	1.81	1.73	1.83	1.75	1.83
P2O5	1.16	1.19	1.23	1.21	1.23	1.21	1.18	1.22	1.21	1.19
Total	98.85	99.50	100.55	100.57	99.88	99.77	99.56	100.18	99.81	98.87
Normalized 100% Anhydrous										
SiO2	48.88	48.50	48.53	48.59	48.77	48.73	48.88	48.57	48.17	48.09
TiO2	1.91	1.94	1.94	1.95	1.85	1.86	1.96	1.97	1.89	1.91
Al2O3	16.86	16.76	16.72	16.68	16.78	16.78	16.87	16.70	16.46	16.45
Fe2O3*	11.78	11.62	11.73	11.67	11.68	11.43	11.90	11.70	11.72	11.49
MnO	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.17	0.16	0.17
MgO	5.89	5.86	6.14	5.85	6.08	5.87	5.99	5.88	6.11	5.91
CaO	8.75	8.66	8.41	8.46	8.62	8.69	8.39	8.36	9.44	9.47
Na2O	2.87	3.49	3.40	3.58	3.07	3.45	2.93	3.60	3.09	3.48
K2O	1.72	1.81	1.75	1.84	1.75	1.81	1.73	1.83	1.75	1.85
P2O5	1.17	1.20	1.22	1.20	1.23	1.21	1.18	1.22	1.21	1.20
Mg#	53.8	54.0	55.0	53.9	54.8	54.5	54.0	53.9	54.8	54.5
(85% FeO)										
V	167	182	166	172	165	182	160	172	165	168
Cr	105	128	107	113	95	110	98	116	104	114
Ni	64	60	78	58	60	49	64	54	70	55
Zn	96	125	103	128	104	127	92	119	101	127
Rb	17	19	17	16	15	17	16	18	14	20
Sr	1341	1453	1292	1489	1255	1426	1334	1496	1288	1453
Y	32	24	27	25	29	28	27	32	27	30
Zr	301	386	316	378	297	367	308	372	302	366
Nb		25		32		33		33		30
Ba		1403	1400	1399	1410	1395	1400	1392	1410	1337

Appendix A: Continued

Sample	LW31	LW31	LW32	LW32
Unit		QL1c		QL1c
SiO2	48.60	48.82	48.23	48.25
TiO2	1.91	1.93	1.95	1.96
Al2O3	16.79	16.74	16.70	16.79
Fe2O3*	11.80	11.58	11.77	11.70
MnO	0.17	0.17	0.17	0.17
MgO	6.19	5.82	5.84	5.75
CaO	8.46	8.54	8.41	8.50
Na2O	3.27	3.58	2.83	3.53
K2O	1.77	1.86	1.72	1.84
P2O5	1.23	1.21	1.19	1.24
Total	100.18	100.24	98.79	99.73
Normalized Anhydrous		100%		
SiO2	48.51	48.70	48.82	48.38
TiO2	1.90	1.93	1.97	1.97
Al2O3	16.75	16.70	16.91	16.84
Fe2O3*	11.77	11.55	11.91	11.73
MnO	0.16	0.17	0.17	0.17
MgO	6.18	5.81	5.91	5.77
CaO	8.44	8.52	8.51	8.52
Na2O	3.26	3.57	2.86	3.54
K2O	1.77	1.86	1.74	1.84
P2O5	1.22	1.21	1.20	1.24
Mg# (85% FeO)	55.0	53.9	53.6	53.4
V	169	181	156	184
Cr	124	142	97	110
Ni	76	64	68	57
Zn	100	127	99	128
Rb	15	19	15	15
Sr	1289	1467	1376	1497
Y	37	19	32	28
Zr	296	377	309	367
Nb		34		31
Ba	1430	1389	1450	1435